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ABSTRACT BOOK

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Table of Contents

320 – Meteorites Posters
321 – Ceres and Vesta Posters
322 – Extrasolar Planets and Systems: Orbital Dynamics Posters
323 – Astrobiology Posters
324 – Asteroid Main Belt Posters
325 – Asteroid Physical Characteristics: Surfaces Posters
326 – Asteroid Spin States Posters
327 – Asteroids: Observational Surveys Posters
328 – Origin and Evolution of Asteroids Posters
329 – Asteroid Dynamics NEO Posters
330 – Comets: Chemical Composition Posters
331 – Comets: Origins and Theory Posters
332 – History Posters
400 – Asteroid Dynamics: Main-belt - Families and Breakups
401 – Outer Icy and Irregular Satellites I: Dynamics and Orbital Evolution
402 – Jovian Planets: Magnetospheres and Aurorae
403 – Jovian Atmosphere I: Upper Atmosphere
404 – Mars Atmosphere Composition and Climate
405 – Asteroids: Observational Surveys I
406 – Citizen and Student Engagement in Space Science: The Latest Educational Research and Future Studies
407 – Mission Showcase: Dawn at Ceres Results
408 – Jovian Atmosphere II: Giant Planets Interiors
409 – Mars Clouds and Aerosols
410 – Asteroids: Observational Surveys II
411 – Asteroid Spin States I: Rotational Surveys
412 – Titan: Views from Cassini
414 – Farinella Prize Lecture: Flavors of Chaos in the Asteroid Belt, Kleomenis Tsiganis (Aristotle University of Thessaloniki)
415 – Harold C. Urey Prize Lecture: In for the Long Haul: Exploring Atmospheric Cycles on the Giant Planets, Leigh Fletcher (University of Leicester)
416 – Plenary Talk: The Ancient Habitability of Gale Crater, Mars, after Four Years of Exploration by Curiosity, Ashwin Vasavada (Jet Propulsion Laboratory)
417 – Capacity Building in Formal and Informal Education Posters
418 – Large-scale Opportunities for Citizen Engagement Posters
419 – Tools and Resources for Education Posters
420 – Inner Planets: Magnetospheres Posters
421 – Jovian Planets: Atmospheres and Interiors Posters
422 – Jovian Planets: Magnetospheres and Aurorae Posters
423 – Outer Icy and Irregular Satellites Posters
424 – Titan Atmosphere Posters
425 – Titan Surface and Interior Posters
426 – Mars: Surface Posters
427 – Mars: Interior Posters
428 – Mars Satellites: Phobos and Deimos Posters
429 – Galilean Satellites Posters
500 – Martian Geology and Habitability
501 – Jovian Atmosphere III: Giant Planet Dynamics
502 – Titan: Hydrocarbon Heaven
503 – Titan: Upper Atmosphere
504 – Asteroid Spin States II: Notable Spinners
505 – Asteroid Physical Characteristics: Surfaces I
506 – Ceres Surface and Interior Processes
507 – Mission Showcase: MSL Progress on Habitability
508 – Jovian Atmospheres IV: Composition of Jupiter and Saturn
509 – Titan: The Stratosphere and Its Evolution
510 – Asteroid Physical Characteristics: Surfaces II
511 – Ceres Surface Properties and Composition
512 – Galilean Satellites I: Chemistry and Particle Interactions
513 – Active Surface Process on Mars: Volatiles, Wind and Impacts
514 – Jovian Atmospheres V: Observations of Saturn, Uranus, Neptune, Exoplanets
515 – Aerosols and Haze on Titan
516 – Asteroid Physical Characteristics: Surfaces III
517 – Galilean Satellites II: Europa and Io
518 – Formation and Evolution of Planets and Satellites
519 – Outer Icy and Irregular Satellites II: Environment, Processes, and Composition
520 – Titan: Lower Atmosphere
521 – Dust and Solar Wind
522 – Origin and Evolution of Asteroids
523 – Mars Satellites: Phobos and Deimos
524 – Inner Planets: Magnetospheres
525 – Meteorites

101 – Plenary Talk: The Rosetta Mission, Matt Taylor (European Space Agency)

101.01 – The Rosetta mission

The Rosetta Mission is the third cornerstone mission the ESA programme Horizon 2000. The aim of the mission is to map the comet 67-P/Churyumov-Gerasimenko by remote sensing, to examine its environment insitu and its evolution in the inner solar system. The lander Philae is the first device to land on a comet and perform in-situ science on the surface. Following its launch in March 2004, Rosetta underwent 3 Earth and 1 Mars flybys to achieve the correct trajectory to capture the comet, including flybys of asteroid on 2867 Steins and 21 Lutetia. For June 2011- January 2014 the spacecraft passed through a period of hibernation, due to lack of available power for full payload operation and following successful instrument commissioning, successfully rendezvoused with the comet in August 2014. Following an intense period of mapping and characterisation, a landing site for Philae was selected and on 12 November 2014, Philae was successfully deployed. Rosetta then embarked on the main phase of the mission, observing the comet on its way into and away from perihelion in August 2015. At the time of writing the mission is planned to terminate with the Rosetta orbiter impacting the comet surface on 30 September 2016. This presentation will provide a brief overview of the mission and its science. The first author is honoured to give this talk on behalf of all Rosetta mission science, instrument and operations teams, for it is they who have worked tirelessly to make this mission the success it is.

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102 – Plenary Talk: The Latest Views of Venus as Observed by the Japanese Orbiter "Akatsuki", Takehiko Satoh (ISAS/JAXA)

102.01 – The latest views of Venus as observed by the Japanese Orbiter "Akatsuki"

Akatsuki, also known as the Venus Climate Orbiter (VCO) of Japan, was launched on 21 May 2010 from Tanegashima Space Center, Kagoshima, Japan. After 6 months of cruising to Venus, an attempt was made to insert Akatsuki in Venus orbit (VOI) on 7 December 2010. However, due to the clogged check valve in a pressurizing system of fuel line, the thrust to decelerate the spacecraft was not enough to allow it captured by the gravitational pull of Venus. After this failure, Akatsuki became an artificial planet around the sun with an orbital period of ~200 days. We waited for 5 earth years (or 9 Akatsuki years), and the second attempt (VOI-R1) was made on the same day, 7 December 2015. It was a great surprise to the world that a "once failed" spacecraft made a successful orbital insertion after many years of time. The orbital period around Venus is slightly shorter than 11 days, with the apoapsis altitude of ~0.37 million km. After Venus Express (VEX), which was in Venus orbit for 8 years, Akatsuki still keeps a unique position and is expected to make a great contribution to the Venus science due primarily to its orbit. In contrast to the polar orbits of Pioneer Venus or VEX, Akatsuki is in a near-equatorial plane and revolves westward, the same direction as the super rotating atmosphere. This orbit allows the spacecraft in a "partial" synchronization with the atmospheric motion when Akatsuki is near the planet. When at greater distances, the atmosphere moves faster than Akatsuki's orbital motion so the spacecraft maps the full longitude range of Venus in several days. This meteorological-satellite-like concept makes Akatsuki the most unique planetary orbiter in the history. To sense the various levels of the atmosphere, to draw 3-dimentional picture of dynamics, Akatsuki is equipped with 5 on-board cameras, UVI (283 and 365 nm wavelength), IR1 (0.90, 0.97, and 1.01 μm), IR2 (1.65, 1.735, 2.02, 2.26, and 2.32 μm), LIR (8-12 μm), and LAC (a special high-speed sensor at visible wavelengths), as well as the ultra-stable oscillator for radio-occultation measurements.
At the lecture, the latest views of Venus as acquired with these instruments on Akatsuki will be presented.

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Contributing team(s): Akatsuki Project Team

103 – Plenary Talk: New Horizons: Overview of Results From and Plans After the Exploration of The Pluto System, S. Stern

103.01 – New Horizons: Overview of Results From and Plans After the Exploration of The Pluto System

Essentially all of the data from the New Horizons Pluto system flyby that culminated in July 2015 is expected to be on Earth by the time of this meeting. As of mid-June 2016, about 75% of those data have been received. All near encounter observations downlinked so far have been examined and were determined to be successful; engineering data from the remaining observations yet to be downlinked indicates they were all successful as well. The first Planetary Data System (PDS) Pluto system delivery has been made; a second PDS delivery is planned for October, with still more deliveries leading to complete and final dataset archiving by late 2017. Numerous scientific results have been obtained, and over 40 scientific papers have been published or submitted by mid-June 2016. This invited review will examine the most interesting geological, compositional, atmospheric, and plasma results obtained about Pluto, Charon and their small moons, and will go on to explore the implications of key results for understanding dwarf planets in general and the origin of the Pluto system in specific. New Horizons is healthy and operating nominally. If its Kuiper Belt Extended Mission is approved, numerous KBO and heliospheric observations are planned for 2016 and beyond, including the very close flyby of the cold, classical KBO 2014 MU_{69} on 1 January 2019. We summarize these and other plans for New Horizons.

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104 – Mission Showcase: Rosetta Results

104.01 – The Nucleus of Comet 67P/Churyumov-Gerasimenko: Lots of Surprises

ESA's Rosetta mission has made many new and unexpected discoveries since its arrival at comet 67P/Churyumov-Gerasimenko in August 2014. The first of these was the unusual shape of the cometary nucleus. Although bilobate nuclei had been seen before, the extreme concavities on 67P were unexpected. Evidence gathered during the mission suggests that two independent bodies came together to form 67P, rather than the nucleus being a single body that was sculpted by sublimation and/or other processes. Although not a surprise, early observations showed that the nucleus rotation period had decreased by ~22 minutes since the previous aphelion passage. A similar rotation period decrease was seen post-perihelion during the encounter. These changes likely arise from asymmetric jetting forces from the irregular nucleus. Initially, Rosetta's instruments found little evidence for water ice on the surface; the presence of surface water ice increased substantially as the nucleus approached perihelion. The nucleus bulk density, 533 ± 6 kg/m^3, was measured with Radio Science and OSIRIS imaging of the nucleus volume. This confirmed previous estimates based on indirect methods that the bulk density of cometary nuclei was on the order of 500-600 kg/m^3 and on measurement of the density of 9P/Tempel 1's nucleus by Deep Impact. Nucleus topography proved to be highly varied, from smooth dust-covered plains to shallow circular basins, to the very rough terrain where the Philae lander came to rest. Evidence of thermal cracking is everywhere. The discovery of cylindrical pits on the surface, typically 100-200m in diameter with similar depths was a major surprise and has been interpreted as sinkholes. "Goose-bump" terrain consisting of apparently random piles of boulders 2-3 m in diameter was another unexpected discovery. Apparent layering with scales of meters to many tens of meters was seen but there was little or no evidence for impact features. Radar tomography of the interior of the "head" of the nucleus showed no evidence of large voids, > 100's of meters, in the interior and the RSI experiment also ruled out large voids > 600m in size. This work was supported by the U.S. Rosetta Project, funded by NASA.

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Contributing team(s): Rosetta Science Working Team

104.02 – Rosetta and Comet Composition of Volatile and Refractories in the Nucleus of 67P/Churyumov-Gerasimenko

The Rosetta mission has been taking measurements of its target comet 67P/Churyumov-Gerasimenko since early 2014 and will complete operations at the end of September 2016.
The mission Science Management Plan, in 1994, laid out the five prime goals and themes of the mission.
1) To study the global characterisation of the nucleus, the determination of the dynamics properties, surface morphology and composition of the comet.
2) Examination of the Chemical, Mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus.
3) Physical interrelation of volatiles and refractories in a cometary nucleus
4) Study of the development of cometary activity and the process in the surface layer of the nucleus and in the inner coma
5) The origins of comets, the relationship between cometary and interstellar material and the implications for the origin of the Solar System.
To cover all aspects of the Rosetta mission in this dedicated session, this abstracts is one of 5, and focuses on theme 2:
In this contribution we will focus on the highlights of the volatile and refractory inventory, the compositional evolution during orbit, and the major constraints from this to the Solar System formation. In particular we will detail the evolution of the volatile composition along the comet's orbit around the Sun ranging from beyond 3 AU to the perihelion at a heliocentric distance of 1.24 AU and back to 3.6 AU and discussion new parent molecules in the cometary volatile inventory that give new insights into the Solar System formation.

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104.03 – Physical interrelation of volatile and refractories in a cometary nucleus

The Rosetta mission has been taking measurements of its target comet Comet 67P/Churyumov-Gerasimenko since early 2014 and will complete operations at the end of September 2016. The mission Science Management Plan, in 1994, laid out the the prime goals and themes of the mission. These five themes were:
1) To study the global characterisation of the Nuclues, the determination of the dynamics properties , surface morpholy and composition of the comet.
2) Examination of the Chemical, Mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus.
3) Physical interrelation of volatile and refractories in a cometary nucleus
4) Study the development of cometary activity and the process in the surface layer of the nucleus and in the inner coma
5) The origins of comets, the relationship between cometary and interstellar material and the implications for the origin of the solar system,
To cover all aspects of the Rosetta mission in this special Show case session, this abstracts is one of 5, with this particular presentation focusing on theme 3, in particular on a) The dust-to-gas ratio; b) distributed sources of volatiles; c) seasonal evolution of the dust size distribution.
a) The dust-to-gas ratio has been provided by coma observations measuring the gas and dust loss rates from the nucleus surface. The ratio of these two loss rates provides a lower limit of the dust-to-gas ratio at the nucleus surface, since it does not take into account the largest chunks unable to leave the nucleus, or falling back due to the dominant gravity. We review the value inferred so far, its time evolution, and new techniques to directly measure it in the nucleus.
b) Evidences offered by Rosetta observations of gas sublimating from dust particles are up to now faint. We report the few available observations and an estimate of the probable average water content in dust particles inferred by 3D gas-dynamical codes of 67P coma.
c) The dust-size distribution tunes the sizes mainly contributing to the mass or to the cross-section, thus providing information on the accuracy of the non-volatile mass measurements, and on the dust particles effectively observed in 67P coma images. Here we review the results obtained in 67P.

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104.04 – Rosetta at 67P: what we have learned about cometary activity

The Rosetta mission has been taking measurements of its target comet Comet 67P/Churyumov-Gerasimenko since early 2014 and will complete operations at the end of September 2016.
The mission Science Management Plan, in 1994, laid out the the prime goals and themes of the mission. These five themes were:
1) To study the global characterisation of the Nuclues, the determination of the dynamics properties, surface morpholy and composition of the comet.
2) Examination of the Chemical, Mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus.
3) Physical interrelation of volatile and refractories in a cometary nucleus
4) Study the development of cometary activity and the process in the surface layer of the nucleus and in the inner coma
5) The origins of comets, the relationship between cometary and interstellar material and the implications for the origin of the solar system,
To cover all aspects of the Rosetta mission in this special Show case session, this abstracts is one of 5, with this particular presentation focusing on theme (4): Cometary Activity
We will report on the progress made in our understanding of how the nucleus activity was monitored by many instruments on board Rosetta, and how it developed over the two years of the mission. Activity is the ensemble of processes leading to the release of volatiles and dust from the surface into the coma. It is a key to understand the evolution of comets, and thus get back to their origins.
We will present how activity features such has jets and outbursts were detected in the coma, and linked to the topography. Due to activity some areas eroded away or collapsed, while other have been covered with a thick layer of dust, very likely transported from the active southern hemisphere to the northern one which is in polar winter at perihelion. Activity coupled with dust transport leads to compositional differences on the surface. Active areas, enriched in volatile material, have appeared or disappeared over time frames of minutes to months.
Finally, we have observed a clear correlation between activity and seasons on the surface. We will report on how the shifting patterns of active areas produce a change of rotation period of 20 minutes per orbit.

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104.05 – The Rosetta mission: Clues on the origin of comet nuclei

The Rosetta mission has been taking measurements of its target Comet 67P/Churyumov-Gerasimenko since
early 2014 and will complete operations at the end of September 2016. The mission Science Management Plan,
in 1994, laid out the the prime goals and themes of the mission. These five themes were:
1) To study the global characterization of the Nucleus, the determination of the dynamics properties ,
surface morphology and composition of the comet.
2) Examination of the Chemical, Mineralogical and isotopic compositions of volatiles and refractories
in a cometary nucleus.
3) Physical interrelation of volatile and refractories in a cometary nucleus
4) Study the development of cometary activity and the process in the surface layer of the
nucleus and in the inner coma
5) The origins of comets, the relationship between cometary and interstellar material and the
implications for the origin of the solar system,
To cover all aspects of the Rosetta mission in this special Show case session, this abstracts is
one of 5, with this particular presentation focusing on theme 5.
Several scenarios for comet nucleus formation have been proposed, such as hierarchical agglomeration,
or gravitational collapse of pebble swarms created either by turbulent eddies or by streaming instabilities.
In addition, the question of survival of such primordial nuclei versus severe collisional processing
has been debated. The pros and cons of these hypotheses are discussed in the light of Rosetta's discoveries.

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Contributing team(s): The Rosetta Science Working Team

105 – Origin and Evolution of Planetary Systems

105.01D – Formation of terrestrial planets in eccentric and inclined giant-planet systems

The orbits of extrasolar planets are more various than the circular and coplanar ones of the Solar system. We study the impact of inclined and eccentric massive giant planets on the terrestrial planet formation process. The physical and orbital parameters of the giant planets considered in this study arise from n-body simulations of three giant planets in the late stage of the gas disc, under the combined action of Type II migration and planet-planet scattering. At the dispersal of the gas disc, the two- and three-planet systems interact then with an inner disc of planetesimals and planetary embryos. We discuss the mass and orbital parameters of the terrestrial planets formed by our simulations, as well as their water content. We also investigate how the disc of planetesimals and planetary embryos modifies the eccentric and inclined orbits of the giant planets.

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105.02 – Dynamical Models to Infer the Core Mass Fraction of Venus

The uncompressed density of Venus is just a few percent lower than Earth's, however the nature of the interior core structure of Venus remains unclear. Employing state-of-the-art dynamical formation models that allow both accretion and collisional fragmentation, we perform hundreds of simulations of terrestrial planet growth around the Sun in the presence of the giant planets. For both Earth and Venus analogs, we quantify the iron-silicate ratios, water/volatile abundances and specific impact energies of all collisions that lead to their formation. Preliminary results suggest that the distributions of core mass fraction and water content are comparable among the Earth and Venus analogs, suggesting that Earth and Venus may indeed have formed with similar structures and compositions.

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105.03 – Dynamical Origins of the Kepler Dichotomy

An overabundance of single-transiting planetary systems relative to those with multiple transits within the Kepler dataset, has been interpreted as evidence for mutual inclinations between planetary orbits. The physical origins of this so-called "Kepler Dichotomy," however, remain elusive. Here we show that the observed prevalence of single-planet systems is a direct consequence of the secular evolution of initially co-planar multi-planet systems that orbit stars whose spin-axes are inclined with respect to the protoplanetary disks they host. Such primordial misalignments arise naturally within the disk-hosting stage by way of gravitational torques from stellar companions, and have been previously invoked as explanations for the commonness of spin-orbit misalignments in hot Jupiter systems. Accordingly, our model places the early dynamical evolution of hot super-Earths and hot Jupiters into a unified theoretical framework.

Author(s): Christopher Spalding[1], Konstantin Batygin[1]
Institution(s): *1. California Institute of Technology*

105.04 – Updates to the dust-agglomerate collision model and implications for planetesimal formation

Since the publication of our first dust-agglomerate collision model in 2010, several new laboratory experiments have been performed, which have led to a refinement of the model. Substantial improvement of the model has been achieved in the low-velocity regime (where we investigated the abrasion in bouncing collisions), in the high-velocity regime (where we have studied the fragmentation behavior of colliding dust aggregates), in the erosion regime (in which we extended the experiments to impacts of small projectile agglomerates into large target agglomerates), and in the very-low velocity collision regime (where we studied further sticking collisions). We also have applied the new dust-agglomerate collision model to the solar nebula conditions and can constrain the potential growth of planetesimals by mass transfer to a very small parameter space, which makes this growth path very unlikely. Experimental examples, an outline of the new collision model, and applications to dust agglomerate growth in the solar nebula will be presented.

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105.05 – A pebbles accretion model with chemistry and implications for the solar system in the lights of Juno

The chemical compositions of the solar system giant planets are a major source of informations on their origins. Since the measurements by the Galileo probe, multiple models have been put forward to try and explain the noble gases enrichment in Jupiter. The most discussed among these are its formation in the outer cold nebula and its formation in a partially photoevaporated disk. In this work I couple a pebbles accretion model to the disk's chemistry and photoevaporation in order to make predictions from both scenarios and compare them to the upcoming Juno measurements. The model include pebbles and gas accretion, type I and II migration, photoevaporation and chemical measurements from meteorites, comets and disks. Population synthesis simulations are used to explore the models free parameters (planets initial conditions), where then the results are narrowed down using the planets chemical, dynamical and core mass costraints. We end up with a population that fits all of the constrains. These are then used to predict the oxygen abundance and core mass in Jupiter, to be compared to results of Juno. Same calculations are also done for Saturn and Neptune for comparison. I will present the results from these simulations as well as the predictions from all of the different models.

Ali-Dib, M. (2016ab, submitted to MNRAS)

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105.06 – Low-mass gas envelopes around accreting cores embedded in radiative 3D discs

Planets with a core mass larger than few Earth masses and a gaseous envelope not exceeding about 10% of the total mass budget are common. Such planets are present in the Solar System (Uranus, Neptune) and are frequently observed around other stars.
Our knowledge about the evolution of gas envelopes is mainly based on 1D models. However, such models cannot investigate the complex interaction between the forming envelope and the surrounding gas disc.
In this work we perform 3D hydrodynamics simulations accounting for energy transfer and radiative cooling using the FARGOCA code (Lega et al., MNRAS 440, 2014). In addition to the usually considered heating
sources, namely viscous and compressional heating, we have modeled the energy deposited by the accretion of solids.
We show that the thermal evolution of the envelope of a 5 Earth mass core is mainly dominated by compressional heating for accretion rates lower than 5 Earth masses per 10^5years.
Additionally, we demonstrate efficient gas circulation through the envelope. Under certain conditions, the competition between gas circulation and cooling of the envelope can efficiently delay the onset of runaway accretion. This could help in explaining the population of planets with low-mass gas envelope.

Author(s): Elena Lega[1], Michiel Lambrechts[1]
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105.07D – Using direct imaging to investigate the formation and migration histories of gas giant exoplanets

Gas giant exoplanets are found around their host stars at orbital separations spanning more than four orders of magnitude (0.01 to 100 AU). However, it is not known whether the planets at the extreme ends of this range could have formed in situ or if they instead formed closer to ice lines between 1-10 AU and then migrated to their present day locations. In this study, we use two direct imaging surveys to explore the potential origins of hot Jupiters and to characterize the population of gas giant planets beyond the ice line. In our first survey, we focus on the role of stellar companions in hot Jupiter formation and migration. We determine that less than 20% of hot Jupiters have stellar companions capable of inducing migration via Kozai-Lidov oscillations. In addition, we find that hot Jupiter hosts are three times more likely to have a stellar companion between 50-2000 AU than field stars, suggesting that binary star systems may be favorable environments for gas giant planet formation. In our second study, we present the results from the first year of a two-year direct imaging planet survey of 200 young M-dwarf stars. By imaging in L-band (3.8 micron) and taking advantage of the new 80 milliarcsecond inner working angle "vortex" coronagraph on Keck NIRC2, we are sensitive to young planets with masses between 1-10 Jupiter masses with projected separations between 1-10 AU. We can compare the semi-major axis distribution of directly imaged planets beyond 10 AU to that of intermediate period gas giants from radial velocity surveys and determine whether or not these two populations form a continuous distribution. If so, this would imply these populations share common formation (core accretion) and migration channels.

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105.08 – Reconstructing the size distribution of the small body population in the Solar System

The size distributions of the populations of small bodies in the solar system (the asteroid belt, the hot Kuiper belt and the cold Kuiper belt) show a striking similarity: they all show an elbow at a diameter of about D=100km. At D<100km, all size distributions have the same slope, dictated by collisional equilibrium. At D>100km, the slopes are different, the cold Kuiper belt having the steepest slope, while the hot Kuiper belt and the asteroid belt have progressively more shallow slopes. Moreover, the asteroid belt and hot Kuiper belt show a turnover to a shallow size distribution at sizes larger than D=300-500km. Johansen et al. (2015) explained the elbow and the transition to a steeper slope assuming that the original planetesimals had D<100km and that they grew further by the process of pebble accretion, the sweep up of small particles aided by gas drag. However, the origin of the differences between the slopes of the three populations remained unclear.

Here we investigate the problem using a particle-in-a-box code, that treats collisional coagulation, fragmentation, dynamical stirring and damping, to which we have added growth by pebble accretion for objects with possibly eccentric and inclined orbits.

We show that the size distribution above D=100km is set by a combination of planetesimal collisions and the sweeping up of pebbles. Thus, the final slopes are diagnostic of the collisionial rate and the initial total mass of the planetesimal population. The size distribution for the largest asteroids and hot Kuiper belt objects are consistent with growth dominated by the accretion of pebbles. The observed size distributions also places constraints on the dominant particle size, the level of midplane turbulence and nebular conditions at different orbital radii in the Solar nebula. Our findings hint that the asteroid belt largely formed close to the dissipation of the gas disc and that its final total mass was comparable to that of the Earth.

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105.09 – Planet 9 and the Inclination of the Solar Equator

It has been recently proposed (Batygin and Brown, 2016; Brown and Batygin, 2016) that the existence of a distant 10-Earth mass planet in the outer Solar System, commonly known as Planet 9, could explain the orbital quasi-alignment of the six objects with the largest semimajor axis in the Kuiper Belt. This putative distant planet should have an orbit with semimajor axis between 300 and 900 AU, perihelion distance between 200 and 350 AU, and orbital inclination of about 30 degrees to the ecliptic plane. Here we evaluate the effects of Planet 9 on the dynamics of the "inner" giant planets of the Solar System: Jupiter, Saturn, Uranus, and Neptune. We find that, given the large distance of Planet 9, the dynamics of the inner giant planets can be decomposed into a classic Lagrange-Laplace dynamics relative to their own invariant plane (the plane orthogonal to their total angular momentum vector) and a slow precession of said plane relative to the total angular momentum vector of the Solar System, including Planet 9. Under some specific configurations for Planet 9, this precession can explain the current tilt between the invariant plane of the inner giant planets and the solar equator. Given that the planes of the proto-planetary disk and of the solar equator should have coincided, the current tilt of ~6 degrees is surprising and was so far unexplained. An analytical model is developed to map the evolution of the inclination of the inner giant planets' invariable plane as a function of the Planet 9's mass, inclination, eccentricity and semimajor axis, and some numerical simulations of the equations of motion of the giant planets and Planet 9 are performed to validade our analytical approach. Some of the Planet 9 configurations that allow explaining the current solar tilt are compatible with those proposed to explain the orbital confinement of the most distant Kuiper belt objects. Thus, this work on the one hand gives an elegant explanation forthe current tilt between the invariant plane of the inner giant planets and the solar equator and on the other hand, adds new constraints to the orbital elements of Planet 9. Acknowledgment FAPESP 2015/18682-6.

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106 – Centaurs/Kuiper I

106.01 – HST observations of Chiron: preliminary results

Chiron is a Centaur object, with a radius of approximately 110km. It is orbiting between Saturn and Uranus, and may be a Transneptunian Object (TNO) that has been recently (less than 10 My) scattered by gravitational perturbations from Uranus, just like its "twin brother" Chariklo. On June 3rd, 2013, a stellar occultation by Chariklo of a R=12.4 magnitude star was observed from seven sites in South America, which led to the detection of a total of twelve secondary events, revealing the presence of two narrow and dense rings (see more details at Braga-Ribas F. et al., Nature, 2014). Up to now, planetary rings have been detected exclusively around the four giant planets of our Solar System and Chariklo. In spite of hundreds of occultations by asteroids and several space missions, no other small bodies have shown the presence of rings. However, two recent papers (Ruprecht et al. 2015 and Ortiz et. al 2015) report secondary events from stellar occultations by Chiron that have been interpreted either as a dust shell or a ring system. Using the Hubble Space Telescope we obtained direct images of Chiron surroundings to search for rings, jets and/or small satellites. First results will be presented.

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106.02 – Physical characteristics of Cenaturs and trans-Neptunian objects from combined K2 and Herschel observations

Here we present the results of a comprehensive rotational and radiometric analysis of trans-Neptunian objects (TNOs) observed with the Kepler Space Observatory in the K2 mission and earlier with the Herschel Space Observatory at infrared wavelengths. The combined optical light curves and thermal emission data revealed a slow rotation rate of ~45h for the large Kuiper belt object 2007 OR10, and we obtained a diameter of ~1535 km that makes 2007 OR10 the third largest TNO after Pluto and Eris. The large size also implies a relatively dark surface, unusual among the dwarf planets in the outer Solar system. We also present rotational curves, physical characteristics and shape models for the Centaur 2002 KY14, for three Classical Kuiper belt objects, 1998 SN165, 2001 QT322 and 2003 QW90, and for two resonant TNOs, 2001 YH140 and 2005 RS43. In the case of 2003 QW90, 2001 YH140 and 2005 RS43 our results are based on so far unpublished thermal emission data from Herschel and Spitzer observations.

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106.03 – Multi-wavelength analysis of a 2011 stellar occultation by Chiron

The centaur (2060) Chiron was originally thought to be asteroid-like; however, photometry in the late 1980s revealed an increase in brightness and eventually a directly-imaged coma (e.g. Meech, K.J., & Belton, M.J.S., 1990, AJ, 100,4). Previous stellar occultation observations for Chiron have detected features thought to be narrow jets, a gravitationally-bound dust coma, and a near-circular ring or shell of material (Elliot, J.L., 1995, Nature, 373, 46; Bus, S.J., et al., 1996, Icarus, 123, 478; Ruprecht, J.D., et al. 2015, Icarus, 252, 271). These detections are unusual given Chiron's relatively large distance from the Sun and its relatively large nucleus compared to comet nuclei. The discovery of a ring system around the centaur Chariklo (Braga-Ribas, F., et al. 2014, Nature, 508, 78) provides context for Chiron. A ring system for Chiron has recently been proposed based on a combined analysis of occultation data, the rotational light curve, and spectral variability (Ortiz, J.L., et al. 2015, A&A, 576, A18).
Chiron occulted a fairly bright star (R = 14.8) on 2011 November 29. We observed the event with high-speed, visible imaging from NASA's 3-m Infrared Telescope Facility (IRTF) on Mauna Kea and the 2-m Faulkes Telescope North at Haleakala (run by the Las Cumbres Observatory Global Telescope network, LCOGT). At the IRTF, we simultaneously obtained low-resolution, near-infrared spectra spanning 0.9-2.4 microns. Here, we present an analysis of the combined visible and near-infrared occultation data. Distinct extinction features were detected in the visible data, located roughly 300 km from the center (Ruprecht, J.D., et al. 2015, Icarus, 252, 271). We investigate flux versus wavelength trends in the near-infrared data in order to constrain the properties of extinction-causing particles.

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106.04 – Carbon monoxide in the distantly active centaur 174P/Echeclus

60558 Echeclus is very unusual. It has a dual asteroid-comet designation, and is classified as a centaur. A dust-rich outburst was observed when it was at a heliocentric distance, r, of 13.1 AU pre-perihelion (Choi & Weissman 2006). Interestingly, the coma's center of brightness was not at the nucleus location, but was offset by up to 7 arcseconds (Weissman et al. 2006, Tegler et al. 2006). This was hypothesized to be a due to a fragment that split off the nucleus and began outgassing on its own (Fernandez 2009). A smaller coma was observed when Echeclus was at r = 8.5 AU, but overall, the object appears dormant with little or no extended coma observed at optical wavelengths for years at a time (Choi et al. 2015, Rousselot et al. 2015). Echeclus is too far from the Sun for any of the activity to be caused by water-ice sublimation, the dominant cause for most comets. Instead, the coma must have been generated by another mechanism, such as impact or supervolatile outgassing. If a substantial amount of the supervolatile CO were relatively near the surface and outgassing, then its emission could be detected, or significant limits could be set, through radio observations when Echeclus was near perihelion, which occurred at 2015 Apr at r = 5.8 AU. In order to better explore the volatile nature of this centaur, we searched for CO emission from the J=2-1 rotational line at 230 GHz with the Arizona Radio Observatory (ARO) 10-m Sub-millimeter Telescope (SMT) during May and June 2016 when the comet was at r = 6.1 AU, post-perihelion. We find that the CO production rate from Echeclus is substantially lower than what is typically observed for 29P/Schwassmann Wachmann 1, another distantly active comet often classified as a centaur. We report on the measurements and implications.
The SMT is operated by the ARO, the Steward Observatory, and the University of Arizona, with support through the NSF University Radio Observatories program (AST-1140030).

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106.05 – Two Color Populations of Kuiper Belt and Centaur Objects

We present new optical colors for 64 Kuiper belt objects (KBOs) and Centaur objects measured with the 1.8-meter Vatican Advanced Technology Telescope (VATT) and the 4.3-meter Discovery Channel Telescope (DCT). By combining these new colors with our previously published colors, we increase the sample size of our survey to 154 objects. Our survey is unique in that the uncertainties in our color measurements are less than half the uncertainties in the color measurements reported by other researchers in the literature. Small uncertainties are essential for discerning between a unimodal and a bimodal distribution of colors for these objects as well as detecting correlations between colors and orbital elements. From our survey, it appears red Centaurs have a broader color distribution than grey Centaurs. We find red Centaurs have a smaller orbital inclination angle distribution than grey Centaurs at the 99.3% confidence level. Furthermore, we find that our entire sample of KBOs and Centaurs exhibits bimodal colors at the 99.4% confidence level. KBOs and Centaurs with $H_V > 7.0$ have bimodal colors at the 99.96% confidence level and KBOs with $H_V < 6.0$ have bimodal colors at the 96.3% confidence level.
We are grateful to the NASA Solar System Observations Program for support, NAU for joining the Discovery Channel Telescope

Partnership, and the Vatican Observatory for the consistent allocation of telescope time over the last 12 years of this project.

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106.06 – Lightcurve Studies of Trans-Neptunian Objects from the Outer Solar System Origins Survey using the Hyper Suprime-Camera

Lightcurves can reveal information about the gravitational processes that have acted on small bodies since their formation and/or their gravitational history.
At the extremes, lightcurves can provide constraints on the material properties and interior structure of individual objects.
In large sets, lightcurves can possibly shed light on the source of small body populations that did not form in place (such as the dynamically excited trans-Neptunian Objects (TNOs)).
We have used the sparsely sampled photometry from the well characterized Outer Solar System Origins Survey (OSSOS) discovery and recovery observations to identify TNOs with potentially large amplitude lightcurves.
Large lightcurve amplitudes would indicate that the objects are likely elongated or in potentially interesting spin states; however, this would need to be confirmed with further follow-up observations.
We here present the results of a 6-hour pilot study of a subset of 17 OSSOS objects using Hyper Suprime-Cam (HSC) on the Subaru Telescope.
Subaru's large aperture and HSC's large field of view allows us to obtain measurements on multiple objects with a range of magnitudes in each telescope pointing.
Photometry was carefully measusured using an elongated aperture method to account for the motion of the objects, producing the short but precise lightcurves that we present here.
The OSSOS objects span a large range of sizes, from as large as several hundred kilometres to as small as a few tens of kilometres in diameter.
We are thus investigating smaller objects than previous light-curve projects have typically studied.

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106.07 – ALMA Observations of TNOs

Some of the most fundamental properties of TNOs are still quite poorly constrained, including diameter and density. Observations at long thermal wavelengths, in the millimeter and submillimeter, hold promise for determining these quantities, at least for the largest of these bodies (and notably for those with companions). Knowing this information can then yield clues as to the formation mechanism of these bodies, allowing us to distinguish between pairwise accretion and other formation scenarios.
We have used the Atacama Large Millimeter/Submillimeter Array (ALMA) to observe Orcus, Quaoar, Salacia, and 2002 UX25 at wavelengths of 1.3 and 0.8 mm, in order to constrain the sizes of these bodies. We have also used ALMA to make astrometric observations of the Eris-Dysnomia system, in an attempt to measure the wobble of Eris and hence accurately determine its density. Dysnomia should also be directly detectable in those data, separate from Eris (ALMA has sufficient resolution in the configuration in which the observations were made). Results from these observations will be presented and discussed.

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106.08 – Taking The Measure of Makemake's Moon

We present the discovery and characterization of S/2015 (136472) 1, a satellite of the dwarf planet Makemake. The satellite was discovered in Hubble Space Telescope (HST) imagery collected in spring of 2015, found at a separation of 0.57” and ~1,300 times fainter than Makemake at the discovery epoch. The system was imaged in two visits separated by two days, and the satellite was visible in the first visit but undetectable in the second. Previous HST satellite searches also did not reveal S/2015 (136472) 1. Current observations constrain the satellite’s orbit to be near an edge-on configuration, placing the system near a mutual event season. Follow-up observations will permit the measurement of Makemake’s mass and density, as well as identify whether there is an upcoming mutual event season. We will discuss the current state of characterization of the system and its implications for Makemake’s bulk, thermal, and surface properties, spin state, and the origin of S/2015 (136472) 1. Finally, we will address the current state of understanding regarding the population of dwarf planet satellites.

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106.09 – 2003 $_{AZ}$84: Size, shape, albedo and first detection of topographic features

We analyze two multi-chord stellar occultations by the Trans-Neptunian Object (TNO) 2003 AZ84 observed on February 3, 2012 and November 15, 2014.
They provide different elliptical limb fits that are consistent to within their respective error bars, but could also suggest a possible precession of the object (assumed here to be a Maclaurin spheroid).
The derived equatorial radius and oblateness are $R_e = 393 \pm 7$ km and $\varepsilon = 0.057$ in 2014 and $R_e = 414 \pm 13$ km and $\varepsilon = 0.165$ in 2012, respectively. Those results are consistent with single-chord events observed in January 2011 and December 2013.
The figures above provide geometric visual albedos of $p_{V(2014)} = 0.112 \pm 0.008$ and $p_{V(2012)} = 0.114 \pm 0.020$. Using the Maclaurin assumption, combined with possible rotational periods of 6.67 h and 10.56 h, we estimate density upper limits of 1.89 ± 0.16g/cm^3 and 0.77 ± 0.07g/cm^3 for the two dates, respectively.
The 2014 event provides (for the first time during a TNO occultation) a grazing chord with a gradual disappearance of the star behind 2003$_{AZ}$84's limb that lasts for more than 10 seconds. We rule out the possibility of a localized dust concentration as it would imply very high optical depth for that cloud. We favor a local topographic feature (chasm) with minimum width and depth of 22 ± 2.5 km and 7 ± 2.0 km, respectively. Features with similar depths are in fact observed on Pluto's main satellite, Charon, which has a radius of about 605 km, comparable to that of 2003$_{AZ}$84.

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107 – Planetary Rings I: Saturn Propellers and Particle Properties

107.01 – Propeller peregrinations: Ongoing observations of disk-embedded migration in Saturn's rings

The "propeller" moons within Saturn's rings are the first objects ever to have their orbits tracked while embedded in a disk, rather than moving through empty space (Tiscareno et al. 2010, ApJL). The km-sized "giant propellers" whose orbits have been tracked in the outer-A ring, as well as their smaller 0.1-km-sized brethren swarming in the mid-A ring, are not seen directly; rather, their locations are inferred by means of the propeller-shaped disturbances they create in the surrounding ring material (Tiscareno et al. 2006, Nature; Sremcevic et al. 2007, Nature; Tiscareno et al. 2008, AJ). The orbits of giant propellers are primarily Keplerian, but with clear excursions of up to several degrees longitude over a decade of observations. Most theories that have been proposed to explain the non-Keplerian motion of propeller moons (e.g., Pan et al. 2012, MNRAS; Tiscareno 2013, P&SS) rely on gravitational and/or collisional interactions between the moon and the surrounding disk, and thus hold out the prospect for directly observing processes that are important in protoplanetary scenarios and other disk systems. We will review the current dynamical models and report on recent ongoing observations by the Cassini imaging camera.

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Contributing team(s): Cassini Imaging Team

107.02 – Simulating the Librational Behaviour of Propeller Moons In The Saturnian Ring System

The propeller structure Blériot orbiting in the outer A ring of the Saturnian ring system has been one of the tremendous discoveries of the spacecraft Cassini [Tiscareno et al., 2010, ApJL]. The reconstruction of the orbital evolution of Blériot from recurrent observations in the ISS images yielded a systematic offset motion from the expected Keplerian orbit. This offset motion can be well described by three sinusoidal harmonics with amplitudes and periods of 1845, 152, 58 km and 11.1, 3.7 and 2.2 years, respectively [Sremčević et al., 2014, EPSC]. Oscillatory deviations from the Keplerian orbit are a known phenomenon for the Saturnian moons, which can be explained by resonant interactions with other moons [Spitale et al., 2006, AJ] and which look similar to the observation of Blériot.
In this work we present our results from N-Body simulations, where we integrated the orbital evolution of a test particle, orbiting at the radial position of the propeller Blériot and 15 other moons of Saturn. Our simulation yield, that gravitational interactions with the larger moons result in reasonable and observable frequencies, but the resulting amplitudes of the librations are by far too small to explain the observations. Further mechanisms are needed, to amplify the amplitudes of the forced librations -- as e.g. by moonlet-ring interactions. Inspired by the recent work of Pan and Chiang [2010, ApJL; 2012, AJ] we introduce an alternative, physically more reasonable model. In our model, the moonlet is allowed to be slightly displaced with respect to its created gaps, resulting in a repulsive force. As a result, the moonlet's longitude starts to oscillate. In the presence of the additional external forcing by the outer moons the libration amplitude gets amplified, if the forcing frequency is close to the eigenfrequency of the system. Applying our model to Blériot, we can indeed reproduce a libration period of 13 years with an amplitude of about 2000 km.

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107.03 – Analyzing Bleriot's propeller gaps in Cassini NAC images

Among the great discoveries of the Cassini mission are the propeller-shaped structures created by small moonlets embedded in Saturn's dense rings. These moonlets are not massive enough to counteract the viscous ring diffusion to open and maintain circumferential gaps, distinguishing them from ring-moons like Pan and Daphnis.
Although one of the defining features of propeller structures, well-formed partial gaps have been resolved by the Imaging Science Subsystem Narrow Angle Camera onboard the Cassini spacecraft only for the largest known propeller named Bleriot. We analyze images of the sunlit side of Saturn's outer A ring showing the propeller Bleriot with clearly visible gaps. By fitting a Gaussian to radial brightness profiles at different azimuthal locations, we obtain the evolution of gap minimum and gap width downstream of the moonlet.
We report two findings:

1) Numerical simulations indicate that the radial separation of the partial propeller gaps is expected to be 4 Hill radii (Spahn and Sremcevic, 2000, A&A). We infer Bleriot's Hill radius to be a few hundred meters, consistent with values given by Sremcevic et al. (2014, DPS) and Hoffmann et al. (2015, Icarus).
2) In order to estimate the ring viscosity in the region of Saturn's outer A ring, where Bleriot orbits, we fit several model functions (one example being the analytic solution derived by Sremcevic, Spahn and Duschl, 2002, MNRAS) describing the azimuthal evolution of the surface density in the propeller gap region to the data obtained from the image analysis. We find viscosity values consistent with the parameterization of ring viscosity by Daisaka et al. (2001, Icarus), but significantly lower than the upper limit given by Esposito et al. (1983, Icarus)

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107.04 – Hydrodynamic simulations of moonlet induced propellers and the size of Blériot

Small moons embedded in Saturn's rings can cause S-shaped density structures in their close vicinity called propellers. These structures have been predicted on base of a combined model involving gravitational scattering of test particles (creating the structure) and diffusion (smearing out the structure, see Spahn and Sremčević (2000, Astron. Astrophys.) and Sremčević et al. (2002,MNRAS)). The propeller model was confirmed later by N-body simulations, which additionally show the appearance of moonlet wakes adjacent to the S-shaped gaps (Seiß et al., 2005, GRL; Lewis and Stewart, 2009, Astron. J.). It was a great success of the Cassini mission when propellers were detected in the data of the ISS (Tiscareno et al., 2006, Nature; Sremčević et al., 2007, Nature; Tiscareno et al., 2008, Astron. J. and 2010, ApJL) and UVIS (Baillié et al., 2013) instruments. Here we present isothermal hydrodynamic simulations of propellers as a further development of the original model (Spahn and Sremčević, 2000, Astron. Astrophys.) where gravitational scattering and diffusion had to be treated separately. We confirm the correctness of the predicted scaling laws for the radial and azimuthal extent of propellers and show that the analytical solution by Sremčević et al. (2002, MNRAS) can be fitted to the azimuthal profile. Furthermore, we show that this new approach is in a good agreement with N-body simulations performed with parameters suitable for the A-ring. Finally, we present simulation results of the giant propeller Blériot and fit them to optical depth profiles gathered by the UVIS experiment aboard of the spacecraft Cassini. The fits are consistent using 600 m for the Hill radius of the moonlet and 350 cm^2/s for the kinematic shear viscosity.

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107.05 – Cause of the Infrared Opposition Surge in Saturn's C Ring

Saturn's C ring shows an opposition surge at infrared wavelengths, perhaps due to inter or intra-particle surface roughness. Blackbody fits to data from the Cassini spacecraft's Composite Infrared Spectrometer at wavelengths 20-200 um yield temperatures that rise about 4 K per radian as the solar phase angle decreases towards zero, while fits at 13.3-16.7 um yield slopes up to 8 K per radian. We explore ring particle structures compatible with this dependence on phase angle and wavelength, using Monte Carlo radiative transfer modeling. The candidate ring particle is illuminated with photon packets having wavelengths drawn from the Solar spectrum. When absorbed and re-emitted within the particle, the packets are given new wavelengths drawn from the local thermal spectrum. Each packet undergoes repeated scattering, absorption and re-emission till it escapes to infinity, so that energy is conserved exactly. The wavelength-dependent volume absorption and scattering coefficients and scattering anisotropy come from Mie calculations in which we assume the meter-sized ring particle is made up of spherical ice grains with a power-law distribution in size from um to cm. Diffraction is removed by the delta-Eddington method, since the grains lie too close together for the diffraction that occurs around isolated bodies. The Monte Carlo transfer calculations thus treat both regolith radiative transfer and the self-illumination possible on irregular surfaces. The results indicate the opposition surge is consistent with the C ring's particles having significant surface roughness in the form of craters or pits.

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107.06 – Regolith microstructure of Saturn's rings from phase and spectral effects with Cassini data

We present our ongoing analysis of the saturnian ring opposition effect seen by Cassini. The opposition effect is a peak in the intensity caused when the observer and the light source are aligned. So far, the exact origin of the ring opposition is still matter of debate. In our previous work (Deau, et al., 2013, Icarus, 226, 591-603), we compared the opposition effect morphology from ISS data with the ring optical depth and found that only the slope of the linear part of the ring phase curves was strongly correlated to the optical depth. We interpreted this as an indication of the predominant role of the interparticle shadowing at moderate phase angles (10-40deg). More recently, (Deau, 2015, Icarus, 253, 311-345), we showed that the interparticle shadowing cannot explain the behavior at low phase angles (< 1 deg), confirming our previous result. These findings led to the idea that the coherent backscatter is preponderant at the smallest phase angles. Since coherent backscatter relies on the microscopic scale of the regolith, there is a growing body of evidence that the properties of the regolith (grain size, porosity, roughness, and composition) are behind the opposition surge behavior at low phase. To confirm this claim, we now compare the surge morphology to spectral properties related to the regolith: water ice band depths and spectral slopes from VIMS data (Hedman et al., 2013, Icarus, 223, 105-130). We find that the surge morphology is strongly correlated to the band depths. We interpret this finding as an evidence that the coherent backscatter manages both the water ice band depths and the surge at low phase. In addition, we note that the correlations of the surge morphology with the spectral slopes are less strong than with the water ice band depths. This result differs from our recent results showing a strong correlation between surge morphology and red spectral slope for laboratory samples (Deau et al., 2016, Icarus, 272, 149-164). This will be discussed in terms of grain size, porosity, roughness, and composition. For the composition, our discussion will be enriched by transposing our methodology to the thermal infrared with the spectral and phase effects of the rings with CIRS data.

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107.07 – HST-STIS Spectra of Saturn's Rings and Implications for Their Reddening Agent

We obtained HST-STIS spectra of Saturn's main rings in May 2011, using the G230L (and G430L) gratings, with final averaged radial resolution of 160 (and 330) km/pixel. The dataset filled a previous 200-330nm "spectral gap" between Cassini and groundbased spectra. The data provide radial profiles as a function of wavelength, but our most basic product at this point is a set of very low-noise spectra, radially averaged over broad regions of the rings (A, B, C, and Cassini Division). The raw spectra required special processing to remove artifacts due to extended-source grating scatter. We have modeled the spectra using a new particle surface model which corrects for on-surface shadowing due to the likely very rough ring particle surfaces, and avoids overestimation of intramixed "neutral absorber". We correct for nonclassical layer effects and finite ring optical depth, and relate our observed reflectivities to the spherical albedos of individual smooth particles. We model these smooth particle albedoes using standard Hapke theory for regolith grain mixtures that are either homogeneous and "intramixed" (nonicy absorbers dispersed in water ice regolith grains) or heterogeneous "intimate" mixtures. As candidates for the nonicy contaminants we have considered amorphous carbon, aromatic-rich and aliphatic-rich organic tholins, silicates, hematite and iron metal. For the A and B rings, we find that iron metal (including a new theoretical estimate of the refractive indices of nanometer-sized grains of iron) is not spectrally steep enough in the 200-300nm range, and that aliphatic-rich tholins are either too steep at short wavelengths or too flat at long wavelengths. However, less than 1% by mass of aromatic-rich tholins provides a very good fit across the entire spectral range with no gratuitous "neutral absorber" needed, and a minimum of additional free parameters. The best fits require forward-scattering regolith grains. For the C Ring and Cassini Division, additional absorbers are needed (updated results will be given).

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107.08 – Sub-cm Particles in Saturn's Rings from VIMS, UVIS, and RSS occultations

Particles sizes in Saturn's rings roughly follow a truncated power law. One way to determine the governing parameters of the size distribution is through the analysis of differential optical depths (Zebker et al. 1983). Non-axisymmetric self-gravity wakes complicate this approach when optical depth measurements at different wavelengths are not made at same viewing geometry. Using occultations spanning a wide range of viewing angles and from multiple instruments onboard Cassini (the Ultraviolet Imaging Spectrograph (UVIS), the Visual and Infrared Mapping Spectrometer (VIMS), and the Radio Science Subsystem (RSS)), we forward-model the properties of the self-gravity wakes in Saturn's A and B rings while simultaneously constraining the parameters of the cm – sub-cm particle size distribution. In the absence of wakes, and in regions where particles smaller than ~ 8.86 mm are present, VIMS stellar occultations measure larger optical depths than UVIS stellar occultations due to the diffraction of 2.9 µm light out of the small (0.25 × 0.5 mrad) VIMS field of view compared with UVIS which measures shorter wavelength (0.15 µm) light over a much larger (6.4 × 6.0 mrad) field of view. This excess optical depth combined with RSS X-band (λ = 3.6 cm) optical depths provides a way to probe both the power law slope and the minimum particle size. In the A and B rings where self-gravity wakes are prevalent, we use the wake model of Colwell et al. (2006, 2007) with an additional free parameter representing the excess optical depth which would be measured through the gaps between opaque wakes, by VIMS compared to UVIS. In the B ring and inner A ring we find and absence of sub-cm particles and power law slopes of q ~ 2.8. In the trans-Encke region, where there are a multitude of satellite driven resonances, we find an increasing abundance of sub-cm particles as the outer edge of the A ring is approached. In the C Ring and the Cassini Division, where self-gravity wakes are absent, we find a lower limit of the size distribution of a_{min} ~ 4mm with power law slopes of q ~ 2.8–3.4 except in the triple band feature of the Cassini Division where we find evidence for self-gravity wakes in the geometrical dependence of optical depths.

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107.09D – Microwave Observations on Saturn's Main Rings

Despite considerable study, Saturn's rings continue to challenge current theories for their provenance. Water ice comprises the bulk of Saturn's rings, yet it is the small fraction of non-icy material that is arguably more valuable in revealing clues about the system's origin and age. Herein, we present new measurements of the non-icy material fraction in Saturn's main rings, determined from microwave observations obtained by Cassini Radar and EVLA.
Our Cassini Radar observations in the C Ring show an exceptionally high brightness at near-zero azimuthal angles, suggesting a high porosity of 70%-75% for the particles. Furthermore, most regions in the C ring contain about 1-2% silicates while with an enhanced abundance concentrated in the middle C ring reaching a maximum of 6%-11%. We proposed that the C ring has been continuously polluted by meteoroid bombardment for 15-90Myr, while the middle C ring was further contaminated by an incoming Centaur disrupted by Saturn tidal force. Owing to the B ring's high opacity, the particles there are likely to have 85% - 90% porosity, with corresponding non-icy material fractions of ~ 0.3% - 0.5% in the inner and outer B ring, and ~0.1% - 0.2% in the middle regions. For the A ring interior to the Encke gap, the derived non-icy material is ~0.2% - 0.3% everywhere for porosities ranging from 55% - 90%. Finally, our results for the Cassini Division indicate a non-icy material fraction of ~1% - 2% similar to most regions in the C ring, except that the Cassini Division particles are more likely to contain ~ 90% porosity due to the high opacity there. Our results here further support the idea that Saturn's rings may be less than 150 Myr old suggesting an origin scenario in which the rings are derived from the relatively recent breakup of an icy moon.
Furthermore, we calibrated and analyzed multi-wavelengths EVLA observation at wavelengths ranging from 0.7cm to 13cm. As the array operates in a wavelength regime where the absorption coefficient of water ice shows dramatic variation, the EVLA observations enable us to disentangle brightness temperature variations from changes in the particle size distribution and non-icy material abundance.

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108 – Mercury

108.01 – An Investigation of Trajectories of Atoms in Mercury's Exosphere

Mercury's neutral exosphere consists of atoms or molecules ejected from the surface that are on individual trajectories that may re-impact the surface if there is insufficient energy to escape the gravity of the planet. This is an investigation of how the radiation pressure, orbital acceleration of the planet, and planetary rotation combine together to produce complicated trajectories. Because of Mercury's non-zero eccentricity the planet is not in uniform circular motion, which leads to radial and tangential accelerations that vary throughout the Mercury year. Besides radiation pressure the trajectory of an exospheric atom is affected by the planet accelerating during the time of flight of the atom that 1) causes the atom's position with respect to the ejection point to vary in a manner that is different than if the planet were not accelerating and 2) causes the planet-atom distance to vary in a manner that is different than for a typical ballistic trajectory resulting in variation of the gravitational force that the planet exerts on the atom. These effects are small but persistent and affect where the atom re-impacts the surface, which may lead to asymmetrical distributions of atoms in the surface regolith and exosphere.
Preliminary results from simulations of ejected atoms that include 1) radiation pressure that varies with the atom's velocity due to Doppler shifting, 2) radial and tangential accelerations of the planet, and 3) the variation of the planet's gravity on the atom with distance above the planet show that atoms ejected at low energies normal to

the surface from the subsolar point re-impact on the dusk side hemisphere of the planet. However atoms ejected at high energies normal to the surface from the subsolar point re-impact on the dawn side hemisphere of the planet. A fraction of atoms ejected normal to the surface from the dawn terminator within an energy range that results in the atom re-impacting and sticking to the night side surface behind the dawn terminator are moved back to the dawn terminator due to planetary rotation. Conversely atoms ejected from the dusk terminator that re-impact and stick to the night side surface behind that terminator are rotated further behind the dusk terminator.

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108.02 – Modelling of the X-ray fluorescence from Mercury's surface and sodium exosphere

We model the fluorescent X-ray signal expected from the Mercury surface. Due to the high solar flux at Mercury, it represents a highly suitable target. Observations of this fluorescence will be performed by the Mercury Imaging X-ray Spectrometer (MIXS) on the upcoming BepiColumbo mission. Accurate modelling is required to plan observation strategies and eventually to quantify the surface composition. In addition, we also investigate the possibility of detecting fluorescence from the exosphere. We are using code modified from that used for the SMART-1 D-CIXS instrument to the Moon. Modifications include detector parameters, solar proximity, likely surface elemental components, and emission from the optically thin exosphere. Modelling of fluorescence from both the surface and exosphere are conducted, with particular emphasis on the sodium component.

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108.04 – Mercury's Pyroclastic Deposits and their spectral variability

Observations of the MESSENGER spacecraft in orbit around Mercury have shown that volcanism is a very important process that has shaped the surface of the planet, in particular in its early history.
In this study, we use the full range of the MASCS spectrometer (300-1400nm) to characterize the spectral properties of the pyroclastic deposits. Analysis of deposits within the Caloris Basin, and on other location of Mercury's surface (e.g., Hesiod, Rachmaninoff, etc.) show two main results: 1) Spectral variability is significant in the UV and VIS range between the deposits themselves, and also with respect to the rest of the planet and other features like hollows, 2) Deposits exhibit a radial variability similar to those found with the lunar pyroclastic deposits of floor fractured craters.
These results are put in context with the latest analysis of other instruments of the MESSENGER spacecraft, in particular the visible observations from the imager MDIS, and the elemental composition given by the X-Ray spectrometer. Although all together, the results do not allow pointing to compositional variability of the deposits for certain, information on the formation mechanisms, the weathering and the age formation can be extrapolated from the radial variability and the elemental composition.

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108.05 – Comparing Central Peak and Central Pit Craters on Mercury and Mars: Implications for Crustal Strength

We have measured and classified 20,782 impact craters on Mercury and 24,495 craters on Mars 5 km in diameter and larger for a comparison study of these features. We identified 1144 floor pit and 638 summit pit craters on Mars and 32 summit pit craters but no floor pits on Mercury. We also identified 1682 central peak craters on Mars and 1764 on Mercury. We computed the ratio of the pit or basal peak diameter to the crater diameter in each case and compared the results for the two bodies. Summit pits on Mars have a median pit-to-crater diameter (D_p/D_c) ratio of 0.12 compared to 0.09 on Mercury, indicating pits are slightly larger relative to their parent crater on Mars. We find no correlation of the distribution of Mercury's central pits with features attributed to volatiles, i.e. radar-bright polar craters and craters containing hollows. This indicates that Mercury's central pits form by collapse of a weak brecciated core in the central peak and do not require the presence of volatiles, as is commonly assumed for central pit formation. The median peak-to-crater diameter (D_{pk}/D_c) ratio for the peaks on which summit pits are found on both bodies is statistically identical to that of the respective normal unpitted central peaks. This indicates that the peaks on which summit pits occur form in the same manner as normal central peaks but subsequently undergo core collapse to create the summit pit. Interestingly, the median D_{pk}/D_c for Martian peaks is twice as high as for their Mercurian counterparts (0.30 versus 0.15, respectively). Because Mercury and Mars have essentially the same surface gravity, the only major difference between the two bodies that could explain this observation is target characteristics. Prior studies of the composition of the crust and the detection of larger-than-normal secondary craters have led to the proposal that Mercury's crust is stronger than the crusts of the other terrestrial planets. Mercury's low number of central pit craters, the smaller median D_p/D_c for its central pits, and the smaller median D_{pk}/D_c for its central peaks provide additional observational support of a stronger crust on the innermost planet.

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108.06 – The influence of an inner core, tides, and precession of the pericenter on the orientation of the rotation axis of Mercury

Mercury's spin axis occupies the Cassini state 1, in which the orbit normal and spin axis precess together with a long period of about 300 000 years. An accurate model of the Cassini state is needed to get a reliable estimate of its polar moment of inertia from the measured orientation of its spin axis. The polar moment of inertia provides a strong constraint on the interior structure. For long, it has been assumed that Mercury precesses as a solid body, meaning that the estimate of the polar moment of inertia may be inaccurate. Recently, there has been renewed interest for the topic, because of the recent determination of Mercury's rotation state (Earth-based radar observations, MESSENGER data), as well as the possibility of future more accurate measurements with the BepiColombo mission. Here, we revisit the influence of the liquid outer core, solid inner core, and precession of the pericenter (period of about 127 000 years). Previous studies have concluded that those effects may have an influence above or up to about an order of magnitude below the present uncertainty on the obliquity. We consider three-layer interior models with a mantle (including the crust), a liquid outer core and a solid inner core. Those models are constrained by the mass, radius, second-degree gravity field coefficients and libration amplitude. We adapt to Mercury a Cassini state model previously developed for synchronous satellites, in which we express the spin axis motion in a frame based on the Laplace plane. We take into account the solar gravitational torque exerted on each layer, the internal gravitational torques between the internal layers and the pressure torques as well as the dissipative viscous torques exerted at the interfaces. We reassess the effect of tidal periodic deformations on the torques, currently thought to be two orders of magnitude below the present uncertainty on the spin orientation determination. Finally, we use the current rotation data to constrain Mercury's interior and evaluate potential improvements with future data.

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109 – Moon Interior

109.01 – Cassini State Transitions with a Fossil Figure

The Moon has experienced large obliquity variations during Cassini state transitions which greatly impact tidal heating, and the long-term stability of polar volatiles. It has been known for centuries that the lunar rotational and tidal bulges are much larger than expected. The South Pole-Aitken basin can explain a large fraction of the excess deformation. Accounting for the contribution of this basin (and other large basins), the remaining excess deformation arises due to a fossil figure established when the Moon orbited much closer to Earth than it does today. Previous studies assume that the present, excess deformation is entirely preserved throughout Cassini state transitions. This ignores basin contributions to the excess deformation, and requires an interior with infinite rigidity. We consider Cassini state transition models that take into account basin contributions to the excess deformation, and the effect of finite rigidity on the fossil figure.

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109.02D – Impact of Infrared Lunar Laser Ranging on Lunar Dynamics

Since 2015, in addition to the traditional green (532nm), infrared (1064nm) has been the preferred wavelength for lunar laser ranging at the Calern lunar laser ranging (LLR) site in France. Due to the better atmospheric transmission of IR with respect to Green, nearly 3 times the number of normal points have been obtained in IR than in Green [*C.Courde et al 2016*]. In our study, in addition to the historical data obtained from various other LLR sites, we include the recent IR normal points obtained from Calern over the 1 year time span (2015-2016), constituting about 4.2% of data spread over 46 years of LLR. Near even distribution of data provided by IR on both the spatial and temporal domain, helps us to improve constraints on the internal structure of the Moon modeled within the planetary ephemeris : INPOP [*Fienga et al 2015*]. IERS recommended models have been used in the data reduction software GINS (GRGS,CNES) [*V.Viswanathan et al 2015*]. Constraints provided by GRAIL, on the Lunar gravitational potential and Love numbers have been taken into account in the least-square fit procedure. New estimates on the dynamical parameters of the lunar core will be presented.

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Contributing team(s): LLR Observers : Astrogeo-OCA, Apache Point, McDonald Laser Ranging Station, Haleakala Observatory, Matera Laser Ranging Observatory

109.03D – Zinc and volatile element loss during planetary magma ocean phases

Zinc is a moderately volatile element and a key tracer of volatile depletion on planetary bodies due to lack of significant isotopic fractionation under high-temperature processes. Terrestrial basalts have δ^{66}Zn values similar to some chondrites (+ 0.15 to 0.3‰; where [{^{66}Zn/^{64}Zn$_{sample}$/^{66}Zn/^{64}Zn$_{JMC-Lyon-1}$} × 1000]) and elevated Zn concentrations (100 ppm). Lunar mare basalts yield a mean δ^{66}Zn value of +1.4 ± 0.5‰ and have low Zn concentrations (~2 ppm). Late-stage lunar magmatic products, such as ferroan anorthosite, Mg-suite and Alkali suite rocks exhibit heavier δ^{66}Zn values (+3 to +6‰). The heavy δ^{66}Zn lunar signature is thought to reflect evaporative loss and fractionation of zinc, either during a giant impact or in a magma ocean phase.
We explore conditions of volatile element loss within a lunar magma ocean (LMO) using models of Zn isotopic fractionation that are widely applicable to planetary magma oceans. For the Moon, our objective was to identify conditions that would yield a δ^{66}Zn signature of ~ +1.4‰ within the mantle, assuming a terrestrial mantle zinc starting composition.
We examine two cases of zinc evaporative fractionation: (1) lunar surface zinc fractionation that was completed prior to LMO crystallization and (2) lunar surface zinc fractionation that was concurrent with LMO crystallization. The first case resulted in a homogeneous lunar mantle and the second case yielded a stratified lunar mantle, with the greatest zinc isotopic enrichment in late-stage crystallization products. This latter case reproduces the distribution of zinc isotope compositions in lunar materials quite well.
We find that hydrodynamic escape was not a dominant process in losing Zn, but that erosion of a nascent lunar atmosphere, or separation of condensates into a proto-lunar crust are possible. While lunar volatile depletion is still possible as a consequence of the giant impact, this process cannot reproduce the variable δ^{66}Zn found in the Moon. Outgassing during magma ocean phases would have led to volatile-depleted planetesimal feed-stocks that would have profoundly affected the ultimate volatile inventories of larger planetary bodies.

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110 – Comets: 67P-CG I: Overview and Primary Results

110.01 – The Rosetta Alice Ultraviolet Spectrograph Investigation: The First UV Spectrograph to Reach a Comet—Results Overview

Numerous scientific results have been obtained from the exploration of comet 67P/Churyumov-Gerasimenko by the ESA/NASA Rosetta mission. The Alice far/extreme-UV spectrograph aboard Rosetta is one of three US instruments provided by NASA to this mission; it is the first UV spectrograph to reach any comet. We will summarize the main results obtained by the Alice instrument to date, including both surface and coma studies. Notable results we will highlight will include: the discovery of electron impact excitation as the dominant UV emission mechanism near the comet, the detection of molecular oxygen at surprisingly high abundance in the coma, the lack of strong water-ice signatures on the comet’s surface during the approach to perihelion, numerous results concerning cometary outbursts, and a large database of systematics relating to atomic and molecular species abundances as the comet approached and then receded from the Sun over a span of two year surrounding the comet’s August 2015 perihelion.

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110.02 – Evolution of the FUV Surface Properties of 67P/Churyumov-Gerasimenko through its 2015 Perihelion Passage

Alice, NASA's lightweight and low-power far-ultraviolet (FUV) imaging spectrograph onboard ESA's comet orbiting spacecraft *Rosetta* (Stern et al. 2007, *Space Sci. Rev*. 128, 507), has just completed its characterization of the nucleus and coma of the Jupiter family comet 67P/Churyumov-Gerasimenko (C-G). With a spectral range from 700-2050 Å, *Alice* was able to monitor the sunlit surface of C-G in order to establish if there was variability in the FUV reflectivity across the nucleus, determine if there were distinct spectral features associated with various morphological regions, and infer compositional makeup of the comet. Using spatially resolved pre-perihelion data, the FUV phase dependence, albedo, and spectral slope were derived for the nucleus (Feaga et al. 2015, *A&A* 583, A27) and were consistent with a homogeneous layer of dust covering the northern hemisphere. During the increase in activity around perihelion and change of seasons on the comet, the *Rosetta* suite of instruments has shown evidence of surface changes, mass movement of material, and transient patches of ice. The FUV properties of the nucleus throughout the perihelion passage inside of 3 AU, including observations during a zero phase flyby and its associated opposition surge and a search for exposed water ice on the surface, will be presented here and compared to the early pre-perihelion characteristics.

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110.03 – Icy outbursts from comet 67P/Churyumov-Gerasimenko as observed by the Alice FUV spectrograph

Since the *Rosetta* spacecraft's historic rendezvous with 67P/Churyumov-Gerasimenko on 6 August 2014, the Alice far-ultraviolet spectrograph (700-2050Å) has monitored gas and dust emissions from the comet. During this time, Alice has observed several large dust outbursts. During such outbursts, the brightness of sunlight reflected from dust can increase by almost two orders of magnitude on timescales of a few tens of minutes. Typically, the reflectance spectrum of dust is very similar to that of the pre-perihelion nucleus: dark and relatively featureless with a blue spectral slope. However, a subset of the dust outbursts show a markedly different character with dust that is bright--in some cases brighter than the sunlit nucleus itself-- and displaying a strong absorption feature around 1700Å, characteristic of water ice. In such outbursts, the observed "dust" is likely to consist primarily of icy grains. We focus on two of these icy outbursts that occurred on 10 July 2015 and 13 September 2015 showing spectra from before, during, and after the events and comparing them to spectra of the nucleus obtained contemporaneously and from several months before and after perihelion.

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110.04 – The dust environment of 67P/Churyumov-Gerasimenko as seen through Rosetta/OSIRIS

The ESA's Rosetta spacecraft had the unique opportunity to stay in the vicinity of the comet for two years, observing how the comet evolved while approaching the Sun, passing through perihelion and then moving outwards. OSIRIS, the Optical, Spectroscopic, and Infrared Remote Imaging System onboard Rosetta, imaged the nucleus and the dust environment of 67/Churyumov-Gerasimenko since the beginning of post-hibernation operations in March 2014. We focus here on dust studies carried on with OSIRIS.
Images obtained in different filters in the visible wavelength range have been used to study the unresolved dust coma, investigating its diurnal and seasonal variations and providing insights into the dust composition. A correlation has been found between the level of diurnal activity and the region of the nucleus surface in sunlight, suggesting that the topography and/or composition of the surface play an important role. The overall activity increases while the comet is approaching the Sun, peaking about a month after perihelion. Comparison with ground-based observations will allow to understand if the dust coma behaves in similar ways at small scales – as observed by Rosetta/OSIRIS – and at large scales – as observed from ground. Several times during the mission, we acquired images spanning the phase angle range 0-165 degrees. They are used to determine the dust phase function in different wavelengths, its evolution with heliocentric distance and to investigate the intimate nature of cometary dust aggregates by solving the inverse scattering problem. A large amount of individual aggregates is present in the vicinity of 67P/Churyumov-Gerasimenko. We used OSIRIS NAC and WAC images to determine the aggregate properties: size and distance distributions, colors and rotation. Thanks to observations performed at different heliocentric distances, we address how those properties are changing with heliocentric distance.

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Contributing team(s): the OSIRIS Team

110.05 – Ground truth of (sub-)micrometre cometary dust – Results of MIDAS onboard Rosetta

The investigation of comet 67P by Rosetta has allowed the comprehensive characterisation of pristine cometary dust particles ejected from the nucleus. Flying alongside the comet at distances as small as a few kilometres, and with a relative velocity of only centimetres per second, the Rosetta payload sampled almost unaltered dust. A key instrument to study this dust was MIDAS (the Micro-Imaging Dust Analysis System), a dedicated atomic force microscope that scanned the surfaces of hundreds of (sub-)micrometre sized particles in 3D with resolutions down to nanometres. This offers the unique opportunity to explore the morphology of smallest cometary dust and expand our current knowledge about cometary material.
Here we give an overview of dust collected and analysed by MIDAS and highlight its most important features. These include the ubiquitous agglomerate nature of the dust, which is found at all size scales from the largest (>10 µm) through to the smallest (<1 µm) dust particles. The sub-units show characteristic sizes and shapes

that are compared with model predictions for interstellar dust. Our findings constrain key parameters of the evolution of the early Solar System. We will discuss which dust growth model is favoured by the observed morphology and how the results restrict cometary formation. Finally, dust particles detected by MIDAS resemble primitive interplanetary dust which is a strong argument for a common cometary origin.

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110.06 – Reconstruction of the Abydos ROSETTA/Philae landing site at very high spatial resolution

The Rosetta/Philae module landed in a very uneven area called Abydos. The landing site has been identified on images of this region acquired by the OSIRIS imaging system aboard the orbiter before (Oct. 2014) and after (Dec. 2014) the landing (Lamy et al., in prep.). Abydos exhibits a complex topography including numerous cliffs, several overhangs and lots of boulders (Lucchetti et al. A&A 585, L1, 2016). This makes its reconstruction a challenging task for 3D reconstruction techniques. We use a very carefully selected set of high-resolution OSIRIS images acquired between March 2016 and August 2016 to reconstruct the detailed topography of the Abydos neighborhood using a method called ``multiresolution photoclinometry by deformation'' (MPCD, Capanna et al., The Visual Computer, 29(6-8): 825-835, 2013). We also check the compatibility of the local DTM comparing the panoramic images obtained by the CIVA-P instrument aboard PHILAE with synthetic images created with the DTM, and we compute the distances, incidence and emission angles during the acquisition of these images.

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Contributing team(s): OSIRIS Team

110.07 – Comet 67P's morphological dichotomy and surface evolution from the Rosetta/OSIRIS camera

The Rosetta mission orbited comet 67P/Churyumov-Gerasimenko from Aug, 2014 to Sep, 2016. During this time, it obtained the most comprehensive image dataset for a comet's nucleus in terms of resolution, as well as spatial and temporal coverage, using the OSIRIS camera. These images have shown the surface of the comet to be very diverse in its texture and geology. In particular, the 2-year duration of the mission permitted imaging of both hemispheres and the possibility to assess the morphology and surface evolution of comet's 67P's northern hemisphere before and after perihelion passage (in Aug, 2015). The northern hemisphere (NH) is morphologically diverse including regions of consolidated, often fractured materials, smooth terrains showing aeolian-like landforms and seasonal variations, dust-covered areas suggestive of an air-fall-like mechanism, and irregular large-scale depressions suggestive of massive outburst activities. On the other hand, the southern hemisphere (SH) shows a clear dichotomy with the North showing regionally rougher terrains with little or no smooth deposits. Similarly, dusty coatings that were observed in the northern hemisphere are generally lacking in addition to the absence of large depressions. Overall, the SH shows significantly less topographical variation in comparison to the NH. The difference in relief between the NH and SH may be explained by the differences in erosional extent between both hemispheres. The SH has a shorter yet more intensive summer (close to perihelion), which could result in levels of erosion in the SH that are up to a factor of 3 higher than that of the NH. Another notable difference between both hemispheres is the absence of smooth deposits and dust coatings in the SH. The absence of similar deposits in the south may suggest that activity in the SH occurs with much higher intensity leading to ejection of dust particles at velocities exceeding comet's escape velocity. During the meeting, we plan to summarize the key morphological attributes of comet 67p and highlight the major morphological changes that occurred in the northern hemisphere before and after perihelion passage.

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Contributing team(s): ROSETTA/OSIRIS

110.08 – Exploring the fission and reconfiguration cycle of comet 67P/Churyumov-Gerasimenko

In Hirabayashi et al. (Nature, 2016) the nucleus of comet 67P/Churyumov-Gerasimenko (67P) is studied with a focus on the straight cracks observed on the Hapi region. These cracks were shown to have formed during a period of fast rotation and led to a proposed evolutionary scenario in which the nuclei may eventually split into two components and recombine to create a new bilobate configuration. Other bilobate nuclei should be subject to such a reconfiguration process, based on the relative sizes of the components, suggesting that this evolutionary scenario may be common for bilobate nuclei which comprise the majority of comet nuclei observed at high spatial resolution. Such reconfigurations could explain the observed occurrence of comet nucleus splitting and brightening events, which still lack a definitive geophysical understanding. Motivated by the proposed theory in Hirabayashi et al., the current work explores the dynamics of the 67P nucleus' rotation rate, fission limits, and subsequent dynamics. One aspect of the theory posits that the comet's distant Jupiter flybys will cause the latitude of the sub-solar point at perihelion to vary chaotically, leading to periods of net positive and negative torques and causing the nucleus to spin-up and spin-down in a random fashion. We analyze the current 67P nucleus shape and orbit to estimate the characteristic time-scale of this rotational evolution, providing an estimate of the current nucleus lifetime in its current configuration. Once the nucleus reaches a spin period shorter than ~7 hours the components will fission into a bound orbit, with the components subsequently reimpacting at speeds less than local escape speed (about 0.4 m/s). The current study extends Hirabayashi et al., explicitly modeling the mutual gravity and orbital dynamics of the head and body, assuming that the head and body rest on each other with the current shape of the 67P nucleus. The results show that when the components are released at a spin period between 6.5 hr and 7 hr, the components will separate and subsequently collide with a low impact speed. The orbital and rotational dynamics of the system components after fission are explored as a function of the initial spin rate at fission.

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110.09D – Laboratory Measurements of Synthetic Pyroxenes and their Mixtures with Iron Sulfides as Inorganic Refractory Analogues for Rosetta/VIRTIS' Surface Composition Analysis of 67P/CG

The Visible and InfraRed Thermal Imaging Spectrometer VIRTIS on board Rosetta provided 0.25-5.1 µm spectra of 67P/CG's surface (Capaccioni et al., 2015). Thermally corrected reflectance spectra display a low albedo of 0.06 at 0.65 µm, different red VIS and IR spectral slopes, and a broad 3.2 µm band. This absorption feature is due to refractory surface constituents attributed to organic components, but other refractory constituents influence albedo and spectral slopes. Possible contributions of inorganic components to spectral characteristics and spectral variations across the surface should be understood based on laboratory studies and spectral modeling. Although a wide range of silicate compositions was found in "cometary" anhydrous IDPs and cometary dust, Mg-rich crystalline mafic minerals are dominant silicate components. A large fraction of silicate grains are Fe-free enstatites and forsterites that are not found in terrestrial rocks but can be synthesized in order to provide a basis for laboratory studies and comparison with VIRTIS data. We report the results of the synthesis, analyses, and spectral reflectance measurements of Fe-free low-Ca pyroxenes (ortho- and clinoenstatites). These minerals are generally very bright and almost spectrally featureless. However, even trace amounts of Fe-ions produce a significant decrease in the near-UV reflectance and hence can contribute to slope variations. Iron sulfides (troilite, pyrrhotite) are among the most plausible phases responsible for the low reflectance of 67P's surface from the VIS to the NIR. The darkening efficiency of these opaque phases is strongly particle-size dependent. Here we present a series of reflectance spectra of fine-grained synthetic enstatite powders mixed in various proportions with iron sulfide powders. The influence of dark sulfides on reflectance in the near-UV to near-IR spectral ranges is investigated. This study can contribute to understand the shape of reflectance spectra of 67P's surface at different spectral ranges. Implications for the VIRTIS data analysis are discussed.

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Contributing team(s): VIRTIS Team

111 – Disk Observations and Processes

111.01 – Coupling protoplanetary disk formation with early protostellar evolution: influence on planet traps

Protoplanetary disk structures are known to be shaped by various thermal and compositional effects such as (though not limited to) shadowed regions, sublimation lines, density bumps... The resulting irregularities in the surface mass density and temperature profiles are key elements to determine the location where planetary embryos can be trapped. These traps provide hints of which planets are most likely to survive, at what distance from the star, and potentially with what composition (Baillié, Charnoz, Pantin, 2015, A&A 577, A65; Baillié, Charnoz, Pantin, 2016, A&A 590, A60). These structures are determined by the viscous spreading of the disk, that is initially formed by the collapse of the molecular cloud.
Starting from the numerical hydrodynamical model detailed in Baillié & Charnoz., 2014, ApJ 786, 35 which couples the disk thermodynamics, its photosphere geometry, its dynamics and its dust composition in order to follow its long-term evolution, we now consider the early stages of the central star. We model the joint formation of the disk and the star: their mass are directly derived from the collapse of the molecular cloud while the star temperature, radius and brightness are interpolated over pre-calculated stellar evolutions. Therefore, our simulations no longer depend on the initial profile of the "Minimum Mass Solar Nebula", and allow us to model the influence of the forming star on the protoplanetary disk. In particular, we will present the resulting distribution of the sublimation lines of the main dust species, as well as the locations of the planet traps at various disk ages. In the longer term, we intend to investigate the influence of the star properties on the selection of the surviving planets.

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111.02 – Stochastic Migration in a Dissipating Disk

It is yet unclear whether the majority of planets formed in situ in their presently observed locations or if they formed distant from their current locations and migrated through the gas and dust protoplanetary disk extant early in their host star's lifetime. Migration simulations generally produce an abundance of planets near mean motion resonances (MMRs); however, statistical analysis of the observed population of exoplanets shows only a very modest enhancement of planets near MMRs and a large number in a continuum of period ratios. It has previously been suggested that migration through a turbulent, dissipating disk may disrupt the resonances formed via migration and approximately reproduce the period ratios of pairs of planets observed in planets observed by Kepler. Here we expand on this analysis to include more realistic dissipation and turbulence parameterizations and compare the results of our simulations to the architectures of higher multiplicity systems observed by Kepler as well as individual planet pairs. We thus place tighter constraints on the turbulence and dissipation properties of disks during planet formation and migration.

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111.03 – A Novel Approach to Constraining the Lifetime of Primordial Gas in Circumstellar Disks

The lifetime of primordial gas in circumstellar disks limits the timescale for gas-giant planet formation, determines the impact of gas-particle dynamics throughout disk evolution, and therefore influences the composition and architecture of planetary systems forming from these disks. Current estimates of the gas lifetime are based mainly on indirect tracers of the primordial gas, predominately IR through sub-mm dust and CO emission, in systems of different ages. However, these conventional gas tracers may be less reliable in older systems where the gas-to-dust ratio is highly uncertain and observations suggest that carbon may be severely depleted from the gas relative to interstellar abundances. Here we investigate the evolution of primordial disk gas using a novel approach based on evidence from our own solar system. The enhanced carbon-to-nitrogen (C/N) ratios in meteorites and comets relative to the solar value suggest that N is less likely than C to be sequestered into the solid phase as the disk evolves. Therefore, observable N-bearing volatile species such as N_2H^+ may be more accurate tracers of the gas than CO in older disks. N_2H^+ was detected in two mature, ~5-11 Myr old, disks in the Upper Scorpious OB Association using ALMA. Comparison with previous CO measurements of these sources by Barenfeld et al. (2016) result in high N_2H^+/CO flux ratios relative to estimates of comparable measurements for younger, gas-rich disks based on a survey by Öberg et al. (2010, 2011). These preliminary results demonstrate that the mature disks retain primordial gas and may suggest a greater depletion of C relative to N from the gas as the disk evolves. Chemical modeling of these systems will aid in determining molecular column densities and relating the observed emission to the total molecular hydrogen mass.

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111.04 – HL Tau's Morphology: Planets, Planetesimals, and Small Grains

Recent observations of HL Tau revealed remarkably detailed structure within the system's circumstellar disc. A range of hypotheses have been proposed to explain the morphology, including, e.g., planet-disc interactions, condensation fronts, and secular gravitational instabilities. While embedded planets seem to be able to explain some of the major structure in the disc through interactions with gas and dust, the substructure (such as minor rings) are not so easily reproduced. Here, we show that dynamical interactions between planets and an initial population of large planetesimals can potentially explain both the major and minor banded features within the system. In this context, the small grains, which are coupled to the gas and reveal the disc morphology, are produced by the collisional evolution of the newly-formed planetesimals, which are ubiquitous in the system and are decoupled from the gas.

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111.05 – The Evolution of the FU Orionis Disk, and the Seeds of Planet Formation

Young stars form new planetary systems during the collapse of a giant cloud of gas and dust. Tiny dust particles and gas parcels collide and stick together, growing slowly into planetary cores and then full-size planets. But is this process a steady and slow one, or are there bumps in the road to planet construction? In 1936, the young star FU Orionis (FU Ori) became 100 times brighter in only a few short months. Although astronomers didn't realize at the time, FU Ori was undergoing a "burst" of accretion -- instead of a slow trickle of material falling into the central star, nearly 20 Jupiters worth of material have fallen in and burned since 1936. This sustained flow is a large fraction of the entire measureable disk mass (both gas and dust) surrounding FU Ori. FU Ori has slowly faded over the past 80 years, reducing by approximately 1 mag. in B. But what changes did this increased brightness wreak upon FU Ori's disk, and what implications would it have for any planets that might have formed or form later? Unlike most observed young stars, FU Ori and its (~ 10) brethren with similar behavior show no evidence of crystalline dust grains like forsterite (peridot), and the temperatures at an Earth-equivalent distance would have risen from room temperature to a scalding 1000 degrees Kelvin.
Our study with SOFIA/FORCAST, in comparison with our previous study with Spitzer/IRS, provides the first multi-epoch infrared spectroscopic study of an FUor, as it appeared in 2004 and 2016. First, the continuum (the energy emitted by viscous heating in the disk) has decreased by 13% but is still fit by a 7200 K blackbody at 13% less strength; second, the heating source behind disk's atmosphere (similar to a stellar atmosphere, as the superheated inner disk is at the same temperature as a typical star) has also decreased, exciting less high temperature water vapor. This change has not completely propagated to the rest of the disk. The silicate dust remains unchanged. We conclude that the material in the innermost portion of the disk, which has been cascading onto the central star, has been slowly reducing, or cooling, and is not being resupplied on this timescale.

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111.06 – ALMA 1.3 mm observations of the Fomalhaut System

We present ALMA Band 6 (1.3 mm) observations of Fomalhaut and its debris disk. Since the system is relatively close at 7.7 pc, it has been the target of numerous studies at multiple wavelengths, and can serve as a testbed for debris disk evolution models and planet-disk interactions. Outstanding issues that need to be resolved to properly characterize the debris include tightening constraints on the spectral index in the submm/mm regime and determining whether there is indeed excess over the stellar emission, indicating the presence of an inner debris disk or ring.
These ALMA 1.3 mm observations provide the highest resolution observations to date of the mm grains the outer ring. Tight constraints are placed on the geometry of the disk and on the mm-wavelength spectral index. We explore fitting the debris disk model in the image plane in addition to the standard method of fitting the visibilities. The results are compared and potential advantages/disadvantages of each approach are discussed.
The central emission detected is indistinguishable from a point source, with 0.89 mJy being the best fit flux of the host star for Fomalhaut itself. This implies that any inner debris component must contribute little to the total central emission. Moreover, the stellar flux is less than 70% of that predicted by extrapolating a blackbody from the constrained photosphere temperature and just over 70% of the flux if extrapolating from the far infrared. This behavior is similar to that seen in the Sun for submm/mm wavelengths, but even more pronounced. Currently, insufficient data exists to properly constrain the degree to which stellar atmospheres affect the observed flux in the submm/mm regime. This result is part of an ongoing larger project focused on measuring the emission from stellar atmospheres at submm/mm wavelengths, which directly impacts inferred excesses for debris disk studies.

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112 – Extrasolar Planets: Discoveries

112.01D – A Neptune-sized transiting planet closely orbiting a 5-10-million-year-old star

Theories of the formation and early evolution of planetary systems postulate that planets are born in circumstellar disks, and undergo radial migration during and after dissipation of the dust and gas disk from which they formed. The precise ages of meteorites indicate that planetesimals - the building blocks of planets - are produced within the first million years of a star's life. A prominent question is: how early can one find fully formed planets like those frequently detected on short orbital periods around mature stars? Some theories suggest the in situ formation of planets close to their host stars is unlikely and the existence of such planets is evidence for large scale migration. Other theories posit that planet assembly at small orbital separations may be common. Here we report on a newly-born, transiting planet orbiting its star every 5.4 days. The planet is 50 per cent larger than Neptune, and its mass is less than

3.6 times Jupiter (at 99.7 per cent confidence), with a true mass likely to be within a factor of several of Neptune's. The 5-10 million year old star has a tenuous dust disk extending outwards from about 2 times the Earth-Sun separation, in addition to the large planet located at less than one-twentieth the Earth-Sun separation.

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112.02 – Ultra-Short-Period Planets in K2: New Results From SuPerPiG

Ultra-short-period planets, with orbital periods of less than 1 day, are a challenge to theories of planet formation. The SuPerPiG collaboration (Short-Period Planet Group) reports on 19 candidates identified in Campaigns 0-5 of the K2 mission. Planet candidates range in size from 0.7-16 Earth radii and in orbital period from 4.2 to 23.5 hours. One candidate (EPIC 203533312, Kp=12.5) is among the shortest-period planet candidates discovered to date (P=4.2 hours), and, if confirmed as a planet, must have a density of at least rho=8.9 g/cm^3 in order to not be tidally disrupted. Five candidates have nominal radius values in the sub-Jovian desert (R_P=3-11 R_E and P<=1.5 days) where theoretical models do not favor their long-term stability; the only confirmed planet in this range is thought to be disintegrating (EPIC 201637175). Based on an assessment of our survey's completeness, we estimate an occurrence rate for ultra-short-period planets among K2 target stars that is about half that estimated from the Kepler sample, raising questions as to whether K2 systems are intrinsically different from Kepler systems, possibly as a result of their different galactic location.

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112.03 – Gemini Planet Imager Exoplanet Survey: Key Results Two Years Into The Survey

The Gemini Planet Imager Exoplanet Survey (GPIES) is targeting 600 young, nearby stars using the GPI instrument. We report here on recent results obtained with this instrument from our team.
Rameau et al. (ApJL, 822 2, L2, 2016) presented astrometric monitoring of the young exoplanet HD 95086 b obtained with GPI between 2013 and 2016. Efficient Monte Carlo techniques place preliminary constraints on the orbital parameters of HD 95086 b. Under the assumption of a coplanar planet–disk system, the periastron of HD 95086 b is beyond 51 AU. Therefore, HD 95086 b cannot carve the entire gap inferred from the measured infrared excess in the SED of HD 95086. Additional photometric and spectroscopic measurements reported by de Rosa et al. (2016, apJ, in press) showed that the spectral energy distribution of HD 95086 b is best fit by low temperature (T~800-1300 K), low surface gravity spectra from models which simulate high photospheric dust content. Its temperature is typical to L/T transition objects, but the spectral type is poorly constrained. HD 95086 b is an important exoplanet to test our models of atmospheric properties of young extrasolar planets.
Direct detections of debris disk are keys to infer the collisional past and understand the formation of planetary systems. Two debris disks were recently studied with GPI:
- Draper et al. (submitted to ApJ, 2016) show the resolved circumstellar debris disk around HD 111520 at a projected range of ~30-100 AU using both total and polarized H-band intensity. Structures in the disks such as a large brightness asymmetry and symmetric polarization fraction are seen. Additional data would confirm if a large disruption event from a stellar fly-by or planetary perturbations altered the disk density
- Esposito et al. (submitted to ApJ, 2016) combined Keck NIRC2 data taken at 1.2-2.3 microns and GPI 1.6 micron total intensity and polarized light detections that probes down to projected separations less than 10 AU to show that the HD 61005 debris disk ("The Moth") support the premise of a planet-perturbed disk.
These new data, and additional interesting targets, will be presented and discussed. This work is partially supported by NASA NNX14AJ80G.

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Contributing team(s): GPIES

113 – Centaurs/Kuiper II

113.01 – Surface Color Frequencies and Ratios Within the Kuiper Belt

We have an understanding of the surface properties for the largest Kuiper belt objects (KBOs) which retain their primordial inventory of volatile ices. The vast majority of the known dwarf-planet sized bodies are bright enough to be studied through optical and infrared spectroscopy. For the typically smaller > 22 mag KBO, we must rely instead on what colors reveal by proxy; yet this picture remains incomplete. Most KBO physical property studies examine the hodgepodge set of objects discovered by various surveys with different and varying detection biases that make it difficult if not impossible to accurately estimate the sizes of the different surface color groups residing in the modern-day Kupier belt. The Colours of the Outer Solar System Origins Survey (Col-OSSOS) probes the surface properties within the Kuiper belt primarily through near simultaneous g,r and J colors with the Gemini North Telescope. The survey targets KBOs brighter than 23.6 r′ mag found by the Outer Solar System Origins Survey (OSSOS). With Col-OSSOS, we have a sample of KBO colors measured for a set of objects detected in a brightness limited survey, with a well-measured detection efficiency. This affords the first opportunity to explore the true frequency of surface colors within the Kuiper belt, subdivided by dynamical classification.
Using the ~30 KBOs studied from the first complete OSSOS block, we present the observed and debiased ratio of neutral to red KBOs. We also measure the populations of the three color KBO subgroups (the red and neutral dynamically excited population and the red cold classical belt). Additionally, Kuiper belt formation models predict that the dynamically excited KBOs (hot classical belt, resonant orbits, and scattered disk) were implanted during Neptune's migration. With the true frequency of neutral to red bodies from Col-OSSOS, we examine the implications for the radial color distribution in the primordial planetesimal disk from which the excited KBOs originated.

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113.02 – Col-OSSOS: A new ugrJ taxonomy for trans-Neptunian objects

The surfaces of trans-Neptunian objects (TNOs) are poorly understood. Very little has been discerned about the compositions of most small TNOs. In recent years however, some concrete knowledge about the surface colour distribution of TNOs has come to light. It is now generally accepted that small TNOs fall into at least three classes of object based on their surface colours and albedo. Despite nearly two decades of gathering TNO surface information however, a taxonomy has still not been agreed upon. From Col-OSSOS u, g, r, and J photometry, we find significantly different clustering of (u-g) colour in the optically red, dynamically cold TNOs as compared to similarly optically coloured dynamically excited TNOs. One of the goals of the Colours of the Outer Solar System Origins Survey is the development of a robust TNO taxonomy. This 4 year program which started in 2014B is simultaneously using the Gemini-North and Canada-France-Hawaii telescopes to gather near simultaneous u, g, r, and J spectral photometry of all targets in the Outer Solar System Origins Survey (OSSOS) brighter than r'=23.6 (120 expected). The focus of Col-OSSOS is completeness and consistency, with the same SNR=25 being reached in all bands, for all targets brighter than our depth limit. Col-OSSOS will provide the first brightness-complete, compositional-dynamical map of the Outer Solar System, from which key hypotheses about the Solar System's cosmogony can be tested. After an overview of the survey's design and techniques, we will present the observed colours from the first complete block. Even with just ~30 targets, the precise photometry afforded by Col-OSSOS has already revealed the existence of 3 separate TNO taxons or classes, which become obvious when their (u-g), (g-r), and (r-J) colours are considered together. In particular, the so-called cold classical TNOs, which stand out because of their dynamically quiescent orbits, while possessing similar (g-r) and (r-J) colours as other red TNOs, exhibit extremely red (u-g) colours, roughly 0.5 magnitudes redder than the typical (u-g) of the red dynamically excited objects. These classes appear to exhibit a continuum in colour, rather than occupying similar mean colours for all class members.

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113.03 – Tracking Neptune's Footprints with High-Perihelion Resonant TNOs

Recent surveys (Sheppard et al. 2016) have significantly increased the known number of high-perihelion trans-Neptunian objects located near mean motion resonances with Neptune. Many of these objects likely had their pericenters raised during Kozai cycling while they were trapped in resonance with Neptune. We numerically model the production of these objects under a variety of Neptune migration scenarios. We find that the modern semimajor axis distribution of this population is dependent on Neptune's early migration. If the total migration time is ~300 Myrs or longer, a significant fraction of high-perihelion objects will be located slightly closer to the Sun than the modern resonance locations. Meanwhile, if Neptune reaches its modern location within ~100 Myrs or less, nearly all high-perihelion objects will still be located at the resonance locations. This effect is strongest for resonances between the 7:3 and 4:1 MMR locations, which are located between ~53 and ~76 AU. For resonances further than the 4:1 (~76 AU), the dependence on Neptune's migration is not present because the timescales required for resonance capture and perihelion-lifting are very long. This distant resonant population represents a more recently generated set of orbits under any plausible migration scenario.

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113.04 – Discovery of A New Retrograde Trans-Neptunian Object: Hint of A Common Orbital Plane for Low Semi-Major Axis, High Inclination TNOs and Centaurs

The origin of high inclination objects beyond Jupiter, including trans-Neptunian objects (TNOs) and Centaurs, remains uncertain. We report the discovery of a retrograde TNO, which we nickname "Niku", detected by the Pan-STARRS 1 Outer Solar System Survey. The numerical integrations show that the orbital dynamics of Niku are very similar to those of 2008 KV42 (Drac), with a half-life of ~ 500 Myr and analogous orbital evolution. Comparing similar high inclination members announced by the Minor-Planet Center (q > 10 AU, a < 100 AU and i > 60), we find these objects exhibit a surprising clustering of ascending node, populating a common orbital plane. The statistical significance of 3.8-sigma suggests it is unlikely to be coincidental. An unknown mechanism is required to explain the observed clustering. This discovery may provide a pathway to investigating a possible reservoir of high-inclination objects.

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Contributing team(s): Pan-STARRS 1 Builders

113.05D – Characterization of Trans-Neptunian Binaries

During the "TNOs are Cool: A Survey of the Trans-Neptunian Region" two important physical properties, such as size and albedo, have been obtained from Herschel and Spitzer thermal emission measurements. In this present work we describe an analysis of 28 binary and 2 triple objects related to the "TNOs are cool" project. Firstly, this analysis contains a comparison of multiples with other TNOs by their albedo and diameter characteristics. Secondly, an analysis on correlations between physical and orbital parameters is performed.
The knowledge of size allows to estimate the bulk density, which is a crucial parameter containing information on the internal structure of TNOs. Hence, the density estimation problem requires known mass, whose measurement is only possible if the object has a satellite with a known orbit. Unfortunately, from our dataset of binaries only few of them have a full orbit solution and, consequently, a derived bulk density. The lack of observations of such distant objects leads to difficulties in close satellite's orbit determination. A statistical approach, based on a Monte-Carlo Markov chain global optimisation algorithm, is proposed for this problem.

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113.06D – Properties of resonant trans-Neptunian objects based on Herschel Space Observatory data

The goal of our work is to characterise the physical characteristics of resonant, detached and scattered disk objects in the trans-Neptunian region, observed in the framework of the "TNOs are Cool!" Herschel Open Time Key Program. Based on thermal emission measurements with the Herschel/PACS and Spitzer/MIPS instruments we were able to determine size, albedo, and surface thermal properties for 23 objects using radiometric modelling techniques. This is the first analysis in which the physical properties of objects in the outer resonances are determined for a larger sample. In addition to the results for individual objects, we have compared these characteristic with the bulk properties of other populations of the trans-Neptunian region. The newly analysed objects show e.g. a large variety of beaming factors, indicating diverse surfaces, and in general they follow the albedo-colour clustering identified earlier for Kuiper belt objects and Centaurs, further strengthening the evidence for a compositional discontinuity in the young solar system.

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113.07 – New features in the structure of the classical Kuiper Belt

We report fascinating new dynamical structures emerging from a higher precision view of the classical Kuiper belt (the plentiful non-resonant orbits with semimajor axes in roughly the a=35-60 au range). The classical Kuiper Belt divides into multiple sub-populations: an 'inner' classical belt (a small group of non-resonant objects with a<39.4 au where the 3:2 resonance is located), an abundant 'main' classical belt (between the 3:2 and the 2:1 at a=47.4 au), and a difficult to study outer classical belt beyond the 2:1. We examine the dynamical structure, as precisely revealed in the detections from OSSOS (the Outer Solar System Origin's Survey); the data set is of superb quality in terms of orbital element and numbers of detections (Kavelaars et al, this meeting).
The previous CFEPS survey showed that the main classical belt requires a complex dynamical substructure that goes beyond a simple 'hot versus cold' division based primarily on orbital inclination; the 'cold' inclination component requires two sub-components in the semimajor axis and perihelion distance q space (Petit et al 2011). CFEPS modelled this as a 'stirred' component present at all a=40-47 AU semimajor axes, with a dense superposed 'kernel' near a=44 AU at low eccentricity; the first OSSOS data release remained consistent with this (Bannister et al 2016). As with the main asteroid belt, as statistics and orbital quality improve we see additional significant substructure emerging in the classical belt's orbital distribution.
OSSOS continues to add evidence that the cold stirred component extends smoothly beyond the 2:1 (Bannister et al 2016). Unexpectedly, the data also reveal the clear existence of a paucity of orbits just beyond the outer edge of the kernel; there are significantly fewer TNOs in the narrow semimajor axis band from a=44.5-45.0 AU. This may be related to the kernel population's creation, or it may be an independent feature created by planet migration as resonances moved in the primordial Kuiper Belt.

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Contributing team(s): The OSSOS collaboration

113.08 – A new high-perihelion a ~ 700 AU object in the distant Solar System

We report the discovery of a trans-Neptunian object (TNO) plausibly diffusing out of the inner Oort Cloud reservoir. This TNO is on an orbit with q ~ 50 AU, a ~ 700 AU, the largest semi-major axis yet detected for an orbit with perihelion q beyond the $q \leq 38$ zone of strong influence of Neptune, exceeding the semi-major axes of (90377) Sedna, 2012 VP113 and 2010 GB174. Such objects are rarely observed. Trans-Neptunian objects with these high orbital perihelia have no confirmed formation mechanism in the present planetary architecture of the Solar System. The orbit of this new TNO can be formed by inward diffusion of objects from a Galactic-tide-dominated population with a ~ 1000-2000 AU; the formation mechanism is highly inefficient, and would require on the order of a hundred times more objects in that population than in the a ~ 700 AU population. We also report colour and light curve measurements of the new TNO with Gemini North and Subaru-HSC. The longitude of the ascending node and argument of perihelion of this TNO's orbit have implications for the hypothesis of a ninth planet.

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113.09 – The First High-Phase Observations of a KBO: New Horizons Imaging of (15810) 1994 JR $_1$ from the Kuiper Belt

(15810) 1994 JR_1, a 3:2 resonant Kupier Belt Object (KBO), was observed by NASA's New Horizons spacecraft using the LOng Range Reconnaissance Imager (LORRI) on November 2, 2015 from a distance of 1.85 AU, and again on April 7, 2016 from a distance of 0.71 AU. These were the first close observations of any KBO other than Pluto, and the first ever of a small KBO at close range. Combining ground-based and HST observations at small phase angles and the LORRI observations at higher phase angles, we produced the first disk-integrated solar phase curve of a typical in-situ KBO from 0.6 to 58 degrees phase angle. Observations at these geometries, a range only attainable using a spacecraft in the outer Solar System, constrain surface properties such as macroscopic roughness and the single particle phase function. 1994 JR_1 has a rough surface with a 37 +/- 5 degrees mean topographic slope angle and has a relatively rapid rotation period of 5.47 +/- 0.33 hours, with a lightcurve amplitude of 0.8 magnitudes from the spacecraft. 1994 JR_1 is currently 2.7 AU from Pluto; our astrometric points enable high-precision orbit determination and integrations which show that it comes this close to Pluto every 2.4 million years (10,000 heliocentric orbits), causing Pluto to perturb 1994 JR_1. During the November spacecraft observation, the KBO was simultaneously observed using the Hubble Space Telescope in two colors, confirming its very red spectral slope. These observations have laid the groundwork for numerous potential future distant KBO observations in the proposed New Horizons-Kuiper Belt Extended Mission.

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Contributing team(s): The New Horizons Science Team

114 – Planetary Rings II: Dynamics and Saturn Ring Mass

114.01 – Localized Perturbations in Saturn's C Ring

Years of high-resolution imaging of Saturn's rings have revealed many examples of perturbations arising from local causes. For example, the presence of 100-m-scale and smaller moonlets is inferred in the A ring based on the propeller-shaped disturbances that they create (Tiscareno et al. 2006, 2010); the F ring is shaped by regular collisions with its shepherd Prometheus, as well as with other smaller bodies orbiting in the vicinity (Murray et al. 2005, 2008); the "wisps" on the outer edge of the Keeler gap (Porco et al. 2005) may mark the locations of small moonlets that have emerged from the A ring (Tiscareno and Arnault 2015); wakes in the Huygens ringlet imply the presence of two multi-km bodies, and the irregular shape of its inner edge suggests the presence of many smaller bodies (Spitale and Hahn 2016); based on shadow measurements, the B ring contains an embedded 300-m object that produces a small propeller-shaped disturbance (Spitale and Porco 2010; Spitale and Tiscareno 2012).
Here, we present evidence for localized perturbations in the C ring. The ringlet embedded in the Bond gap, near 1.470 Saturn radii, shows discrete clumps orbiting at the Keplerian rate in images spanning about eight years. The clumps are not detected in all image sequences at the expected longitudes. The Dawes ringlet, near 1.495 Saturn radii, has an irregular edge that does not appear as a simple superposition of low-wavenumber normal modes.

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114.02 – Kronoseismology: An update on Saturnian waves in the C Ring

In previous work (Hedman & Nicholson [2013] Astron. J. 146, 12; Ibid [2014] MNRAS 444, 1369; French et al. [2016] Icarus, in press) we have identified 9 inward-propagating density waves in Saturn's middle C ring with resonances generated by internal oscillations in Saturn. The oscillations involved are sectoral f-modes (ie., fundamental modes with l = m) with m = 1, 2, 3, 4 and 10. In addition, 5 outward-propagating waves in the outer C ring have been identified as density waves driven by 3:2 resonances with fixed gravitational anomalies within the planet (see abstract by El Moutamid et al.)

We have now examined several additional C ring waves from the catalog of Baillie et al. [2011], in an attempt to identify weaker and shorter-wavelength waves in the inner C ring. We use a modified version of our previous wavelet-based technique to co-add phase-corrected spectra from multiple occultations, using trial values of \`m' and the pattern speed to predict their relative phases. This enables us to detect waves too weak to see in individual occultations. To date, 6 new waves have been identified. Two appear to be due to additional saturnian f-modes, but at unexpected locations. The other 4 waves appear to be a new variety: outward-propagating bending waves driven at vertical resonances with Saturn internal oscillations with l = m + 1. We find bending waves with m = 4, 7, 8 & 9. Only the m = 4 wave is near the location predicted by Marley & Porco [1993].

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Contributing team(s): Cassini VIMS team, Cassini RSS team

114.03 – Evidence of differential rotation inside Saturn from waves of its rings

Saturn's average interior rotation rate has been estimated based on various analyses of its shape (Anderson and Schubert, 2007; Read et al., 2009; Helled et al., 2015), but we still have no clear information on its exact value and the degree of differential rotation versus depth.
However, Hedman et al., (2009), Hedman and Nicholson (2014) and El Moutamid et al., (2016) have identified several structures in the main rings of Saturn which appear to be related to the planet's rotation rate.
These structures (waves and perturbed edges) appear to be generated by so-called Tesseral Resonances, which are associated with gravity anomalies that rotate with Saturn's interior, rather than being driven by a satellite. Their locations are given by the usual formula for inner or outer Lindblad resonances.
We have searched for additional wave-like signatures in stellar occultation data for the main rings which are related to the rotation period of Saturn and have identified several signatures consistent with other differential rotation in Saturn's interior. Our study of the behavior of the A, B and C rings uses images and occultation data obtained by the Cassini spacecraft over a period of 10 years from 2006 to 2015.

Author(s): Maryame El Moutamid[1], Matthew M. Hedman[2], Philip D. Nicholson[1], Peter J. Gierasch[1], Joseph A. Burns[1]
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114.04 – Estimating the mass of Saturn's B ring

The B ring is the brightest and most opaque of Saturn's rings, but it is also amongst the least well understood because basic parameters like its surface mass density have been poorly constrained. Elsewhere in the rings, spiral density waves driven by resonances with Saturn's various moons provide precise and robust mass density estimates, but for most the B ring extremely high opacities and strong stochastic optical depth variations obscure the signal from these wave patterns. We have developed a new wavelet-based technique that combines data from multiple stellar occultations (observed by the Visual and Infrared Mapping Spectrometer instrument onboard the Cassini spacecraft) that has allowed us to identify signals that appear to be due to waves generated by the strongest resonances in the central and outer B ring. These wave signatures yield new estimates of the B-ring's mass density and indicate that the B-ring's total mass could be quite low, between 1/3 and 2/3 the mass of Saturn's moon Mimas.

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114.05 – The Evolution of Saturn's Rings Under the Influence of the Edgeworth-Kuiper Belt Micrometeoroid Flux: Tightening the Constraints on Ring Age

Results of the Cassini Dust Analyzer (CDA) experiment indicate that the determined range of the micrometeoroid flux at infinity for Saturn (Altobelli et al., 2015) may be comparable to the nominal value of the incident, flat-plate and one-sided meteoroid flux value currently adopted for use in ballistic transport applications and models (e.g., Estrada et al., 2015). Moreover, the source of the micrometeoroid flux has been localized to the Edgeworth-Kuiper Belt (EKB) and is not cometary in origin as previously assumed. Apart from suggesting an altogether different composition for the ring pollutant, a major consequence of these new measurements is that the EKB flux is much more gravitationally focused than the cometary case because it is isotropic in the planet rather than the heliocentric frame. Thus, the lower velocities at infinity that characterize the EKB flux can increase the impact flux on the rings by a factor of ∼25. This means that even for the lower bound of the range of the newly measured flux, the amount of material hitting the rings may be considerably higher and thus the process of micrometeoroid bombardment and ballistic transport is likely even more influential in the rings' structural and compositional evolution over time. Here, we calculate the new EKB ejecta distribution using the model of Cuzzi and Durisen (1990) and compare this with the nominal cometary one, and then demonstrate using new simulations the consequences of the EKB flux on the evolution of ring composition and structure. The constraining of the micrometeoroid flux represents a very important step in being able to associate an absolute age for the rings. We argue that the new EKB flux poses a serious problem for "primordial" or "old" ring origin scenarios and favors more a scenario in which the rings, at least the way we see them today, cannot be much older than a few 100 Myrs.

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114.06 – The Case for Massive and Ancient Rings of Saturn

Analysis of Voyager and Pioneer 11 results give a mass for Saturn's rings, M = 5 x 10^{-8} M_{sat}. This is about the mass of Saturn's small moon Mimas. This has been interpreted as a lower limit to the ring mass (Esposito et al 1983), since the thickest parts of the rings were not penetrated by the stellar occultstion, and this calculation assumes an unvarying particle size throughout the rings. Because the rings are constantly bombarded by micrometeroids, their current composition of nearly pure water ice implies such low mass rings must have formed recently. The case is particularly strong for Saturn's A ring, where the data are the best, implying the A ring is less than 10% of the age of the Saturn (Esposito 1986). Cassini results compound this problem. UVIS spectra are consistent with either young rings or rings about 10x as massive as the Voyager estimate (Elliott and Esposito (2011). CDA confirms the impacting mass flux is similar to that assumed for the pollution calculations (Kempf etal 2015). VIMS analysis of density wave signatures in the B ring gives a value of about 1/3 the Voyager value (Hedmann etal 2016). This VIMS result implies the rings are even younger! The problem is that young rings are very unlikely to be formed recently, meaning that we live in a very special epoch, following some unlikely recent origin… like disruption of a medium sized moon or capture of the fragments of a disrupted comet (Charnoz etal 2009).
To take the VIMS results at face value, Saturn's low mass rings must be very young. The optically thick B ring must be made of small, porous or fractal particles. An alternative is that we accept the higher mass interpretation of the Pioneer 11 results (Esposito etal 2008) using the granola bar model of Colwell etal 2007. This would imply that the density wave structure seen by VIMS is not sensing all the mass in the rings, where structure near strong resonances is dominted by temporary aggregates, and where non-linear effects cause the particles to jam (Lewis and Stewart 2009). The density waves may be seeing the mass density in the gaps between self-gravity wakes, whose optical depth is roughly contant and considerably lower than the total B ring opacity (Colwell etal 2007).

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114.07D – Collisional Features in Saturn's F Ring

Saturn's highly dynamic F ring contains a population of small (radius ~ 1 km) moonlets embedded within its core or on nearby orbits. These objects interact, both gravitationally and collisionally, with the ring producing a range of features, some of which are unique to it. Here we present a brief overview of F ring collisional processes, investigated using a combination of Cassini imaging, simulations and orbital dynamics. Collisions produce linear debris clouds, known as 'jets' and 'mini-jets', which evolve, due to differential orbital motion, over periods ranging from hours to months. Mini-jet-forming collisions occur daily in the F ring whilst larger, more dramatic, events are rarer but produce jets that persist for many months, 'wrapping around' the ring to form almost parallel strands. Measuring jet properties, such as formation rates and relative orbits, allows us to infer a local population of order hundreds of objects colliding at relative velocities of a few metres per second. N-body modelling of the collisions shows good agreement with observations when two aggregates are allowed to impact and partially fragment (as opposed to a solid moonlet encountering dust), implying massive objects both in the core and nearby. Multiple, repeated collisions by the same, or fragments of the same, object are also important in explaining some jet morphology, showing that many objects survive the collisions. The F ring represents a natural laboratory for observing low-velocity collisions between icy objects as well as the ongoing aggregation and accretion that most-likely forms them.

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114.08D – Numerical Simulations of Saturn's B-Ring: Granular Friciton as a Mediator between Self-Gravity and Viscous Overstability

We study the B-ring's complex optical depth structure with pkdgrav. pkdgrav is a N-body code capable of simulating gravitational and collisional physics. The code has recently been modified to allow for the accurate modeling of inter-particle static and rolling friction. These changes have given us new insight into two mechanisms responsible for large km-scale structure in the rings: self-gravity wakes and viscous overstability. As previous studies have shown, we also find that ring particles with low internal densities are able to produce viscous overstability wakes, and ring particles with high internal densities produce self-gravity waves. However, for high density particles, an increase in the inter-particle friction parameters causes the self-gravity wakes to subside and the viscous overstability wakes begin to dominate. The increase in friction causes an enhancement in the bulk viscosity in the ring simulations and is clearly manifested through the visible formation of vertical axisymmetric structure even at large (greater than 0.45 g/cc) particle densities. We have completed a systematic study of the effects of granular-scale interactions, which include inter-particle friction and cohesion on the macro-scale ring structure. We present a large parameter space sweep of these particle properties in order to constrain the range of possible structure formation scenarios. We then attempt to constrain the values of these ring properties by comparing our simulations to observational signatures of ring structure. This work has important implications for understanding the physical properties of ring particles, and for determining the masses of the rings.

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114.09 – Saturn Ring Radiation Environment for the Cassini Grand Finale Orbits

Grand Finale (proximal) orbits of Cassini from April to September 2017 will provide an unprecedented opportunity for further in-situ exploration of the energetic radiation environment primarily arising from galactic cosmic ray interactions with the main rings. Improved modeling of these interactions contributes to ring mass properties, radiation chemistry, and source modeling for trapped radiation within and beyond the rings. Our new GEANT simulations show that these interactions produce very substantial fluxes of secondary gamma rays, neutrons, electrons, protons, and more short-lived particles. Cosmic ray albedo neutron decay from ring neutron emissions provides the primary source of trapped protons near and above 10 MeV in the radiation belts extending from beyond the F ring to the orbit of Tethys. Fluxes of these high-energy trapped protons increased as expected with declining solar activity from 2004 through 2009, consistent with decreasing modulation of the galactic cosmic ray protons and heavier ions by the solar wind. In 2017 solar activity and modulation will again be declining from earlier maximum levels in 2012 – 2014, while solar illumination of the rings will be near solstice levels. There may then be similarities in the ring radiation and plasma environment to conditions in 2004. In comparison, the 1979 traversal of the main rings by Pioneer 11 occurred during peak solar activity but declining cosmic ray flux. The questions are then what radiation environment we might expect to find during the Grand Finale orbits, how would the Cassini MIMI LEMMS sensor respond to this environment, and how might these new measurements change our understanding of the rings? During SOI flyover of the rings, LEMMS nominal data showed intensities higher than those from Pioneer 11 to an extent that cannot be explained by the updated interaction model. LEMMS more likely responded to penetrating high-energy radiation at energies outside its nominal ranges for electrons and protons. Work is in progress to model these responses, particularly for gamma rays which could be decisive in confirmation of the total ring mass. We also consider prospects for detection of the innermost Van Allen belt of Saturn inwards of the D ring.

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115 – Venus Express and Ground-Based Observations

115.01 – Observed longitude variations of zonal wind, UV albedo and H_2O at Venus cloud top level: the role of stationary gravity waves generated by Venus topography

Based on the analysis of UV images (at 365 nm) of Venus cloud top (altitude 67±2 km) collected with VMC (Venus Monitoring Camera) on board Venus Express (VEX), it is found that the zonal wind speed south of the equator (from 5°S to 15°S) shows a conspicuous variation (from -101 to -83 m/s) with geographic longitude of Venus, correlated with the underlying relief of Aphrodite Terra. We interpret this pattern as the result of stationary gravity waves produced at ground level by the up lift of air when the horizontal wind encounters a mountain slope. These waves can propagate up to the cloud top level, break there and transfer their momentum to the zonal flow. Such upward propagation of gravity waves and influence on the wind speed vertical profile was shown to play an important role in the middle atmosphere of the Earth but is not reproduced in the current GCM of Venus atmosphere from LMD.
In the equatorial regions, the UV albedo of clouds at 365 nm and the H_2O mixing ratio at cloud top varies also with longitude, with an anti-correlation: the more H_2O, the darker are the clouds. We argue that these variations may be simply explained by the divergence of the horizontal wind field. In the longitude region (from 60° to -10°) where the horizontal wind speed is increasing in magnitude (stretch), it triggers air upwelling which brings both the UV absorber and H_2O at cloud top level and decreases the albedo, and vice-versa when the wind is decreasing in magnitude (compression). This picture is fully consistent with the classical view of Venus meridional circulation, with upwelling at equator revealed by horizontal air motions away from equator: the longitude effect is only an additional but important modulation of this effect. We argue that H_2O enhancement is the sign of upwelling because the H_2O mixing ratio decreases with altitude, comforting the view that the UV absorber is also brought to cloud top by upwelling.

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115.02 – Energy Estimates of Lightning-Generated Whistler-Mode Waves in the Venus Ionosphere

The dual fluxgate magnetometer on the Venus Express Mission sampled at 128 Hz allowing for signals up to 64 Hz to be detected. These signals are found at all local times and at altitudes up to 600 km while near periapsis. The spacecraft had a periapsis within 15 degrees of the north pole for nearly the entire mission, concentrating observations at high latitudes. At solar minimum, when the ionosphere can become strongly magnetized, the waves were more readily guided along the field up to the spacecraft. During this time, whistlers were observed 3% of the time while VEX was at 250 km altitude. Detection rates reached 5% at this altitude while near the dawn terminator due to a low altitude magnetic belt that provides a radial component enabling better access of the signals to the spacecraft.
Since the majority of these observations were made at relatively low altitudes, reasonable assumptions can be made about the ionospheric conditions along the wave's path from the base of the ionosphere to the spacecraft. The electron density can be inferred by utilizing the VERA model and scaling it to match the solar cycle conditions during the Venus Express campaign. With the electron density and the three components of the magnetic field measurement, we then calculate the Poynting flux to determine the energy density of the wave. This enables us to determine the strength of the source lightning and compares this strength to that on Earth.

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115.03D – Location and extent of recently active lava flows on the eastern flank of Idunn Mons on Venus

The eastern flank of Idunn Mons, Imdr Regio's single large volcano, was identified in VIRTIS data as one of the regions with relatively high values of thermal emissivity at 1 µm wavelength. Our study intends to identify location and extent of the sources of such anomalies, thus the lava flows responsible for the relatively high emissivity observed by VIRTIS over the eastern flank of Idunn Mons. We perform a simulation iterating the geologic mapping made over Magellan radar images of the same area with modeling of the blurring caused by the scattering of the 1 µm radiation in the atmosphere. At every iteration, we map the lava flow units in the surroundings of Idunn Mons and we assign each unit an assumed value of emissivity. We observed a good match between the mapped flows and the clusters resulting from the consistency of the mapped lava flows through the ISO clustering analysis. We tested eight different configurations, calculating the total RMS error compared to VIRTIS observations. The best-fit configuration is that where we assigned high values of emissivity to the flank lava flows. Results also show a correlation between the ISO clustering analysis and the best-fit configuration. We reconstructed the post-eruption stratigraphy of the eastern flank of Idunn Mons, displaying the three flank lava flows units likely responsible for the relatively high 1 µm emissivity anomalies observed by VIRTIS. The average microwave emissivity provides a further evidence of the basaltic composition of the mapped lava flows.

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115.04 – 2-D Chemical-Dynamical Modeling of Venus's Sulfur Variability

Over the last decade a combination of ground based and Venus Express observations have been made of the concentration of sulfur species in Venus's atmosphere, both above [1, 2] and below the clouds [3, 4]. These observations put constraints on both the vertical and meridional variations of the major sulfur species in Venus's atmosphere.. It has also been observed that SO2 concentrations varies on both timescales of hours and years [1,4]. The spatial and temporal distribution of tracer species is owing to two possibilities: mutual chemical interaction and dynamical tracer transport. Previous Chemical modeling of Venus's middle atmosphere has only been explored in 1-D. We will present the first 2-D (altitude and latitude) chemical-dynamical model for Venus's middle atmosphere. The sulfur chemistry is based on of the 1D model of Zhang et al. 2012 [5]. We do model runs over multiple Venus decades testing two scenarios: first one with varying sulfur fluxes from below, and second with secular dynamical perturbations in the atmosphere [6]. By comparing to Venus Express and ground based observations, we put constraints on the dynamics of Venus's middle atmosphere.

References: [1] Belyaev et al. Icarus 2012 [2] Marcq et al. Nature geoscience, 2013 [3] Marcq et al. JGR:Planets, 2008 [4] Arney et al. JGR:Planets, 2014 [5] Zhang et al. Icarus 2012 [6] Parish et al. Icarus 2012

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115.05 – The Magnetic Field in the Lower Ionosphere of Venus as Seen by Venus Express

In June 2014, the Venus Express mission conducted its aerobraking campaign that allowed the spacecraft to get to its lowest altitude of 130 km. This provided the first measurements of the lower ionosphere over the north polar region. The data show below ~140 km the magnetic field becomes relatively constant in magnitude and direction. Over the month long aerobraking period, the magnetic field in the lower ionosphere is dominantly horizontal and shows a distinct bias in the +Bx and –By direction despite the field direction at higher altitudes. Here we analyze the relationship between the direction of the lower ionosphere and the long-term average of the interplanetary magnetic field direction.

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115.06 – Venus' night side atmospheric dynamics using near infrared observations from VEx/VIRTIS and TNG/NICS

We present night side Venus' winds based on coordinated observations carried out with Venus Express' VIRTIS instrument and the Near Infrared Camera (NICS) of the Telescopio Nazionale Galileo (TNG). With NICS camera, we acquired images of the continuum K filter at 2.28 µm, which allows to monitor motions at the Venus' lower cloud level, close to 48 km altitude. We will present final results of cloud tracked winds from ground-based TNG observations and from coordinated space-based VEx/VIRTIS observations.
The Venus' lower cloud deck is centred at 48 km of altitude, where fundamental dynamical exchanges that help maintain superrotation are thought to occur. The lower Venusian atmosphere is a strong source of thermal radiation, with the gaseous CO_2 component allowing radiation to escape in windows at 1.74 and 2.28 µm. At these wavelengths radiation originates below 35 km and unit opacity is reached at the lower cloud level, close to 48 km. Therefore, it is possible to observe the horizontal cloud structure, with thicker clouds seen silhouetted against the bright thermal background from the low atmosphere. By continuous monitoring of the horizontal cloud structure at 2.28 µm (NICS Kcont filter), it is possible to determine wind fields using the technique of cloud tracking. We acquired a series of short exposures of the Venus disk. Cloud displacements in the night side of Venus were computed taking advantage of a phase correlation semi-automated technique. The Venus apparent diameter at observational dates was greater than 32” allowing a high spatial precision. The 0.13” pixel scale of the NICS narrow field camera allowed to resolve ~3-pixel displacements. The absolute spatial resolution on the disk was ~100 km/px at disk center, and the (0.8–1") seeing-limited resolution was ~400 km/px. By co-adding the best images and cross-correlating regions of clouds the effective resolution was significantly better than the seeing-limited resolution. In order to correct for scattered light from the (saturated) day side crescent into the night side, a set of observations with a Br Y filter were performed. Cloud features are invisible at this wavelength, and this technique allowed for a good correction of scattered light.

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115.07 – Meridional transport in the Venusian atmosphere

Atmospheric superrotation on Venus and to a lesser extent, on Titan, is thought to be maintained by opposing transfers of angular momentum between the mean meridional circulation and large-scale planetary waves. The details of this transfer depend on the presence of wave-generating dynamical instabilities and on the strength and direction of the meridional flow. Observational constraints have been gathered over the course of the Venus Express mission. The upper cloud exhibits global meridional motions which are consistent with the upper branch of a Hadley cell circulation (Sánchez-Lavega et al., 2008 ; Hueso et al., 2012). Peralta et al. (2012) determined the meridional structure for the amplitude of the diurnal tide affecting the meridional component of the wind, while VMC cloud-tracked features allowed to detect a diurnal component peaking in the early afternoon (Khatuntsev et al., 2013). New measurements of the meridional flow were simultaneously gathered by VEx/VIRTIS-M and CFHT/ESPaDOnS from the ground with a significant temporal and spatial overlap in April 2014. A symmetrical, poleward meridional Hadley flow is evidenced at cloud top in both hemispheres peaking at v = 22.5 ± 15.5 ms-1 at 9-10am near 40°N-S with a sharp drop poleward of 50° (Machado et al., submitted).
The lower cloud meridional motions are less organized with some cloud features moving with intense northwards and southwards

motions up to v = ±15 m s-1 but, on average, with almost null global meridional motions at all latitudes. Due to the unfavourable viewing geometry and poor UV contrast of polar clouds, only a fraction of the total wind measurements have been reported for the polar regions. Existing data indicate a circumpolar circulation close to solid-body rotation. The VEM instrument on board VERITAS (Smrekar et al., 2016 ; Helbert et al., 2016) will allow for a comprehensive study of lower cloud climatology spanning at least one Venusian year. Three filter bands of VEM at 1.195, 1.310 and 1.510 µm will acquire very accurate images of the clouds contraining their and/or size distribution. As the zonal component breaks down poleward of 50°, the mission will provide a large database for wind statistical analyses.

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115.08 – Variability of H2O and SO2 on Venus between 2012 and 2016

Since January 2012, we have been using the TEXES high-resolution imaging spectrometer at the NASA Infrared Telescope Facility to map sulfur dioxide and deuterated water over the disk of Venus. Data have been recorded in two spectral ranges around 1348 cm-1 (7.4 microns) and 530 cm-1 (19 microns), in order to probe the cloudtop at an altitude of about 64 km (SO2 and HDO at 7 microns) and a few kilometers below (SO2 at 19 microns). Observations took place during six runs between January 2012 and January 2016. The diameter of Venus ranged between 12 and 33 arcsec. Data were recorded with a spectral resolving power as high as 80000 and a spatial resolution of about 1 arcsec (at 7 microns) and 2.5 arcsec (at 19 microns). Mixing ratios have been estimated from HDO/CO2 and SO2/CO2 line depth ratios, using weak neighboring transitions of comparable depths. All data show that the two molecules have a very different behavior. The HDO maps are globally uniform over the disk. The variations of the disk-integrated H2O mixing ratio (estimated assuming a D/H of 200 VSMOW in the mesosphere of Venus) varies by about a factor 1.5 over the four-year period. A constant value of 1.0 - 1.5 pppmv is obtained in most of the cases. The SO2 maps, in contrast, show strong variations over the disk of Venus, by a factor as high as 5. Long-term variations of SO2 show that the disk-integrated SO2 mixing ratio varies between 2012 and 2016 by a factor as high as 10, with a minimum value of 30 +/- 5 ppbv in February 2014 an a maximum value of 300 +/- 50 ppbv in January 2016. The SO2 maps also show a strong short-term variability, with a timescale of a few hours.

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115.09 – The thermal field of the terminator mesosphere of Venus using solar transit data

We exploit the solar transits of Venus in 2004 and 2012, to derive useful constraints on the mesosphere of the planet by the observation of the so-called "aureole" resulting from direct sunlight refraction. In 2012 we organized an extensive campaign, involving observations through both space- and ground- based telescopes. A specific design adapted from the Lyot coronograph was developed and replicated in several copies to improve the SNR in proximity of the solar disk (Venus Twilight Experiment).
we report on the different data sets collected during the 2012 transit, and present lightcurve analyses based on imaging from NASA's Solar Dynamic Observatory (SDO), JAXA's Hinode, and by the instruments of the Venus Twilight Experiment.
We explored different approaches to model the variation of the aureole brightness, ranging from simple isothermal modeling to multi-layer.
Although less resolved than the local measurements obtained by Venus Express (SOIR experiment), aureole modeling has the advantage of being able to cover simultaneously a wide range of latitudes. We were able to compare the aureole-derived vertical refractivity profiles to density profiles obtained simultaneously by SOIR during the transit itself. Our inverse model, constraining the vertical temperature profiles at all latitudes, detects a cold layer (at ~86-94 km altitude on average) whose vertical extent depends on latitude (thicker towards the N pole than at the Equator), and a latitude-dependent aerosol slanted-opacity altitude (τ=1).
Eventually our model shows that a relevant contribution to the aureole flux comes from deep layers where aerosol absorption cannot be neglected, allowing us to put some constraints on the scale height of aerosol dispersion.

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116 – 67P/Churyumov-Gerasimenko Posters

116.01 – First Results from The PACA_Rosetta67P Group in Support of ESA/Rosetta Mission

The PACA_Rosetta67P Facebook group is the amateur observing program, complementary to the ground-based professional observations, in support of ESA/Rosetta mission to the comet 67P/Churyumovs-Gerasimenko (CG). The amateur campaign has followed the ESA/Rosetta's escort of 67P from August 2014 to present. Although 67P/CG is faint in its current apparition (it is a Jupiter Family comet, with a period of 6.45 years and is on its seventh passage of the inner solar system), the comet is known to brighten from about a month before perihelion and post perihelion. The comet behaved as expected. With the vast amount of data collected by the global amateur network, we are now able to (i) archive the data to allow it to be crowdsourced by the professionals; (ii) mine the data to determine various trends such as the variation of magnitude with respect to heliospheric distance; map the changes in Afrho (the dust activity parameter) and a long baseline of observations that show features similar to the features seen in the ground-based observations of the professionals. We will highlight the campaign and the results now possible to determine and compare with other observations taken at the same time. We will highlight the first results of the campaign, with the challenges and lessons learned to apply when developing other amateur observing programs.

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116.02 – Ground-based observation of 67P/Churyumov-Gerasimenko

I will present a summary of the key results from the world-wide campaign of observations of comet 67P/Churyumov-Gerasimenko in support of the Rosetta mission. This campaign made use of nearly all major observing facilities to provide large-scale context for Rosetta.

This is important as the spacecraft sampled only the inner coma region, while remote observations revealed the total activity of the comet and its large scale coma and tails structure. Furtehrmore, ground-based observations of 67P during the Rosetta mission allow comparison with other comets observed purely with telescopes.

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Contributing team(s): 67P observing campaign team

116.03 – Changes in Comet 67P/Churyumov-Gerasimenko during the ROSETTA Era - Shape, Topography and Rotation

The ROSETTA orbiter began mapping comet 67P/Churyumov-Gerasimenko on 1 Aug 2014. It was high summer on the comet, with a subsolar latitude of 45 degrees, meaning that little of the South was illuminated. At that time, the comet was rotating at a rate of 696 deg/day and was 3.6 AU from the Sun. From September through January 2015, ROSETTA was mostly within 30 km of the comet, at times venturing within 10 km. This allowed for detailed mapping of 67P's northern hemisphere. By the end of January, with the Sun still at 27 degrees North, the comet was at 2.4 AU and was becoming too active for close operations. At the same time, torques due to this activity began slowing the rotation rate until it reached a minimum of 694 deg/day around the end of April, shortly before the autumnal equinox. Except for a daring close approach (8 km) on Valentine's day 2015, ROSETTA would not get within 30 km for another year, just before the vernal equinox, precluding very high resolution mapping of the South. Meanwhile, increasing torques as the comet passed through perihelion in mid August 2015 (1.24 AU) were increasing the rotation rate - it is currently at 716 deg/day - while the direction of the pole has remained unchanged. Some areas of the comet, most notably in the Imhotep region, have shown significant changes in topography during the comet's passage by the Sun. These are being mapped and it is hoped that we shall be able to map additional changes by comparing early and late imaging. By the end of the mission in late September, 67P will have receded to about 3.8 AU and the rotation rate will probably have stabilized to its new value. By early August, the Sun will be about 16 degrees North, but the increased distance from the Sun will reduce the power available and an increasing distance from Earth will reduce data rates. 1 Aug 2016 will be our data cutoff for this work. Removing pre-perihelion images with subsolar latitude > 15 deg still provided enough data to map the North, so with the new data we should be able to map the changes that have occurred during perihelion passage.

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Contributing team(s): The OSIRIS team

116.04 – Study of the dusty environment of comet 67P/Churyumov-Gerasimenko with allowance of dust grains asphericity

The Grain Impact Analyser and Dust Accumulator (GIADA) instrument onboard the Rosetta spacecraft has been measuring speed, mass and, with the support of calibrations curves, their geometrical cross section, of individual dust particles in the coma of comet 67P/Churyumov-Gerasimenko since 1st August 2014.
In this work we consider the observational period November – December 2015 during which GIADA registered a high dust particles detection rate. We performed numerical simulations of dust grains dynamics measured by GIADA during this period. As a shape model of dust grains we used not only spheres, but also, as a first departure from the sphere, ellipsoids of revolution, prolate and oblate with various aspect ratios. The size range under consideration is from 50 to 500 microns, in diameter, which corresponds to the particle size range measured by GIADA in the period of interest.
We discuss the influence of the grain's shape model on the dust spatial distribution and dynamics of individual grains. The results allow to constrain the density range of the collected particles based on the comparison between their computed terminal velocities and the GIADA measured dust speeds.

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116.05 – ROSETTA/COSIMA at comet 67P/Churyumov-Gerasimenko – 2 years of in-situ dust analysis

In August 2014 the ROSETTA spacecraft rendezvoused with comet 67P/Churyumov-Gerasimenko and escorted it for more than 2 years along its orbit around the Sun from 4 AU preperihelion to 4 AU postperihelion. During this time the COSIMA instrument (COmetary Secondary Ion Mass Analyser) onboard ROSETTA collected more than 25,000 dust particles in the vicinity of the comet nucleus. All these particles were collected on a number of specially designed metal target plates which were regularly imaged with a microscope (14 µm pixel/pixel resolution, 14mm x 14mm FOV) enabling the analysis of their individual morphologies, certain physical properties, e.g. tensile strength, albedo, as well as the overall flux and size distribution of the dust entering the COSIMA instrument. The images were also used to choose which of the particles shall go through compositional measurements with the time-of-flight mass spectrometer (sometimes repeated at a later time). All these investigations were done over 2 years. This allows to study the compositional and morphological differences of the particles collected at the various sections of the pre- and postperihelion orbit, the evolution of the morphology of the particles on the target plate with time, and the search for spatial heterogeneity of the composition within a particle by taking mass spectra at different locations on the same particle. An overview will be given on the available data and the results obtained so far in view to the analysis of dust composition and morphology, as well as dust flux and size distribution along the orbit.

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14. Universität Bremen, 15. Universität der Bundeswehr , 16. Universität Münster, 17. Universität Wuppertal, 18. University of Bern, 19. University of Chicago, 20. University of Turku, 21. Vienna University of Technology, 22. Von Hörner & Sulger

116.06 – Ion composition at comet 67P near perihelion: Rosetta/ROSINA measurements and modeling

On August 13th, 2015, comet 67P/Churyumov-Gerasimenko reached its perihelion at 1.24 AU, a milestone for its cometary activity observed by the European Space Agency's Rosetta spacecraft which arrived in August 2014. The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA)/Comet Pressure Sensor (COPS) instrument onboard Rosetta measured local outgassing rates over 10^{28} molecules.s^{-1} in summer 2015. In the meantime, the ROSINA/Double Focusing Mass Spectrometer (DFMS) instrument measured the ion composition in the coma which was expected to be more diversified than during the early phase of the mission. Indeed, the increase in the cometary activity is expected to trigger new chemical pathways, yielding the formation of new cometary ions, other than the major water ions observed at larger heliocentric distances. Such new ion species can be produced from minor neutral species, such as those with proton affinity higher than that of water. This includes NH_4^+ whose detection has been recently reported (Beth et al., 2016).
In this study, we propose to investigate other ion species during the perihelion period by:
- analysing DFMS data to find any signature of substantial ion species,
- modeling the ionosphere of 67P by driving the model with the neutral densities measured by DFMS and COPS to support or constrain the absence or the presence of these ion species,
- discussing any discrepancy between observations and simulations.

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116.07 – Statistical analysis of dust signals observed by ROSINA/COPS onboard of the Rosetta spacecraft at comet 67P/Churyumov-Gerasimenko

ROSINA is the in situ Rosetta Orbiter Spectrometer for Ion and Neutral Analysis on board of Rosetta, one of the corner stone missions of the European Space Agency (ESA) to land and orbit the Jupiter family comet 67P/Churyumov-Gerasimenko (67P). ROSINA consists of two mass spectrometers and a pressure sensor. The Reflectron Time of Flight Spectrometer (RTOF) and the Double Focusing Mass Spectrometer (DFMS) complement each other in mass and time resolution.
The Comet Pressure Sensor (COPS) provides density measurements of the neutral molecules in the cometary coma of 67P. COPS has two gauges, a nude gauge that measures the total neutral density and a ram gauge that measures the dynamic pressure from the comet. Combining the two COPS is also capable of providing gas dynamic information such as gas velocity and gas temperature of the coma. While Rosetta started orbiting around 67P in August 2014, COPS observed diurnal and seasonal variations of the neutral gas density in the coma. Surprisingly, additional to these major density variation patterns, COPS occasionally observed small spikes in the density that are associated with dust. These dust signals can be interpreted as a result of cometary dust releasing volatiles while heated up near COPS. A statistical analysis of dust signals detected by COPS will be presented.

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116.08 – Co-registration and comparison of high-resolution shape models of comet 67P/C-G

Several methods are used nowadays for the 3D reconstruction of small bodies from visible images at high-resolution. These methods are classified in two categories: stereophotogrammetry (SPG, Gwinner et al. E&PSL 294, 506, 2010) and stereophotoclinometry (SPC, Gaskell et al., M&PS 43, 1049-1061, 2008 and MPCD, Capanna et al., The Visual Computer 29, 825-835, 2013). The comparison of the reconstructed models is important to assess the accuracy of these two approaches and to better understand their respective strengths and weaknesses. In the future, these two methods shall be combined to achieve the best possible accuracy on the digital terrain models from the available set of images.
In the frame of the Rosetta mission, two models have been reconstructed with SPG (Preusker et al. A&A 583, A33, 2015) and SPC (Jorda et al., Icarus 277, 257-278, 2016). However, these two models have been reconstructed in two different reference frames, which complicates their comparison. We use the point-to-plane algorithm (Pomerleau et al., Autonomous Robots 34, 133-148, 2013) implemented in the "pc_align" function of the NASA Ames Stereo Pipeline to find the transformation matrix between the models. We also use a quantitative comparison of a set of images acquired by the OSIRIS instrument aboard the Rosetta orbiter with corresponding synthetic images generated with the shape models using the OASIS simulator (Jorda et al., SPIE 7533, 753311, 2010).

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Contributing team(s): OSIRIS Team

116.09 – The internal density distribution of comet 67P/C-G based on 3D models

The OSIRIS camera aboard the Rosetta spacecraft observed the nucleus of comet 67P/C-G from the mapping phase in summer 2014 until now. The images have allowed the reconstruction in three-dimension of nucleus surface with stereophotogrammetry (Preusker et al., Astron. Astrophys.) and stereophotoclinometry (Jorda et al., Icarus) techniques. We use the reconstructed models to constrain the internal density distribution based on: (i) the measurement of the offset between the center of mass and the center of figure of the object, and (ii) the assumption that flat areas observed at the surface of the comet correspond to iso-gravity surfaces. The results of our analysis will be presented, and the consequences for the internal structure and formation of the nucleus of comet 67P/C-G will be discussed.

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Contributing team(s): OSIRIS Team

116.10 – Direct Simulation Monte-Carlo Modeling of the Major Volatile Species of Comet 67P/Churyumov-Gerasimenko observed by ROSINA and VIRTIS

During the past few decades, modeling of cometary coma has known tremendous improvements notably with the increase of computer capacity. While the Haser model is still widely used for interpretation of cometary observations, its rather simplistic assumptions such as spherical symmetry and constant outflow velocity prevent it to explain some of the coma observations. Hence, more complex coma models have emerged taking full advantage of the numerical approach. The only method that can resolve all the flow regimes encountered in the coma due to the drastic changes of Knudsen numbers is the Direct Simulation Monte-Carlo (DSMC) approach.
The data acquired by the instruments on board of the Rosetta spacecraft provides a large amount of observations regarding the spatial and temporal variations of comet 67P/Churyumov-Gerasimenko's coma. These measurements provide constraints that can be applied to the coma model in order to describe best the rarefied atmosphere of 67P. We present the last results of our 3D multi-species DSMC model using the Adaptive Mesh Particle Simulator (Tenishev et al. 2008 and 2011, Fougere 2014). The model uses a realistic nucleus shape model from the OSIRIS team and takes into account the self-shadowing created by its concavities. The gas flux at the surface of the nucleus is deduced from the relative orientation with respect to the Sun and an activity distribution that enables to simulate both the non-uniformity of the surface activity and the heterogeneities of the outgassing.
The model results are compared to the ROSINA and VIRTIS observations. Progress in incorporating Rosetta measurements from the last half of the mission into our models will be presented. The good agreement between the model and these measurements from two very different techniques reinforces our understanding of the physical processes taking place in the coma.

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Contributing team(s): VIRTIS team and ROSINA team

116.11 – Spectrophotometry of the Khonsu region on the comet 67P/Churyumov-Gerasimenko in the context of OSIRIS images

Since the Rosetta spacecraft rendezvoused with the comet 67P/Churyumov-Gerasimenko in August 2014, OSIRIS (Optical,Spectroscopic and Infrared Remote Imaging System) has been instrumental in characterising and studying both the nucleus as well as the coma of the comet. OSIRIS has thus far contributed to a plethora of scientific results. OSIRIS observations have revealed a bilobate nucleus accreted from a pair of cometesimals each having an irregular shape and a size, populated with numerous geomorphological features. Among the well defined 26 regions of the comet, Khonsu region inherits a heterogeneous terrain composed of smooth areas, scarps, outcroppings, large boulders, an intriguing 'pancake' feature, both transient and long-lived bright patches plus many other geological features.
Our work focuses on the spectrophotometric analysis of some selected terrain and bright patches in the Khonsu region. Despite the variety of geological features, their spectrophotometric properties appear to share a similar composition. It is noticeable also that the smooth areas in Khonsu possess similar spectrophotometric behaviour to some other regions of the comet. By comparing the spectrophotometric characteristics of observed bright patches on Khonsu with those described and attributed to the presence of H_2O ice on the comet by Barucci et al. (2016) utilising infrared data, we suggest that the bright patches we present could plausibly be derived from H_2O ice. One of the studied bright patches has been observed to exist on the surface for more than 4 months without a major diminution of its size, which implies the existence of potential subsurface icy layers. The location of this feature is strongly correlated with a cometary outburst during the perihelion passage of the comet in August 2015, and we interpret it to have triggered the surface modifications necessary to unearth the stratified icy layers beneath the surface.

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Contributing team(s): OSIRIS team

116.12 – Spectral mapping of comet 67P/Churyumov-Gerasimenko with VLT/MUSE and SINFONI

Comets are supposedly the most primitive objects in the solar system, preserving the earliest record of material from the nebula out of which our Sun and planets were formed, and thus holding crucial clues on the early phases of the solar system formation and evolution. For most small bodies in the solar system we can only access the surface properties, whereas active comet nuclei lose material from their subsurface, so that understanding cometary activity represents an unique opportunity to assess their internal composition, and by extension the composition, the temperature and pressure conditions of the protoplanetary disk at their place of formation.
The ESA/Rosetta mission is performing the most thorough investigation of a comet ever made. Rosetta is measuring properties of comet 67P/Churyumov-Gerasimenko at distances between 5 and hundreds of km from the nucleus. However, it is unable to make any measurement over the thousands of km of the rest of the coma. Fortunately, the outer coma is accessible from the ground. In addition, we currently lack an understanding of how the very detailed information gathered from space-based observations can be extrapolated to the many ground-based observations that we can potentially perform. Combining parallel in situ observations with observations from the ground therefore gives us a great opportunity, not only to understand the behavior of 67P, but also to other comets observed exclusively from Earth. As part of the many observations taken from the ground, we have performed a spectral mapping of 67's coma using two IFU instruments mounted on the VLT: MUSE in the visible, and SINFONI in the near-infrared. The observations, carried out in March 2016, will be presented and discussed.

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116.13 – On the origin of 67/P Churyumov-Gerasimenko

Comet 67P Churyumov-Gerasimenko is dynamically a Jupiter-family comet. Its current orbit is very chaotic and it had recently a close encounter with Jupiter. During numerical simulations of its backward evolution it is influenced by mean motion resonances with Jupiter (e.g. J2:1 and J3:1), but also with Mars (M1:3) and Vesta (Ve4:7), but in particular with Ceres (Ce5:7 at about 3.46 au, where currently the comet is with its semi-major axis).
We performed a backward integration for 50 Myrs of 67/P (499 clones plus the nominal orbit) considering only gravitational forces from all the solar system's planets (apart from Mercury, whose mass was added to the Sun) plus gravitational perturbations of 4 Vesta and 1 Ceres. We report on the locations of highest residence times of the clones and discuss the regions from which it is most likely to have originated from in the near- and long-term.

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116.14 – Modelling of the outburst on July 29th , 2015 observed with OSIRIS in the southern hemisphere of comet 67P/Churyumov-Gerasimenko

Images of the nucleus and the coma (gas and dust) of comet 67P/Churyumov- Gerasimenko have been acquired by the OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) cameras system since March 2014 using both the wide angle camera (WAC) and the narrow angle camera (NAC). We are using the NAC camera to study the bright outburst observed on July 29th, 2015 in the southern hemisphere. The NAC camera's wavelength ranges between 250-1000 nm with a combination of 12 filters. The high spatial resolution is needed to localize the source point of the outburst on the surface of the nucleus. At the time of the observations, the heliocentric distance was 1.25AU and the distance between the spacecraft and the comet was 126 km. We aim to understand the physics leading to such outgassing: Is the jet associated to the outbursts controlled by the micro-topography? Or by ice suddenly exposed? We are using the Direct Simulation Monte Carlo (DSMC) method to study the gas flow close to the nucleus. The goal of the DSMC code is to reproduce the opening angle of the jet, and constrain the outgassing ratio between outburst source and local region. The results of this model will be compared to the images obtained with the NAC camera.

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Contributing team(s): OSIRIS Team

116.15 – Effect of meter-scale heterogeneities inside 67P nucleus on CONSERT data

Since their arrival at comet 67P in August 2014, a number of instruments onboard Rosetta's main spacecraft and Philae lander have been observing the surface of the nucleus and revealed details of amazing surficial structures (hundreds of meters deep pits and cliffs, surface roughness of the order of a couple of meters in size, non-continuous apparent layers on both lobes of the comet). After two years of observations, the activity of the comet has also been better constrained, while the origin of sporadic jet activities remains debated. This surficial information is complemented by relevant measurements assessing the nucleus internal structure that have been collected by the CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) experiment in order to constrain the nucleus formation and evolution.
The CONSERT experiment is a bistatic radar with receivers and transmitters on-board both Rosetta's main spacecraft and the Philae lander. The instrument transmits electromagnetic waves at 90 MHz (10 MHz bandwidth) between Philae and Rosetta. The signal propagated through the small lobe of 67P over distances ranging from approximately 200 to 800 meters depending on the spacecraft location and probed a maximum depth of about one hundred meters in the vicinity of the final landing site Abydos. The CONSERT data have been used to obtain an estimate of the permittivity mean value. Thanks to the 10 MHz frequency bandwidth of the signal used by the instrument, a spatial resolution around 10m is obtained inside the sounded volume of the nucleus.
In this work, we analyze the effect of internal heterogeneities of 67P on the CONSERT data by simulating the propagation of the signal through a fractal model of the comet interior. We considered for the simulations a range of realistic permittivity values and characteristic sizes of the material heterogeneities. The different parameters values used have an impact on the width of the signal propagating through the modeled nucleus. Comparison with the values measured by CONSERT will allow us to determine the possible permittivity variations and heterogeneities size compatible with 67P internal structure.

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116.16 – Multispectral comparison of water ice deposits observed on cometary nuclei

Cometary missions Deep Impact, EPOXI and Rosetta investigated the nuclei of comets 9P/Tempel 1, 103P/Hartley 2 and 67P/Churyumov-Gerasimenko respectively. Each of these three missions was equipped with multispectral cameras, allowing imaging at various wavelengths from NUV to NIR. In this spectral range, water ice-rich features display bluer spectral slopes than the average surface and some have very flat spectra. Features enriched in water ice are bright in the monochromatic images and are blue in the RGB color composites generated by using images taken in NUV, visible and NIR wavelentghs. Using these properties, water ice-rich features were detected on the nuclei of comets 9P [1], 103P [2] and 67P [3] via multispectral imaging cameras. Moreover, there were visual detections of jets and outbursts associated to some of these water ice-rich features when the right observing conditions were fulfilled [4, 5].
We analyzed multispectral properties of different types of water ice-rich features [3] observed via OSIRIS NAC on comet 67P in the wavelength range of 260 nm to 1000 nm and then compared with those observed on comets 9P and 103P. Our multispectral analysis shows that the water ice deposits observed on comet 9P are very similar to the large bright blue clusters observed on comet 67P, while the large water ice deposit observed on comet 103P is similar to the large isolated water ice-rich features observed on comet 67P. The ice-rich deposits on comet 103P are the bluest of any comet, which indicates that the deposits on 103P contain more water ice than the ones observed on comets 9P and 67P [6].

[1] Sunshine et al 2006, Science
[2] Sunshine et al 2011, LPSC
[3] Pommerol et al 2015, A&A

[4] Oklay et al 2016, A&A
[5] Vincent et al 2016, A&A
[6] Oklay et al 2016, submitted
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Contributing team(s): The OSIRIS Team

116.17 – Probing 67P/Churyumov-Gerasimenko's Electron Environment Through Ultraviolet Emission by Rosetta Alice Observations

The Alice Far-Ultraviolet (FUV) Spectrograph onboard ESA's *Rosetta* spacecraft has observed the coma of comet 67P/Churyumov-Gerasimenko from far approach in summer 2014 until the end of mission in September 2016. We present an overall perspective of the bright FUV emission lines (HI 1026 Å, OI 1302/1305/1306 Å multiplet, OI] 1356 Å, CO 1510 (1-0) Å, and CI 1657 Å) above the sunward hemisphere, detailing their spatial extent and brightness as a function of time and the heliocentric distance of the comet. We compare our observed gas column densities derived using electron temperatures and densities from the Ion Electron Sensor (IES) with those derived using the Inner Coma Environment Simulator (ICES) models in periods when electron-impact excited emission dominates over solar fluorescence emission. The electron population is characterized with 2 three-dimensional kappa functions, one dense and warm, one rarefied and hot.

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116.18 – Understanding Phosphorous Chemistry in Comets in Light of Rosetta Results

Introduction: Phosphorous is a key element in all known forms of life. P-bearing compounds have been observed in the ISM and other regions of space. They are ubiquitous in meteorites, have been detected in the dust component in comets 1P/Halley and 81P/Wild 2, and in the gas phase (atomic P) of 67P/Churyumov-Gerasimenko by the Rosetta Mission. We present results from the first quantitative study of P-bearing molecules in comets to aid in future searches for this important element in comets, shedding light on issues of comet formation and prebiotic to biotic evolution of life.
Results and Discussion: Our gas dynamics model of cometary comae with chemical kinetics has been adapted to study this problem. We used phosphine (PH_3) as a native molecule with a cosmic abundance mixing ratio. Over 100 photo and gas-phase reactions and 30 P-bearing species were added to the chemical network. The chemistry of PH_3 in the inner coma shows the major destruction channels are photo-dissociation and protonation with water-group ions, leading to the recycling of PH_3 in this region and the eventual production of atomic P.
Conclusion: The model identifies the relevant phosphine chemistry in cometary coma. Protonation reactions of PH_3 with water-group ions are important due to its high proton affinity. Abundances are found to be on the order of 10^{-4} relative to water, about the same as isotopic species. The scale length of PH_3 in the coma is about 13,000–16,000 km. We also comment on other Rosetta findings (e.g., O_2 and H^-). Collaborations with observers using modern telescopic facilities (e.g., Keck 2 and Subaru) are underway to search for phosphorus in comets.
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116.19 – An interpretation of the CONSERT and SESAME-PP results based on new permittivity measurements of porous water ice and ice-basaltic/organic dust mixtures suggests an increase of porosity with depth in 67P.

The CONSERT bistatic radar on Rosetta and Philae sounded the interior of the small lobe of 67P/C-G at 90 MHz and determined the average of the real part of the complex permittivity (hereafter ε') to be equal to 1.27±0.05 [1,2]. The permittivity probe (PP) of the SESAME package sounded the near-surface in the 400–800 Hz range and derived a lower limit of ε' equal to 2.45±0.20 [3,4]. At the time of the measurements, the temperature was found to be below 150 K at Philae's location and expected to be close or below 100 K inside the nucleus [4-6].
The complex permittivity depends of the frequency, the composition, the porosity and the temperature of the material [7,8,9]. These parameters have to be taken into account to interpret the permittivity values. The non-dispersive behavior of *ε'* below 150 K [9], allows us to compare the CONSERT and SESAME-PP results and to interpret their difference in terms of porosity and/or composition. For this purpose we use a semi-empirical formula obtained from reproducible permittivity measurements performed in the laboratory at 243 K on water ice particles and ice-basaltic dust mixtures [10], with a controlled porosity in the 26–91% range and dust-to-ice volumetric ratios in the 0.1–2.8 range. The influence of the presence of organic materials on *ε'* is also discussed based on new measurements of analogues of complex extraterrestrial organic matter [11]. Our results suggest an increase of the porosity of the small lobe of 67P with depth [11], in agreement Lethuillier *et al.* [4]'s conclusion using a different method.

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[11]Brouet et al., 2016. MNRAS, Rosetta special issue, submitted.
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116.20 – A Possible Mechanism for the Formation of Magnetic Field Dropouts Observed by RPC-MAG in the Inner Coma of Comet 67P/Churyumov-Gerasimenko

The Rosetta Plasma Consortium MAGnetometer (RPC-MAG) has detected signatures of a diamagnetic cavity associated with the comet 67P/Churyumov-Gerasimenko at a distance of 170 km, which is two to three times larger than what has been predicted by numerical simulations of the cometary plasma environment. It remains unclear how this extended diamagnetic cavity forms. In the present work, we investigate this problem with our newly developed multi-fluid plasma-neutral interaction model (Huang et al., 2016). The multi-fluid model solves the governing multifluid MHD equations (for the cometary ions, the solar wind protons and the electrons) and the Euler equations for the neutral gas fluid. We find that a strong increase of electron pressure along a magnetic flux tube is capable of generating similar features of the diamagnetic cavity as those observed by the RPC-MAG. Direct comparison of our model results with the RPC observations shows reasonable agreement in terms of key characteristics of the cavity crossings, such as the duration and the magnetic field variations, suggesting that the mechanism proposed here based on localized enhancement of electron pressure may provide a possible explanation for the unusually large distance of the observed cavity.

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116.21 – Reflectance spectroscopy of natural organic solids, iron sulfides and their mixtures as refractory analogues for Rosetta/VIRTIS' surface composition analysis of 67P/CG

Analysis of 0.25-5 µm reflectance spectra provided by the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) onboard Rosetta orbiter revealed that the surface of 67P/CG is dark from the near-UV to the IR and is enriched in refractory phases such as organic and opaque components. The broadness and complexity of the ubiquitous absorption feature around 3.2 µm suggest a variety of cometary organic constituents. For example, complex hydrocarbons (aliphatic and polycyclic aromatic) can contribute to the feature between 3.3 and 3.5 µm and to the low reflectance of the surface in the visible. Here we present the 0.25-5 µm reflectance spectra of well-characterized terrestrial hydrocarbon materials (solid oil bitumens, coals) and discuss their relevance as spectral analogues for a hydrocarbon part of 67P/CG's complex organics. However, the expected low degree of thermal processing of cometary hydrocarbons (high (H+O+N+S)/C ratios and low carbon aromaticities) suggests high IR reflectance, intense 3.3-3.5 µm absorption bands and steep red IR slopes that are not observed in the VIRTIS spectra. Fine-grained opaque refractory phases (e.g., iron sulfides, Fe-Ni alloys) intimately mixed with other surface components are likely responsible for the low IR reflectance and low intensities of absorption bands in the VIRTIS spectra of the 67P/CG surface. In particular, iron sulfides are common constituents of cometary dust, "cometary" chondritic IDPs, and efficient darkening agents in primitive carbonaceous chondrites. Their effect on reflectance spectra of an intimate mixture is strongly affected by grain size. We report and discuss the 0.25-5 µm reflectance spectra of iron sulfides (meteoritic troilite and several terrestrial pyrrhotites) ground and sieved to various particle sizes. In addition, we present reflectance spectra of several intimate mixtures of powdered iron sulfides and solid oil bitumens. Based on the reported laboratory data, we discuss the ability of iron sulfides to suppress absorption bands of other cometary refractory components and to affect the spectral slopes and reflectance values of the 67P/CG surface at different wavelengths from the near-UV to the IR.

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Contributing team(s): the VIRTIS Team

116.22 – End of Mission, High Resolution Observations of the Coma and Surface of Comet 67P from the Rosetta-Alice, UV Spectrograph

On or about 2016 September 30, just prior to this DPS meeting, the Rosetta spacecraft will end its two-year exploration of comet 67P/Churyumov-Gerasimenko with a controlled impact onto the nucleus. Rosetta provided revolutionary results from the first long-term, in situ orbital study of a cometary nucleus and its inner coma. Among the suite of instruments on Rosetta is the NASA Alice ultraviolet spectrograph, the first UV spectrograph to collect data on a cometary mission. During the final two months of operations before impact, the Rosetta project plans to execute over a dozen flybys at altitudes closer than 2 km from the surface, resulting in unprecedented Alice spatial resolutions on the nucleus at 1-10 meter scales; coma observations at low altitudes also are planned and will provide observations on length scales as small as 10s of meters. We will report on this unique, late breaking, final dataset from the Rosetta-Alice project.

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116.23 – An empirical model of H_2O, CO_2 and CO coma distributions and production rates for comet 67P/Churyumov-Gerasimenko based on ROSINA/DFMS measurements and AMPS-DSMC simulations

We have previously used results from the AMPS DSMC (Adaptive Mesh Particle Simulator Direct Simulation Monte Carlo) model to create an empirical model of the near comet water (H_2O) coma of comet 67P/Churyumov-Gerasimenko. In this work we create additional empirical models for the coma distributions of CO_2 and CO. The AMPS simulations are based on ROSINA DFMS (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis, Double Focusing Mass Spectrometer) data taken over the entire timespan of the Rosetta mission. The empirical model is created using AMPS DSMC results which are extracted from simulations at a range of radial distances, rotation phases and heliocentric distances. The simulation results are then averaged over a comet rotation and fitted to an empirical model distribution. Model coefficients are then fitted to piecewise-linear functions of heliocentric distance. The final product is an empirical model of the coma distribution which is a function of heliocentric distance, radial distance, and sun-fixed longitude and latitude angles. The model clearly mimics the behavior of water shifting production from North to South across the inbound equinox while the CO_2 production is always in the South.

The empirical model can be used to de-trend the spacecraft motion from the ROSINA COPS and DFMS data. The ROSINA instrument measures the neutral coma density at a single point and the measured value is influenced by the location of the spacecraft relative to the comet and the comet-sun line. Using the empirical coma model we can correct for the position of the spacecraft and compute a total production rate based on single point measurements. In this presentation we will present the coma production rates as a function of heliocentric distance for the entire Rosetta mission.

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Contributing team(s): The ROSINA team

116.24 – Mass-loading of the solar wind around 67P/CG as seen by the Rosetta Plasma Consortium Ion Composition Analyzer (RPC-ICA)

The Rosetta Plasma Consortium (RPC) has been observing the plasma environment in the vicinity of the comet 67P/Churyumov-Gerasimenko for the last two years. We focus here on how the solar wind (SW) flow is affected by its interaction with the partially ionized coma, using data from the Ion Composition Analyzer (RPC-ICA).

At large heliocentric distances (*i.e.* low nucleus activity), the entire coma is permeated by the SW, and plasma boundaries such as bow shock or ionopause are not yet formed. Mass-loading (initially, neutral particles being ionized within an undisturbed plasma flow) is the main mechanism through which the coma affects the SW.

Observations show that the SW deflection from the comet-Sun line is controlled by the convective electric field, as expected for mass-loading. For heliocentric distances larger than 2.2 AU, deflection of the observed SW from the comet-Sun line remains bellow 90°, while its deceleration is very low: it is efficiently deflected but doesn't lose much energy.

When the nucleus draws closer to the Sun, activity keeps increasing, and the effects of this denser coma on the SW flow become accordingly larger. Proton velocity distributions become much more complex than the previous beam-like distribution, exhibiting parts of the proton population with a main sunward velocity component (*i.e.* deflection reaching almost 180°). The deceleration remains fairly low, the speed stays above 75% of the expected upstream speed.

Even closer to the Sun, the SW is not observed at the spacecraft position anymore. A SW free region has been created.

The SW then re-appears after perihelion, when the comet moves away from the Sun. We rewind the same scenario as described above, with a noticeable time-lag indicating a possible asymmetry in the nucleus activity along the inbound and outbound legs of the comet orbit around the Sun.

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116.25 – 67P Through the Lens of Art

I am an artist, who is deeply inspired by science. Since the landing of the robotic probe Philae on the comet I have been working on an art project called 67P. Having a goal of discovering our place in the universe, I chose ESA's Rosetta mission as a successful example of such discovery. During the conference I'd like to expand the dialogue to include an artistic research of the comet 67P. I invite the participants to explore 67P through the lens of art and create inspirational reciprocity in between two spheres, creative and scientific. New ideas often originate when two vocabularies are smashed together. Via this path we perhaps will be able to get a new way of exploring the topic of cometary science.

During the conference I'd like to present:

- 67p artwork in the art section
- poster outlining the major focuses of my project

Art project focuses:

- 67P water:

In the art studio I re-create water that is close in composition to the water on the comet, by enriching it with D2O. With this water I paint large scale paintings, based on the photographs by Rosetta (OSIRIS, Nav. Cam.).

- spectroscopic data:

Inspired by data from OSIRIS, I create an additional layer to my work using augmented reality to reveal a "hidden" from the view layer. I am making a parallel with the idea that some scientific information could be viewed only by using special instruments, in this case - instruments on board of Rosetta spacecraft, such as OSIRIS. You will be able to see a virtual layer on top of my paintings using a readily available instrument - your cellphone. Red, Green and Blue colors, of particular wavelength, will be introduced to the monochromatic paintings.

- magnetometer readings:

International music collaboration inspired by the "Singing comet" composition, based on the magnetometer data of 67P will be offered for any interested spectators.

- 67P smell:

In collaboration with The Open University, UK, postcards with a smell of the comet were created, introducing the chemical components of the comet. The cards will be also presented during the conference.

View my work:

paintings: http://ekaterina-smirnova.com/67p/

music: http://www.ekaterina-smirnova.com/67p-music/

50 ESLAB symposium: http://bit.ly/2aYpaKs

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Institution(s): *1. Ekaterina Smirnova*

Contributing team(s): ESA, The Open University, OSIRIS

116.26 – Stellar Occultations in the Coma of Comet 67/P Chuyumov-Gerasimenko Observed by the OSIRIS Camera System

In this paper we present the results of an analysis on a large part of the existing Image data from the OSIRIS camera system onboard the Rosetta Spacecraft, in which stars of sufficient brightness (down to a limiting magnitude of 6) have been observed through the coma of Comet 67/P Churyumov-Gerasimenko ("C-G"). Over the course of the Rosetta main mission the Coma of the comet underwent large changes in density and structure, owed to the changing insolation along the orbit of C-G. We report on the changes of the stellar signals in the wavelength ranges, covered by the filters of the OSIRIS Narrow-Angle (NAC) and Wide-Angle (WAC) cameras.

Acknowledgements: OSIRIS was built by a consortium led by the Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, in collaboration with CISAS, University of Padova, Italy,

the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Scientific Support Office of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany.

Author(s): Richard Moissl[1], Michael Kueppers[1]
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116.27 – Mass, Density, Internal Structure and Mass Loss of the Nucleus 67P/Churyumov-Gerasimenko

Cometary nuclei consist mostly of dust and water ice, but the internal structure of a comet nucleus were essentially unknown. Bulk properties such as mass, volume (size and shape), and particularly the density, must be known for constraining its internal structure. The radio science experiment RSI on the Rosetta spacecraft derived the mass and the gravity field of comet 67P/Churyumov-Gerasimenko at distances varying between 100 km and 10 km, and together with the current best estimates of the volume by the OSIRIS camera, the bulk density of the nucleus. A model of the internal structure is derived from the information of two shape models by comparing observed and theoretical gravity coefficients. The comet nucleus appears to be a body of low mass, low density and high porosity. Individual bulk densities of the two lobes were derived by a bimodal gravity field approach which are, however, not very different from the global bulk density. The currently still on-going second gravity field determination will reveal a statistically significant mass loss by the outgassing activity which peaked during the perihelion passage.

Author(s): Martin Paetzold[3], Tom Andert[4], Matthias Hahn[3], Sami W. Asmar[1], Jean-Pierre Barriot[5], Michael K. Bird[3], Bernd Häusler[4], Kerstin Susanne Peter[3], Silvia Tellmann[3], Eberhard Gruen[2], Paul R. Weissman[1]
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116.28 – 67P/Churyumov-Gerasimenko inner coma dust spatial distribution from 2.2 au inbound to the Sun to 2 au outbound

GIADA (Grain Impact Analyzer and Dust Accumulator) is an in-situ dust instrument onboard Rosetta devoted to measure physical and dynamical properties of the dust particles ejected by comet 67P/Churyumov-Gerasimenko (67P/C-G) nucleus. GIADA provides individual dust particle momentum, mass and speed. From August 2014 to June 2016 Rosetta escorted comet 67P/C-G during its journey around the Sun that will last till September 2016. We focus here on GIADA data from February 2015 to February 2016. To contribute studying cometary activity, more specifically, to understand to the dust structures observed in cometary comas, we obtained from GIADA measurements maps of 67P/C-G coma dust spatial distribution. These maps allowed us to follow the evolution of the high dust density regions and their connection with nucleus illumination conditions, more in general with 67P/C-G seasons.

Acknowledgements
GIADA was built by a consortium led by the Univ. Napoli "Parthenope" & INAF- Oss. Astr. Capodimonte, in collaboration with the Inst. de Astrofisica de Andalucia, Selex-ES, FI and SENER. GIADA is presently managed & operated by Ist. di Astrofisica e Planetologia Spaziali-INAF, IT. GIADA was funded and managed by the Agenzia Spaziale Italiana, IT, with the support of the Spanish Ministry of Education and Science MEC, ES. GIADA was developed from a PI proposal from the University of Kent; sci. & tech. contribution were provided by CISAS, IT, Lab. d'Astr. Spat., FR, and Institutions from UK, IT, FR, DE and USA. We thank the RSGS/ESAC, RMOC/ESOC & Rosetta Project/ESTEC for their outstanding work. Science support provided was by NASA through the US Rosetta Project managed by the Jet Propulsion Laboratory/California Institute of Technology. GIADA calibrated data will be available through ESA's PSA web site (www.rssd.esa.int/index.php?project=PSA&page=in dex).

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Contributing team(s): and the GIADA International TEAM

117 – Mercury Posters

117.01 – Study of the internal magnetic field of Mercury through 3D hybrid simulations

In 1974, Mariner 10 discovered the intrinsic magnetic field of Mercury which interacts with the solar wind, leading to the formation of a magnetosphere. In spite of the recent MESSENGER observations, this magnetosphere remains quite unknown, especially in the Southern hemisphere. In order to improve our understanding of the Hermean magnetosphere, and to prepare the Bepi-Colombo mission (ESA/JAXA), we simulated the magnetized environment of Mercury using the model named LatHyS (LATMOS Hybrid Simulation). LatHyS is a 3D parallel multi-species hybrid code which has been applied to Mars, Titan and Ganymede, which has recently be improved by the implementation of a multi-grid method allowing to refine the spatial resolution near the planetary object (40 km in the case of Mercury). In order to investigate the Hermean environment, several hybrid simulations have been performed considering different internal field models, and results are compared with MESSENGER observations.

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117.02 – MESSENGER observations of energetic electron acceleration in Mercury's magnetotail

Energetic particle bursts within Mercury's magnetosphere have been a source of curiosity and controversy since Mariner 10's flybys. Unfortunately, instrumental effects prevent an unambiguous determination of species, flux, and energy spectrum for the Mariner 10 events. MESSENGER data taken by the Energetic Particle Spectrometer (EPS) have now shown that these energetic particle bursts are composed entirely of electrons. EPS made directional measurements of these electrons from ~30 to 300 keV at 3 s resolution, and while the energy of these electrons sometimes exceeded 200 keV, the energy distributions usually exhibited a cutoff near 100 keV. The Gamma Ray Spectrometer (GRS) has also provided measurements of these electron events, at higher time resolution (10 ms) and energetic threshold (> 50 keV) compared to EPS. We focus on GRS electron events near the plasma sheet in Mercury's magnetotail to identify reconnection-associated acceleration mechanisms. We present observations of acceleration associated with dipolarization events (betratron acceleration), flux ropes (Fermi acceleration), and tail loading/unloading (X-line acceleration). We find that the most common source of energetic electron events in Mercury's magnetosphere are dipolarization events similar to those first observed by Mariner 10. Further, a significant dawn-dusk asymmetry is found with dipolarization-associated energetic particle bursts being more common on the dawn side of the magnetotail.

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117.03 – Mercury's core evolution

Remote sensing data of Mercury's surface by MESSENGER indicate that Mercury formed under reducing conditions. As a consequence, silicon is likely the main light element in the core together with a possible small fraction of sulfur. Compared to sulfur, which does almost not partition into solid iron at Mercury's core conditions and strongly decreases the melting temperature, silicon partitions almost equally well between solid and liquid iron and is not very effective at reducing the melting temperature of iron. Silicon as the major light element constituent instead of sulfur therefore implies a significantly higher core liquidus temperature and a decrease in the vigor of compositional convection generated by the release of light elements upon inner core formation.
Due to the immiscibility in liquid Fe-Si-S at low pressure (below 15 GPa), the core might also not be homogeneous and consist of an inner S-poor Fe-Si core below a thinner Si-poor Fe-S layer. Here, we study the consequences of a silicon-rich core and the effect of the blanketing Fe-S layer on the thermal evolution of Mercury's core and on the generation of a magnetic field.

Author(s): Marie-Hélène Deproost[1], Attilio Rivoldini[1], Tim Van Hoolst[1]
Institution(s): *1. Royal Observatory of Belgium*

117.04 – Mercury's interior structure constrained by geodesy and present-day thermal state

Recent measurements of Mercury's spin state and gravitational field strongly constrain Mercury's core radius and core density, but provide little information on the size of its inner core. Both a fully molten liquid core and a core differentiated into a large solid inner core and a liquid outer part are consistent with the observations, although the observed tides seem to exclude an extremely large inner core. The observed global magnetic field could be generated even without a growing inner core, since remelting of iron snow inside the core might produce a sufficiently large buoyancy flux to drive magnetic field generation by compositional convection.
Further constraints on Mercury's internal structure can be obtained by studying its thermal state. The inner core radius depends mainly on the thermal state and on the light elements present in the core. Secular cooling and subsequent formation of an inner core lead to the global contraction of the planet, estimated to be about 7 km.
In this study we combine geodesy data (88 day libration amplitude, polar moment of inertia, and tidal Love number) with the recent estimate of the radial contraction of Mercury and thermal evolution calculations in order to constrain its interior structure and in particular its inner core. We consider bulk compositions that are in agreement with the reducing formation conditions suggested by remote sensing data of Mercury's surface.

Author(s): Attilio Rivoldini[1], Tim Van Hoolst[1], Mikael Beuthe[1], Marie-Hélène Deproost[1]
Institution(s): *1. Royal Observatory of Belgium*

117.05 – The 2016 Transit of Mercury Observed from Major Solar Telescopes and Satellites

We report observations from the ground and space of the 9 May 2016 transit of Mercury. We build on our explanation of the black-drop effect in transits of Venus based on spacecraft observations of the 1999 transit of Mercury (Schneider, Pasachoff, and Golub, *Icarus* 168, 249, 2004). In 2016, we used the 1.6-m New Solar Telescope at the Big Bear Solar Observatory with active optics to observe Mercury's transit at high spatial resolution. We again saw a small black-drop effect as 3rd contact neared, confirming the data that led to our earlier explanation as a confluence of the point-spread function and the extreme solar limb darkening (Pasachoff, Schneider, and Golub, in IAU Colloq. 196, 2004). We again used IBIS on the Dunn Solar Telescope of the Sacramento Peak Observatory, as A. Potter continued his observations, previously made at the 2006 transit of Mercury, at both telescopes of the sodium exosphere of Mercury (Potter, Killen, Reardon, and Bida, *Icarus* 226, 172, 2013). We imaged the transit with IBIS as well as with two RED Epic IMAX-quality cameras alongside it, one with a narrow passband. We show animations of our high-resolution ground-based observations along with observations from XRT on JAXA's Hinode and from NASA's Solar Dynamics Observatory. Further, we report on the limit of the transit change in the Total Solar Irradiance, continuing our interest from the transit of Venus TSI (Schneider, Pasachoff, and Willson, *ApJ* 641, 565, 2006; Pasachoff, Schneider, and Willson, AAS 2005), using NASA's SORCE/TIM and the Air Force's TCTE/TIM. See http://transitofvenus.info and http://nicmosis.as.arizona.edu.
Acknowledgments: We were glad for the collaboration at Big Bear of Claude Plymate and his colleagues of the staff of the Big Bear Solar Observatory. We also appreciate the collaboration on the transit studies of Robert Lucas (Sydney, Australia) and Evan Zucker (San Diego, California). JMP appreciates the sabbatical hospitality of the Division of Geosciences and Planetary Sciences of the California Institute of Technology, and of Prof. Andrew Ingersoll there. The solar observations lead into the 2017 eclipse studies, for which JMP is supported by grants from the NSF AGS and National Geographic CRE.

Author(s): Jay M. Pasachoff[7], Glenn Schneider[6], Dale Gary[4], Bin Chen[4], Alphonse C. Sterling[3], Kevin P. Reardon[5], Ronald Dantowitz[1], Greg A. Kopp[2]
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117.06 – A comprehensive study of Mercury and MESSENGER orbit determination

The MErcury, Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft orbited the planet Mercury for more than 4 years. The probe started its science mission in orbit around Mercury on 18 March 2011. The Mercury Laser Altimeter (MLA) and radio science system were the instruments dedicated to geodetic observations of the topography, gravity field, orientation, and tides of Mercury. X-band radio-tracking range-rate data collected by the NASA Deep Space Network (DSN) allowed the determination of Mercury's gravity field to spherical harmonic degree and order 100, the planet's obliquity, and the Love number k_2.
The extensive range data acquired in orbit around Mercury during the science mission (from April 2011 to April 2015), and during the three flybys of the planet in 2008 and 2009, provide a powerful dataset for the investigation of Mercury's ephemeris. The proximity of Mercury's orbit to the Sun leads to a significant perihelion precession attributable to the gravitational flattening of the Sun (J_2) and the Parameterized Post-Newtonian (PPN) coefficients γ and β, which describe the space curvature produced by a unit rest mass and the nonlinearity in superposition of gravity, respectively. Therefore, the estimation of Mercury's ephemeris can provide

crucial information on the interior structure of the Sun and Einstein's general theory of relativity. However, the high correlation among J_2, γ, and β complicates the combined recovery of these parameters, so additional assumptions are required, such as the Nordtvedt relationship $\eta = 4\beta - \gamma - 3$.
We have modified our orbit determination software, GEODYN II, to enable the simultaneous integration of the spacecraft and central body trajectories. The combined estimation of the MESSENGER and Mercury orbits allowed us to determine a more accurate gravity field, orientation, and tides of Mercury, and the values of *GM* and J_2 for the Sun, where *G*is the gravitational constant and *M* is the solar mass. Several test cases illuminate results on the estimation of PPN parameters.

Author(s): Antonio Genova[4], Erwan Mazarico[5], Sander Goossens[1], Frank G. Lemoine[5], Gregory A. Neumann[5], Joseph B. Nicholas[2], David D. Rowlands[5], David E. Smith [4],Maria Zuber[4], Sean C. Solomon[3]
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118 – Moon: Interior Posters

118.01 – Lunar Tidal Deformation and the Deep Interior

The gravitational attractions of the Earth and Sun raise tides on the Moon. The amplitudes of vertical tidal variations are typically 0.1 to 0.15 m in size. The GRAIL mission determines the potential Love number k_2 = 0.02422 with <1% uncertainty. Models with a crust, mantle, deep dissipating region, and fluid core can match the k_2. Lunar Laser Ranging determines tidal dissipation *Q*=38 at 1 month period and *Q*=41 at 1 yr. Dissipation in the deep mantle appears to cause the low tidal *Q* and *Q* versus tidal period is a clue about the dissipation mechanism. The dissipating region has an upper radius of at least 535 km. The vertical displacement Love number h_2 is detected.

Author(s): James G. Williams[1], Alex S. Konopliv[1], Ryan Park[1], Dale H. Boggs[1], Sami W. Asmar[1], Dah-Ning Yuan[1], James Ratcliff[1], Michael M. Watkins[1], David E. Smith [2],Maria Zuber[2]
Institution(s): *1. JPL, 2. MIT*

118.02 – An improved Bernese Moon gravity field and tidal Love number k2 solution from GRAIL Doppler and KBRR data

The NASA mission GRAIL inherits its concept from the GRACE mission to determine the gravity field of the Moon. Beside one-way and two-way Doppler tracking from Earth, GRAIL uses inter-satellite Ka-band range-rate (KBRR) observations to enable data acquisition even when the spacecraft are not tracked from the Earth. The data allows for a highly accurate estimation of the lunar gravity field on both sides of the Moon, which is leading to huge improvements in our understanding of its internal structure and thermal evolution. This led to a spectacular resolution of as few as 7 km for the gravity field in the latest solutions by NASA JPL and GSFC teams.
The Astronomical Institute of the University of Bern (AIUB) recently started the development of deep space Doppler data processing within the Bernese GNSS Software, which has been long used in orbit determination of low Earth orbiting satellites and Earth gravity field determination. In this presentation we discuss the latest GRAIL-based orbit and gravity field solutions generated with the Celestial Mechanics Approach using the Bernese GNSS Software.
Based on Doppler data, we perform orbit determination by solving six initial orbital elements, dynamical parameters, and stochastic parameters in daily arcs using least-squares adjustment. The pseudo-stochastic parameters are estimated to absorb deficiencies in our dynamical modeling (e.g. due to non-gravitational forces). Doppler and KBRR data are then used together with an appropriate weighting for a combined orbit and gravity field determination process.
We present our independent solutions of the lunar gravity field up to d/o 300, where KBRR data and Doppler 1-way and 2-way observations from the primary mission phase (PM, March-May 2012) are used. We compare and evaluate the impact of 1-way and 2-way Doppler data on our results. Moreover, we present our first solution for the Moon tidal Love number k2.
We compare all of our results from the PM with the most recent lunar gravity field models released by other groups, as well as their consistency with topography-induced gravity.

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118.03 – Two Approaches in the Lunar Libration Theory: Analytical vs. Numerical Methods

Observation of the physical libration of the Moon and the celestial bodies is one of the astronomical methods to remotely evaluate the internal structure of a celestial body without using expensive space experiments. Review of the results obtained due to the physical libration study, is presented in the report.
The main emphasis is placed on the description of successful lunar laser ranging for libration determination and on the methods of simulating the physical libration. As a result, estimation of the viscoelastic and dissipative properties of the lunar body, of the lunar core parameters were done. The core's existence was confirmed by the recent reprocessing of seismic data Apollo missions. Attention is paid to the physical interpretation of the phenomenon of free libration and methods of its determination.
A significant part of the report is devoted to describing the practical application of the most accurate to date the analytical tables of lunar libration built by comprehensive analytical processing of residual differences obtained when comparing the long-term series of laser observations with numerical ephemeris DE421 [1].
In general, the basic outline of the report reflects the effectiveness of two approaches in the libration theory - numerical and analytical solution. It is shown that the two approaches complement each other for the study of the Moon in different aspects: numerical approach provides high accuracy of the theory necessary for adequate treatment of modern high-accurate observations and the analytic approach allows you to see the essence of the various kind manifestations in the lunar rotation, predict and interpret the new effects in observations of physical libration [2].
[1] Rambaux, N., J. G. Williams, 2011, The Moon's physical librations and determination of their free modes, Celest. Mech. Dyn. Astron., 109, 85–100.
[2] Petrova N.**,** A. Zagidullin, Yu. Nefediev. Analysis of long-periodic variations of lunar libration parameters on the basis of analytical theory / // The Russian-Japanese Workshop, 20-25 October, Tokyo (Mitaka) - Mizusawa, Japan. – 2014.

Author(s): Natalia Petrova[1], Arthur Zagidullin[1], Yurii Nefediev[1], Valerii Kosulin[2]
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118.04 – Solution of the main problem of the lunar physical libration by a numerical method

Series of the lunar programs requires highly accurate ephemeris of the Moon at any given time. In the light of the new requirements on the accuracy the requirements to the lunar physical libration theory increase.
At the Kazan University there is the experience of constructing the lunar rotation theory in the analytical approach. Analytical theory is very informative in terms of the interpretation of the observed data, but inferior to the accuracy of numerical theories. The most accurate numerical ephemeris of the Moon is by far the ephemeris DE430 / 431 built in the USA. It takes into account a large number of subtle effects both in external perturbations of the Moon, and in its internal structure. Before the Russian scientists the task is to create its own numerical theory that would be consistent with the American ephemeris. On the other hand, even the practical application of the american ephemeris requires a deep understanding of the principles of their construction and the intelligent application.
As the first step, we constructed a theory in the framework of the main problem. Because we compare our theory with the analytical theory of Petrova (1996), all the constants and the theory of orbital motion are taken identical to the analytical theory. The maximum precision, which the model can provide is 0.01 seconds of arc, which is insufficient to meet the accuracy of modern observations, but this model provides the necessary basis for further development.
We have constructed the system of the libration equations, for which the numerical integrator was developed. The internal accuracy of the software integrator is several nanoseconds. When compared with the data of Petrova the differences of order of 1 second are observed at the resonant frequencies. The reason, we believe, in the inaccuracy of the analytical theory. We carried out a comparison with the Eroshkin's data [2], which gave satisfactory agreement, and with Rambaux data. In the latter case, as expected, the residual differences are limited, but have many periodic harmonics with the amplitudes of a few seconds.
Author(s): Arthur Zagidullin[1], Natalia Petrova[1], Yurii Nefediev[1]
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118.05 – Developments in Lunar Gravity Field Recovery Within the Project GRAZIL

The project GRAZIL addresses the highly accurate recovery of the lunar gravity field using intersatellite Ka-band ranging (KBR) measurements collected by the Lunar Gravity Ranging System (LGRS) of the Gravity Recovery And Interior Laboratory (GRAIL) mission. Dynamic precise orbit determination is an indispensable task in order to recover the lunar gravity field based on LGRS measurements. The concept of variational equations is adopted to determine the orbit of the two GRAIL satellites based on radio science data. In this contribution we focus on the S-band two-way Doppler data collected by the Deep Space Network.
As far as lunar gravity field recovery is concerned, we apply an integral equation approach using short orbital arcs. In this contribution we demonstrate the progress of Graz lunar gravity field models (GrazLGM) from the beginning, till the end of the projet GRAZIL. For the latest GrazLGM version special attention is given to the refinement of our processing strategy in conjunction with an increase of the spectral resolution. Furthermore, we present the first GrazLGM based on KBR observations during the primary and the extended mission phase. Our results are validated against state of the art lunar gravity field models computed at NASA-GSFC and NASA-JPL.
Author(s): Harald Wirnsberger[1], Beate Klinger[2], Sandro Krauss[1], Torsten Mayer-Gürr[2]
Institution(s): *1. Austrian Academy of Sciences, 2. Graz University of Technology*

119 – Origin and Evolution of Planetary Systems Posters

119.01 – Forming Gaps in Debris Disks with Fewer Planets via Planet Migration

Debris disks across a wide range of ages can possess wide gaps of several AU or more; these gaps have been attributed to the presence of multiple planets. While at least two planets are likely needed for maintaining the edges of such gaps, large gaps may require more than two in more dynamically packed configurations to be able to have cleared material within the gap in the present day. As an alternative to currently packed planets occupying gaps in debris disks, we assess whether planetesimal and dynamical instability-driven planet migration could produce wide gaps with lower mass, fewer planets on relevant timescales to be consistent with the observed properties of debris disk systems. We also discuss implications for the disk properties in which these mechanisms could operate within the broader evolutionary context linking planets, debris disks, and the protoplanetary disks from which they originated.
Author(s): Sarah J. Morrison[1], Kaitlin M. Kratter[1]
Institution(s): *1. Univ. of Arizona*

119.02 – Planetary Diversity through Instability and Consolidation of High Multiplicity STIPs

In previous work, we conducted a series of simulations to demonstrate the feasibility of in situ formation of giant planets at short orbital periods through the consolidation of planets in high multiplicity STIPs. The resulting planet-planet collisions can generate planetary diversity, depending on the timing of instability in the system. If instability occurs while significant gas is still present, then consolidation can produce critical cores massive enough to initiate runaway gas accretion within the lifetime of the gaseous disk. At the time, however, we did not include gas damping effects. Here, we explore how eccentricity and inclination damping can affect the outcomes of STIP metastability
Author(s): Agueda Paula Granados-Contreras[1], Aaron C. Boley[1]
Institution(s): *1. University of British Columbia*

119.03 – The Solar System Origin Revisited

A novel theory will be presented based in part on astronomical observations, plasma physics experiments, principles of physics and forensic techniques. The new theory correctly predicts planetary distances with a 1% precision. It accounts for energy production mechanism inside all of the planets including our Earth. A log-log mass-luminosity plot of G2 class stars ***and*** solar system planets results in a straight line plot, whose slope implies that a fission rather than a proton-proton fusion energy production is operating. Furthermore, it is a confirmation that all our planets had originated from ***within*** our Sun. Other still-born planets continue to appear on the Sun's surface, they are mislabeled as sunspots.
Author(s): Fred M. Johnson[1]
Institution(s): *1. California State Univ.*

119.04 – The Dynamics of Orbit-Clearing for Planets on Eccentric Orbits

The third requirement in the 2006 International Astronomical Union (IAU) definition of a planet is that the object has cleared the neighborhood around its orbit. Margot (2015) proposed a metric that quantitatively determines if an object has enough mass to clear an orbital zone of a specific extent within a defined time interval. In this metric, the size of the zone to be cleared is given by CR_H, where C is a constant and R_H is the Hill Radius. Margot (2015) adopts $C=2*3^{1/2}$ to describe the minimum extent of orbital clearing on the basis of the planet's feeding zone. However, this value of C may only apply for eccentricities up to about 0.3 (Quillen & Faber 2006). Here, we explore the timescales and boundaries of orbital clearing for planets over a range of orbital eccentricities and planet-star mass ratios using the MERCURY integration package (Chambers 1999). The basic setup for the integrations includes a single planet orbiting a star and a uniform distribution of massless particles extending beyond CR_H. The system is integrated for at least 10^6revolutions and the massless particles are tracked in order to quantify the timescale and extent of the clearing.

Author(s): Danielle Hastings[1], Jean-Luc Margot[1]
Institution(s): *1. University of California, Los Angeles*

119.05 – Grain Growth and Settling: An Implication for Disk Instability and Giant Planet Formation

Formation of super-massive planets at a distance ranging from around 5 to 20 AU cannot be adequately explained by core accretion, even in the most optimistic scenario. The only promising alternative is the fragmentation mechanism in which giant planets are formed directly from the contraction of a clump of gas produced by gravitational instability. Here, we investigate whether simultaneous grain growth and settling can trigger gravitational instability at these distances. We study the physics of grain growth and how grains of different sizes are subject to sedimentation using a sophisticated collision and settling model starting with an MRN dust size distribution consistent with that of ISM. We capture the full physics of disk turbulence, dust diffusion and vertical settling, followed by a wavelength dependent opacity calculation including constant porosity. The thermal profile of the disk is re-calculated frequently with a detailed radiative transfer code RadMC. More importantly, our aim is to check whether grain growth and dust settling can effectively change the opacity for the gas and affect the stability of the disk by changing the ToomreQ parameter. We take a prototype disk which is hot on the surface and has a quiescent midplane, which, because of being less turbulent allows the grains to grow more efficiently. In this context, we examine the gravitational stability of a layered accretion disk experiencing dust-settling and review the possibilities of super-massive planet formation at the range of distances concerned. We also present a steady state grain abundance and the opacity profile at different time of disk evolution. We compare that with the standard viscous accretion disk.

Author(s): Debanjan Sengupta[1], Sarah Dodson-Robinson[1]
Institution(s): *1. University of Delaware*

119.06 – Impact cratering of the terrestrial planets and the Moon during the giant planet instability

The dynamical instability of the giant planets and the planetesimal driven migration both have major implications for the crater record of the terrestrial planets and the Moon. The crater record can thus provide contraints to the behavior of the planets in the early Solar System. Here we determine the impact fluxes and the crater production rates on the terrestrial planets and the Moon from impactors originating in the primordial asteroid main belt (2.1 to 3.2 au) and the E-belt (1.5 to 2.1 au - Bottke et al. 2012). We determine the impact flux over the age of the Solar System, with particular focus on the instability of the giant planets in the jumping Jupiter model. We start with a population of asteroids uniformly distributed in the orbital parameters space, and numerically evolve them as test particles under the gravitational perturbations of the giant and terrestrial planets. We test the effects on this population due to different jumping Jupiter evolutions (the idealized jump as in Bottke et al. 2012 or models taken from Nesvorny & Morbidelli 2012). The number of impacts is determined by applying Opik's theory. We compute the impact rates on different targets (Mercury, Venus, Earth, Moon, and Mars) and from different source regions in the asteroid belt (E-belt, inner belt, outer belt). By properly calibrating the impact rates, and using crater scaling laws, we estimate the number and size distribution of craters. We show how the impact flux and crater production rates depend on the different parameters of the model such as the initial orbital distribution of the asteroids, time of the instability, different evolution of the planets, initial size distribution of the impactors, etc.

Author(s): Fernando Virgilio Roig[1], David Nesvorny[2], William Bottke[2]
Institution(s): *1. Observatorio Nacional, 2. Southwest Research Institute*

120 – Centaurs and Kuiper Belt Objects Posters

120.01 – Position of planet X obtained from motion of near-parabolic comets

The authors of paper (Batygin and Brown, 2016) proposed that a planet with 10 earth's mass and an orbit of 700 AU semi major axis and 0.6 eccentricity can explain the observed distribution of Kuiper Belt objects around Sedna. Then Fienga et al.(2016) used the INPOP planetary ephemerides model as a sensor for testing for an additional body in the solar system. They defined the planet position on the orbit using the most sensitive data set, the Cassini radio ranging data.

Here we use near-parabolic comets for determination of the planet's position on the orbit. Assuming that some comets approached the planet in the past, we made a search for the comets with low Minimum Orbit Intersection Distance (MOID) with the planet's orbit. From the list of 768 near-parabolic comets five "new" comets with hyperbolic orbits were chosen. We considered two cases of the planet's motion: the direct and the inverse ones. In case of the direct motion the true anomaly of the planet lies in interval [176^0, 184^0] and, thus, the right ascension, the declination and geocentric distance of the planet are in intervals [83^0, 90^0], [8^0,10^0], and [1110, 1120] AU, correspondingly. In case of the inverse motion the true anomaly is in [212^0, 223^0] and the other values are in intervals [48^0, 58^0], [-12^0,-6^0] and [790, 910] AU. For comparison with the direct motion the true anomaly for the inverse motion, v, should be transformed by 360^0-v. That gives us the interval [137^0, 148^0] that belongs to the intervals of the true anomaly of possible planet's position given by Fienga et al.(2016).

References

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Fienga A. A. Fienga1,J. Laskar, H. Manche, and M. Gastineau, 2016, *Constraints on the location of a possible 9th planet derived from the Cassini data* , Astronomy & Astrophysics, v. 587, L8

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120.02 – Primary results from the Pan-STARRS-1 Outer Solar System Key Project

We have completed a search for slow moving bodies in the data obtained by the Pan-STARRS-1 (PS1) Science Consortium from 2010 to 2014. The data set covers the full sky north of -30 degrees declination, in the PS1 g, r, i, z, y, and w (g+r+i) filters. Our novel distance-based search is effective at detecting and linking very slow moving objects with sparsely sampled observations, even if observations are widely separated in RA, Dec and time, which is relevant to the future LSST solar system searches. In particular, our search is sensitive to objects at heliocentric distances of 25-2000 AU with magnitudes brighter than approximately r=22.5, without limits on the inclination of the object. We recover hundreds of known TNOs and Centaurs and discover hundreds of new objects, measuring phase and color information for many of them. Other highlights include the discovery of a second retrograde TNO, a number of Neptune Trojans, and large numbers of distant resonant TNOs.

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Contributing team(s): Pan-STARRS 1 Science Consortium

120.03 – Digging up ice-rocks: clues to our origin frozen in the outer Solar System

As of 2016, almost 2000 trans-Neptunian objects (TNOs) and Centaurs have been discovered, and this is only a small fraction of the estimated total population. These ice-rocks are the relics of the formation of the Solar System and keep deep in their frozen interior the code to decipher the first stages of its formation. However, after more than 20 years of studies from ground- and space-based telescopes, we are not able, as yet, to unravel the conditions in the outer nebula into a clear picture of the chemical, dynamical, and thermal history of the outer Solar System.
The big picture of this region shows the trans-Neptunian belt as a population of icy objects, covered by a mixture of water ice, silicates and complex organics, with varied sizes (9 to 2400 km) and albedos (4 to 96%). In some particular cases the presence of volatiles (CO, N2) or other ices (CH3OH) has also been detected. Two space-based observatories have made exceptional contributions to our understanding of the physical nature of TNOs: *Spitzer Space Telescope* and the *Herschel Space Telescope*. *Spitzer*, detected for the first time thermal radiation from TNOs, and together with *Herschel* provided constraints on the sizes, albedos, and thermal properties of over 100 of them.
Moreover, *IRAC/Spitzer* data combined with existing observations at wavelengths < 2.5µm, and with the thermal properties addressed by *Herschel* and *Spitzer*, have proven to be a treasure trove that provides unprecedented insights into the surface composition of TNOs.
In the near future, *James Webb Space Telescope* (JWST, to be launched in 2018) will succeed the *Hubble Space Telescope* as NASA's premier space-based telescope for planetary science. This telescope will offer much more detailed characterization of TNO's composition via NIRCam photometry, or NIRSpec spectroscopy, from 1 – 5 µm.
Here we show the results of the study of TNOs' surface composition by means of the analysis of 0.4 to 5 µm albedos. We will also show how IRAC data can be used as the foundation for target selection and successful observation planning. Spitzer's results are key to our understanding of the composition of TNOs, and will provide a firm footing for studying the trans-Neptunian belt using JWST.

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120.04 – A Ninth Planet Would Produce a Distinctly Different Kuiper Belt

The orbital element distribution of trans-Neptunian objects (TNOs) with large pericenters has been suggested to be influenced by the presence of an undetected, large planet at 200 or more AU from the Sun. We perform 4 Gyr N-body simulations with the currently known Solar System planetary architecture, plus a 10 Earth mass planet with similar orbital parameters to those suggested by Batygin and Brown (2016) or Trujillo and Sheppard (2014), and a hundred thousand test particles in an initial planetesimal disk. We find that including a distant superearth-mass ninth planet produces a substantially different orbital distribution for the scattering and detached TNOs, raising the pericenters and inclinations of moderate semimajor axis (50 < a < 500 AU) objects. We test whether this signature is detectable via a simulator with the observational characteristics of four precisely characterized TNO surveys. We find that the qualitatively very distinct Solar System models that include a ninth planet are essentially observationally indistinguishable from an outer Solar System produced solely by the four giant planets. We also find that the mass of the Kuiper Belt's current scattering and detached populations is required be 3-10 times larger in the presence of an additional planet. Wide-field, deep surveys targeting inclined high-pericenter objects will be required to distinguish between these different scenarios.

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120.05 – Status of the Transneptunian Automated Occultation Survey (TAOS II)

The Transneptunian Automated Occultation Survey (TAOS II) will aim to detect occultations of stars by small (~1 km diameter) objects in the Kuiper Belt and beyond. Such events are very rare ($<0.001 events per star per year) and short in duration (~200 ms), so many stars must be monitored at a high readout cadence. TAOS II will operate three 1.3 meter telescopes at the Observatorio Astronomico Nacional at San Pedro Martir in Baja California, Mexico. With a 2.3 square degree field of view and a high speed camera comprising CMOS imagers, the survey will monitor 10,000 stars simultaneously with all three telescopes at a readout cadence of 20 Hz. Construction of the site began in the fall of 2013, and the survey will begin in the summer of 2017. This poster will provide an update on the status of the survey development and the schedule leading to the beginning of survey operations.

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120.06 – Centaur's ring system formation by close encounters

Rupture of small bodies due to close approach to a massive body is a frequent event in the Solar System. Some of these small bodies can just disintegrate completely or suffer a material loss.
In this work we study the gravitational interaction between a giant planet and a small body in close encounters in order to simulate the formation of a planetary ring system around a centaur by the partial rupture of the small body.

Considering the current Chariklo's body and a disk of particles around it, we simulated the system under close encounters with one of giant planets.
Another motivation for the study is also the centaur Chiron, that is a candidate to have a ring system like Chariklo. The characteristics of the encounters are defined by the impact parameter and the velocity at infinity.
The results are presented in terms of conditions that could lead to a rupture that could generate a ring like system.
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120.07 – Sensitivity of Saturn's orbit to a hypothetical distant planet

Several distant scattered Kuiper belt objects have similar perihelion directions that might be aligned due to the influence an unknown planet well outside the orbit of Neptune (Batygin & Brown, 2016 Astronomical J. 151:22). Such a planet, with a mass up to an order of magnitude larger than the Earth, would affect the rest of the solar system. Saturn, which is well observed from radio range and VLBI observations of the Cassini spacecraft, provides an opportunity to look for these perturbations. An unknown large planet would be expected to affect the orbit of Saturn, but the effect might be partially absorbed in the estimation of parameters used to fit the planetary ephemerides. Ephemeris parameters include the planetary orbital elements, the mass of the Sun and the masses of asteroids that perturb the orbit of Mars. Earlier analysis of the Cassini data showed no effect as suggested by the Modified Newtonian Dynamics theory (Hees et al., 2014 Phys. Rev. D 89:102002). We present an updated Cassini data set, with the accuracy of ranges to Saturn improved through updated estimates of the Cassini spacecraft orbit, and an analysis of the largest possible perturbing distant planet mass consistent with the ranging data.
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120.08 – The Outer Solar System Origins Survey (OSSOS): Survey Status and Highlights

We report the discovery, tracking and detection circumstances for 562 trans- Neptunian objects (TNOs) from the first 128 deg2 of the Outer Solar System Origins Survey (OSSOS). This ongoing r-band Solar System survey uses the ~1 deg^2 field-of-view MegaPrime camera on the 3.6 m Canada-France-Hawaii Telescope. The orbital elements for these TNOs are precise to a fractional semi-major axis uncertainty of between 0.1 - 0.01%. We achieve this precision in just two oppositions, as compared to the normal 3--5 oppositions, via a dense observing cadence and innovative astrometric technique. These discoveries are free of ephemeris bias, a first for large trans-Neptunian surveys. Using the current OSSOS sample we confirm the existence of a cold "kernel" of objects within the main cold classical Kuiper belt, and infer the existence of an extension of the "stirred" cold classical Kuiper belt to at least several AU beyond the 2 :1 mean motion resonance with Neptune. We find that the population model of Petit et al. (2011) provides a plausible 1st order representation of the Kuiper belt, but more detailed structure has begun to emerged. The full survey, to be completed in 2017, will provide an exquisitely characterized sample of important resonant TNO populations, ideal for testing models of giant planet migration during the early history of the Solar System.
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Contributing team(s): The OSSOS Collaboration

120.09 – An exploration of the trans-Neptunian region through stellar occultations and MIOSOTYS

As the Kuiper belt is located far from the sun, it is difficult to observe the small objects that are composing it. To understand how the Kuiper belt was formed , we need to study the size distribution of its objects. We have to be able to detect sub-kilometric objects . This is possible only by random stellar occultations. In order to perform those observations, we have an instrument called MIOSOTYS. MIOSOTYS (Multi-object Instrument for Occultations in the SOlar system and TransitorY Systems) is a fibre-based, high speed photometer which is designed mainly for serendipitously monitoring the occultation events caused by small Trans-Neptunian Objects (TNOs) located at the distance of 40 AU and beyond from the Sun, the so-called Kuiper Belt. Because of the small angular size of the star, the passing TNO through the line of sight of the star will produce a diffraction-dominated phenomena.
This is a visitor instrument mounted on the 193 cm telescope at the Observatoire de Haute-Provence, France and on the 123 cm telescope at the Calar Alto Observatory, Spain. Our immediate goal is to characterize the spatial distribution and extension of the Kuiper Belt, and the physical size distribution of TNOs. We present the observation campaigns during 2010-2014, objectives and observing strategy. We report the detection of potential candidates for occultation events of TNOs. We will discuss more specifically the method used to process the data and the modelling of diffraction patterns. We, finally present the results obtained concerning the distribution of sub-kilometer TNOs in the Kuiper Belt.
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Contributing team(s): Miosotys team

120.10 – Observations of Mutual Eclipses by the Binary Kuiper Belt Object Manwe-Thorondor

The binary Kuiper Belt Object (385446) Manwe-Thorondor (aka 2003 QW111) is currently undergoing mutual events whereby the two ~100-km bodies alternately eclipse and occult each other as seen from Earth [1]. Such events are extremely rare among KBOs (Pluto-Charon and Sila-Nunam being notable exceptions). For Manwe-Thorondor, the events occur over ~0.5-d periods 4 to 5 times per year until the end of 2019. Here we report the results of observations to be made with the Soar 4m telescope at Cerro Pachon, Chile on 2016 Aug 25 and 26 UT, covering one of the deepest predicted eclipses. We use these observations to constrain the rotational variability of the two bodies, determine their physical properties (size, shape, albedo, density), and set limits on the presence of any prominent surface features.
[1] Grundy, W. et al. 2012, Icarus, 220, 74
Author(s): David L. Rabinowitz[4], Susan D Benecchi[2], William M. Grundy[1], Audrey Thirouin[1], Anne J. Verbiscer[3]
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120.11 – Evidence for a distant unseen solar system planet: Assessing the observational biases in the extreme Kuiper belt population

Several recent studies have appealed to peculiarities in the observed distribution of very distant, extreme Kuiper belt objects (eKBOs) to argue for the existence of an Earth-mass or larger planet in the distant solar system. Trujillo and Sheppard (2014) noted that the arguments of perihelion of the observed eKBOs cluster near 0, and Batygin & Brown (2016) noted that the eKBOs also have clustered orbit poles and eccentricity vectors (which result in clustered longitudes of perihelion and longitudes of ascending node). Both papers argue that observational biases are unlikely to explain the observed clustering. Because the observed population of eKBOs is far from complete, a thorough assessment of the observational biases in the population is warranted. Very accurate assessment of observational biases is only possible for objects discovered by well-characterized surveys, but the number of eKBOs found by such surveys is small. We instead use the set of observed KBOs in the Minor Planet Center catalog along with published survey pointings and limiting magnitudes to approximately reconstruct the biases in the observed eKBO population. We will report on the role of observational biases in either strengthening or weakening the case for a distant unseen planet in our solar system. This research was supported by NASA (grant NNX14AG93G).

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120.12 – Photometry of Scattered Disk Objects at 3.6 and 4.5 µm

Scattered disk objects (SDO) are some of the most intriguing of the estimated 100,000 icy bodies located in the outer Solar System. SDOs have been gravitationally disturbed and scattered by the orbital migration of Neptune. The surface compositions of these objects provide a window into formation conditions and dynamics of the outer Solar System. Characterization of volatiles and organic materials, in particular, provide important constraints on formation conditions and subsequent surface processing of these objects. We measured fluxes of 38 SDOs at 3.6 and 4.5 µm using the Infrared Array Camera (IRAC) aboard the *NASA Spitzer Space Telescope* in order to characterize volatiles, silicates, and complex organics on their surfaces. Albedos calculated from these fluxes are combined with broadband albedos from ground-based observations at shorter wavelengths (spanning 0.55 – 2.22 µm) to provide spectrophotometry from 0.5 to 4.5 µm. Much of those ground-based data are from previously published literature. However, we have also conducted new ground-based Y, J, H, K observations of several of the targets. Sizes and visible geometric albedos, which are required to convert IRAC fluxes to geometric albedos, were extracted from published literature when available and computed from absolute magnitudes otherwise. Data were available to construct complete 0.55 to 4.5 µm spectrophotometric curves for 14 SDOs and partial curves for the remaining 24 SDOs. The resulting spectrophotometry of these 38 SDOs indicates a wide range of surface compositions. Several of the SDOs we observed show red visible and near-infrared spectral slopes and strong absorptions at 3.6 and 4.5 µm. These absorption features suggest the presence of complex organics. Other SDOs appear red as well, but show only moderate absorptions at 3.6 and 4.5 µm. Moderate absorption features at these wavelengths may indicate a mixture of H_2O ice and refractory material on the surface. Finally, some objects show no absorption at 3.6 and 4.5 µm, most likely characteristic of silicate dust.

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120.13 – A Search for slowly moving planets in the distant Solar System

Objects beyond several hundred AU from the Sun move so slowly that even at opposition their tiny apparent sky motions result in them not being detected in common search algorithms applied to imaging spaced at roughly hourly intervals. We are searching roughly 160 square degrees of imaging data from the Outer Solar System Origins Survey (OSSOS) running on CFHT, which has a usable multi-night cadence. In that data, objects beyond about 300 AU appear to be stationary (within tolerances) on the sky on a given 2 hour period, but will move between days. Our search will thus be senstive to objects in the 300-1000 AU distance range (with rough corresponding minimum diameters, respectively, of 2,000-30,000 km). This will be acheived by creating catalogue of sources that are stationary in three images spaced an hour apart (known as a triplet) and matching it in catalogues of sources in nights that are up to two months either side of the triplet. Absence outside the triplet night yields candidates that could be very slowly moving planetary scale objects. Obviously dozens of planets are needed in the 300-1000 AU distance range if the expected number of found planets is one. We report our progress in this effort.

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120.14 – The Hunt for Planet Nine: Atmosphere, Spectra, Evolution, and Detectability

We investigate the physical characteristics of the Solar System's proposed Planet Nine using modeling tools with a heritage in studying Uranus and Neptune. For a range of plausible masses and interior structures, we find upper limits on the intrinsic Teff, from ~35-50 K for masses of 5-20 M_Earth, and we also explore lower Teff values. Possible planetary radii could readily span from 2.7 to 6 R_Earth depending on the mass fraction of any H/He envelope. Given its cold temperature, the planet encounters significant methane condensation, which dramatically alters the atmosphere away from simple Neptune-like expectations. We find the atmosphere is strongly depleted in molecular absorption at visible wavelengths, suggesting a Rayleigh scattering atmosphere with a high geometric albedo approaching 0.75. We highlight two diagnostics for the atmosphere's temperature structure, the first being the value of the methane mixing ratio above the methane cloud. The second is the wavelength at which cloud scattering can be seen, which yields the cloud-top pressure. Surface reflection may be seen if the atmosphere is thin. Due to collision-induced opacity of H2 in the infrared, the planet would be extremely blue (instead of red) in the shortest wavelength WISE colors if methane is depleted, and would, in some cases, exist on the verge of detectability by WISE. For a range of models, thermal fluxes from ~3-5 microns are ~20 orders of magnitude larger than blackbody expectations. We report a search of the AllWISE Source Catalog for Planet Nine, but find no detection.

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120.15 – Equilibrium figures of dwarf planets

Dwarf planets including transneptunian objects (TNO) and Ceres are >500 km large and display a spheroidal shape. These protoplanets are left over from the formation of the solar System about 4.6 billion years ago and their study could improve our knowledge of the early solar system. They could be formed in-situ or migrated to their current positions as a consequence of large-scale solar system dynamical evolution. Quantifying their internal composition would bring constraints on their accretion environment and migration history. That information may be inferred from studying their global shapes from stellar occultations or thermal infrared imaging. Here we model the equilibrium shapes of isolated dwarf planets under the assumption of hydrostatic equilibrium that forms the basis for interpreting shape data in terms of interior structure. Deviations from hydrostaticity can shed light on the thermal and geophysical history of the bodies. The dwarf planets are generally fast rotators spinning in few hours, so their shape modeling requires numerically integration with Clairaut's equations of rotational equilibrium expanded up to third order in a small parameter m, the geodetic parameter, to reach an accuracy better than a few kilometers depending on the spin velocity and mean density. We also show that the difference between a 500-km radius homogeneous model described by a MacLaurin ellipsoid and a stratified model assuming silicate and ice layers can reach several kilometers in the long and short axes, which could be measurable. This type of modeling will be instrumental in assessing hydrostaticity and thus detecting large non-hydrostatic contributions in the observed shapes.

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120.16 – The absolute magnitude distribution of cold classical Kuiper belt objects

We report measurements of the low inclination component of the main Kuiper Belt showing a size freqency distribution very steep for sizes larger than H_r ~ 6.5-7.0 and then a flattening to shallower slope that is still steeper than the collisional equilibrium slope.
The Outer Solar System Origins Survey (OSSOS) is ongoing and is expected to detect over 500 TNOs in a precisely calibrated and characterized survey. Combining our current sample with CFEPS and the Alexandersen et al. (2015) survey, we analyse a sample of ~180 low inclination main classical (cold) TNOs, with absolute magnitude H_r (SDSS r' like flter) in the range 5 to 8.8. We confirm that the H_r distribution can be approximated by an exponential with a very steep slope (>1) at the bright end of the distribution, as has been recognized long ago. A transition to a shallower slope occurs around H_r ~ 6.5 - 7.0, an H_r mag identified by Fraster et al (2014). Faintward of this transition, we find a second exponential to be a good approximation at least until H_r ~ 8.5, but with a slope significantly steeper than the one proposed by Fraser et al. (2014) or even the collisional equilibrium value of 0.5.
The transition in the cold TNO H_r distribution thus appears to occur at larger sizes than is observed in the high inclination main classical (hot) belt, an important indicator of a different cosmogony for these two sub-components of the main classical Kuiper belt. Given the largish slope faintward of the transition, the cold population with ~100 km diameter may dominate the mass of the Kuiper belt in the 40 AU < a < 47 au region.

Author(s): Jean-Marc Petit[2], Michele T Bannister[6], Mike Alexandersen[1], Ying-Tung Chen[1], Brett Gladman[5], Stephen Gwyn[3], JJ Kavelaars[3], Kathryn Volk[4]
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120.17 – Exploratory spectra of intermediate-sized KBOs with IRTF/SpeX+MORIS

We observed 4 Kuiper Belt Objects (KBOs) for 2-3 half-nights each with the SpeX instrument on NASA's 3-meter IRTF. The 4 KBOs were 2007 OR_{10} (third largest KBO, possible presence of volatile ices), Salacia (potential Haumea family member but no previously detected water ice absorption), 2003 AZ_{84} (large enough to expect differentiation and water ice absorption, but none previously detected), and 2004 NT_{33} (only previous spectrum was inconclusive). Guiding on these faint targets (*V* magnitudes between 20.4 and 21.5) was made possible with the MORIS visible guide camera. Raw spectra were reduced with the *spextool* program (Cushing et al., 2004, PASP 116, 362-376). Combining all the spectra for a single object resulted in an average spectrum with an SNR that reached or exceeded 20 at a resolution of about 100; these are the highest-SNR near-infrared spectra ever obtained of these 4 objects. Analysis is currently underway to search for broad absorption features due to CH_4, H_2O (crystalline and amorphous), and CH_3OH (methanol). Water ice models will also be fit to each average spectrum to quantify water ice fraction and spectral slope.

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120.18 – Title: Near-UV behaviour of observed TNO reflectance spectra

Observed spectra provide the best diagnostics of the surface compositions of Trans-Neptunian Objects (TNOs). We have observed the spectra of 7 TNOs, from across almost the full range of dynamical classes, using the VLT's X-Shooter spectrograph. Compared to the 5 targets in our sample which exhibit linear spectra in the UV-optical range, two of of our targets show highly unusual spectral behaviour, whereby their reflectance decreases sharply at wavelengths below ~440nm. Those same objects exhibit typically unremarkable spectra in the optical and near-IR spectral regions. In these regions where available, our observed spectra of the targets are in agreement with spectra or photometry available in the literature. Using a different solar analogue to produce our reflectance spectra does not remove the UV decrease exhibited by the two targets. Further, it appears that neither reducing the spectra with different pipelines, nor using drastically different parameters in those pipelines changes this general behaviour. Based on laboratory spectra of complex hydrocarbons it is plausible that the near-UV behaviour is the result of a surface coating of organic substances on the TNOs which exhibit it. The spectra of organics are also consistent in having a general red slope similar to that observed in the spectra of many TNOs. While laboratory spectra of some silicate substances also show a decrease in reflectance in the near-UV spectral region that is in principle consistent with our observations, those silicates do not exhibit a red slope consistent with our optical spectra. Hence, the hypothesis that silicates are present seems less likely than the hypothesis that this UV decrease is due to the presence of organics on the surfaces of these objects.

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120.19 – Absolute V-R colors of trans-Neptunian objects

The absolute magnitude of a minor body is the apparent magnitude that the body would have if observed from the Sun at a distance of 1AU. Absolute magnitudes are measured using phase curves, showing the change of the magnitude, normalized to unit helio and geo-centric distance, vs. phase angle. The absolute magnitude is then the Y-intercept of the curve. Absolute magnitudes are related to the total reflecting surface of the body and thus bring information of its size, coupled with the reflecting properties.

Since 2011 our team has been collecting data from several telescopes spread in Europe and South America. We complemented our data with those available in the literature in order to construct phase curves of trans-Neptunian objects with at least three points. In a first release (Alvarez-Candal et al. 2016, A&A, 586, A155) we showed results for 110 trans-Neptunian objects using V magnitudes only, assuming an overall linear trend and taking into consideration rotational effects, for objects with known light-curves.
In this contribution we show results for more than 130 objects, about 100 of them with phase curves in two filters: V and R. We compute absolute magnitudes and phase coefficients in both filters, when available. The average values are $H_V = 6.39 \pm 2.37$, $\beta_V = (0.09 \pm 0.32)$ mag per degree, $H_R = 5.38 \pm 2.30$, and $\beta_R = (0.08 \pm 0.42)$ mag per degree.
Author(s): Alvaro Alvarez-Candal[2], Carmen Ayala-Loera[2], Jose-Luis Ortiz[1], Rene Duffard[1], Fernandez-Valenzuela Estela[1], Pablo Santos-Sanz[1]
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120.20 – HST observations of faint Cold Classical KBOs

The size distribution of the known Kuiper Belt Objects has been described by a double power law, with a break at R magnitude 25. There are two leading interpretations to this break: 1) It is the result of the collisional evolution, with the objects smaller than the break being the population most affected by collisional erosion. 2) The size distribution break is primordial, set during the Kuiper Belt formation. The low inclination KBOs, the Cold Classical population, is thought to have been dynamically isolated since the formation of the Solar System, and thus only collisions between Cold Classicals would have affected their size distribution. If the distribution is collisional, it probes parameters of the Kuiper Belt history: strengths of the bodies, impact energies and frequency, and the the number of objects. If the distribution is primordial, it reveals parameters of the Kuiper Belt accretion, as well as limits on its subsequent collisional history.
We obtained HST observations of 16 faint Cold Classicals, which we combine with archival HST observations of 20 others, to examine the distribution of two properties of the smallest KBOs: colors and binary fraction. These properties can differentiate between a primordial and a collisional origin of the size distribution break. If the smaller bodies have been through extensive collisional evolution, they will have exposed materials from their interiors, which has not been exposed to weathering, and thus should be bluer than the old surfaces of the larger bodies. Another constraint can be derived from the fraction of binary objects: the angular momentum of the observed binaries is typically too high to result from collisions, thus a collisionally-evolved population would have a lower binary fraction, due to the easier separation of binaries, compared to the disruption of similar-sized bodies, and the easier disruption of the binary components, due to the smaller size.
We present the constraints to the color and binary fraction distributions we obtained from observations probing probe the smallest observable KBOs.
Support for programs 13031 and 13716 was provided by NASA through a grant from STScI.
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120.21 – A Tool for Optimizing Observation Planning for Faint Moving Objects

Observations of small solar system bodies such as trans-Neptunian objects and Centaurs are vital for understanding the basic properties of these small members of our solar system. Because these objects are often very faint, large telescopes and long exposures may be necessary, which can result in crowded fields in which the target of interest may be blended with a field star. For accurate photometry and astrometry, observations must be planned to occur when the target is free of background stars; this restriction results in limited observing windows. We have created a tool that can be used to plan observations of faint moving objects. Features of the tool include estimates of best times to observe (when the object is not too near another object), a finder chart output, a list of possible astrometric and photometric reference stars, and an exposure time calculator. This work makes use of the USNOFS Image and Catalogue Archive operated by the United States Naval Observatory, Flagstaff Station (S.E. Levine and D.G. Monet 2000), the JPL Horizons online ephemeris service (Giorgini et al. 1996), the Minor Planet Center's MPChecker (http://cgi.minorplanetcenter.net/cgi-bin/checkmp.cgi), and source extraction software SExtractor (Bertin & Arnouts 1996).
Support for this work was provided by NASA SSO grant NNX15AJ82G.
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120.22 – The moon of the large Kuiper-belt object 2007 OR_{10}

We have identified a candidate satellite of the large Kuiper-belt object 2007 OR_{10}. The moon has clearly been observed in one set of images and we obtained a tentative detection in a previous epoch. The moon orbits the central body at a distance of at least 15 000 km. Apart from this satellite no sign of binarity was observed, i.e. 2007 OR_{10} is likely a single large body. The low brightness of the moon also indicates that it cannot contribute notably to the total thermal emission of the system, i.e. 2007 OR_{10} has a size of ~1535 km obtained previously from Herschel and K2 data.
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120.23 – The Dynamical Classification of Centaurs which Evolve into Comets

Centaurs are small Solar system bodies with semi-major axes between Jupiter and Neptune and perihelia beyond Jupiter. Centaurs can be further subclassified into two dynamical categories – random walk and resonance hopping. Random walk Centaurs have mean square semi-major axes ($< a^2 >$) which vary in time according to a generalized diffusion equation where $< a^2 > \sim t^{2H}$. *H* is the Hurst coefficient with $0 < H < 1$, and *t* is time. The behavior of $< a^2 >$ for resonance hopping Centaurs is not well described by generalized diffusion.
The aim of this study is to determine which dynamical type of Centaur is most likely to evolve into each class of comet. 31,722 fictional massless test particles were integrated for 3 Myr in the 6-body problem (Sun, Jovian planets, test particle). Initially each test particle was a member of one of four groups. The semi-major axes of all test particles in a group were clustered within 0.27 au from a first order, interior Mean Motion resonance of Neptune. The resonances were centered at 18.94 au, 22.95 au, 24.82 au and 28.37 au.
If the perihelion of a test particle reached $\leq$ 4 au then the test particle was considered to be a comet and classified as either a random walk or resonance hopping Centaur. The results showed that over 4,000 test particles evolved into comets within 3 Myr. 59% of these test particles were random walk and 41% were resonance hopping. The behavior of the semi-major axis in time was usually well described by generalized diffusion for random walk Centaurs ($r_{avg} = 0.98$) and poorly described for resonance hopping Centaurs ($r_{avg} = 0.52$). The average Hurst coefficient was 0.48 for random walk

Centaurs and 0.20 for resonance hopping Centaurs. Random walk Centaurs were more likely to evolve into short period comets while resonance hopping Centaurs were more likely to evolve into long period comets. For each initial cluster, resonance hopping Centaurs took longer to evolve into comets than random walk Centaurs. Overall the population of random walk Centaurs averaged 143 kyr to evolve into comets, and the population of resonance hopping Centaurs averaged 164 kyr.
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120.24 – Non-spherical KBO shape identification in the TAOS-2 project

We explore the possibility of determining a non-spherical shape for Kuiper Belt Objects (KBOs) by analyzing diffraction effects in the context of the TAOS-2 occultation survey. We show how discrepancies between simulated diffraction patterns for spherical and irregular shapes, are related to the occulting KBO structure. Our results indicate that the possibility to constrain the KBO's shape is strongly related to the detectability of the diffraction pattern Poisson spot in the data. The consequence of this result is the restraint of size and distance for a KBO in order to detect a non-spherical shape. Since TAOS-2 will operate with three telescopes observing the same field simultaneously, the impact factor also plays an important role in shape detectability, since for non-spherical KBO occultations each telescope will have slightly different diffraction lightcurve. TAOS-2 will deliver a nominal photometry at 20 Hz, however in some cases it might be increased up to 40 Hz depending on the detector region and star brightness. This opens the possibility of improving the likelihood of measuring the Poisson spot, even in cases of maximum KBO relative motion, which diminishes the sampling resolution. In this context we propose the observation parameters that may lead to a better identification of the KBO occulting structure, in particular for the TAOS-2 survey.
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Contributing team(s): TAOS-2

121 – Planetary Rings Posters

121.01 – Structures in the D ring and Roche division tied to asymmetries in Saturn's magnetosphere

Saturn's dusty rings contain multiple patterns that appear to be rotating around the planet at about the same rate as Saturn itself, and so are probably generated by resonances with asymmetries in the planet's gravitational or magnetic fields. These structures are found in the D ring (which lies interior to the main rings) and in the Roche Division (which is located just outside the main rings, between the A and F rings). In 2007 the strongest patterns in both of these regions appeared to track magnetospheric anomalies associated with the Saturn Kilometric Radiation (SKR). This implied that these rings were responding to structures in the planet's magnetosphere, which is not unreasonable since the particles in both these ring regions are very small and therefore sensitive to non-gravitational forces. Over the last few years, the frequencies of the SKR and related magnetospheric asymmetries have shifted, and we have observed some changes in the ring patterns that might be connected with these shifts. However, there are also patterns in these rings that appear to have more stable rotation rates and so could reflect more persistent asymmetries in Saturn's magnetosphere. These patterns can therefore provide novel insights into the structure and evolution of Saturn's magnetosphere.
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121.02 – The dynamics of the outer edge of Saturn's A ring disturbed by Janus-Epimetheus

We developed an analytical model to study the dynamics of the outer edge of Saturn's A ring. The latter is influenced by 7:6 mean motion resonances with Janus and Epimetheus. Because of the horseshoe motion of the two co-orbital moons, the location of the resonances shift inwards or outwards every four years, making the ring edge particles alternately trapped in a corotation eccentricity resonance (CER) or a Lindblad eccentricity resonance (LER). However, the oscillation periods of the resonances are longer than the four-year interval between the switches in the orbits of Janus and Epimetheus.
Averaged equations of motion are used, and our model is numerically integrated to describe the effects of the periodic sweeping of the 7:6 CER and LER over the ring edge region.
We show that four radial zones (ranges 136715-136723, 136738-136749, 136756-136768, 136783-136791 km) are chaotic on decadal timescales, within which particle semimajor axes have periodic changes due to partial libration motions around the CER fixed points. After a few decades, the maximum variation of semimajor axis is about eleven (resp. three) kilometers in the case of the CER with Janus (resp. Epimetheus).
Similarly, particle eccentricities have partial oscillations forced by the LERs every four years, and are in good agreement with the observed eccentricities (Spitale and Porco 2009, El Moutamid et al. 2015). For initially circular orbits, the maximum eccentricity reached (~0.001) corresponds to the value obtained from the classical theory of resonance (proportional to the cube root of the satellite-to-planet mass ratio).
We notice that the fitted semimajor axes for the object recently discovered at the ring edge (Murray et al. 2014) are just outside the chaotic zone of radial range 136756-136768 km.
We compare our results to Cassini observations, and discuss how the periodic LER/CER perturbations by Janus/Epimetheus may help to aggregate ring edge particles into clumps, as seen in high-resolution images.
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121.03 – Searching for a traveling feature in Saturn's rings in Cassini Imaging Science Subsystem data

Introduction: Using Cassini UVIS occultation data, a traveling wave feature has been identified in the Saturn rings that is most likely caused by the radial positions swap of the moons Janus and Epimetheus [1]. The hypothesis is that non-linear interferences between the linear density waves when being relocated by the moon swap create a solitary wave that is traveling outward through the rings. The observations in [1] further lead to the derivation of values for the radial travel speeds of the identified traveling features, from 39.6 km/yr for the Janus 5:4 resonance up to 45.8 for the Janus 4:3 resonance.

Previous confirmations in ISS data: Work in [1] also identified the feature in Cassini Imaging Science Subsystem (ISS) data that was taken around the time of the UVIS occultations where the phenomenon was first discovered, so far one ISS image for each Janus resonances 2:1, 4:3, 5:4, and 6:5.

Search guided by predicted locations: Using the observation-fitted radial velocities from [1], we can extrapolate these to identify Saturn radii at which the traveling feature should be found at later times. Using this and new image analysis and plotting tools available in [2], we have identified a potential candidate feature in an ISS image that was taken 2.5 years after the feature causing moon swap in January 2006. We intend to expand our search by identifying candidate ISS data by a meta-database search constraining the radius at future times corresponding to the predicted future locations of the hypothesized solitary wave and present our findings at this conference.

References: [1] Rehnberg, M.E., Esposito, L.W., Brown, Z.L., Albers, N., Sremčević, M., Stewart, G.R., 2016. A Traveling Feature in Saturn's Rings. Icarus, accepted in June 2016. [2] K.-Michael Aye. (2016). pyciss: v0.5.0. Zenodo. **10.5281/zenodo.53092**

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121.04 – A Direct Examination of Gaps in Saturn's A Ring

Theory and indirect evidence suggest that Saturn's A ring hosts density wakes which form on scales of tens of meters through particle self-gravitation. Stellar occultations observed by the High Speed Photometer on Cassini's Ultraviolet Imaging Spectrograph can resolve meter-scale structure in the rings of Saturn, making them an ideal tool for the detection of these structures. We describe the results of an m-test-based search for gaps within the A ring. The number density of these structures displays substantial radial variation, with particular fluctuation observed at known resonance locations, and their radial widths span more than an order of magnitude. We compare the features of these detections with other A-ring observations.

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121.05 – Small-Scale Gaps Near Resonance Locations in Saturn's A Ring

High-resolution Cassini stellar occultation data has allowed for the direct investigation of self-gravity wakes and other disturbances in ring-particle density that cause an observed azimuthal brightness asymmetry. Using Cassini UVIS occultation data collected between May 19 2005 and June 2 2013 (Cassini revolutions 8 - 191), we investigate small-scale gaps in Saturn's A ring, which may form between adjacent self-gravity wakes. Factors that affect the radial width and observation frequency of tenuous gap regions are investigated, including a discussion of how various occultation parameters alter gap detection. Here we show that gaps are wider within the wave trains than in surrounding unperturbed regions of the following inner Lindblad resonances (ILR): Janus 4:3, Janus 5:4, Janus 6:5 and Mimas 5:3. These trends are compared to those found at the Mimas 5:3 bending wave. Radial gap width and number density are compared in the peak and trough regions of the ILR wave trains.

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121.06 – Structure of the Mimas 5:3 Bending Wave in Saturn's Rings

Saturn's moon Mimas is on an inclined orbit with several strong vertical orbital resonances in Saturn's rings. The 5:3 inner vertical resonance with Mimas lies in the outer A ring and produces a prominent spiral bending wave (BW) that propagates away from Mimas. While dozens of density waves in Saturn's rings have been analyzed to determine local surface mass densities and viscosities, the number of bending waves is limited by the requirement for a moon on an inclined orbit and because, unlike the Lindblad resonances that excite density waves, there can be no first order vertical resonances. The Mimas 5:3 BW is the most prominent in the ring system. Bending wave theory was initially developed by Shu et al. (1983, *Icarus*, **53**, 185-206) following the Voyager encounters with Saturn. Later, Gresh et al. (1986, *Icarus*, **68**, 481-502) modeled radio science occultation data of the Mimas 5:3 BW with an imperfect fit to the theory. The multitude of high resolution stellar occultations observed by Cassini UVIS provides an opportunity to reconstruct the full three-dimensional structure of this wave and learn more about local ring properties. Occultations at high elevation angles out of the ring plane are insensitive to the wave structure due to the small angles of the vertical warping of the rings in the wave. They thus reveal the underlying structure in the wave region. There is a symmetric increase in optical depth throughout the Mimas 5:3 BW region. This may be due to an increase in the abundance of small particles without a corresponding increase in surface mass density. We include this feature in a ray-tracing model of the vertical structure of the wave and fit it to multiple UVIS occultations. The observed amplitude of the wave and its damping behavior of are not well-described by the Shu et al. model, which assumes a fluid-like damping mechanism. A different damping behavior of the ring, perhaps radially varying across the wave region due to differences in the particle size distribution and/or structure of the self-gravity wakes in the ring, is needed to match observations.

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121.07 – How Mimas cleared the Cassini Division

Recent measurements of the dissipation of Saturn (Lainey et al. 2016, Icarus, in press) combined with a theoretical study by Fuller et al. (2016, MNRAS) require to revisit the energy dissipation models in planetary systems and the way it affects their satellite system. In addition, the measurements of the large librations of Mimas (Tajeddine et al. 2014, Science) could point to a global ocean underneath the surface of the satellite. These results allowed us to refine the scenarios of the opening of the Cassini Division that we initially presented at the DPS 2012. Assuming a dissipation that is consistent with these latest results, we propose scenarios of combined evolutions of Mimas and the main rings of Saturn, that explain the current size and location of the Division, the excess of density in the outer B ring, a past episode of intense heating of Mimas required to create a global ocean, and its current eccentricity. For that, we show that a past resonance with Tethys increased the eccentricity of Mimas up to 0.2, possibly triggering the melting of Mimas and an episode of inward migration, which created the Cassini Division: the 2:1 resonance between Mimas and the rings pushed the ring material inner to accumulate in the B ring. Once its eccentricity is damped, Mimas resumes its outward migration, leading to a trapping into the current vertical resonance with Tethys. These results are supported by numerical simulations, in which Mimas is driven by the tides, and the rings are simulated with the 1-D hydrodynamical code Hydrorings (Charnoz et al., 2010, Nature). This study has been partially supported by the International Space Sciences Institute in Bern, Switzerland.

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121.08 – Sizes of the Smallest Particles at the Outer B Ring Edge, Huygens Ringlet, and Strange Ringlet

The Cassini Ultraviolet Imaging Spectrograph (UVIS)'s High Speed Photometer (HSP) has observed stellar occultations of Saturn's rings that reveal ring structure at high resolution. We observe diffraction spikes at the sharp edges of some rings and ringlets where the observed signal exceeds the unocculted star signal, indicating that small particles are diffracting light into the detector. Becker et al. (2015 *Icarus* doi:10.1016/j.icarus.2015.11.001) analyzed data at the A ring edge and edges of the Encke gap. The smallest particle sizes were a few mm. We use the same technique to analyze the diffraction signal at the outer edge of the B ring and the edges of the so-called Strange ringlet near the outer edge of the Huygens Gap. While we see diffraction from sub-cm particles in the Strange Ringlet, detections from the wider Huygens Ringlet which resides in between the Strange Ringlet and the outer edge of the B ring are weaker and narrower, indicating a cutoff of the size distribution above 1 cm. At the outer edge of the B ring we find strong diffraction signals in 7 of 19 occultations for which the signal and geometry make the detection possible. The typical value of the smallest particle size (a_{min}) is 4 mm and the derived slope of the power-law size distribution (q) is 2.9. The average a_{min} is similar to the 4.5 mm average observed at the A ring outer edge while the q value is lower than the A ring outer edge value of 3.2. In the Strange Ringlet we find strong diffraction signals in 2 of 19 possible occultations for the outer edge and 1 of 17 possible occultations for the inner edge. The smallest particle size is ~5 mm and the derived slope of the power-law size distribution is 3.3. These values are similar to the average values at the A ring outer edge. The absence of a broad diffraction signal at the Huygens Ringlet suggests a different size distribution for that ring than for the Strange Ringlet and the outer several km of the B ring or perhaps less vigorous collisions so that fewer small particles are liberated from the regolith of larger particles.

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121.09 – Radial Variations in Particle Clumping in Perturbed Regions of Saturn's Rings from Cassini UVIS Stellar Occultations

Showalter and Nicholson (1990, Icarus 87, 285-306) showed that the variance in the Voyager 2 stellar occultation by Saturn's rings could be analyzed to extract information on the sizes of particles in the rings, or, more precisely, on the autocorrelation length, R, of the distribution of ring particles. We have previously reported on applying this principle to the many stellar occultations observed by Cassini's Ultraviolet Imaging Spectrograph (UVIS). Here we present results of the variance at 2 km radial resolution, fine enough to examine changes in the autocorrelation length within the broad troughs of the strongest density waves. We find dips in R in the first several wavelengths of the Janus 2:1 density wave in the inner B ring. In addition, we find a decrease in R in the Mimas 5:3 bending wave. Strong Janus density waves in the A ring show an increase in R in the peaks of the density waves, but no dip below the background level in the troughs. We also see a decrease in R in the broad "halo" regions of the A ring around the strongest resonances, implying less-well-organized self-gravity wakes in those regions and/or smaller or more abundant particles in the gaps between the wakes. We will present our results from multiple occultations and their implications for the collisional environment in strongly perturbed regions in the rings.

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121.10 – N-body ray-tracing modeling of Saturn's rings for analysis of UVIS/VIMS optical depths and CIRS temperatures

Various observations of Saturn's A and B rings indicate that ring particles are highly compacted near the mid-plane, making non-uniform structures. Such structures complicate deduction of properties of individual ring particles characterized by, for example, the albedo and the size distribution. Modeling using N-body simulations and ray-tracing calculations is one of the most promising approaches to understanding the dense rings of Saturn. We are developing a ray-tracing code that is applicable to analysis of UVIS/VIMS optical depths and CIRS temperatures. In the presentation, we report optical depth profiles of dense rings produced by large-scale N-body simulations (Ballouz et al. 2016; in preparation) and compare them with those from UVIS/VIMS occultation observations. Ballouz et al. (2016) find that prominent overstability wakes are produced at B ring locations either if the internal density is low and/or the friction forces are strong enough. For low internal density cases, the photometric optical depths become as high as those for the B ring, but rings are not necessarily most transparent when the line of sight is aligned to overstability wakes, in contrast to observations of the outer B ring (Colwell et al. 2007). For cases with high internal density and strong friction, rings become most transparent when the line of sight is roughly aligned to overstability wakes, but the photometric optical depths become much lower than the observed values due to highly transparent inter-wake gaps. These facts may indicate that small particles not considered in the simulations fill inter-wake gaps. We also report the progress of code modifications for analysis of CIRS temperature data. For calculations of the energy balance of ring particles, effects due to multiply scattered photometric light and to mutual heating between ring particles are added to the code.

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121.11 – A Comparative Analysis of the Far Infrared Spectra of Saturn's Rings and Icy Satellites with Cassini CIRS

We will report on a campaign to observe Saturn's main rings and major icy satellites with the Composite Infrared Spectrometer onboard Cassini. CIRS' three infrared detectors cover a combined spectral range of 10 to 1400 cm^{-1} (1 mm down to 7 microns). We focus on data from Focal Plane 1, which covers the 10 to 600 cm^{-1} range (1 mm to 16 microns). The apodized spectral resolution of the instrument can be varied from 15 cm^{-1} to 0.5 cm^{-1} (Flasar *et al.* 2004).

The spectral behavior of Saturn's main rings and icy satellites in the far infrared has been the subject of previous studies with CIRS FP1 data (Spilker *at al.* 2005, Carvano *et al.*2007, Morishima *et al.* 2012). These studies have shown that the infrared spectra of these icy rings and bodies are remarkably flat between about 40 to 200 microns. Longward of this, CIRS observations, as well as older spacecraft data, show a gradual decrease in ring emissivity. This roll-off in emissivity

may be due to varying optical constants of water ice, which dominates the rings' composition, as one moves towards microwave wavelengths. Carvano et al. (2007), who analyzed spectra of the icy satellites Phoebe, Iapetus, Enceladus, Tethys and Hyperion, investigated the absence of emissivity features in spectra of those satellites. This absence is intriguing, as water ice, which dominates their surface composition, contains absorption features in the FP1 spectral range. They conclude that high porosity in these satellites' regoliths may explain this lack of spectral variability.
To better characterize the far infrared spectra of the rings and satellites, we have implemented a series of dedicated observations. The goal is to obtain thousands of infrared spectra at 3 cm^{-1} resolution of each individual ring region and as many satellites as possible. We will have more spectra than Spilker *et al.* had for their work at a higher spectral resolution than in the analyses of Carvano *et al.* and Morishima *et al*. A preliminary analysis of these observations will be given.
This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

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121.12 – Ring formation by tidal disruption of a passing body
The origin of rings around giant planets remains elusive. Here we investigate the tidal disruption of a passing object and the subsequent formation of planetary rings. First, we perform SPH simulations of the tidal destruction of differentiated objects with the mass of $M{\sim}10^{22}$kg that experience close encounters with Saturn or Uranus. We find that about 0.1-10% of the mass of the passing body is gravitationally captured around the planet. However, these fragments are initially big chunks and have highly eccentric orbits around the planet. Therefore, in order to see their long-term evolution, we perform N-body simulations including the planet's oblateness up to J_4 starting with data obtained from the SPH simulations. Our N-body simulations show that the chunks are tidally destructed during their next several orbits and become collections of smaller particles. Their individual orbits then start to precess incoherently around the planet's equator, which enhances their encounter velocities on longer-term evolution, resulting in more destructive impacts. These collisions would damp their eccentricities resulting in a progressive collapse of the debris cloud into a thin equatorial and low-eccentricity ring.
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121.13 – Simulation of Rings about Ellipsoidal Bodies
Recent discovery of rings around Chariklo, a centaur orbiting the Sun (F. Braga-Ribas et al., 2014) and speculations of rings around minor planet, Chiron (Ortiz et al., 2015), Saturn's satellites, Rhea (Jones et al., 2008; Schenk et al., 2011), Iapetus (Ip, 2006) or exoplanets, suggest that rings about non-spherical bodies is perhaps a more general phenomenon than anticipated. As a first step towards understanding such systems, we examine the dynamical behavior of rings around similar bodies using N-body simulations. Our code employs the `local simulation method' (Wisdom & Tremaine, 1988; Salo, 1995) and accounts for particle interactions via collisions using Discrete Element Method (Cundall & Strack, 1978; Bhateja et al., 2016) and mutual gravitation. The central body has been modeled as an axisymmetric ellipsoid characterized by its axis ratio, or defined via characteristic frequencies (circular, vertical and epicyclic frequency) representing the gravitational field of an axisymmetric body. We vary the central body's characterizing parameter and observe the change in various ring properties like the granular temperature, impact frequency, radial width and vertical thickness. We also look into the effect on ring properties upon variation in the size of the central body-ring system. Further, we investigate the role of characteristic frequencies in dictating the ring dynamics, and how this could help in qualitatively estimating the ring dynamics about any arbitrary central body with symmetry about the equatorial plane and the axis normal to it.
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121.14 – Precision Navigation of Cassini Images Using Rings, Icy Satellites, and Fuzzy Bodies
Before images from the Cassini spacecraft can be analyzed, errors in the published pointing information (up to ~110 pixels for the Imaging Science Subsystem Narrow Angle Camera) must be corrected so that the line of sight vector for each pixel is known. This complicated and labor-intensive process involves matching the image contents with known features such as stars, rings, or moons. Metadata, such as lighting geometry or ring radius and longitude, must be computed for each pixel as well. Both steps require mastering the SPICE toolkit, a highly capable piece of software with a steep learning curve. Only after these steps are completed can the actual scientific investigation begin.
We have embarked on a three-year project to perform these steps for all 400,000+ Cassini ISS images as well as images taken by the VIMS, UVIS, and CIRS instruments. The result will be a series of SPICE kernels that include accurate pointing information and a series of backplanes that include precomputed metadata for each pixel. All data will be made public through the PDS Ring-Moon Systems Node (http://www.pds-rings.seti.org). We expect this project to dramatically decrease the time required for scientists to analyze Cassini data.
In a previous poster (French et al. 2014, DPS #46, 422.01) we discussed our progress navigating images using stars, simple ring models, and well-defined icy bodies. In this poster we will report on our current progress including the use of more sophisticated ring models, navigation of "fuzzy" bodies such as Titan and Saturn, and use of crater matching on high-resolution images of the icy satellites.
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121.15 – Collision of Dual Aggregates (CODA): Experimental observations of low-velocity collisions
Low-velocity collisions are one of the driving factors that determine the particle size distribution and particle size evolution in planetary ring systems and in the early stages of planet formation. Collisions of sub-micron to decimeter-sized objects may result in particle growth by accretion, rebounding, or erosive processes that result in the production of additional smaller particles. Numerical simulations of these systems are limited by a need to understand these collisional parameters over a range of conditions. We present the results of a sequence of laboratory experiments designed to explore collisions over a range of parameter space . We are able to observe low-velocity collisions by conducting experiments in vacuum chambers in our 0.8-sec drop tower apparatus. Initial experiments utilize a variety of impacting spheres, including glass, Teflon, aluminum, stainless steel, and brass. These spheres are either used in their natural state or are "mantled" - coated with a few-mm thick layer of a cohesive powder. A high-speed, high-resolution video camera is

used to record the motion of the colliding bodies. We track the particles to determine impactor speeds before and after collision, the impact parameter, and the collisional outcome. In the case of the mantled impactors, we can assess how much rotation is generated by the collision and estimate how much powder is released (i.e. how much mass is lost) due to the collision. We also determine how the coefficient of restitution varies as a function of material type, morphology, and impact velocity. With impact velocities ranging from about 20-100 cm/s we observe that mantling of particles significantly reduces their coefficients of restitution, but we see basically no dependence of the coefficient of restitution on the impact velocity, impact parameter, or system mass. The results of this study will contribute to a better empirical model of collisional outcomes that will be refined with numerical simulation of the experiment to improve our understanding of the collisional evolution of ring systems and early planet formation.

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121.16 – Orbital evolution of Neptune's ring arcs

Voyager 2 spacecraft sent several images of the Neptune's ring system in 1989. These images show a set of arcs (Courage, Liberté, Egalité and Fraternité), previously detected by stellar occultation in 1984, embedded in the tenuous Adams ring. In order to maintain the confinement of the arcs against the spreading, Renner et al. (2015) proposed
a model which the Adams ring has a collection of small coorbital satellites placed in specific positions. These coorbitals would be responsible for maintaining the arcs particles. In this work we analyse the orbital evolution of the particles coorbital to the satellites by adding the effects of the solar radiation force. Our numerical results show that due to this dissipative effect the smallest particles, 1μm in size, leave the arc in less than 10years. Larger particles leave the arc, but can stay confined between the coorbital satellites. De Pater et al. (2005) suggested that a small moonlet embedded in the arc Fraternité can be the source of the arcs and even the
Adams ring through an erosion mechanism. Our preliminary results showed that a moonlet up to 200m in radius can stay in the arc without causing any significant variation in the eccentricities of the coorbitals and the particles.

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121.17 – Radar Scans of the Saturn Rings

The Cassini mission is now heading into its last year of observations. Part of the mission plan includes orbits that bring the spacecraft close to Saturn's rings prior to deorbiting into Saturn's atmosphere. These orbits are providing a unique opportunity to obtain backscatter measurements and relatively high-resolution brightness temperature measurements from the rings. We plan to scan the rings with the radar central beam and obtain backscatter measurements as a function of radial distance with some variation of incidence angle. Active mode radar scans are planned for four of the final high inclination orbits that bring the spacecraft close to the rings. These radar observations will be designed to sweep the A through C rings with varying bandwidth chirps selected to optimize the tradeoff between radial resolution and measurement variance. Pulse compression will deliver radial resolutions varying from about 200 m to around 4 km depending on the bandwidth used. These measurements will provide a 1-D profile of backscatter obtained at 2.2 cm wavelength that will complement similar passive profiles obtained at optical, infrared, and microwave wavelengths. This presentation will summarize the detailed designs and tradeoffs made for these observations. Such measurements will further constrain and inform models of the composition and structure of the ring particle distributions. This work is supported by the NASA Cassini Program at JPL - CalTech.

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Contributing team(s): Cassini Radar Team

121.18 – Damping of Resonantly Forced Density Waves in Dense Planetary Rings

We address the stability of resonantly forced density waves in dense planetary rings.
Already by Goldreich and Tremaine (1978) it has been argued that density waves might be unstable, depending on the relationship between the ring's viscosity and the surface mass density. In the recent paper (Schmidt et al. 2016) we have pointed out that when - within a fluid description of the ring dynamics - the criterion for viscous overstability is satisfied, forced spiral density waves become unstable as well. In this case, linear theory fails to describe the damping.
We apply the multiple scale formalism to derive a weakly nonlinear damping relation from a hydrodynamical model.
This relation describes the resonant excitation and nonlinear viscous damping of spiral density waves in a vertically integrated fluid disk with density dependent transport coefficients. The model consistently predicts linear instability of density waves in a ring region where the conditions for viscous overstability are met. In this case, sufficiently far away from the Lindblad resonance, the surface mass density perturbation is predicted to saturate to a constant value due to nonlinear viscous damping. In general the model wave damping lengths depend on a set of input parameters, such as the distance to the threshold for viscous overstability and the ground state surface mass density.
Our new model compares reasonably well with the streamline model for nonlinear density waves of Borderies et al. 1986.
Deviations become substantial in the highly nonlinear regime, corresponding to strong satellite forcing.
Nevertheless, we generally observe good or at least qualitative agreement between the wave amplitude profiles of both models. The streamline approach is superior at matching the total wave profile of waves observed in Saturn's rings, while our new damping relation is a comparably handy tool to gain insight in the evolution of the wave amplitude with distance from resonance, and the different regimes of wave formation and the dependence on the parameters of the model.

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121.19 – Evolution of Fractional Pollution of Saturn's Rings and Bidirectional Reflectance with Effects of Surface Roughness compared to UVIS spectra

Recent estimates of the mass flux if exogenous meteoritic material into the Saturnian system by Kempf et.al., suggest a mass flux up to an order of magnitude higher than previously thought (Cuzzi and Estrada 1998). Using these recent estimates, we model the evolution of the regolith depth and fractional pollution of Saturn's rings. We present calculated abundance ratios of exogenous meteoritic material and endogenous icy material present on the surfaces of a system of ring particles; particle sizes characteristic of the B and C rings are examined. We use these ratios to calculate the bidirectional reflectance spectra for the simulated rings. We use UV spectra of comet 67P/Churyumov–Gerasimenko from the Rosetta Alice UV spectrometer as the exogenous material. Effects of regolith grain size and surface roughness on bidirectional reflectance are also taken into account. Finally, a comparison to spectra from the Cassini UVIS instrument, and best-fit reflectance spectra are calculated for each ring particle size examined.

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121.20 – Thermal Modeling of the Main Rings of Saturn through random distribution particle arrays and ray-tracing simulations

Saturn's rings are a complex collection of icy particles with diameters from 1 m to few meters. Their natural window of study is the infrared because its temperatures are between 40K and 120K. The main driver of the temperature of these rings is the direct solar radiation as well as the solar radiation reflected off Saturn's atmosphere. The second most important energy source is the infrared radiation coming from Saturn itself. The study of the variations of temperatures of the rings, or, in general, their thermal behavior, may provide important information on their composition, their structure and their dynamics. Models that consider these and other energy sources are able to explain, to a first approximation, the observed temperature variations of the rings. The challenge for these models is to accurately describe the variation of illumination on the rings, i. e., how the illuminated and non-illuminated regions of the ring particles change at the different observation geometries. This shadowing mainly depends on the optical depth, as well as the general structure of the rings.
In this work, We show a semi-analytical model that considers the main energy sources of the rings and their average properties (e.g., optical depth, particle size range and vertical distribution). In order to deal with the shadowing at specific geometries, the model uses the ray-tracing technique. The goal is to describe the ring temperatures observed by the Composite Infrared Spectrometer, CIRS, onboard the Cassini spacecraft, which is in orbit around Saturn since 2004. So far, the model is able to reproduce some of the general features of specific regions of the A, B and C rings.

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122 – Extrasolar Planets and Systems Posters

122.01 – Using Small Telescopes, Citizen Science, and Network Surveys to find Exoplanets - An Overview of the Kelt team and the Exoplanets Found to Date

The Kelt-North and Kelt-South transit survey is a wide angle search for hot Jupiters around some of the brightest stars in the night sky. Survey operations are based out of the Ohio State and Vanderbilt Universities, with observing facilities at Winer Observatory in Arizona and in Sutherland, South Africa. KELT stands for Kilodegree Extremely Little Telescope, where "Kilodegree" refers to the large area on the sky that the telescope can observe in a single shot. These "Little Telescopes" monitor the brightness of hundreds of thousands of stars night after night, month after month, for many years. Stars that show apparent changes in brightness are put through a careful vetting process and the best transiting planet candidates are sent on for photometric follow-up by a ground based team made up of nearly 40 members in 10 countries across 4 continents. The KELT Follow-Up Network is the largest, most coordinated network of its kind, and their work has contributed to the discovery of multiple new planets: including Kelt-1b which is a 30 Jupiter-mass object at an orbital period of 1.2 days; Kelt-6b wich is a Hot Saturn on a 7.9 day orbital period; and Kelt-8b which is a highly inflated Hot Jupiter that required the development of new techniques to extract high-precision radial velocities.
In this presentation I will highlight all of the Kelt Exoplanets discovered to date and how the Kelt team is using small telescopes, citizen science, and network surveys to make these discoveries possible.

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Contributing team(s): Kelt North Survey Team, Kelt South Survey Team

122.02 – Wavelet-based filter methods for the detection of small transiting planets: Application to Kepler and K2 light curves

The Rheinisches Institut für Umweltforschung (RIU-PF) has developed the software package EXOTRANS for the detection of transits of exoplanets in stellar light curves. This software package was in use during the CoRoT space mission (2006-2013). EXOTRANS was improved by different wavelet-based filter methods during the following years to separate stellar variation, orbital disturbances and instrumental effects from stellar light curves taken by space telescopes (Kepler, K2, TESS and PLATO). The VARLET filter separates faint transit signals from stellar variations without using a-priori information about the target star. VARLET considers variations by frequency, amplitude and shape simultaneously. VARLET is also able to extract most instrumental jumps and glitches. The PHALET filter separates periodic features independent of their shape and is used with the intention to separate diluting stellar binaries. It is also applied for the multi transit search. Stellar light curves of the K2 mission are constructed from the processing of target pixel files which corrects disturbances caused by the reduced pointing precision of the Kepler telescope after the failure of two gyroscopes. The combination of target pixel file processing with both filter techniques and the proven detection pipeline EXOTRANS lowers the detection limit, reduces false alarms and simplifies the detection of faint transits in light curves of the K2 mission. Using EXOTRANS many new candidates were detected in K2 light curves by using EXOTRANS which were successfully confirmed by ground-based follow-up observation of the KEST collaboration. New candidates and confirmed planets are presented.

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Contributing team(s): KEST

122.03 – Photochemical aerosols in warm exoplanetary atmospheres

Recent transit observations of exoplanets have demonstrated the possibility of a wide prevalence of haze/cloud layers at high altitudes. Hydrocarbon photochemical haze could be the candidate for such haze particles on warm sub-Neptunes, but the lack of evidence for methane poses a puzzle for such hydrocarbon photochemical haze. The CH_4/CO ratios in planetary atmospheres vary substantially from their temperature and dynamics. We have conducted a series of laboratory simulations to investigate how atmospheric compositions, specifically CH_4/CO ratios, affect the haze production rates and their optical properties. The mass production rates in the H_2-CH_4-CO gas mixtures are rather insensitive to the CH_4/CO ratios larger than at 0.3. Significant formation of solid material is observed in a H_2-CO gas mixture even without CH_4. The complex refractive indices of the aerosol analogue from the H_2-CO gas mixture show strong absorption at the visible/near-IR wavelengths. These experimental facts imply that substantial carbonaceous aerosols may be generated in warm H_2-CO-

CH_4 exoplanetary atmospheres, and that it might be responsible for the observed dark albedos at the visible wavelengths.

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122.04 – Spectral signatures of Raman scattering as probes of exoplanetary atmospheres

Raman scattering by molecules in a planetary atmosphere leaves specific spectral signatures imprinted in the reflected light and the geometric albedo spectrum of the planet. Raman-scattered light causes filling-in of absorption lines in the incident spectrum, thus producing sharp peaks in the geometric albedo. It also shifts the wavelengths of spectral features in the reflected light causing the so-called Raman ghost lines. Signatures of Raman scattering have been observed and studied in the atmospheres of planets in the Solar System. We investigate whether they could be detected in nearby exoplanets using the next-generation observational facilities. We explore which stellar types are the most promising candidates for hosting exoplanets with strong Raman features in their albedo spectra. If observed, Raman albedo peaks could be used to distinguish between clear and cloudy atmospheres -- even for atmospheres composed of heavy molecular species. Raman ghost lines, although typically much fainter than the albedo peaks, could give valuable information on the composition and the temperature of the atmosphere.

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122.05 – Laboratory Simulation of Haze/Aerosol formation in warm and hot Jupiters

During the transit of an exoplanet across its host star, transmitted starlight through exoplanet atmosphere is absorbed and scattered, and the recorded transit spectra reveal important chemical information. There are many detected exoplanets in which hazes/aerosols obscure the incident photons, and consequently, fewer photons are transmitted through the atmosphere, contributing to a flat/nearly flat transit spectrum. Here, we have carried out two complementary approaches to address haze formation. First, laboratory simulations of haze condensation in exoplanet atmospheres are carried out using an electric discharge tube. A mixture of likely gas species (i.e. H_2, He, H_2O, CH_4, N_2 and H_2S) is inserted into a glass manifold on a vacuum line, at a pressure ~100-10 mbar, and depending on the exoplanet category (e.g., warm or hot Jupiters), the temperature is set. Applying a few kilovolts produces plasma in the discharge tube, and as a result, particles are formed. We use spectroscopic ellipsometry to measure the optical constants (complex refractive index) of the collected laboratory hazes. Then, chemical characterization is made using RBS (Rutherford Backscattering Spectroscopy) and XPS (X-ray Photoelectron Spectroscopy). Second, we developed a transit modeling code by which the transit spectra are generated using observational and laboratory data as an input. The model accounts for Mie scattering from haze particles in the vis-NIR spectral region, and Rayleigh scattering which comes from gases and particles (effective in UV-vis). The measured refractive indexes (real and imaginary part) describe the absorption and scattering in the vis-NIR transmission region, and, by generating transit spectra close to the observed ones from exoplanets, constraints on atmospheric chemical characterization can be revealed. Our laboratory results show that haze particles formed in the presence of water and with the solar C/O ratio = 0.5. The other outcome of our experiment is that sulfur (from H_2S) contributes to particle formation at 800K. Chemical characterization and elemental analysis of the produced haze particles are in progress.

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122.06 – Deciphering the Hot Giant Atmospheres Orbiting Nearby Extrasolar Systems with *JWST*

Unique and exotic planets give us an opportunity to understand how planetary systems form and evolve over their lifetime, by placing our own planetary system in the context of the vastly different extrasolar systems that are being continually discovered by present space missions. With orbital separations that are less than one-tenth of the Mercury-Sun distance, these close-in planets provide us with valuable insights about the host stellar atmosphere and planetary atmospheres subjected to their enormous stellar insolation. Observed spectroscopic signatures reveal all spectrally active species in a planet, along with information about its thermal structure and dynamics, allowing us to characterize the planet's atmosphere. NASA's upcoming missions will give us the high-resolution spectra necessary to constrain the atmospheric properties with unprecedented accuracy. However, to interpret the observed signals from exoplanetary transit events with any certainty, we need reliable atmospheric retrieval tools that can model the expected observables adequately. In my work thus far, I have built a Markov Chain Monte Carlo (MCMC) convergence scheme, with an analytical radiative equilibrium formulation for the thermal structures, within the NEMESIS atmospheric modeling tool, to allow sufficient (and efficient) exploration of the parameter space. I also augmented the opacity tables to improve the speed and reliability of retrieval models. I then utilized this upgraded version to infer the pressure-temperature (P-T) structures and volume-mixing ratios (VMRs) of major gas species in hot Jupiter dayside atmospheres, from their emission spectra. I have employed a parameterized thermal structure to retrieve plausible P-T profiles, along with altitude-invariant VMRs. Here I show my retrieval results on published datasets of HD189733b, and compare them with both medium and high spectral resolution JWST/NIRSPEC simulations. In preparation for the upcoming JWST mission, my current work expands on these efforts by exploring the observable impacts of chemistry in the hot Jupiter models and retrievals.

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122.07 – Study of the Retrieval Problem with BART

Retrieving atmospheric parameters from noisy data has been recognized as a challenging problem requiring Bayesian methods, a number of which have been developed. We test the reliability of this approach by using our Bayesian Atmospheric Radiative Transfer (BART) code on a series of modeled planetary observations. These tests include simple atmospheric models of hot Jupiters and super-Earths, orbiting a variety of stars, with model observations by the Spitzer, Hubble, and James Webb Space Telescopes. Our goal is to determine what signal-to-noise ratio is required on eclipse depths to achieve 3σ or better constraints on atmospheric parameters. This work was supported by NASA Planetary Atmospheres grant

NX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

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122.08 – The Third Transit of Snow-Line Exoplanet *Kepler*-421b

The *Kepler* Mission has uncovered a handful of long-period transiting exoplanets that orbit from the cold outer reaches of their systems, despite their low transit probabilities. The atmospheres of these cold gas giant exoplanets are amenable to transit transmission spectroscopy enabling tests of planetary formation and evolution theories. Of particular scientific interest is *Kepler*-421b, a Neptune-sized exoplanet with a 704-day orbital period residing near the snow-line. Since the *Kepler* Spacecraft only observed two transits of*Kepler*-421b, the transit ephemeris is relatively uncertain. We observed *Kepler*-421 during the anticipated third transit of *Kepler*-421b in order to constrain the existence and extent of transit timing variations (TTVs). Barring significant TTVs, our visible light, time-series observations from the 4.3-meter Discovery Channel Telescope (DCT) were designed to capture pre-transit baseline and the partial transit of *Kepler*-421b. We find strong evidence in favor of transit models with no TTVs, suggesting that *Kepler*-421b is either alone in its system or is only experiencing minor dynamic interactions with an unseen companion. With the combined *Kepler* and DCT observations, we calculate the timing of future transits and discuss the unique opportunity to characterize the atmosphere of this cold, long-period exoplanet via transmission spectroscopy.

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122.09 – Development of a Net Flux Radiometer for the Hera Saturn Probe Mission

In situ exploration of all the giant planets in the outer solar system is an imperative and a Saturn probe is the next compelling step beyond Galileo's in situ exploration of Jupiter, the remote investigation of its interior, gravity, and magnetic fields by the Juno mission, and the Cassini spacecraft's similar orbital reconnaissance of Saturn. One such proposed future mission is "HERA: an international atmospheric probe to unveil the depths of Saturn"; a nominal configuration is a combined ESA/Class-M probe mission accompanied by a launch vehicle and carrier relay spacecraft provided by NASA. One of the instruments being considered for inclusion on the probe is a Net Flux Radiometer (NFR) to unravel the vertical structure and properties of Saturn's cloud and haze layers. A NFR concept is presented that can be included in an atmospheric structure instrument suite for the Hera mission. The current design has two spectral channels i.e., a solar channel (0.4-to-5 µm) and a thermal channel (4-to-50 µm). The NFR is capable of viewing five distinct viewing angles during the descent. Non-imaging Winston cones with window and filter combinations define the spectral channels with a 5° Field-Of View (FOV). Uncooled thermopile detectors are used in each spectral channel and are read out using a custom designed radiation-hard Application Specific Integrated Circuit (ASIC).

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Contributing team(s): Hera Probe Mission Team

122.10 – Inferring Temperature Inversions in Hot Jupiters Via Spitzer Emission Spectroscopy

We present a systematic study of 35 hot Jupiter secondary eclipses, including 16 hot Jupiters never before characterized via emission, observed at the 3.6 µm and 4.5 µm bandpasses of Warm *Spitzer* in order to classify their atmospheric structure, namely, the existence of temperature inversions. This is a robust study in that these planets orbit stars with a wide range of compositions, temperatures, and activity levels. This diverse sample allows us to investigate the source of planetary temperature inversions, specifically, its correlation with stellar irradiance and magnetic activity. We correct for systematic and intra-pixel sensitivity effects with a pixel level decorrelation (PLD) method described in Deming *et al*. (2015). The relationship between eclipse depths and a best-fit blackbody function versus stellar activity, a method described in Knutson *et al.* (2010), will ultimately enable us to appraise the current hypotheses of temperature inversions.

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122.11 – Spitzer Secondary Eclipses of WASP-32b

We report two secondary eclipses of the exoplanet WASP-32b. Discovered Maxted et al. in 2010, this hot-Jupiter exoplanet has a mass of 3.6 ± 0.07 Mj a radius of 1.18 ± 0.07 Rj and an orbital period of 2.71865 ± 0.00008 days around a G-type star. We observed two secondary eclipses in the 3.6 µm} and 4.5 µm channels using the Spitzer Space Telescope in 2010 as a part of the Spitzer Exoplanet Target of Opportunity program (program 60003). We present eclipse depth measurements of 0.0013 ± 0.00023 in the 4.5 µm band and a three sigma upper limit on the eclipse depth in the 3.6 µm band of 0.04 ± 0.0333. We also report an infrared brightness temperature of 1538 ± 110 K in the 4.5 µm channel and refinements of orbital parameters for WASP-32b from our eclipse timing as well as amatuer and professional data that reduce the uncertanties of previous results.

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122.12 – What we could learn from observations of terrestrial exoplanets

Observations of terrestrial exoplanet environments remain an important frontier in comparative planetology. Studies of habitable zone terrestrial planets will set our own Earth in a broader context. Hot, post-runaway terrestrial exoplanets can provide insights into terrestrial planet evolution - and may reveal planetary processes that could mimic signs of life, such as photochemically-produced oxygen. While transmission spectroscopy observations of terrestrial planet atmospheres with JWST will be extremely challenging, they will afford our first chance to characterize the atmospheres of planets orbiting in the habitable zone of M dwarfs. However, due to the effects of refraction, clouds and hazes, JWST will likely sample the stratospheres of habitable zone terrestrial planets, and will not be able to observe the planetary surface or near-surface atmosphere. These limitations will hamper the search for signs of habitability and life, by precluding detection of water vapor in the deep atmosphere, and confining biosignature searches to gases that are prevalent in the stratosphere, such as evenly-mixed O_2, or photochemical byproducts of biogenic gases. In contrast, direct imaging missions can potentially probe the entire atmospheric column and planetary surface, and can typically obtain broader wavelength coverage for habitable zone planets orbiting more Sun-like stars, complementing the M dwarf planet observations favored by transmission spectroscopy. In this presentation we will show results from theoretical modeling of terrestrial exoplanet environments for habitable Earth-like, early Earth and highly-evolved hot terrestrial planets - with photochemistry and climates that are driven by host stars of different spectral types. We will also present simulated observations of these planets for both transmission (JWST) and direct imaging (LUVOIR-class) observations. These photometric measurements and spectra help us identify the most - and least - observable features of these planetary environments, and illuminate the strengths and limitations of each class of observation for future terrestrial planet characterization studies.

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Contributing team(s): NASA Astrobiology Institute - Virtual Planetary Laboratory

122.13 – Pale Orange Dots: The Impact of Organic Haze on the Habitability and Detectability of Earthlike Exoplanets

Hazes are common in planetary atmospheres, and geochemical evidence suggests early Earth occasionally supported an organic haze. The formation of organic hazes is initiated by methane photochemistry sensitive to the host star UV spectrum. Because methane can be produced by a variety of biological and geological processes, organic-rich terrestrial planets with hazes may be common in the galaxy. We use a 1D photochemical-climate model to examine the production of fractal organic haze on Archean Earthlike planets orbiting several different stars: the modern and early Sun, AD Leo (M3.5V), GJ 876 (M4V), a modeled quiescent M dwarf (M3.5V), ε Eridani (K2V), and σ Boötis (F2V). For the planetary atmospheric compositions used, planets orbiting stars with the highest or lowest UV fluxes do not form haze. Low UV-stars are unable to drive the photochemistry needed for haze formation. High UV stars generate photochemical oxygen radicals that halt haze production. Organic hazes can impact planetary habitability via UV shielding and surface cooling, but this cooling is minimized for hazy M dwarf planets whose incident stellar radiation arrives at wavelengths where organic hazes are largely transparent. We generate synthetic planetary spectra to test the detectability of haze. For 10 transits of an Archean-analog planet orbiting GJ 876 observed by the James Webb Space Telescope, gaseous absorption features at wavelengths < 2.5μm are 2-10σ shallower in the presence of a haze compared to a clear-sky planet, and methane and carbon dioxide are detectable at >5σ assuming photon-limited noise levels. An absorption feature from the haze can be detected at the 5σ level near 6.3μm, but higher signal-to-noise would be needed to uniquely distinguish haze from other absorbers in this spectral region. For direct imaging of a planet at 10 parsecs using a coronagraphic 10-meter class ultraviolet-visible-near infrared telescope, a UV-blue haze absorption feature would be strongly detectable at >12σ in 200 hours. Although haze is often considered a feature that conceals planetary features, organic haze can indicate a geologically active planet – and therefore a potentially habitable one – and possibly even reveal the presence of life.

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122.14 – Was Venus the first Habitable World of our Solar System?

Recent simulations have been completed with the Goddard Institute for Space Studies 3-D General Circulation Model of paleo Venus for a range of early solar system ages from 3Gya to 0.7Gya when the sun was less luminous than today. We use this and Magellan topography to provide Venus an ocean of average depth 310m and an atmosphere similar to present day Earth. A combination of a less luminous Sun and a slow rotation rate reveal that Venus could have had conditions on its surface amenable to surface liquid water in its early history. It is possible that fewer assumptions have to be made to make Venus an early habitable world of our solar system than have to be made for Mars or Earth, even though Venus is a much tougher world on which to confirm this hypothesis. These results could have implications in the search for planets within the habitable zones of stars.

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122.15 – A synthetic high fidelity, high cadence spectral Earth database

Earth is currently our only, and will always be our best, example of a living planet. While Earth data model comparisons have been effectively used in recent years to validate spectral models, observations by interplanetary spacecraft are limited to “snapshots” in terms of viewing geometry and Earth’s dynamic surface and atmosphere state. We use the well-validated Virtual Planetary Laboratory 3D spectral Earth model to generate both simulated disk-averaged spectra and high resolution, spatially resolved spectral data cubes of Earth at a viewing geometry consistent with Lunar viewing angles at wavelengths from the far UV (0.1 μm) the to the far IR (200 μm). The database includes disk-averaged spectra from dates 03/19/2008 to 04/23/2008 at one-hour cadence and fully spectral data cubes for a subset of those times. These spectral products have a wide range of applications including calibration of spacecraft instrumentation (Robinson et al. 2014), modeling the radiation environment of permanently shadowed Lunar craters due to Earthshine (Glenar et al., in prep), and testing the detectability of atmospheric and surface features of an Earth-like planet orbiting a distant star with a large space-based telescope mission concepts such as LUVOIR. These data include the phase and time-dependent changes in spectral biosignatures (O_2, O_3, CH_4, VRE) and habitability markers (N_2, H_2O, CO_2, ocean glint). The advantages of the VPL Earth model data products over 1D spectra traditionally used for testing instrument architectures include accurate modeling of Earth’s surface inhomogeneity (continental distribution and ice caps), cloud cover and variability, pole to equator temperature gradients, obliquity, phase-dependent scattering effects, and rotation. We present a subset of this spectral data including anticipated signal-to-noise calculations of an exoEarth twin at different phases using a coronagraph instrument model (Robinson et al. 2015). We also calculate time-dependent UBVRIJHK absolute magnitudes of Earth and binned intensities (W m^{-2} sr^{-1}) in wavelength ranges (0.4-1 μm, 0.2-2 μm, 5-25 μm, and > 10 μm) relevant for planet detection with proposed space telescope missions.

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122.16 – Determination of cloud coverage of Earth-like exoplanets by polarimetry

The properties of clouds in atmospheres of exoplanets will play a key role in the processes determining their radiative balance and climate.They also complicate the detection of chemical species in the atmospheres by flattening the spectra or by creating degeneracies between observables (Kitzmann et al. 2011, Line and Parmentier 2016).
Polarimetry promises to be a powerful tool to detect and study exoplanets (Stam et al. 2004). The polarisation of the light scattered by the atmospheres of those planets contains a lot of information about the vertical structure of the atmosphere and about the composition of the clouds (Karalidi et al. 2012) and has already been very successful in the retrieval of atmospheric properties of Venus (Rossi et al. 2015, 2016 in prep).
We will show that the degree of polarization of the light scattered by a cloudy exoplanet can be used to discriminate between different types of cloud coverage and to quantify the amount of cloud coverage on the planetary scale. We simulated the disk-integrated polarization of light scattered by exoplanets with various patchy cloud patterns, subsolar clouds and polar cusps. We show that flux and polarization can be used to differentiate between patchy and polar clouds. Observations at various wavelengths in the visible range and of different Stokes parameters would allow to differentiate between cloud coverage and cloud top altitudes.
We also propose an observational strategy that could help to retrieve orbital parameters and percentage of cloud coverage with minor ambiguities.

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122.17 – Comparison of BiLinearly Interpolated Subpixel Sensitivity Mapping and Pixel-Level Decorrelation

Exoplanet eclipse signals are weaker than the systematics present in the Spitzer Space Telescope's Infrared Array Camera (IRAC), and thus the correction method can significantly impact a measurement. BiLinearly Interpolated Subpixel Sensitivity (BLISS) mapping calculates the sensitivity of the detector on a subpixel grid and corrects the photometry for any sensitivity variations. Pixel-Level Decorrelation (PLD) removes the sensitivity variations by considering the relative intensities of the pixels around the source. We applied both methods to WASP-29b, a Saturn-sized planet with a mass of 0.24 ± 0.02 Jupiter masses and a radius of 0.84 ± 0.06 Jupiter radii, which we observed during eclipse twice with the 3.6 µm and once with the 4.5 µm channels of IRAC aboard Spitzer in 2010 and 2011 (programs 60003 and 70084, respectively). We compared the results of BLISS and PLD, and comment on each method's ability to remove time-correlated noise. WASP-29b exhibits a strong detection at 3.6 µm and no detection at 4.5 µm. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

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Contributing team(s): The WASP Consortium

122.18 – M Dwarf Exoplanet Survey by the Falcon Telescope Network

The Falcon Telescope Network (FTN) consists of twelve automated 20-inch telescopes located around the globe. We control it at the US Air Force Academy in Colorado Springs, Colorado from the Cadet Space Operations Center. We have installed 10 of the 12 sites and anticipate full operational capability by the beginning of 2017. The network's worldwide geographic distribution provides advantages. The primary mission of the FTN is Space Situational Awareness and studying Near Earth Objects. However, we are employing the FTN with its 11' x 11' field-of-view for a five-year, M dwarf exoplanet survey. Specifically, we are searching for Earth-radius exoplanets. We describe the FTN, design considerations going into the FTN's M dwarf exoplanet survey including automated operations, and initial results of the survey.

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122.19 – Inter-pixel Size Variations as Source of Spitzer Systematics

In the astrophysical sciences imaging devices are commonly assumed to contain evenly sized pixels, with each pixel converting light to signal with a slightly different efficiency. These variations are accounted for by exposing the detector to a uniform light source and comparing each value to the mean of the exposure and dividing by the result (flatfielding) . If the detector instead had pixels which varied in size, the same variations to uniform illumination would be recorded and subsequently removed. However, in the presence of a flux gradient such as a star, the flatfielding will alter these flux values which in turn affects any analysis of the data. This alteration would be due to varying size pixels being corrected to a unit area through the flatfield, when the pixels themselves rightfully record a non-uniform area of the point-spread function (PSF). We believe that this may be the source of Spitzer's systematic error attributed to gain variations. We demonstrate what an imaging device with inter-pixel size differences looks like from a data standpoint, its effects on estimating the widths of a point source, and investigations to properly account for size variations without altering flux values.

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122.20 – Extrasolar giant magnetospheric response to steady-state stellar wind pressure at 10, 5, 1, and 0.2 AU

A three-dimensional, multifluid simulation of a giant planet's magnetospheric interaction with steady-state stellar wind from a Sun-like star was performed for four different orbital semi-major axes - 10, 5, 1 and 0.2 AU. We simulate the effect of the increasing, steady-state stellar wind pressure related to the planetary orbital semi-major axis on the global magnetospheric dynamics for a Saturn-like planet, including an Enceladus-like plasma torus. Mass loss processes are shown to vary with orbital distance, with the centrifugal interchange instability displayed only in the 10 AU and 5 AU cases which reach a state of mass loss equilibrium more slowly than the 1 AU or 0.2 AU cases. The compression of the magnetosphere in the 1 AU and 0.2 AU cases contributes to the quenching of the interchange process by increasing the ratio of total plasma thermal energy to corotational energy. The strength of field-aligned currents (FAC), associated with auroral radio emissions, are shown to increase in magnitude and latitudinal coverage with a corresponding shift equatorward from increased dynamic ram pressure experienced in the hotter orbits. Similar to observed hot Jovian planets, the warm exo-Saturn simulated in the current work shows enhanced ion density in the magnetosheath and magnetopause regions, as well as the plasma torus which could contribute to altered transit signals, suggesting that for planets in warmer (> 0.1 AU) orbits, planetary magnetic field strengths and possibly exomoons - via the plasma torus - could be observable with future missions.

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122.21 – A numerical Method for exploring possible Compositions of small Exoplanets Interiors

Thousands of extrasolar planets have been discovered over the last two decades. These worlds come in a huge variety of sizes and orbits, and hints on their compositions can be inferred from density measurements. One step beyond this first approximation is the modeling of planetary interiors. Here we describe a model aiming at computing the internal structure of Super-Earths and mini-Neptunes (up to ~10 Earth masses) from their measured masses and radii. Similarly to existing models, it assumes that the planet is differentiated into several layers: a central metal core surrounded by silicate mantles and water layers. The core mass fraction (CMF) and the water mass fraction (WMF) of the planet control the thickness of these layers. The CMF and WMF variations allow us to model various compositions from rocky planets to ocean planets, as well as Mercury-like planets. Coupled to an adapted numerical scheme, our model explores the full range of compositions given by the “Core-Mantle-Water” ternary diagram, and thus provides a range of compositions compatible with the planet's measurements. Next generations of space missions (CHEOPS, PLATO) will provide exoplanet parameters with an unrivaled precision. By connecting these data to a self-consistent model of internal structure, we should be able to break the degeneracies on the possible exoplanets compositions.

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122.22 – How do sharp transmission boundaries change the effective radius of a transiting exoplanet?

Most radiative transfer codes for exoplanet transmission spectroscopy either use or are validated against the formalism of Lecavelier des Etangs et al. (2008). Although extremely useful to understand what shapes transmission spectra, this formalism does not consider the effects of sharp boundaries below which an exoplanet’s limb transmission suddenly decreases. However, with recent advances on the effects of refraction in transmission spectroscopy (Bétrémieux & Kaltenegger 2014, Bétrémieux 2016), it turns out that all exoplanets possess one such boundary in the form of either a surface, optically-thick clouds, or in the form of a refractive boundary. We have deriveda first-order analytical expression for an exoplanet’s effective radius, which can be used to further validate or improve radiative transfer codes, which accounts for the presence of these boundaries, and discuss their effects on exoplanetary transmission spectra.

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122.23 – A Study of the Effects of Underlying Assumptions in the Reduction of Multi-Object Photometry of Transiting Exoplanets

The analysis of ground-based photometric observations of planetary transits must treat the effects of the Earth’s atmosphere, which exceed the signal of the extrasolar planet. Generally, this is achieved by dividing the signal of the host star and planet from that of nearby field stars to reveal the lightcurve. The lightcurve is then fit to a model of the planet’s orbit and physical characteristics, also taking into account the characteristics of the star. The fit to the in and out-of-transit data establish the depth of the lightcurve. The question arises, what is the best way to select and treat reference stars to best characterize and remove the shared atmospheric systematics that plague our transit signal. To explore these questions we examine the effects of several assumptions that underline the calculation of the light curve depth. Our study involves repeated photometric observations of hot Jupiter primary transits in the U and B filters. Data were taken with the University of Arizona’s Kuiper 1.55m telescope/Mont4K CCD. Each exoplanet observed offers a unique field with stars of various brightness, spectral types and angular distance from the host star. While these observations are part of a larger study of the Rayleigh scattering signature of hot Jupiter exoplanets, here we study the effects of various choices during reduction, specifically the treatment of reference stars and atmospheric systematics.We calculate the lightcurve for all permutations of reference stars, considering several out-of-transit assumptions (e.g. linear, quadratic or exponential). We assess the sensitivity of the transit depths based on the spread of values. In addition we look for characteristics that minimize the scatter in the reduced lightcurve and analyze the effects of the treatment of individual variables on the resultant lightcurve model. Here we present the results of an in depth statistical analysis that classifies the effect of various parameters and choices involved in multi-object photometric reduction. The AzGOE research group is made primarily of undergraduate students from the University of Arizona.

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Contributing team(s): AzGOE

122.24 – Independet Component Analyses of Ground-based Exoplanetary Transits

Most observations of exoplanetary atmospheres are conducted when a “Hot Jupiter” exoplanet transits in front of its host star. These Jovian-sized planets have small orbital periods, on the order of days, and therefore a short transit time, making them more ameanable to observations. Measurements of Hot Jupiter transits must achieve a 10-4 level of accuracy in the flux to determine the spectral modulations of the exoplanetary atmosphere. In order to accomplish this level of precision, we need to extract systematic errors, and, for ground-based measurements, the effects of Earth’s atmosphere, from the signal due to the exoplanet, which is several orders of magnitudes smaller. Currently, the effects of the terrestrial atmosphere and the some of the time-dependent systematic errors are treated by dividing the host star by a reference star at each wavelength and time step of the transit. More recently, Independent Component Analyses (ICA) have been used to remove systematic effects from the raw data of space-based observations (Waldmann 2014,2012; Morello et al.,2015,2016). ICA is a statistical method born from the ideas of the blind-source separation studies, which can be used to de-trend several independent source signals of a data set (Hyvarinen and Oja, 2000). One strength of this method is that it requires no additional prior knowledge of the system. Here, we present a study of the application of ICA to ground-based transit observations of extrasolar planets, which are affected by Earth’s atmosphere. We analyze photometric data of two extrasolar planets, WASP-1b and GJ3470b, recorded by the 61" Kuiper Telescope at Stewart Observatory using the Harris B and U filters. The presentation will compare the light curve depths and their dispersions as derived from the ICA analysis to those derived by analyses that ratio of the host star to nearby reference stars.

References: Waldmann, I.P. 2012 ApJ, 747, 12, Waldamann, I. P. 2014 ApJ, 780, 23; Morello G. 2015 ApJ, 806; Morello et al. 2016 ApJ, 820, 86; Hyvarinen, A., and Oja, E. 2000 IEEE Transactions on Neural Networks, 13, 411.

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122.25 – Ground-based Multi-object Spectroscopy of XO-2b using a Systematic Wavelength Calibration

Here we present multiple observations of the primary transit of the bright hot-Jupiter XO-2b with visible wavelength spectroscopy. Repeated observations of XO-2b record simulatenous measurements of both the exoplanet host star and one or more comparison stars. Ideally, the comparison star measures errors, such as airmass variations and telescope jitter. The hypothesis is that these errors can then be divided out from the target star to achieve higher SNR and improve estimation of the small transit signal. However, we find that the astrophysical signals are subject to time-varying translations along the spectroscopic dispersion axis that change according to wavelength. Improper alignment prior to dividing the astrophysical signals can result in spurious spectral features or inadequate removal of shared systematics. We showcase ways to check for inadequate alignment and offer corrections to such problems.

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122.26 – Solar system neighbors as proxies for exoplanets; Peering through the atmospheres of Titan and Saturn with Cassini

A transiting exoplanet is a planet that orbits another star, and periodically passes directly in front of its parent star, blocking out a small fraction of the stellar light. We can study the atmospheres of these planets by looking at the tiny fraction of the star's light that passes through the planet's thin outer atmosphere, called a transmission spectrum. This is one of the few ways to probe an exoplanet's atmosphere with current technology. This field will rapidly expand with the launch of the Transiting Exoplanet Survey System (TESS) in 2017, to find more planets, and the James Webb Space Telescope (JWST) in 2018, to characterize exoplanet atmospheres. The need to validate the models we use to calculate exoplanet atmosphere properties in the regime of high signal-to-noise data has become increasingly important. Thankfully, with the help of NASA's Cassini orbiter we can test our transmission spectra models against transmission spectra of real planetary bodies for which we have "ground truth" measurements. Using the CHIMERA Transmission spectra model of Line et al. (2013a) and the Python multinesting framework pyMultinest, from the Saturn and Titan transmission spectra we retrieve the abundances of the important molecules CH4, CO, CO2, NH3, and C2H2 along with atmospheric temperature, a reference or "surface" pressure, and the cloud pressure. Here we discuss the current status of this work, and potential problems facing our models, including a C-H stretching feature between 3-4 microns and haze scattering.

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122.28 – Investigation of the K Band Spectral Shapes of Brown Dwarfs and Exoplanets

Massive, gaseous exoplanets have been found to be spectroscopically similar to young, low gravity brown dwarfs. We aim to assess this similarity in the K band (1.9 – 2.4 microns), the highest-resolution and highest signal to noise ratio wavelength range of exoplanet spectra. In order to do so, we present a method to quantify the K band spectral shape of a sample of field gravity, low gravity, and planetary mass sources, including HR8799b,c and 2MASS 1207b. We investigate the dependence of the K band spectral shape on spectral type, temperature, and gravity. We find that the shorter wavelength region of the K band (2.03 – 2.10 microns) is more strongly correlated with temperature, while the longer wavelength region (2.219 – 2.290 microns) is more gravity dependent. We also performed our analysis on BT Settl 2013 model spectra in order to examine how closely temperature and gravity trends in model K bands match those in observed K bands. We find that though model and observed K band shapes show the same general trends as a function of temperature and gravity, model spectra show some intricacies not seen in the observed spectra.

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122.29 – The search for radio emission from the 55 Cnc exoplanetary system using LOFAR

Detection of radio emission from exoplanets can provide information on the star-planet system that is very difficult or impossible to study otherwise, such as the planet's magnetic field, magnetosphere, rotation period, orbit inclination, and star-planet interactions. Such a detection in the radio would open up a whole new field in exoplanets, however, currently there are no confirmed detections of an exoplanet at radio frequencies. In this study, we search for non-thermal radio emission from 55 Cnc, an exoplanetary system with 5 planets. 55 Cnc is among the best targets for this search according to theoretical studies. We observed for 18 hours with the Low-Frequency Array (LOFAR) in the frequency range 26-73 MHz with full-polarization and covered the entire orbital phases of the innermost planet. During the observations four beams were recorded simultaneously on 55 Cnc, a patch of nearby "empty" sky, the nearby pulsar B0823+26, and a bright radio source in the field. The extra beams make this setup unique since they can be used for control of the telescope gain and to verify that a detection in the exoplanet beam is not a false-positive detection (e.g. ionospheric fluctuations). An automatic pipeline was created to automatically find Radio Frequency Interference (RFI) and to search for emission in the exoplanet beam. We will apply this observational technique and pipeline to more of the theoretically best candidates in the future.

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122.30 – Searching the Nearest Stars for Exoplanetary Radio Emission: VLA and LOFAR Observations

Six of the eight solar system planets and one moon (Ganymede) exhibit present-day dynamo magnetic fields. To date, however, there are no conclusive detections of exoplanetary magnetic fields. Low frequency radio emission via the cyclotron maser instability (CMI) from interactions between a planet and the solar/stellar wind is the most direct means of detecting and characterizing planetary/exoplanetary magnetic fields. We have undertaken a survey of the very nearest stars in low frequency radio (30 MHz - 4 GHz) in order to search for yet-undiscovered planets. The closest stars are chosen in order to reduce the attenuation of the magnetospheric radio signal by distance dilution, thereby increasing the chances of making a detection if a planet with a strong magnetic field is present. The VLA telescope (P-band: 230-470 MHz, L-band: 1-2 GHz, S-band: 2-4 GHz) and LOFAR telescope (LBA: 30-75 MHz) have

been used to conduct this survey.
This work focuses on VLA and LOFAR observations of an M-dwarf binary system: GJ 725. We present upper limits on radio flux as a function of frequency. Since the peak emission frequency of CMI-type emission is the local plasma frequency in the emission region, the peak frequency of planetary radio emission is a direct proxy for the magnetic field strength of the planet. Our spectral irradiance upper limits therefore represent upper limits on the magnetic field strengths of any planets in the GJ 725 system.
Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.
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Institution(s): *1. JPL, 2. MIT*

122.31 – Generating an optimal target list for a space mission dedicated to transit spectroscopy

Nowadays several space missions and ground-based surveys discovered more than 3000 exoplanets. The characterization of their atmospheres is necessary to understand how were they formed, how do they evolve, how are they affected by starlight, stellar winds and other fundamental questions. ARIEL and Twinkle are two dedicated space mission for the study of exoplanetary atmospheres. ARIEL is one the three candidates for the next ESA medium class mission expected to be launched in 2026. Twinkle, proposed to be launched in 2019, is a small, low-cost mission. In order to draft the target lists of the two missions, it is important to look for the best targets that can be observed with the instrumentationassembled on the two satellites. The final lists have to take into account both the number of already known exoplanets and the number of existing exoplanets still not discovered (thanks to the Kepler space mission we can estimate the occurrence rate of exoplanets around the stars, Fressin et al, 2013). Future space missions (GAIA, Cheops, PLATO, Kepler II and TESS) and ground-based surveys will deliver many new exoplanets in the next decade. For this reason a trustworthy target list of exoplanets for a space mission planned to be launched in 2026 (or 2019) needs to take into
account a more complete list than the currently available.
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122.32 – Assessing the Chemistry of Tidally Locked Earth-like Planets around M-type Stars Using a 3D Coupled Chemistry-Climate Model (CESM/WACCM)

Given recent discoveries there is a very real potential for tidally-locked Earth-like planets to exist orbiting M stars. To determine whether these planets may be habitable it is necessary to understand the nature of their atmospheres. In our investigation we simulate the evolution of present-day Earth while placed in tidally-locked orbit (meaning the same side of the planet always faces the star) around an M dwarf star. We are particularly interested in the evolution of the planet's ozone layer and whether it will shield the planet, and therefore life, from harmful radiation.
To accomplish the above objectives we use a state-of-the-art 3-D terrestrial model, the Whole Atmosphere Community Climate Model (WACCM), which fully couples chemistry and climate, and therefore allows self-consistent simulations of atmospheric constituents and their effects on a planet's climate, surface radiation and thus habitability. Preliminary results show that this model is stable and that a tidally-locked Earth is protected from harmful UV radiation produced by G stars. The next step shall be to adapt this model for an M star by including its UV and visible spectrum.
This investigation will both provide an insight into the potential for habitable exoplanets and further define the nature of the habitable zones for M class stars. We will also be able to narrow the definition of the habitable zones around distant stars, which will help us identify these planets in the future. Furthermore, this project will allow for a more thorough analysis of data from past and future exoplanet observing missions by defining the atmospheric composition of Earth-like planets around a variety of types of stars.
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122.33 – Investigation of the sub-Neptune photoevaporation desert for M-dwarfs to Sun-like stars

Short-period sub-Neptunes with substantial volatile envelopes are among the most common type of known exoplanets. However, these planets are typically on highly-irradiated orbits where they are vulnerable to atmospheric photoevaporation. In particular, recent studies of the Kepler planet population have suggested a dearth of sub-Neptunes on orbits receiving more than 650x the broadband irradiation of the Earth (Lundkvist et al. 2016). Physically, we expect this "photoevaporation desert" to depend on the lifetime integrated X-ray and extreme ultraviolet flux, which is the main driver of atmospheric escape for these planets. In this work, we compute planet occurrence as a function of integrated X-ray flux for the latest samples of confirmed Kepler and K2 planets. Our objective is to constrain the desert in a parameter space that ties directly to the photoevaporation process. We find a sharp drop-off in planet occurrence for integrated X-ray flux greater than 4 x 10^21 erg/cm^2, and we also investigate how this drop-off varies with stellar spectral type.
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122.34 – Modeling Earth's Disk-Integrated, Time-Dependent Spectrum: Applications to Directly Imaged Habitable Planets

Earth is our only example of a habitable world and is a critical reference point for potentially habitable exoplanets. While disk-averaged views of Earth that mimic exoplanet data can be obtained by interplanetary spacecraft, these datasets are often restricted in wavelength range, and are limited to the Earth phases and viewing geometries that the spacecraft can feasibly access. We can overcome these observational limitations using a sophisticated UV-MIR spectral model of Earth that has been validated against spacecraft observations in wavelength-dependent brightness and phase (Robinson et al., 2011; 2014). This model can be used to understand the information content – and the optimal means for extraction of that information – for multi-wavelength, time-dependent, disk-averaged observations of the Earth.
In this work, we explore key telescope parameters and observing strategies that offer the greatest insight into the wavelength-, phase-, and rotationally-dependent variability of Earth as if it were an exoplanet. Using a generalized coronagraph instrument simulator (Robinson et al., 2016), we synthesize multi-band, time-series observations of the Earth that are consistent with large space-based telescope mission concepts, such as the Large UV/Optical/IR (LUVOIR) Surveyor. We present fits to this dataset that leverage the rotationally-induced variability to infer the number of large-scale planetary surface types, as well as their respective longitudinal distributions and broadband albedo spectra. Finally, we discuss the feasibility of using such methods to identify and map terrestrial exoplanets surfaces with the next generation of space-based telescopes.
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Contributing team(s): NAI Virtual Planetary Laboratory, ISSI 'The Exo-Cartography Inverse Problem'

122.35 – 1-D Radiative-Convective Model for Terrestrial Exoplanet Atmospheres

We present a one dimensional radiative-convective model to study the thermal structure of terrestrial exoplanetary atmospheres. The radiative transfer and equilibrium chemistry in our model is based on similar methodologies in models used for studying Extrasolar Giant Planets (Fortney et al. 2005b.) We validated our model in the optically thin and thick limits, and compared our pressure-temperature profiles against the analytical solutions of Robinson & Catling (2012). For extrasolar terrestrial planets with pure hydrogen atmospheres, we evaluated the effects of H_2-H_2 collision induced absorption and identified the purely roto-translational band in our modeled spectra. We also examined how enhanced atmospheric metallicities affect the temperature structure, chemistry, and spectra of terrestrial exoplanets. For a terrestrial extrasolar planet whose atmospheric compostion is 100 times solar orbiting a sun-like star at 2 AU, our model resulted in a reducing atmosphere with H_2O, CH_4, and NH_3 as the dominant greenhouse gases.

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122.36 – A parameter study of the effect of the diurnal cycle on the atmospheric dynamics of slowly-rotating planets using a simple GCM

The large set of discovered exoplanets provides a multitude of possible planetary characteristics that need to be understood. To analyse and compare the dominant contributions to their atmospheric circulation in the most general way, it is beneficial to study the properties of different circulation regimes with reference to non-dimensional parameter spaces. Our work is concerned with the nonlinear responses to the diurnal heating cycle and their impact on the broader circulation in order to understand the emergence and maintenance of equatorial super-rotation in atmospheres of bodies similar to Venus and Titan.
We use a hierarchy of simple GCMs with increasing temporal resolution in thermal forcing (i.e. annually averaged, seasonal cycle, diurnal cycle) using a simple 2-band, semi-gray radiation scheme for a terrestrial-style planetary atmosphere. In our parameter space we vary key parameters such as the thermal Rossby number (planetary rotation rate), the Greenhouse parameter (the ratio between short- and long-wave optical thickness), the thermal inertia of the surface, and atmospheric equilibrium time-scale. The resulting circulations show an increased equatorial super-rotating wind due to the diurnal cycle when the atmosphere is heated at the top. We investigate and quantify the accelerating effect of the thermal tides.

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123 – Future Missions, Instruments and Facilities Posters

123.01 – BepiColombo – Status update and Science goals

BepiColombo is a joint project between ESA and the Japanese Aerospace Exploration Agency (JAXA) to explore Mercury. The Mission consists of two orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The mission scenario foresees a launch of both spacecraft with an ARIANE V in 2018 and an arrival in their dedicated orbits around Mercury in 2025. From these orbits the two spacecraft will be studying the planet and its environment.
The MPO scientific payload comprises eleven instruments/instrument packages; the MMO scientific payload consists of five instruments/instrument packages. Together, the scientific payload of both spacecraft will perform measurements to find clues to the origin and evolution of a planet close to its parent star.
The MPO on BepiColombo will focus on a global characterization of Mercury through the investigation of its interior, surface, exosphere and magnetosphere. In addition, it will be testing Einstein's theory of general relativity. The MMO provided by JAXA focuses on investigating the wave and particle environment of the planet from an eccentric orbit. Together, the scientific payload of both spacecraft will provide the detailed information necessary to understand the process of planetary formation and evolution in the hottest part of the proto-planetary nebula as well as the similarities and differences between the magnetospheres of Mercury and the Earth.
All scientific instruments have been integrated into the spacecraft and both spacecraft are now under final acceptance testing.

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123.02 – In Situ Analysis of the Volatiles in the Lunar Regolith with the Gas Analytical Package Experiment: Calibration of a GCMS Protoype

Volatiles were recently shown to be present at the Lunar pole. They probably come from meteorites and micrometeorites which continuously deliver their material at the surface of the satellite. Thus, their characterisation would enable to better constrain the nature of the species brought by the meteorites to the solar system bodies, evaluate their evolution under Moon surface conditions. Within a few years, it could be done in situ with the Gas Analytical Package experiment onboard the Russian Luna Ressource mission, in part devoted to analyse regolith samples. With this aim, our team proposes an instrumentation to characterize in situ the content of volatiles in the lunar soil and rocks. This instrumentation would provide important reference data about the samples collected. It is based on pyrolysis coupled with gas chromatography and mass spectrometry, and could have the capability to: extract volatile materials (either condensed or present in the minerals) from the solid samples, separate the volatile and analyze their structure for identification and quantification, and analyze isotopic ratios in a certain extent. This instrumentation is based on an inheritance of the GAP instrument that was present onboard the late Phobos-Grunt probe. The instrumentation would be composed of : i. a pyrolyzer capable to heat the samples up to about 1000°C, and developed by IKI (Rus), which is also in charge to the whole instrument (PI M. Gerasimov); ii. a gas chromatograph devoted to separate and detect the volatile species released from the samples, developed by LATMOS and LISA (Fr.) ; iii. a time of flight mass spectrometer for the structural identification of the molecules, developed by the University of Bern (Sw.). This instrumentation should allow the identification of inorganic volatile molecules and small organic molecules (up to about benzene). This communication aims at presenting this instrumentation that should be onboard the Luna Ressource probe to the lunar South pole, and it could be used for a return sample mission to get ground truth data about the returned samples. A focus will be done to present the performances of the GCMS determined from calibrations done in the laboratory with prototypes of the GC & MS.

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123.03 – Preparations for ExoMars: Learning Lessons from Curiosity

In 2020, the European Space Agency will launch its first Mars rover mission, ExoMars. The rover will use a drill to obtain samples from up to 2m below the Martian surface that will then be analysed using a variety of analytical instruments, including the Raman Laser Spectrometer (RLS), which will be the first Raman spectrometer to be used on a planetary mission.
To prepare for ExoMars RLS operations, we report on a series of experiments that have been performed in order to investigate the response of a representative Raman instrument to a number of analogue samples (selected based on the types of material known to be important, following investigations performed by NASA's Mars Science Laboratory, MSL, on the Curiosity rover). Raman spectroscopy will provide molecular and mineralogical information about the samples obtained from the drill cores on ExoMars. MSL acquires similar information using the CheMin XRD instrument which analyses samples acquired from drill holes several centimetres deep. Like Raman spectroscopy, XRD also provides information on the mineralogical makeup of the analysed samples. The samples in our study were selected based on CheMin data obtained from drill sites at Yellowknife Bay, one of the first locations visited by Curiosity (supplemented with additional fine scale elemental information obtained with the ChemCam LIBS laser instrument). Once selected (or produced), the samples were characterised using standard laboratory XRD and XRF instruments (in order to compare with the data obtained by CheMin) and a standard, laboratory based LIBS system (in order to compare with the ChemCam data). This characterisation provides confirmation that the analogue samples are representative of the materials likely to be encountered on Mars by the ExoMars rover.
A representative, miniaturised Raman spectrometer was used to analyse the samples, using acquisition strategies and operating modes similar to those expected for the ExoMars instrument. The type of minerals detected are identified and compared to the information typically acquired using other analytical science techniques investigating in order to highlight the benefits and drawbacks of using Raman spectroscopy for planetary science applications.

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123.04 – The ExoMars Raman Laser Spectrometer: Performance and Optimisation

The ExoMars rover, which is due for launch in 2020, will incorporate an analytical laboratory for interrogating the composition of drill cores retrieved from the near sub-surface of the planet. The laboratory includes a Raman spectrometer with a green laser (532 nm) that will be used to investigate the molecular and structural properties of the material within the samples. The ExoMars, Raman Laser Spectrometer (RLS) is expected to be the first instrument of its kind to be used on another planet.
In preparation for the deployment and operation of the RLS instrument, a broad range of laboratory and fieldwork activities are currently being performed in order to ensure optimum scientific return from the mission. These studies include: science operations and data exploitation, terrestrial analogue studies (and laboratory simulations) and lessons learned from previous planetary mission experiences.
Here we report on the status of the RLS science team activities related to studies of terrestrial analogues. This work includes the recovery and characterisation of appropriate samples from various field-site locations (e.g. clay based samples and materials recovered from dry deserts) that reflect the nature of the materials that are expected to be present in the landing site locations currently anticipated for the ExoMars rover mission. Other work includes the detailed analysis of such analogue samples using flight-like prototype instruments, both in-situ and in the laboratory.
A summary of the results obtained from all of these studies is presented along with an overview of the anticipated performance capabilities of the instrument. Particular emphasis is placed on the design and performance of the camera system (including both the detector and data processing sub-systems).

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123.05 – Performance of the future MOMA GC-ITMS instrument

The Mars Organic Molecule Analyzer (MOMA) experiment aboard the future ExoMars mission will be the continuation of the SAM expirement aboard the Curiosity rover, with the search for the organic composition of the Mars surface. With ExoMars the sample will be extracted as deep as 2 meters below the martian surface to minimize effects of radiation and oxidation on organic materials. To analyze the wide range of organic composition (volatile and non-volatiles compounds) of the Martian soil MOMA is composed with an UV laser desorption / ionization (LDI) and a pyrolysis gas chromatography ion trap mass spectrometry (*pyr*-GC-ITMS). In order to analyze refractory organic compounds and chirality samples which undergo GC-ITMS analysis may be submitted to a derivatization process, consisting of the reaction of the sample components with specific reactants (MTBSTFA [1], DMF-DMA [2] or TMAH [3]).
To optimize and test the performance of the GC-ITMS instrument we have performed several coupling tests campaigns between the GC, providing by the French team (LISA, LATMOS, CentraleSupelec), and the MS, providing by the US team (NASA, GSFC). Last campaign has been done with the ETU models which is similar to the flight model and which include the oven and the taping station providing by the German team (MPS).
The results obtained demonstrate the current status of the end-to-end performance of the gas chromatography-mass spectrometry mode of operation.

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123.06 – The ExoMars science data archive: status and plans

The ExoMars program is a co-operation between ESA and Roscosmos comprising two missions: the first, launched on 14 March 2016, includes the Trace Gas Orbiter and Schiaparelli lander; the second, due for launch in 2020, will be a Rover and Surface Platform

(RSP). The Schiaparelli lander for the 2016 mission is due to land on 19th October, during this conference. The status of that landing will be included as part of this presentation.
The archiving and management of the science data to be returned from ExoMars will require a significant development effort for the new Planetary Science Archive (PSA). These are the first data in the PSA to be formatted according to the new PDS4 Standards, and there are also significant differences in the way in which a scientist will want to query, retrieve, and use data from a suite of rover instruments as opposed to remote sensing instrumentation from an orbiter. NASA has a strong user community interaction for their rovers, and a similar approach to their 'Analysts Notebook' will be needed for the future PSA.
In addition to the archiving interface itself, there are differences with the overall archiving process being followed for ExoMars compared to previous ESA planetary missions. The first level of data processing for the 2016 mission, from telemetry to raw, is completed by ESA at ESAC in Madrid, where the archive itself resides. Data continuously flow direct to the PSA, where after the given proprietary period, they will be released to the community via the user interfaces. For the rover mission, the data pipelines are being developed by European industry, in close collaboration with ESA PSA experts and with the instrument teams. The first level of data processing will be carried out for all instruments at ALTEC in Turin where the pipelines are developed, and from where the rover operations will also be run.

This presentation will focus on the challenges involved in archiving the data from the ExoMars Program, and will outline the plans and current status of the system being developed to respond to the needs of the missions.
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123.07 – The MEDA's Radiometer TIRS for the MARS2020 Mission

The TIRS (Thermal InfraRed Sensor) instrument is one of the payloads of NASA MARS2020 mission, that is expected to take off in 2020, and is designed to operate for at least three Martian years on surface. The TIRS is part of the Mars Environmental Dynamics Analyzer (MEDA), formed for other environmental sensors, which will be placed in the MARS2020 Rover, and is been developing by the Spanish Center of Astrobiology (CAB).
The main objectives of MEDA's Thermal InfraRed Sensor are:
-Characterize the net radiative forcing (within 10%), and constrain the conductive forcing at the local surface and near-surface atmosphere.
-Record the surface skin temperature and the UV-VIS-NIR irradiance solar flux at an accuracy of [10%] at full range of the atmosphere.
TIRS design has heritage from GTS-REMS on the Mars Science Laboratory, in the Curiosity Rover. The aim of the instrument is to measure the radiative flux emitted from the Martian surface, sky and the CO_2 atmosphere using five thermopiles sensors in four wavelength bands, model TS100 provided by IPHT (Institute of Photonic Technology, Jena, Germany). The TIRS has three downward pointing thermopiles to measure the IR fluxes emitted by the surface, separating brightness surface temperature from emissivity and surface reflected upward short wave radiation, using the thermopiles IR3 (0.3-3 µm), IR4 (6.5-inf µm), IR5 (8-14 µm). Additionally, it has two more thermopiles pointing to the sky, the thermopiles IR1 (6.5-inf µm) and IR2 (14.5-15.5 µm), which captures the downward fluxes of thermal infrared radiation and air temperature nearby the sensor.
Thermopiles are accommodated inside a mechanical assembly that is designed to ensure a low thermal gradient. This assembly also accommodates a calibration plate, aimed to intercept part of the thermopiles FOV, and capable to do an in-flight recalibration.
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123.08 – SHERLOC: An investigation for Mars 2020

The next rover to explore Mars, currently known as Mars2020, is in development for a 2020 launch. The primary goal of the mission is to better understand the geologic and climate history of Mars including the identification of potential signs of past life on Mars. Samples will be characterized by the Mars2020 payload elements. Samples with high science interest will then be collected and stored by the rover for potential return to the earth for analysis in terrestrial laboratories.
As part of the payload, NASA selected the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) investigation. SHERLOC consists of a Deep UV (DUV) native fluorescence and resonance Raman spectrometer that includes a built-to-print version of the Mars Hand Lens Imager (MAHLI) instrument on the Mars Science Laboratory (MSL). It utilizes a DUV laser to generate characteristic Raman and fluorescence photons from a targeted spot. These spectral features are resolvable when a high-radiance, narrow line-width, laser source illuminates a sample. In fluorescence, the incident photons are absorbed and re-emitted at a longer wavelength. Typical fluorescence cross-sections are 10^4 greater than traditional Raman, enabling the detection of sub-picograms levels of aromatic organic compounds. The DUV laser is co-boresighted to a context imager and integrated into an autofocusing/scanning optical system that allows us to correlate spectral signatures to surface textures, morphology and visible features. An internal scanning mirror enables the generation of maps that allow for the identification of spatially resolved organic structure.
SHERLOC's science goals include the detection and classification organics and astrobiologically relevant minerals on the surface and near subsurface of Mars. It is capable of organic sensitivity of 10^{-5} to 10^{-6} w/w over the entire observation region of 7 mm x 7 mm. It is capable of alaphatic organic sensitivity of 10^{-2} to 10^{-4} w/w spatially resolved at 100µm and can detect astrobiologically relevant aqueously formed mineral grains with sizes <100µm.
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123.09 – The SuperCam Remote Sensing Suite for MARS 2020: Nested and Co-Aligned LIBS, Raman, and VISIR Spectroscopies, and color micro-imaging

As chartered by the Science Definition Team, the Mars 2020 mission addresses four primary objectives: A. Characterize the processes that formed and modified the geologic record within an astrobiologically relevant ancient environment, B. Perform astrobiologically relevant investigations to determine habitability, search for materials with biosignature presentation potential, and search for evidence of past life, C. Assemble a returnable cache of samples and D. Contribute to preparation for human exploration of Mars. The SuperCam instrument, selected for the Mars 2020 rover, as a suite of four instruments, provides nested and co-aligned remote investigations: Laser Induced Breakdown Spectroscopy (LIBS), Raman spectroscopy and time-resolved fluorescence (TRF), visible and near-infrared spectroscopy (VISIR), and high resolution

color imaging (RMI). SuperCam appeals broadly to the four Mars 2020 objectives.
In detail, SuperCam will perform:
1. Microscale mineral identification by combining LIBS elemental and VISIR mineralogical spectroscopies, especially targeting secondary minerals
2. Determine the sedimental stratigraphy through color imaging and LIBS and VISIR spectroscopy
3. Search for organics and bio-signatures with LIBS and Raman spectroscopy
4. Quantify the volatile content of the rocks by LIBS spectroscopy to determine the degree of aquaeous alteration
5. Characterize the texture of the rocks by color imaging to determine their alteration processes
6. Characterize the rocks' coatings by LIBS spectroscopy
7. Characterize the soil and its potential for biosignature preservation
8. Monitor the odd-oxygen atmospheric chemistry.
To meet these goals SuperCam will perform LIBS spectroscopy on 0.5 mm spot up to 7-meter distance, perform Raman and time-resolved fluoresence up to 12-m distance with a 0.8 mrad angular resolution, a 100 ns time gating in the 534-850 nm spectral range, acquire VISIR spectra in the range 0.4-0.85 µm with a resolution of 0.35 nm, and in the IR range over 1.3-2.6 µm, rich in mineral signatures, with a resolution of 20 nm, and provide RGB images with an angular resolution of 40 µrad over a FOV of 20 mrad.
We will present the science performances of SuperCam and the forecasted operation plans.

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123.10 – On the Raman Detectability of Biomarkers in Geological Matrices in preparation for Mars Exploration

In 2020, Raman spectrometers will be launched to Mars as part of the ESA/ROSCOSMOS's ExoMars 2020 mission and the NASA's Mars 2020 mission. The miniaturized Raman instrument on board the ExoMars rover has two scientific goals: characterize the geochemistry of the surface and subsurface of Mars, and search for molecular evidence of past and present life. Raman spectrometers have indeed the capability to characterize non-destructively the geology of the rocky surface of Mars. Information on the nature and the molecular composition of the surface and subsurface of Mars will provide valuable information about the habitability of the red planet. In addition, Raman spectrometers have the ability to detect potential molecular biomarkers which are substances obtained by biochemical processes or their derivatives preserved in a protective geological niche. In preparation for Mars mission, studying the detection capability of miniaturized Raman spectrometers (specifically developed for space missions and therefore compromised by the associated challenging constraints) is highly important, on both lab synthetic samples and natural terrestrial analogues samples. We present here an analytical strategy to determine the limit of detection achievable based on Raman spectral images. Raman data were recorded with benchtop instruments and a Raman Laser Spectrometer prototype developed at the University of Leicester to optimize/characterize the camera system that will be used for the ExoMars mission.

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123.11 – A Miniature Electron Probe for In Situ Elemental Microanalysis

The Mini-EPMA will provide advanced, fine-scale *in situ* determination of the elemental composition of planetary, asteroidal, and cometary material. Composition provides key evidence about the processes by which rocks, soils, and ices were formed and altered (for example, accretion, differentiation, and hydrothermal alteration) thus recording past stages in solar system evolution. The high spatial resolution achievable with a focused electron beam will permit sub-millimeter scale compositional mapping in a flight instrument. Our goal is to produce spot sizes under 100 microns using microscale field emitters in an array, with focusing achieved by a compact electrostatic lens stack. The instrument prototype discussed here would be a valuable payload element for a future landed lunar, asteroid or comet mission.

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123.12 – Ongoing Mars Missions: Extended Mission Plans

Many key scientific discoveries in planetary science have been made during extended missions. This is certainly true for the Mars missions both in orbit and on the planet's surface. Every two years, ongoing NASA planetary missions propose investigations for the next two years. This year, as part of the 2016 Planetary Sciences Division (PSD) Mission Senior Review, the Mars Odyssey (ODY) orbiter project submitted a proposal for its 7th extended mission, the Mars Exploration Rover (MER-B) *Opportunity* submitted for its 10th, the Mars Reconnaissance Orbiter (MRO) for its 4th, and the Mars Science Laboratory (MSL) *Curiosity* rover and the Mars Atmosphere and Volatile Evolution (MVN) orbiter for their 2nd extended missions, respectively. Continued US participation in the ongoing Mars Express Mission (MEX) was also proposed. These missions arrived at Mars in 2001, 2004, 2006, 2012, 2014, and 2003, respectively. Highlights of proposed activities include systematic observations of the surface and atmosphere in twilight (early morning and late evening), building on a 13-year record of global mapping (ODY); exploration of a crater rim gully and interior of Endeavour Crater, while continuing to test what can and cannot be seen from orbit (MER-B); refocused observations of ancient aqueous deposits and polar cap interiors, while adding a 6th Mars year of change detection in the atmosphere and the surface (MRO); exploration and sampling by a rover of mineralogically diverse strata of Mt. Sharp and of atmospheric methane in Gale Crater (MSL); and further characterization of atmospheric escape under different solar conditions (MVN). As proposed, these activities follow up on previous discoveries (e.g., recurring slope lineae, habitable environments), while expanding spatial and temporal coverage to guide new detailed observations. An independent review panel evaluated these proposals, met with project representatives in May, and made recommendations to NASA in June 2016. In this presentation, we will highlight the planned activities of these NASA Mars missions, as they start new chapters in their historic exploration of the dynamic and complex planet that is Mars.

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123.13 – Planetary SUrface Portal (PSUP): a tool for easy visualization and analysis of Martian surface

PSUP is two software application platforms for working with raster, vector, DTM, and hyper-spectral data acquired by various space instruments analyzing the surface of Mars from orbit. The first platform of PSUP is MarsSI (Martian surface data processing Information System, http://emars.univ-lyon1.fr). It provides data analysis functionalities to select and download ready-to-use products or to process data though specific and validated pipelines. To date, MarsSI handles CTX, HiRISE and CRISM data of NASA/MRO mission, HRSC and OMEGA data of ESA/MEx mission and THEMIS data of NASA/ODY mission (Lozac'h et al., EPSC 2015). The second part of PSUP is also open to the scientific community and can be visited at http://psup.ias.u-psud.fr/. This web-based user interface provides access to many data products for Mars: image footprints and rasters from the MarsSI tool; compositional maps from OMEGA and TES; albedo and thermal inertia from OMEGA and TES; mosaics from THEMIS, Viking, and CTX; high level specific products (defined as catalogues) such as hydrated mineral sites derived from CRISM and OMEGA data, central peaks mineralogy,… In addition, OMEGA C channel data cubes corrected for atmospheric and aerosol contributions can be downloaded. The architecture of PSUP data management and visualization is based on SITools2 and MIZAR, two CNES generic tools developed by a joint effort between CNES and scientific laboratories. SITools2 provides a self-manageable data access layer deployed on the PSUP data, while MIZAR is 3D application in a browser for discovering and visualizing geospatial data. Further developments including the addition of high level products of Mars (regional geological maps, new global compositional maps,…) are foreseen. Ultimately, PSUP will be adapted to other planetary surfaces and space missions in which the French research institutes are involved.

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123.14 – Formulation Assessment and Support Team (FAST) for the Asteroid Redirect Mission (ARM)

The Formulation Assessment and Support Team (FAST) for the Asteroid Redirect Mission (ARM) was a two-month effort, chartered by NASA, to provide timely inputs for mission requirement formulation in support of the Asteroid Redirect Robotic Mission (ARRM) Requirements Closure Technical Interchange Meeting held December 15-16, 2015. Additionally, the FAST was tasked with developing an initial list of potential mission investigations and providing input on potential hosted payloads and partnerships. The FAST explored several aspects of potential science benefits and knowledge gain from the ARM. Expertise from the science, engineering, and technology communities was represented in exploring lines of inquiry related to key characteristics of the ARRM reference target asteroid (2008 EV_5) for engineering design purposes. Specific areas of interest included target origin, spatial distribution and size of boulders, surface geotechnical properties, boulder physical properties, and considerations for boulder handling, crew safety, and containment. In order to increase knowledge gain potential from the mission, opportunities for partnerships and accompanying payloads that could be provided by domestic and international partners were also investigated. The ARM FAST final report was publicly released on February 18, 2016 and represents the FAST's final product. The report and associated public comments are being used to support mission requirements formulation and serve as an initial inquiry to the science and engineering communities relating to the characteristics of the ARRM reference target asteroid. This report also provides a suggested list of potential investigations sorted and grouped based on their likely benefit to ARM and potential relevance to NASA science and exploration goals. These potential investigations could be conducted to reduce mission risks and increase knowledge return in the areas of science, planetary defense, asteroid resources and in-situ resource utilization (ISRU), and capability and technology demonstrations. This summary presentation will provide an overview of the FAST's effort and associated final report.

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123.15 – Overview and Updated Status of the Asteroid Redirect Mission (ARM)

The National Aeronautics and Space Administration (NASA) is developing a mission to visit a large near-Earth asteroid (NEA), collect a multi-ton boulder and regolith samples from its surface, demonstrate a planetary defense technique known as the enhanced gravity tractor, and return the asteroidal material to a stable orbit around the Moon. Once returned to cislunar space in the mid-2020s, astronauts will explore the boulder and return to Earth with samples. This Asteroid Redirect Mission (ARM) is part of NASA's plan to advance the technologies, capabilities, and spaceflight experience needed for a human mission to the Martian system in the 2030s and other destinations, as well as provide other broader benefits. Subsequent human and robotic missions to the asteroidal material would also be facilitated by its return to cislunar space. Although ARM is primarily a capability demonstration mission (i.e., technologies and associated operations), there exist significant opportunities to advance our knowledge of small bodies in the synergistic areas of science, planetary defense, asteroidal resources and in-situ resource utilization (ISRU), and capability and technology demonstrations. Current plans are for the robotic mission to be launched in late 2021 with the crewed mission segment conducted using an Orion capsule via a Space Launch System rocket in 2026. In order to maximize the knowledge return from the mission, NASA is providing accommodations for payloads to be carried on the robotic segment of the mission and also organizing an ARM Investigation Team. The Investigation Team will be comprised of scientists, technologists, and other qualified and interested individuals from US industry, government, academia, and international institutions to help plan the implementation and execution of ARM. The presentation will provide a mission overview and the most recent update concerning the robotic and crewed segments of ARM, including the mission requirements, and potential NEA targets. Details about the mission operations for each segment will also be provided along with a discussion of the potential opportunities associated with the mission.

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123.16 – The Asteroid Impact and Deflection Assessment (AIDA) mission: Science Proximity Operations

The moon of the near-Earth binary asteroid 65803 Didymos is the target of the Asteroid Impact and Deflection Assessment (AIDA) mission. This mission is a joint effort between NASA and ESA to investigate the effectiveness of a kinetic impactor in deflecting an asteroid. The mission is composed of two components: the NASA-led Double Asteroid Redirect Test (DART) that will impact Didymos' moon (henceforth Didymos B), and the ESA-led Asteroid Impact Mission (AIM) that will survey the Didymos system. Both will undertake proximity operations to characterize the physical and dynamical properties of the Didymos system that are of maximum importance in the joint AIDA mission to understand the factors at play when assessing the mometum transfer that follows DART's impact into Didymos B. Using much of ESA's Rosetta experience, the AIM mission will undertake proximity operations both before and after DART's impact. AIM's chracterization includes measuring the precise orbital configuration, masses, internal properties, surface geology and regolith properties of the primary and secondary, using visible and thermal imaging, radar measurements and radio science data. AIM will also release the small MASCOT-2 lander, as well as a suite of a CubeSats to help achieve these objectives. DART proximity observations include two phases of imaging. The first makes use of a suite of long range images that will add light curve data to what will be collected from Earth. These data will refine the orbit period of Didymos B, and provide constraints for modeling the shape of both Didymos A and B. The second phase begins just under an hour before impact when resolved imaging of the Didymos system provides further shape model constraints for the visble parts of both Didymos A and B, some possible constraints on the mass of Didymos B and key geological information of both objects and the impact site. In this presentation, we will summarize the proximity operations undertaken by both DART and AIM needed to achieve the scientific objectives of the AIDA mission using a broad suite of scientific experiments.

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123.17 – Dynamical and Physical Properties of 65803 Didymos, the Proposed AIDA Mission Target

Binary near-Earth asteroid (NEA) 65803 Didymos is the proposed Asteroid Impact & Deflection Assessment (AIDA) mission target, combining an orbiter [1] and a kinetic impactor for a planned encounter in fall 2022 [2]. The Dynamical and Physical Properties of Didymos Working Group supports this mission by addressing questions related to understanding the dynamical state of the system and inferring physical properties. Didymos is an Apollo-class NEA that likely reached its current orbit by exiting the inner main belt near or within the nu-6 resonance (> 82% chance) [3]. Remote observations [4] show Didymos is spectroscopically most consistent with ordinary chondrites. The diameters of the binary components are measured to be about 780 and 160 m [5]. A model of the short-term binary dynamics suggests possible librations of the secondary with up to ~10-deg amplitude, depending on its axial ratio. However, an equilibrium orbital and rotational solution is consistent with a libration amplitude of only ~1 deg. The primary, with an estimated 2.1 g/cc bulk density (uncertainty 30%) has a possibly super-critical rotation period of 2.26 h that may imply a cohesive strength of several tens of Pa. At this rate, perturbed regolith material may go through take-off/landing cycles and cause loss of fines due to solar radiation pressure. Based on a continuum analysis [6], the internal structure would likely fail before the equatorial region. A discrete analysis [7,8] shows that a minimum of 2.5 g/cc bulk density is needed for the structure to hold without cohesion. The system may be subject to weak thermal radiation forces (BYORP) with a period drift of no greater than 1 s/yr [9]. Experiments using the ISAE-SUPAERO drop tower [10] are underway to model the possible deployment of a lander on the secondary. References: [1] Michel et al. 2016, ASR 57, 2529; [2] Cheng et al. 2016, P&SS 127, 27; [3] Granvik et al. 2015, DPS 47, 214.07; [4] Dunn et al. 2013, LPSC 44, 1719; [5] Osip et al. 2016, this meeting; [6] Hirabayashi & Scheeres 2015, IAU 29, 2256185; [7] Barnouin et al. 2015, DPS 47, 402.09; [8] Zhang et al. 2016, this meeting; [9] McMahon et al. 2016, LPSC 47, 1903; [10] Sunday et al. 2016, Rev. Sci. Instr., accepted.

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123.18 – Determining the mass of Didymos' secondary by visual imaging

A critical requirement for the Asteroid Impact Mission (AIM) is the ability to determine the mass of Didymos' secondary with an accuracy of about 10 %. The conventional approach to estimate the mass of a solar system body through its gravitational effect by tracking the spacecraft trajectory is only marginally viable for Didymos' secondary. Instead, the idea to measure the "wobble" of the primary around the common centre of gravity has been put forward. This wobble with an expected radius of about 10 m can

possible be measured either by means of optical or radar ranging devices or by direct observation with the Visual Imaging System (VIS). Here, we investigate the latter approach.
We approach the problem of estimating the wobble in two steps: In the first step, the spacecraft trajectory relative to the primary asteroid is reconstructed from the locations of landmarks in images. This relative trajectory comprises the wobble. In the second step, the magnitude of the wobble is extracted from the reconstructed trajectory.
In this preliminary investigation, we do not deal with the problem of landmark identification and determination of their location in images. We just randomly generate landmark positions in the body fixed frame employing a shape model based on radar observations and simulate observations as inertial viewing directions from the spacecraft (with some error). Then we solve simultaneously for the landmark positions in the body fixed frame, the orientation of the asteroid at each image acquisition time, and the spacecraft trajectory relative to the asteroid. This reconstruction is done without any a priori knowledge or modelling of spacecraft trajectory or asteroid rotation. In order to extract the wobble from the reconstructed trajectory in the second step, we only assume that we know the period and the direction of the wobble from the orbit of the secondary.
We conduct Monte Carlo simulations for various scenarios and assess the accuracy of the determination of the wobble. Under reasonably conservative assumptions, the magnitude of the wobble (and hence the mass of the secondary) can be estimated with an accuracy of 3.5 %.
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123.19 – Asteroid Impact Deflection and Assessment (AIDA) mission - Full-Scale Modeling and Simulation of Ejecta Evolution and Fates

The proposed Asteroid Impact Deflection and Assessment (AIDA) mission includes NASA's Double Asteroid Redirection Test (DART), whose impact with the secondary of near-Earth binary asteroid 65803 Didymos is expected to liberate large amounts of ejecta. We present efforts within the AIDA Impact Simulation Working Group to comprehensively simulate the behavior of this impact ejecta as it moves through and exits the system. Group members at JPL, OCA, and UMD have been working largely independently, developing their own strategies and methodologies. Ejecta initial conditions may be imported from output of hydrocode impact simulations or generated from crater scaling laws derived from point-source explosion models. We started with the latter approach, using reasonable assumptions for the secondary's density, porosity, surface cohesive strength, and vanishingly small net gravitational/rotational surface acceleration. We adopted DART's planned size, mass, closing velocity, and impact geometry for the cratering event. Using independent N-Body codes, we performed Monte Carlo integration of ejecta particles sampled over reasonable particle size ranges, and over launch locations within the crater footprint. In some cases we scaled the number of integrated particles in various size bins to the estimated number of particles consistent with a realistic size-frequency distribution. Dynamical models used for the particle integration varied, but all included full gravity potential of both primary and secondary, the solar tide, and solar radiation pressure (accounting for shadowing). We present results for the proportions of ejecta reaching ultimate fates of escape, return impact on the secondary, and transfer impact onto the primary. We also present the time history of reaching those outcomes, i.e., ejecta clearing timescales, and the size-frequency distribution of remaining ejecta at given post-impact durations. We find large numbers of particles remain in the system for several weeks after impact. Clearing timescales are nonlinearly dependent on particle size as expected, such that only the largest ejecta persist longest. We find results are strongly dependent on the local surface geometry at the modeled impact locations.
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123.20 – Asteroid Impact Deflection and Assessment (AIDA) mission - Properties of Impact Ejecta

The Asteroid Impact Deflection and Assessment (AIDA) mission is composed of NASA's Double Asteroid Redirection Test (DART) mission and ESA's Asteroid Impact Monitor (AIM) rendezvous mission. The DART spacecraft is designed to impact the small satellite of near-Earth asteroid 65803 Didymos in October 2022, while the in-situ AIM spacecraft observes. AIDA's Modeling and Simulation of Impact Outcomes Working Group is tasked with investigating properties of the debris ejected from the impact. The orbital evolution of this ejecta has important implications for observations that the AIM spacecraft will take as well as for the safety of the spacecraft itself. Ejecta properties including particle sizes, bulk densities, and velocities all depend on the poorly-known physical properties of Didymos' moon. The moon's density, internal strength, and especially its porosity have a strong effect on all ejecta properties. Making a range of assumptions, we perform a suite of numerical simulations to determine the fate of the ejected material; we will use simulation predictions to optimize AIM observations and safety. Ultimately, combining AIM's observations of the ejecta with detailed numerical simulations will help constrain key satellite parameters.
We use distinct types of numerical tools to explore ejecta properties based on additional target parameters (different forms of friction, cohesion), e.g., the shock physics code iSALE, smoothed particle hydrodynamics codes, and the granular code PKDGRAV. Given the large discrepancy between the 6 km/s impact speed of DART and the moon's 6 cm/s escape speed, a great challenge will be to determine properties of the low-speed ejecta. Very low-speed material relevant to the safety of the AIM spacecraft and its ability to conduct its observations may loft from the crater at late stages of the impact process, or from other locations far from the impact site due to seismic energy propagation. The manner in which seismic waves manifests in asteroid regolith is extremely speculative at present. Through experiment, simulation, and observational strategies, we are working to gain insight into this and related phenomenon and will present the ongoing progress of our working group.
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123.21 – The Double Asteroid Redirection Test (DART) for the AIDA Mission

The Asteroid Impact Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate asteroid impact hazard mitigation using a kinetic impactor. AIDA is a joint ESA-NASA cooperative project, consisting of the NASA Double Asteroid Redirection Test (DART) mission, which provides the kinetic impactor, and the ESA Asteroid Impact Mission (AIM) rendezvous spacecraft. DART is a Phase A study supported by NASA, and AIM is a Phase B1 study supported by ESA. The AIDA target is the near-Earth binary asteroid 65803 Didymos, which will make a close approach to Earth in October, 2022. The DART spacecraft is designed to impact the Didymos secondary at ~6 km/s and deflect its trajectory, changing the orbital period of the binary. This change can be measured by Earth-based optical and radar observations. The primary goals of AIDA are to (1) perform a full-scale demonstration of asteroid deflection by kinetic impact; (2) measure the resulting deflection; and (3) validate and improve models for momentum transfer in high-speed impacts on an asteroid. The combined DART and AIM missions will provide the first measurements of momentum transfer efficiency from a kinetic impact at full scale on an asteroid, where the impact conditions of the projectile are known, and physical properties and internal structures of the target asteroid are also characterized. In addition to a predicted 4.4 minute change in the binary orbit period, assuming unit momentum transfer efficiency, the DART kinetic impact is predicted to induce forced librations of the Didymos secondary of possibly several degrees amplitude. Models predict the impact will create a 6-17 meter diameter crater, depending on target physical properties, and it will release a volume of particulate ejecta that may be directly observable from Earth or even resolvable as a coma or an ejecta tail by ground-based telescopes. Current simulations of the DART impact provide predictions for momentum transfer, crater size, and ejecta mass following impact. Additional work benchmarking impact hydrocodes with one another provides a way to bound the uncertainty in these critical simulations, allowing better predictions for the momentum transfer to the moon of Didymos.

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123.22 – The Observing Working Group for the Asteroid Impact & Delfection Assessment (AIDA) Mission

The Asteroid Impact & Deflection Assessment (AIDA) mission is a joint ESA-NASA mission concept currently under study. AIDA has two components: the Double Asteroid Redirect Test (DART) is the US component designed to demonstrate a kinetic impactor, while the Asteroid Impact Mission (AIM) spacecraft is on station to do a thorough pre- and post-impact survey of the Didymos system. Members of the DART and AIM Investigation teams have been organized into several joint and independent working groups. While there is overlap in subject matter and membership between the groups, we focus here on the activities of the Observing Working Group.

The first work by the group was undertaken during the spring of 2015, before DART entered Phase A. During this period Didymos made an apparition reaching roughly *V* ~ 20.5 in brightness, and our top priority was constraining which of two very different pole positions for the Didymos system was correct. Several telescopes in the 2–4-m aperture range around the world attempted observations. An observed mutual event allowed the one pole position to be ruled out. Didymos is now thought to be a low-obliquity, retrograde rotator, similar to many other asteroid binary systems and consistent with expectations from a YORP-driven origin for the satellite.

We have begun planning for the 2017 apparition, occurring in the first half of the year. Didymos will be ~20% brighter at opposition than the 2015 apparition. Scaling from the successful observations with the 4.3-m Lowell Discovery Channel Telescope indicates that we will need telescopes at least 4 m (or larger, for some of the tasks, or at times longer before or after the opposition) in primary diameter for the advanced characterization in 2017.

Currently, we have four goals for this apparition: 1) confirming the preferred retrograde pole position; 2) gathering data to allow BYORP-driven changes in the mutual orbit to potentially be determined by later observations; 3) establishing whether or not the secondary is in synchronous rotation with the primary; and 4) constraining the inclination of the satellite orbit.

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123.23 – The Asteroid Impact Mission (AIM): Studying the geophysics of small binaries, measuring asteroid deflection and studying impact physics

Binary asteroids and their formation mechanisms are of particular interest for understanding the evolution of the small bodies in the solar system. Also, hazards to Earth from impact of near-Earth asteroids and their mitigation have drawn considerable interest over the last decades.

Those subjects are both addressed by ESA's Asteroid Impact mission, which is part of the Asteroid Impact & Deflection Assessment (AIDA) currently under study in collaboration between NASA and ESA. NASA's DART mission will impact a projectile into the minor component of the binary near-Earth asteroid (65803) Didymos in 2022. The basic idea is to demonstrate the effect of the impact on the orbital period of the secondary around the primary. ESA's AIM will monitor the Didymos system for several months around the DART impact time.

AIM will be launched in aurumn 2020. It is foreseen to arrive at Didymos in April 2022. The mission takes advantage of a close approach of Didymos to Earth. The next opportunity would arise in 2040 only.

AIM will stay near Didymos for approximately 6 months. Most of the time it will be placed on the illuminated side of the system, at distances of approximately 35 km and 10 km. AIM is expected to move away from Didymos for some time around the DART impact. The reference payload for AIM includes two visual imagers, a hyperspectral camera, a lidar, a thermal infrared imager, a monostatic high frequency radar, and a bistatic low frequency radar. In addition, AIM will deploy a small lander on the secondary asteroid, and two cubesats that will be used for additional, more risky investigations close to or on the surface of the asteroid.

Major contributions from AIM are expected in the study of the geophysics of small asteroids (including for the first time, radar measurements of an interior structure), the formation of binary asteroids, the momentum enhancement factor from the DART impact (through measuring the mass and the change of orbit of the seondary), and impact physics through observing the outcome of an impact with well known impact conditions. In addition, AIM will test new technologies (Cubesats in interplanetary space, Intersatellite links, optical telecommunication in deep space, infrared navigation).

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123.24 – JUICE: A European Mission to Jupiter and its Icy Moons

JUICE - JUpiter ICy moons Explorer - is the first large mission in the ESA Cosmic Vision programme [1]. The implementation phase started in July 2015. JUICE will arrive at Jupiter in October 2029, and will spend 3 years characterizing the Jovian system, the planet itself, its giant magnetosphere, and the giant icy moons: Ganymede, Callisto and Europa. JUICE will then orbit Ganymede.
The first goal of JUICE is to explore the habitable zone around Jupiter [2]. Ganymede is a high-priority target because it provides a unique laboratory for analyzing the nature, evolution and habitability of icy worlds, including the characteristics of subsurface oceans, and because it possesses unique magnetic fields and plasma interactions with the environment. On Europa, the focus will be on recently active zones, where the composition, surface and subsurface features (including putative water reservoirs) will be characterized. Callisto will be explored as a witness of the early Solar System.
JUICE will also explore the Jupiter system as an archetype of gas giants. The circulation, meteorology, chemistry and structure of the Jovian atmosphere will be studied from the cloud tops to the thermosphere and ionosphere. JUICE will investigate the 3D properties of the magnetodisc, and study the coupling processes within the magnetosphere, ionosphere and thermosphere. The mission also focuses on characterizing the processes that influence surface and space environments of the moons.
The payload consists of 10 instruments plus a ground-based experiment (PRIDE) to better constrain the S/C position. A remote sensing package includes imaging (JANUS) and spectral-imaging capabilities from UV to sub-mm wavelengths (UVS, MAJIS, SWI). A geophysical package consists of a laser altimeter (GALA) and a radar sounder (RIME) for exploring the moons, and a radio science experiment (3GM) to probe the atmospheres and to determine the gravity fields. The in situ package comprises a suite to study plasma and neutral gas environments (PEP) with remote sensing capabilities via energetic neutrals, a magnetometer (J-MAG) and a radio and plasma wave instrument (RPWI).

[1] JUICE Definition Study Report, ESA/SRE(2014)1. [2] Grasset et al., Plan. Space Sci., 78, 2013

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123.25 – The Science Operations of the ESA JUICE mission

The JUpiter ICy moons Explorer (JUICE) mission was selected by ESA as the first L-Class Mission in the Cosmic Vision Programme. JUICE is an ESA-led mission to investigate Jupiter, the Jovian system with particular focus on habitability of Ganymede and Europa.
JUICE will characterise Ganymede and Europa as planetary objects and potential habitats, study Ganymede, Europa, Callisto and Io in the broader context of the system of Jovian moons, and focus on Jupiter science including the planet, its atmosphere and the magnetosphere as a coupled system.
The Science Operation Centre (SOC) is in charge of implementing the science operations of the JUICE mission. The SOC aims at supporting the Science Working Team (SWT) and the Science Working Groups (WGs) performing studies of science operation feasibility and coverage analysis during the mission development phase, high level science planning during the cruise phase, and routine consolidation of instrument pointing and commanding timeline during the nominal science phase.
We will present the current status of the SOC science planning activities with an overview of the tools and methods in place in this early phase of the mission.

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123.26 – Science of the Europa Multiple Flyby Mission

The Europa Multiple Flyby Mission, in formulation for launch in the 2020s, would investigate the habitability of Jupiter's moon Europa. The mission would send a solar-powered, radiation-tolerant spacecraft into an elliptical orbit about Jupiter to conduct more than 40 close flybys of Europa, most in the range 25 km–100 km. The payload comprises a suite of nine science instruments that together would support three key objectives: detailed investigation of Europa's interior, both its internal ocean (including its salinity and depth) and its ice shell (including thickness and potential water pockets within); composition of the icy surface, notably dark reddish areas that may evince linkages between the ocean and the surface; and geology at the regional and local scales, especially areas that may show signs of recent or current activity. The science objectives and project status will be summarized.

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123.27 – The Plasma Instrument for Magnetic Sounding (PIMS) on The Europa Clipper Mission

The Europa Clipper mission is equipped with a sophisticated suite of 9 instruments to study Europa's interior and ocean, geology, chemistry, and habitability from a Jupiter orbiting spacecraft. The Plasma Instrument for Magnetic Sounding (PIMS) on Europa Clipper is a Faraday Cup based plasma instrument whose heritage dates back to the Voyager spacecraft. PIMS will measure the plasma that populates Jupiter's magnetosphere and Europa's ionosphere. The science goals of PIMS are to: 1) estimate the ocean salinity and thickness by determining Europa's magnetic induction response, corrected for plasma contributions; 2) assess mechanisms responsible for weathering and releasing material from Europa's

surface into the atmosphere and ionosphere; and 3) understand how Europa influences its local space environment and Jupiter's magnetosphere and vice versa.
Europa is embedded in a complex Jovian magnetospheric plasma, which rotates with the tilted planetary field and interacts dynamically with Europa's ionosphere affecting the magnetic induction signal. Plasma from Io's temporally varying torus diffuses outward and mixes with the charged particles in Europa's own torus producing highly variable plasma conditions at Europa. PIMS works in conjunction with the Interior Characterization of Europa using Magnetometry (ICEMAG) investigation to probe Europa's subsurface ocean. This investigation exploits currents induced in Europa's interior by the moon's exposure to variable magnetic fields in the Jovian system to infer properties of Europa's subsurface ocean such as its depth, thickness, and conductivity. This technique was successfully applied to Galileo observations and demonstrated that Europa indeed has a subsurface ocean. While these Galileo observations contributed to the renewed interest in Europa, due to limitations in the observations the results raised major questions that remain unanswered. PIMS will greatly refine our understanding of Europa's global liquid ocean by accounting for contributions to the magnetic field from plasma currents.
In this presentation we describe the principles of PIMS operations, detail the PIMS science goals, and discuss how to assess Europa's induction response.

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123.28 – HERA: an atmospheric probe to unveil the depths of Saturn

The *Hera* Saturn entry probe mission is proposed as an M-class mission led by ESA with a significant collaboration with NASA. It consists of a Saturn atmospheric probe and a Carrier-Relay spacecraft. *Hera* will perform *in situ* measurements of the chemical and isotopic compositions as well as the dynamics of Saturn's atmosphere, with the goal of improving our understanding of the origin, formation, and evolution of Saturn, the giant planets and their satellite systems, with extrapolation to extrasolar planets.
The primary science objectives will be addressed by an atmospheric entry probe that would descend under parachute and carry out *in situ* measurements beginning in the stratosphere to help characterize the location and properties of the tropopause, and continue into the troposphere to pressures of at least 10 bars. All of the science objectives, except for the abundance of oxygen, which may be only addressed indirectly via observations of species whose abundances are tied to the abundance of water, can be achieved by reaching 10 bars. As in previous highly successful collaborative efforts between ESA and NASA, the proposed mission has a baseline concept based on a NASA-provided carrier/data relay spacecraft that would deliver the ESA-provided atmospheric probe to the desired atmospheric entry point at Saturn. ESA's proposed contribution should fit well into the M5 Cosmic Vision ESA call cost envelope.
A nominal mission configuration would consist of a probe that detaches from the carrier one to several months prior to probe entry. Subsequent to probe release, the carrier trajectory would be deflected to optimize the over-flight phasing of the probe descent location for both probe data relay as well as performing carrier approach and flyby science, and would allow multiple retransmissions of the probe data for redundancy. The Saturn atmospheric entry probe would in many respects resemble the Jupiter Galileo probe. It is anticipated that the probe architecture for this mission would be battery-powered and accommodate a data relay to the carrier for data collection, storage on board the carrier/data relay, for later retransmission to Earth.

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123.29 – Exploring Saturn - The Saturn PRobe Interior and aTmosphere Explorer (SPRITE) Mission

A Saturn Probe mission was identified by the Vision and Voyages Planetary Decadal Survey as a mission target of high priority for the New Frontiers program. To better constrain models of Solar System formation, as well as to provide an improved context for exoplanet systems, fundamental measurements of noble gas abundances and isotope ratios of hydrogen, carbon, oxygen, and nitrogen, as well as the interior structure of Saturn are needed. The SPRITE mission will fulfill the scientific goals defined in the Decadal Survey, as well as provide ground truth for remote sensing and conduct new investigations to improve understanding of Saturn's interior structure and composition, and by proxy, those of extrasolar giant planets.
Many key questions regarding the structure and composition of Saturn's atmosphere remain elusive, including the abundance of noble gases and key isotopes, the abundance of helium, needed to understand the formation history and evolution of Saturn, and the water abundance in the deep atmosphere, a key diagnostic of Saturn's formation since it is thought that the heavy elements were delivered to Saturn by water-bearing planetesimals. Additionally, the structure of Saturn's deep interior including the presence of a core and any layered structure will test instability models in the protosolar nebula.
SPRITE will make measurements that address these key questions through delivery of an atmospheric entry probe, as well as remote sensing from the carrier spacecraft. SPRITE will provide direct measurement of composition and atmospheric structure (including dynamics) along the probe descent path, providing science that is not accessible to remote sensing measurements, as well as providing

ground truth for tropospheric measurements from carrier remote sensing. SPRITE will measure the deep atmospheric composition, as well as temperature, pressure and wind speeds.

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123.30 – A new generation of high resolution mass analyzer to study organic and mineral matters simulating those of Titan and Enceladus: the Cosmorbitrap project

Cassini mission highlighted for the first time, among many discoveries, the chemistry occurring in Titan atmosphere (with the detection of positive and negative ions at very high masses) and the presence of organic matter hidden in Enceladus plumes (1; 2). Can you imagine which results would have been obtained with a better resolution?

Today, in lab, a new generation of high resolution mass analyzer called Orbitrap™ can reach a resolution of 10^6 at m/z=200 (3; 4). It gives a precise reading of the mass on charge, using a purely electric field and applying a Fourier transform. A project named Cosmorbitrap is trying to incorporate an Orbitrap™ analyzer, as a part of a mass spectrometer instrument, in order to propose it for a future mission toward the Saturn moons but also toward many other objects in the Solar System (5).

Among the various tests required, we are optimizing the analysis of mineral and organic matter. This includes mass precision, resolution, isotopic detection, isotopic ratios and identification of unknown molecules. Starting with simple molecules, we will study more and more complex molecules and mixtures like Titan and Enceladus analogs. This meeting could be a great opportunity to explain our last results, to present benefits and limits of this instrument.

(1) Waite *et al*, 2007, Science
(2) Waite *et al*, 2009, Nature
(3) Makarov, 2000
(4) Denisov *et al*, 2012
(5) Briois *et al*, 2016, Planetary and Space Science (in press)

Author(s): Laura Selliez-Vandernotte[2], Christelle Briois[2], Nathalie Carrasco[1], Laurent Thirkell[2]

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Contributing team(s): Cosmorbitrap Team

123.31 – Results from the Science Instrument Definition Team for the Gondola for High Altitude Planetary Science Project

The Gondola for High Altitude Planetary Science (GHAPS) is an observing asset under development by NASA's Planetary Science Division that will be hosted on stratospheric balloon missions intended for use by the broad planetary science community. GHAPS is being designed in a modular fashion to interface to a suite of instruments as called for by science needs. It will operate at an altitude of 30+ km and will include an optical telescope assembly with a 1-meter aperture and a pointing stability of approximately 1 arcsecond with a flight duration of ~100 days. The spectral grasp of the system is envisaged to include wavelengths spanning the near-ultraviolet to near/mid-infrared (~0.3-5 μm) and possibly to longer wavelengths.

The GHAPS Science Instrument Definition Team (SIDT) was convened in May 2016 to define the scope of science investigations, derive the science requirements and instrument concepts for GHAPS, prioritize the instruments according to science priorities that address Planetary Science Decadal Survey questions, and generate a report that is broadly disseminated to the planetary science community. The SIDT examined a wide range of solar system targets and science questions, focusing on unique measurements that could be made from a balloon-borne platform to address high-priority planetary science questions for a fraction of the cost of space missions. The resulting instrument concepts reflect unique capabilities offered by a balloon-borne platform (e.g., observations at spectral regions inaccessible from the ground due to telluric absorption, diffraction-limited imaging, and long duration uninterrupted observations of a target). We discuss example science cases that can be addressed with GHAPS and describe a notional instrument suite that can be used by guest observers to pursue decadal-level science questions.

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123.32 – Stratospheric Observatory for Infrared Astornomy and Planetary Science

The Stratospheric Observatory for Infrared Astronomy enables observations at far-infrared wavelengths, including the range 30-300 microns that is nearly completely obscured from the ground. By flying in the stratosphere above 95% of atmospheric water vapor, access is opened to photometric, spectroscopic, and polarimetric observations of Solar System targets spanning small bodies through major planets. Extrasolar planetary systems can be observed through their debris disks or transits, and forming planetary systems through protoplanetary disks, protostellar envelopes, and molecular cloud cores. SOFIA operates out of Southern California most of the year. For the summer of 2016, we deployed to New Zealand with 3 scientific instruments. The HAWC+ far-infrared photopolarimeter was recently flown and is in commissioning, and two projects are in Phase A study to downselect to one new facility instrument. The Cycle 5 observing proposal results are anticipated to be be released by the time of this DPS meeting, and successful planetary proposals will be advertised.

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Contributing team(s): SOFIA Sciece Mission Operations

123.33 – TWINKLE – A Low Earth Orbit Visible and Infrared Exoplanet Spectroscopy Observatory

Twinkle is a space mission designed for visible and near-IR spectroscopic observations of extrasolar planets. Twinkle's highly stable instrument will allow the photometric and spectroscopic observation of a wide range of planetary classes around different types of stars, with a focus on bright sources close to the ecliptic. The planets will be observed through transit and eclipse photometry and spectroscopy, as well as phase curves, eclipse mapping and multiple narrow-band time-series. The targets observed by Twinkle will be composed of known exoplanets mainly discovered by existing and upcoming ground surveys in our galaxy and will also feature new discoveries by space observatories (K2, GAIA, Cheops, TESS). Twinkle is a small satellite with a payload designed to perform high-quality astrophysical observations while adapting to the design of an existing Low Earth Orbit commercial satellite platform. The SSTL-300 bus, to be launched into a low-Earth sun-synchronous polar orbit by

2019, will carry a half-meter class telescope with two instruments (visible and near-IR spectrographs - between 0.4 and 4.5µm - with resolving power R~300 at the lower end of the wavelength scale) using mostly flight proven spacecraft systems designed by Surrey Satellite Technology Ltd and a combination of high TRL instrumentation and a few lower TRL elements built by a consortium of UK institutes.
The Twinkle design will enable the observation of the chemical composition and weather of at least 100 exoplanets in the Milky Way, including super-Earths (rocky planets 1-10 times the mass of Earth), Neptunes, sub-Neptunes and gas giants like Jupiter. It will also allow the follow-up photometric observations of 1000+ exoplanets in the visible and infrared, as well as observations of Solar system objects, bright stars and disks.
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123.34 – Development and Testing of an Optimised Combined Analytical Instrument for Planetary Applications

Miniaturised, analytical instruments that can simultaneously obtain complementary (molecular and elemental) information about the composition of a sample are likely to be a key feature of the next generation of planetary exploration missions.
Certain spectroscopic techniques, such as Raman spectroscopy, can provide information on the molecular composition of an unknown sample whereas others, such as Laser-Induced Breakdown Spectroscopy (LIBS) and X-Ray Fluorescence (XRF), enable the determination of the elemental composition of a material. Combining two or more of these techniques into one instrument package enables a broader range of the scientific goals of a particular mission to be obtained (i.e. full composition analysis and structural information about the sample and therefore geological history).
In order to determine the most appropriate design for such an instrument, we have developed some radiometric models to assess the overall scientific capability of various analytical technique combinations. We have then used these models to perform a number of trade-offs to evaluate the optimum instrument design for a particular set of science requirements (such as, to acquire composition information with suitable sensitivity and uncertainty). The performance of one of these designs was then thoroughly investigated by building a prototype instrument.
The construction of our instrument focuses on the optimum design for combining the multiple instrument sub-systems so that the overall mass, power and cost budgets can be minimised, whilst achieving the wider and more comprehensive range of scientific goals.
Here we report on measurements obtained from field test campaigns that have been performed in order to verify model predictions and overall scientific performance. These tests include operation in extreme environments such as dry deserts and under water.
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123.35 – SMILE: A new way to explore solar-terrestrial relationships

SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) will investigate the dynamic response of the Earth's magnetosphere to the impact of the solar wind in a unique and global manner, never attempted before. From a highly elliptical Earth orbit, SMILE will combine soft X-ray imaging of the Earth's magnetic boundaries and polar cusps with simultaneous UV imaging of the Northern aurora, while self-sufficiently measuring solar wind/magnetosheath plasma and magnetic field conditions in situ. X-ray imaging of the dayside magnetosheath and cusps is an innovative technique made possible by the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comets, and subsequently found to occur in the vicinity of the Earth's magnetosphere.
For the first time we will be able to trace and link the processes of solar wind injection in the magnetosphere with those acting on the charged particles precipitating into the cusps and eventually the aurora. While the basic theory of magnetospheric circulation is well known and the microscale has been explored by many in situ measurements, the reality of how this complex interaction takes place on a global scale, and how it evolves, is still not understood. SMILE will answer questions such as: What are the fundamental modes of the dayside solar wind/magnetosphere interaction and the large-scale structure of the interaction region? What defines the substorm cycle? How do CME-driven storms arise and how do they relate to substorms?
SMILE is a joint space mission between ESA and the Chinese Academy of Sciences. This presentation will cover the science that will be delivered by SMILE and its impact on our understanding of the way the solar wind interacts with the Earth's environment, and will give an overview of its payload and of the mission's development.
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123.36 – Ultra Compact Imaging Spectrometer (UCIS)

The Ultra Compact Imaging Spectrometer (UCIS) is a modular visible to short wavelength infrared imaging spectrometer architecture which could be adapted to a variety of mission concepts requiring low mass and low power. Imaging spectroscopy is an established technique to address complex questions of geologic evolution by mapping diagnostic absorption features due to minerals, organics, and volatiles throughout our solar system. At the core of UCIS is an Offner imaging spectrometer using M^3 heritage and a miniature pulse tube cryo-cooler developed under the NASA Maturation of Instruments for Solar System Exploration (MatISSE) program to cool the focal plane array. The TRL 6 integrated spectrometer and cryo-cooler provide a basic imaging spectrometer capability that is used with a variety of fore optics to address lunar, mars, and small body science goals. Potential configurations include: remote sensing from small orbiters and flyby spacecraft; in situ panoramic imaging spectroscopy; and in situ micro-spectroscopy. A micro-spectroscopy front end is being developed using MatISSE funding with integration and testing planned this summer.
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123.37 – ARIEL – Atmospheric Remote-Sensing Infrared Exoplanet Large-survey

The Atmospheric Remote-Sensing Infrared Exoplanet Large-survey (ARIEL) is one of the three candidate missions selected by the European Space Agency (ESA) for its next medium-class science mission due for launch in 2026. The goal of the ARIEL mission is to

investigate the atmospheres of several hundreds planets orbiting distant stars in order to address the fundamental questions on how planetary systems form and evolve.
During its four (with a potential extension to six) years mission ARIEL will observe 500+ exoplanets in the visible and the infrared with its meter-class telescope in L2. ARIEL targets will include Jupiter- and Neptune-size down to super-Earth and Earth-size around different types of stars. The main focus of the mission will be on hot and warm planets orbiting very close to their star, as they represent a natural laboratory in which to study the chemistry and formation of exoplanets. In cooler planets, different gases separate out through condensation and sinking into distinct cloud layers. The scorching heat experienced by hot exoplanets overrides these processes and keeps all molecular species circulating throughout the atmosphere.
The ARIEL mission concept has been developed by a consortium of more than 50 institutes from 12 countries, which include UK, France, Italy, Germany, the Netherlands, Poland, Spain, Belgium, Austria, Denmark, Ireland and Portugal. The analysis of ARIEL spectra and photometric data will allow to extract the chemical fingerprints of gases and condensates in the planets' atmospheres, including the elemental composition for the most favorable targets. It will also enable the study of thermal and scattering properties of the atmosphere as the planet orbit around the star.
ARIEL will have an open data policy, enabling rapid access by the general community to the high-quality exoplanet spectra that the core survey will deliver.

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Contributing team(s): ARIEL consortium, ARIEL ESA Study Team

123.39 – New high spectral resolution spectrograph and mid-IR camera for the NASA Infrared Telescope Facility

The NASA Infrared Telescope Facility (IRTF) is a 3.0 m infrared telescope located at an altitude of 4.2 km near the summit of Mauna Kea on the island of Hawaii. The IRTF was established by NASA to support planetary science missions. We show new observational capabilities resulting from the completion of iSHELL, a 1–5 µm echelle spectrograph with resolving power of 70,000 using a 0.375 arcsec slit. This instrument will be commissioned starting in August 2016. The spectral grasp of iSHELL is enormous due to the cross-dispersed design and use of a 2Kx2K HgCdTe array. Raw fits files will be publicly archived, allowing for more effective use of the large amount of spectral data that will be collected. The preliminary observing manual for iSHELL, containing the instrument description, observing procedures and estimates of sensitivity can be downloaded at
http://irtfweb.ifa.hawaii.edu/~ishell/iSHELL_observing_manual.pdf. This manual and instrument description papers can be downloaded at http://bit.ly/28NFiMj. We are also working to restore to service our 8–25 µm camera, MIRSI. It will be upgraded with a closed cycle cooler that will eliminate the need for liquid helium and allow continuous use of MIRSI on the telescope. This will enable a wider range of Solar System studies at mid-IR wavelengths, with particular focus on thermal observations of NEOs. The MIRSI upgrade includes plans to integrate a visible CCD camera that will provide simultaneous imaging and guiding capabilities. This visible imager will utilize similar hardware and software as the MORIS system on SpeX. The MIRSI upgrade is being done in collaboration with David Trilling (NAU) and Joseph Hora (CfA). For further information on the IRTF and its instruments including visitor instruments, see: http://irtfweb.ifa.hawaii.edu/. We gratefully acknowledge the support of NASA contract NNH14CK55B, NASA Science Mission Directorate, and NASA grant NNX15AF81G (Trilling, Hora) for the upgrade of MIRSI.

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123.40 – Immersion Gratings for Infrared High-resolution Spectroscopy

High-resolution spectroscopy in the infrared wavelength range is essential for observations of minor isotopologues, such as HDO for water, and prebiotic organic molecules like hydrocarbons/P-bearing molecules because numerous vibrational molecular bands (including non-polar molecules) are located in this wavelength range. High spectral resolution enables us to detect weak lines without spectral line confusion. This technique has been widely used in planetary sciences, e.g., cometary coma (H2O, CO, and organic molecules), the martian atmosphere (CH4, CO2, H2O and HDO), and the upper atmosphere of gas giants (H3+ and organic molecules such as C2H6). Spectrographs with higher resolution (and higher sensitivity) still have a potential to provide a plenty of findings. However, because the size of spectrographs scales with the spectral resolution, it is difficult to realize it.
Immersion grating (IG), which is a diffraction grating wherein the diffraction surface is immersed in a material with a high refractive index (n > 2), provides n times higher spectral resolution compared to a reflective grating of the same size. Because IG reduces the size of spectrograph to 1/n compared to the spectrograph with the same spectral resolution using a conventional reflective grating, it is widely acknowledged as a key optical device to realize compact spectrographs with high spectral resolution.
Recently, we succeeded in fabricating a CdZnTe immersion grating with the theoretically predicted diffraction efficiency by machining process using an ultrahigh-precision five-axis processing machine developed by Canon Inc. Using the same technique, we completed a practical germanium (Ge) immersion grating with both a reflection coating on the grating surface and the an AR coating on the entrance surface. It is noteworthy that the wide wavelength range from 2 to 20 um can be covered by the two immersion gratings.
In this paper, we present the performances and the applications of the immersion gratings, including the development of a long-NIR (2-5um) high-resolution (R=80,000) spectrograph with Ge-immersion grating, VINROUGE, which is a prototype for the TMT MIR instrument.

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123.41 – NASA Lunar and Planetary Mapping and Modeling

NASA's Lunar and Planetary Mapping and Modeling Portals provide web-based suites of interactive visualization and analysis tools to enable mission planners, planetary scientists, students, and the general public to access mapped lunar data products from past and current missions for the Moon, Mars, and Vesta. New portals for additional planetary bodies are being planned. This presentation will recap some of the enhancements to these products during the past year and preview work currently being undertaken.
New data products added to the Lunar Mapping and Modeling Portal (LMMP) include both generalized products as well as polar

data products specifically targeting potential sites for the Resource Prospector mission. New tools being developed include traverse planning and surface potential analysis. Current development work on LMMP also includes facilitating mission planning and data management for lunar CubeSat missions. Looking ahead, LMMP is working with the NASA Astromaterials Office to integrate with their Lunar Apollo Sample database to help better visualize the geographic contexts of retrieved samples. All of this will be done within the framework of a new user interface which, among other improvements, will provide significantly enhanced 3D visualizations and navigation.
Mars Trek, the project's Mars portal, has now been assigned by NASA's Planetary Science Division to support site selection and analysis for the Mars 2020 Rover mission as well as for the Mars Human Landing Exploration Zone Sites, and is being enhanced with data products and analysis tools specifically requested by the proposing teams for the various sites. NASA Headquarters is giving high priority to Mars Trek's use as a means to directly involve the public in these upcoming missions, letting them explore the areas the agency is focusing upon, understand what makes these sites so fascinating, follow the selection process, and get caught up in the excitement of exploring Mars.
The portals also serve as outstanding resources for education and outreach. As such, they have been designated by NASA's Science Mission Directorate as key supporting infrastructure for the new education programs selected through the division's recent CAN.
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123.42 – PHOTOMETRYPIPELINE - An Automated Pipeline for Calibrated Photometry

Telescopes acquire massive amounts of imaging data every night. The goal of a large fraction of these observations is to obtain calibrated photometry for point sources - stars or moving Solar System targets - in different filters.
We present PHOTOMETRYPIPELINE (PP, github.com/mommermi/photometrypipeline), an automated pipeline to obtain calibrated photometry from imaging data. PP is an open-source Python 2.7 software suite that provides image registration, aperture photometry, photometric calibration, and target identification with only minimal human interaction. For image registration, PP utilizes Source Extractor (Bertin & Arnouts 1996, A&AS, 117) and SWARP (Bertin et al. 2002, ASP Conf. S., 228) to find a plate solution for each frame, providing accurate target astrometry. Circular aperture photometry is performed using Source Extractor; an optimum aperture radius is identified using a curve-of-growth analysis. Photometric calibration is obtained through matching the background source catalog with star catalogs with reliable photometry (e.g., SDSS, URAT-1) in an iterative process; magnitude zeropoint accuracies are usually of the order of 0.03 mag, or better. Final calibrated photometry for each field source is written into a queriable database; target photometry is extracted from this database. Moving targets are identified using JPL Horizons (Giorgini et al. 1996, BAAS, 28) ephemerides. Image combination capabilities (using SWARP, Bertin 2006, ASP Conf. S., 112) are also available to improve the target's signal.
PP is well-suited for data covering a few square arcminutes of the sky due to its dependence on background sources for registration and calibration. PP can be run on Unix-based systems on a simple desktop machine and is capable of realtime data analysis. PP has been developed for observations of moving targets, but can also be used on other observations. Efforts to improve the sky coverage for phometric calibration are in progress. Also, a module will be added to identify and extract data on serendipitously observed asteroids.
PP was developed in the framework of the "Mission Accessible Near-Earth Object Survey" (MANOS) and is supported by NASA SSO grants NNX15AE90G and NNX14AN82G.
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123.43 – Titanbrowse: a new paradigm for access, visualization and analysis of hyperspectral imaging

Currently there are archives and tools to explore remote sensing imaging, but these lack some functionality needed for hyperspectral imagers: 1) Querying and serving only whole datacubes is not enough, since in each cube there is typically a large variation in observation geometry over the spatial pixels. Thus, often the most useful unit for selecting observations of interest is not a whole cube but rather a single spectrum. 2) Pixel-specific geometric data included in the standard pipelines is calculated at only one point per pixel. Particularly for selections of pixels from many different cubes, or observations near the limb, it is necessary to know the actual extent of each pixel. 3) Database queries need not only metadata, but also by the spectral data. For instance, one query might look for atypical values of some band, or atypical relations between bands, denoting spectral features (such as ratios or differences between bands). 4) There is the need to evaluate arbitrary, dynamically-defined, complex functions of the data (beyond just simple arithmetic operations), both for selection in the queries, and for visualization, to interactively tune the queries to the observations of interest. 5) Making the most useful query for some analysis often requires interactive visualization integrated with data selection and processing, because the user needs to explore how different functions of the data vary over the observations without having to download data and import it into visualization software. 6) Complementary to interactive use, an API allowing programmatic access to the system is needed for systematic data analyses. 7) Direct access to calibrated and georeferenced data, without the need to download data and software and learn to process it.
We present *titanbrowse*, a database, exploration and visualization system for Cassini VIMS observations of Titan, designed to fullfill the aforementioned needs. While it originallly ran on data in the user's computer, we are now developing an online version, so that users do not need to download software and data. The server, which we maintain, processes the queries and communicates the results to the client the user runs. http://ppenteado.net/titanbrowse.
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123.45 – The new Planetary Science Archive (PSA): Exploration and discovery of scientific datasets from ESA's planetary missions

The Planetary Science Archive (PSA) is the European Space Agency's (ESA) repository of science data from all planetary science and exploration missions. The PSA provides access to scientific datasets through various interfaces at http://archives.esac.esa.int/psa. All datasets are scientifically peer-reviewed by independent scientists, and are compliant with the Planetary Data System (PDS) standards.
The PSA is currently implementing a number of significant improvements, mostly driven by the evolution of the PDS standard, and the growing need for better interfaces and advanced applications to support science exploitation.
The newly designed PSA will enhance the user experience and will significantly reduce the complexity for users to find their data promoting one-click access to the scientific datasets with more specialised views when needed. This includes a better integration with Planetary GIS analysis tools and Planetary interoperability services (search and retrieve data, supporting e.g. PDAP, EPN-TAP).
It will be also up-to-date with versions 3 and 4 of the PDS standards,

as PDS4 will be used for ESA's ExoMars and upcoming BepiColombo missions. Users will have direct access to documentation, information and tools that are relevant to the scientific use of the dataset, including ancillary datasets, Software Interface Specification (SIS) documents, and any tools/help that the PSA team can provide. A login mechanism will provide additional functionalities to the users to aid / ease their searches (e.g. saving queries, managing default views).
This contribution will introduce the new PSA, its key features and access interfaces.

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Contributing team(s): ESDC (European Space Data Centre) team

123.46 – A Standardized Interface for Obtaining Digital Planetary and Heliophysics Time Series Data

We describe a low level interface for accessing digital Planetary and Heliophysics data, focusing primarily on time-series data from in-situ instruments. As the volume and variety of planetary data has increased, it has become harder to merge diverse datasets into a common analysis environment. Thus we are building low-level computer-to-computer infrastructure to enable data from different missions or archives to be able to interoperate. The key to enabling interoperability is a simple access interface that standardizes the common capabilities available from any data server: 1. identify the data resources that can be accessed; 2. describe each resource; and 3. get the data from a resource. We have created a standardized way for data servers to perform each of these three activities. We are also developing a standard streaming data format for the actual data content to be returned (i.e., the result of item 3). Our proposed standard access interface is simple enough that it could be implemented on top of or beside existing data services, or it could even be fully implemented by a small data provider as a way to ensure that the provider's holdings can participate in larger data systems or joint analysis with other datasets. We present details of the interface and of the streaming format, including a sample server designed to illustrate the data request and streaming capabilities.

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123.47 – Observer's Interface for Solar System Target Specification

When observing an asteroid or comet with HST, it has been necessary for the observer to manually enter the target's orbital elements into the Astronomer's Proposal Tool (APT). This allowed possible copy/paste transcription errors from the observer's source of orbital elements data. In order to address this issue, APT has now been improved with the capability to identify targets in and then download orbital elements from JPL Horizons. The observer will first use a target name resolver to choose the intended target from the Horizons database, and then download the orbital elements from Horizons directly into APT. A manual entry option is also still retained if the observer does not wish to use elements from Horizons. This new capability is available for HST observing, and it will also be supported for JWST observing. The poster shows examples of this new interface.

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123.48 – A review of thermophysical surface models in preparation for E-THEMIS observations of Europa

One of the primary science objectives of the Europa Thermal Emission Imaging System (E-THEMIS) is to determine the regolith particle size, block abundance, and sub-surface layering for landing site assessment and surface process studies. To accomplish this, E-THEMIS will obtain thermal infrared images in three spectral bands from 7 to 70 microns at multiple times of day. The Galileo Photo-Polarimeter Radiometer (PPR) also obtained thermal infrared images of Europa, but at a very low spatial resolution. Rathbun et al. (2010) used a simple thermal model to determine the thermal inertia and albedo of ~20% of Europa's surface at a scale of hundreds of km. E-THEMIS will acquire images at several orders of magnitude better spatial resolution, enabling the use of more sophisticated thermal models. Here, we will conduct an initial survey of the thermal models and techniques that have been employed to determine surface properties of other planetary bodies from thermal infrared images. We will identify what physical processes are included in each model and which independent variables they account for. Since those models have been used on primarily rocky planetary surfaces, we will determine which aspects apply to icy surfaces and what changes might need to be made when considering icy surfaces.

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123.49 – A Cubesat to Image Comet Wirtanen at its 2018 Close Approach?

In Dec. 2018, Comet Wirtanen will pass 0.077 AU from Earth, the best opportunity for a fly by of an active comet on a low-energy orbit in the next 40 years. In 2013, the late Robert Farquhar presented a paper, "A Unique Multi-Comet Mission Opportunity for China in 2018" [1]. He used a 1.4-year-Earth-return orbit with launch C3 <3 km^2/s^2 that, after flying by Wirtanen, would use an Earth swingby to fly by SW3C in 2022. While at the 2013 conference, Dr. Farquhar visited the China National Space Administration, which said that all of their funds were committed to their lunar program, precluding a new mission. Other agencies Farquhar approached had similar views.
NASA announced its SIMPLEx opportunity in 2014 for cubesats deployed from the second stage of the 1st SLS mission (EM-1) to the Moon. We are on the Arizona State Univ. team that is developing the Lunar Polar Hydrogen Mapper (LunaH-Map) cubesat selected for EM-1. LunaH-Map will use an iodine solar electric propulsion system by Busek (Natick, MA) to enter an elliptical lunar orbit with periselene over the lunar south pole. The 1st launch date for EM-1 was in Dec. 2017, but in May 2016, NASA changed it to October 7, 2018. That's 2 months before Wirtanen's closest approach, so we looked into sending a cubesat with LunaH-Map's propulsion system to Wirtanen. The lunar swingby that might send a cubesat to Wirtanen would occur on Oct. 12 when the Earth C3 to reach Wirtanen is 2.25 km^2/s^2. We tried realistic simulations, finding that a LunaH-Map-like cubesat could not reach Wirtanen, but a spacecraft with 4 times the thrust could. Another cubesat with a more capable propulsion system might reach Wirtanen from EM-1. EM-1 can deploy 13 cubesats, all taken except for 3 for foreign partners. If EM-1 launches a month earlier, then a LunaH-Map-like cubesat could reach Wirtanen; the lowest C3 is 0.95 km^2/s^2 with an Earth departure on Sept. 5. If there is another launch with the possibility of carrying a cubesat then, the authors would be interested.

[1] Farquhar, R., Jing, Qian, Veverka, and Dunham, Paper IAC-13-

!3.4.12, Proceedings of the International Astronautical Congress (Beijing, 2013 September).

Author(s): David W. Dunham[2], Kjell Stakkestad[2], Craig Hardgrove[1], Peter W. Vedder[2], David Gaylor[3], John Kidd[3], Carl W. Hergenrother[3]
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123.50 – Analyzing Serendipitous Asteroid Observations in Imaging Data using PHOTOMETRYPIPELINE

Asteroids are nearly ubiquitous in the night sky, making them present in the majority of imaging data taken every night. Serendipitous asteroid observations represent a treasure trove to Solar System researchers: accurate positional measurements of asteroids provide important constraints on their sometimes highly uncertain orbits, whereas calibrated photometric measurements can be used to establish rotational periods, intrinsic colors, or photometric phase curves.
We present an add-on to the PHOTOMETRYPIPELINE (PP, github.com/mommermi/photometrypipeline, see Poster presentation 123.42) that identifies asteroids that have been observed serendipitously and extracts astrometry and calibrated photometry for these objects. PP is an open-source Python 2.7 software suite that provides image registration, aperture photometry, photometric calibration, and target identification with only minimal human interaction.
Asteroids are identified based on approximate positions that are pre-calculated for a range of dates. Using interpolated coordinates, we identify potential asteroids that might be in the observed field and query their exact positions and positional uncertainties from the JPL Horizons system. The method results in robust astrometry and calibrated photometry for all asteroids in the field as a function of time. Our measurements will supplement existing photometric databases of asteroids and improve their orbits.
We present first results using this procedure based on imaging data from the Vatican Advanced Technology Telescope.
This work was done in the framework of NAU's REU summer program that is supported by NSF grant AST-1461200. PP was developed in the framework of the "Mission Accessible Near-Earth Object Survey" (MANOS) and is supported by NASA SSO grants NNX15AE90G and NNX14AN82G.

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123.51 – Early development of Science Opportunity Analysis tools for the Jupiter Icy Moons Explorer (JUICE) mission

JUICE is the first large mission in the framework of ESA’s Cosmic Vision 2015-2025 program. JUICE will survey the Jovian system with a special focus on three of the Galilean Moons: Europa, Ganymede and Callisto.
The mission has recently been adopted and big efforts are being made by the Science Operations Center (SOC) at the European Space and Astronomy Centre (ESAC) in Madrid for the development of tools to provide the necessary support to the Science Working Team (SWT) for science opportunity analysis and early assessment of science operation scenarios. This contribution will outline some of the tools being developed within ESA and in collaboration with the Navigation and Ancillary Information Facility (NAIF) at JPL.
The Mission Analysis and Payload Planning Support (MAPPS) is developed by ESA and has been used by most of ESA's planetary missions to generate and validate science observation timelines for the simulation of payload and spacecraft operations. MAPPS has the capability to compute and display all the necessary geometrical information such as the distances, illumination angles and projected field-of-view of an imaging instrument on the surface of the given body and a preliminary setup is already in place for the early assessment of JUICE science operations.
NAIF provides valuable SPICE support to the JUICE mission and several tools are being developed to compute and visualize science opportunities. In particular the WebGeoCalc and Cosmographia systems are provided by NAIF to compute time windows and create animations of the observation geometry available via traditional SPICE data files, such as planet orbits, spacecraft trajectory, spacecraft orientation, instrument field-of-view "cones" and instrument footprints. Other software tools are being developed by ESA and other collaborating partners to support the science opportunity analysis for all missions, like the SOLab (Science Operations Laboratory) or new interfaces for observation definitions and opportunity window databases.

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123.52 – SSERVI Analog Regolith Simulant Testbed Facility

The Solar System Exploration Research Virtual Institute (SSERVI) at NASA’s Ames Research Center in California’s Silicon Valley was founded in 2013 to act as a virtual institute that provides interdisciplinary research centered on the goals of its supporting directorates: NASA Science Mission Directorate (SMD) and the Human Exploration & Operations Mission Directorate (HEOMD).
Primary research goals of the Institute revolve around the integration of science and exploration to gain knowledge required for the future of human space exploration beyond low Earth orbit.
SSERVI intends to leverage existing JSC1A regolith simulant resources into the creation of a regolith simulant testbed facility. The purpose of this testbed concept is to provide the planetary exploration community with a readily available capability to test hardware and conduct research in a large simulant environment.
SSERVI's goals include supporting planetary researchers within NASA, other government agencies; private sector and hardware developers; competitors in focused prize design competitions; and academic sector researchers.
SSERVI provides opportunities for research scientists and engineers to study the effects of regolith analog testbed research in the planetary exploration field. This capability is essential to help to understand the basic effects of continued long-term exposure to a simulated analog test environment.
The current facility houses approximately eight tons of JSC-1A lunar regolith simulant in a test bin consisting of a 4 meter by 4 meter area, including dust mitigation and safety oversight.
Facility hardware and environment testing scenarios could include, Lunar surface mobility, Dust exposure and mitigation, Regolith handling and excavation, Solar-like illumination, Lunar surface compaction profile, Lofted dust, Mechanical properties of lunar regolith, Surface features (i.e. grades and rocks)
Numerous benefits vary from easy access to a controlled analog regolith simulant testbed, and planetary exploration activities at NASA Research Park, to academia and expanded commercial opportunities, as well as public outreach and education opportunities.

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123.53 – Technology for a Thermo-chemical Ice Penetrator for Icy Moons

The ability to place sensors or to take samples below the ice surface enables a wide variety of potential scientific investigations. Penetrating an ice cap can be accomplished via a mechanical drill, laser drill, kinetic impactor, or heated penetrator. This poster reports on the development of technology for the latter most option, namely a self-heated probe driven by an exothermic chemical reaction: a Thermo-chemical ice penetrator (TChIP). Our penetrator design employs a eutectic mix of alkali metals that produce an exothermic reaction upon contact with an icy surface. This reaction increases once the ice starts melting, so no external power is required. This technology is inspired by a classified Cold-War era program developed at Northrop Grumman for the US Navy. Terrestrial demonstration of this technology took place in the Arctic; however, this device cannot be considered high TRL for application at the icy moons of the solar system due to the environmental differences between Earth's Arctic and the icy moons. These differences demand a TChIP design specific to these cold, low mass, airless worlds. It is expected that this model of TChIP performance will be complex, incorporating all of the forces on the penetrator, gravity, the thermo-chemistry at the interface between penetrator and ice, and multi-phase heat and mass transport, and hydrodynamics. Our initial efforts are aimed at the development of a validated set of tools and simulations to predict the performance of the penetrator for both the environment found on these icy moons and for a terrestrial environment. The purpose of the inclusion of the terrestrial environment is to aid in model validation. Once developed and validated, our models will allow us to design penetrators for a specific scientific application on a specific body. This poster discusses the range of scientific investigations that are enabled by TChIP. We also introduce the development plan to advance TChIP to the point where it can be considered for infusion into a program.

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123.54 – Concept of Science Data Management for the Korea Pathfinder Lunar Orbiter

South Korea has a plan to explore the Moon in 2018 or 2019. For the plan, the Korea Aerospace Research Institute which is a government funded research institute kicked off the Korea Lunar Exploration Development Program in January, 2016 in support of Ministry of Science, ICT and Future Planning, South Korea.
As the 1st stage mission of the program, named as the Korea Pathfinder Lunar Orbiter(KPLO), will perform acquisition of high resolution images and science data for investigation of lunar environment as well as the core technology demonstration and validation for space explorations. The scientific instruments consists of three Korean domestic developed science instruments except an imaging instrument and several foreign provided instruments. We are developing a science data management plan to encourage scientific activities using science data acquired by the science instruments.
I introduce the Korean domestic developed science instruments and present concept of the science data management plan for data delivery, processing, and distribution for the science instruments.

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123.55 – Recovery of Europa's geophysical attributes with the radio science component of a Europa Multiple-Flyby Mission

NASA has approved the development of a multiple-flyby mission to Jupiter's satellite Europa. Important science questions about Europa's interior structure and sub-surface ocean can be addressed by measuring Europa's gravity field, tidal Love number, and spin state. The mission's radio science investigation will rely on tracking the Doppler shift between the spacecraft and Deep Space Network (DSN) antennas. Here, we simulate the X-band two-way coherent Doppler link between the spacecraft and DSN antennas to evaluate the precision with which geophysical parameters can be recovered. We use the project's 15F10 reference trajectory and simulate Doppler measurements within ±2 h of the spacecraft's closest approach to Europa for each one of 42 flybys. After adding noise to the simulated observables, we solve for Europa's *GM*, degree and order 2 gravity coefficients (J_2 and C_{22}), tidal love number k_2, pole position (right ascension and declination), and spin rate. The results of our simulations show that the precision in the recovery of geophysical parameters is sufficient to answer questions related to the presence of a global ocean in some tracking scenarios but not in others. We compare our results to an independent analysis by the Europa Mission Gravity Science Working Group (GSWG, 2016).

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123.56 – New Space at Airbus Defence & Space to facilitate science missions

In addition to Airbus legacy activities, where Airbus satellites usually enable challenging science missions such as Venus Express, Mars Express, Rosetta with an historic landing on a comet, Bepi Colombo mission to Mercury and JUICE to orbit around Jupiter moon Ganymede, Swarm studying the Earth magnetic field, Goce to measure the Earth gravitational field and Cryosat to monitor the Earth polar ice, Airbus is now developing a new approach to facilitate next generation missions.
After more than 25 years of collaboration with the scientists on space missions, Airbus has demonstrated its capacity to implement highly demanding missions implying a deep understanding of the science mission requirements and their intrinsic constraints such as
- a very fierce competition between the scientific communities,
- the pursuit of high maturity for the science instrument in order to be selected,
- the very strict institutional budget limiting the number of operational missions.

As a matter of fact, the combination of these constraints may lead to the cancellation of valuable missions.
Based on that and inspired by the New Space trend, Airbus is developing an highly accessible concept called HYPE.
The objective of HYPE is to make access to Space much more simple, affordable and efficient.
With a standardized approach, the scientist books only the capacities he needs among the resources available on-board, as the HYPE satellites can host a large range of payloads from 1kg up to 60kg.
At prices significantly more affordable than those of comparable dedicated satellite, HYPE is by far a very cost-efficient way of bringing science missions to life.
After the launch, the scientist enjoys a plug-and-play access to two-way communications with his instrument through a secure high-speed portal available online 24/7.
Everything else is taken care of by Airbus: launch services and the associated risk, reliable power supply, setting up and operating the communication channels, respect of space law regulation.
We will present the HYPE opportunity, being open to the scientists view with the concern to have the concept tuned as close as possible to their needs.

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123.57 – TEAM – Titan Exploration Atmospheric Microprobes

The astrobiological potential of Titan's surface hydrocarbon liquids and probable interior water ocean has led to its inclusion as a destination in NASA's "Ocean Worlds" initiative, and near-term investigation of these regions is a high-level scientific goal. TEAM is a novel initiative to investigate the lake and sea environs using multiple dropsondes –scientific probes derived from an existing cubesat bus architecture (CAPE – the Cubesat Application for Planetary Exploration) developed at NASA GSFC. Each 3U probe will parachute to the surface, making atmospheric structure and composition measurements during the descent, and photographing the surface – land, shoreline and seas - in detail. TEAM probes offer a low-cost, high-return means to explore multiple areas on Titan, yielding crucial data about the condensing chemicals, haze and cloud layers, winds, and surface features of the lakes and seas. These microprobes may be included on a near-term New Frontiers class mission to the Saturn system as additional payload, bringing increased scientific return and conducting reconnaissance for future landing zones. In this presentation we describe the probe architecture, baseline payload, flight profile and the unique engineering and science data that can be returned.

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123.58 – Planetary plasma data analysis and 3D visualisation at the French Plasma Physics Data Centre

The CDPP (the French plasma physics data center http://cdpp.eu/) is engaged for nearly two decades in the archiving and dissemination of plasma data products from space missions and ground-based observatories. Besides these activities, the CDPP developed services like **AMDA** (http://amda.cdpp.eu/)
and **3DView** (http://3dview.cdpp.eu/). AMDA enables in depth analysis of a large amount of data through dedicated functionalities such as: visualisation, data mining, cataloguing. 3DView provides immersive visualisations in planetary environments: spacecraft position and attitude, ephemerides. Magnetic field models (Cain, Tsyganenko), visualisation of cubes, 2D cuts as well as spectra or time series along spacecraft trajectories are possible in 3Dview. Both tools provide a joint access to outputs of simulations (MHD or Hybrid models) in planetary sciences as well as planetary plasma observational data (from AMDA, CDAWeb, Cluster Science Archive, ...). Some of these developments were funded by the EU IMPEx project, and some of the more recent ones are done in the frame of Europlanet 2020 RI project. The role of CDPP in the analysis and visualisation of planetary data and mission support increased after a collaboration with the NASA/PDS which resulted in the access in AMDA to several planetary datasets like those of GALILEO, MESSENGER, MAVEN, etc. In 2014, AMDA was chosen as the quicklook visualisation tool for the Rosetta Plasma Consortium through a collaboration with Imperial College, London. This presentation will include several use cases demonstrating recent and new capabilities of the tools.

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123.59 – Development of megapixel HgCdTe detector arrays with 15 micron cutoff

I. History
HgCdTe is a versatile II-VI semiconductor with a direct-bandgap tunable via the Hg:Cd ratio. Hg:Cd ratio = 53:47 (2.5 micron cutoff) was used on the NICMOS instrument on HST and the 2MASS. Increasing Hg:Cd ratio to 70:30 leads to a 5.4 micron cutoff, utilized in NEOWISE and many JWST instruments. Bailey, Wu et al. (1998) motivated extending this technology to 10 microns and beyond. Bacon, McMurtry et al. (2003, 2004) indicated significant progress toward this longwave (LW) goal.
Warm-Spitzer has pioneered passive cooling to below 30 K in space, enabling the JWST mission.
II. Current
NASA's proposed NEOcam mission selected HgCdTe with a 10.6 micron cutoff because it promises natural Zodiacal background limited sensitivity with modest cooling (40 K). Teledyne Imaging Systems (TIS) is producing megapixel arrays with excellent performance (McMurtry, Lee, Dorn et al. (2013)) for this mission.
III. Future
Modest cooling requirements (circa 30 K) coupled with megapixel arrays and LW sensitivity in the thermal IR make HgCdTe attractive for many infrared instruments. For instance, the spectral signature of a terrestrial planet orbiting in the habitable zone of a nearby star will be the deep and wide absorption by CO_2 centered at 15 microns (Seager and Deming, 2010). LW instruments can enhance Solar System missions, such as exploration of the Enceladus geysers (Spencer, Buratti et al. 2006). Passive cooling will be adequate for these missions. Modern ground-based observatories will benefit from infrared capability out to the N band (7.5-13.6 microns). The required detector temperatures (30-40 K) are easily achievable using commercially available mechanical cryo-coolers (refrigerators).
IV. Progress to date
TIS is developing megapixel HgCdTe arrays sensitive out to 15 microns under the direction of the University of Rochester. As a first step, we have produced arrays with a 13 micron cutoff. The initial measurements indicate very promising performance. We will present the measurements of dark current, noise, and quantum efficiency for these devices and discuss our plans to reach our 15 micron target wavelength.

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123.60 – Solar System Exploration with LUVOIR

The Large UV/Optical/IR (LUVOIR) Surveyor is one of four mission concepts under study as a next-generation space observatory in the post Webb Telescope era. LUVOIR is envisioned as a large, 10 m class, remotely serviceable observatory with a suite of advanced-technology instruments designed to leap beyond the current generation of space-based telescopes to explore fundamental astrophysical phenomena on all scales. A 24-member science and technology definition team (STDT) represents all sectors of the astronomy and technologist communities, and it is charged with identifying the observational challenges best addressed with LUVOIR and the instrumental innovations that are required to achieve them. This presentation describes the developing science case for LUVOIR as a Solar System observatory for the study of Sun-planet interactions, thick and sublimation based atmospheres, the small body populations in the inner and outer solar system, surface volatility, and planet/satellite surfaces. We will provide an overview of several key science and technical drivers for each scientific target and how they can be addressed with a LUVOIR facility. We also solicit community input to refine these individual programs and to identify additional areas of emphasis in the development of a final report to NASA.

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123.61 – High spectral resolution observation of extended sources in future interplanetary missions

The most commonly used technique for high spectral resolution (R) studies are grating spectrometers. They can achieve broad bandpasses but they have small FOV and relatively low étendue so they have to be paired with large aperture telescopes such Keck (10m), Hubble (2.4m) or JWST (6.5m). Fabry-Pérot Interferometers (FPI) and FTS are the other best known types of high étendue, high R spectrometers used in astronomy. But their opto-mechnical tolerances becomes challenging and they use transmitting optics, where transmission drops especially below 130 nm. Spatial Heterodyne Spectrometer (SHS) is a candidate for high étendue, high spectral R spectroscopy in compact low cost, low-mass, low-power architecture using no or small aperture telescope for UV to IR wavelengths. High R spectrometers are usually limited by the telescope aperture size and complicated opto-mechanical tolerances but that's not the case for SHS. SHS provides integrated spectra at high spectral R, over a wide FOV in compact designs in which it offers the ability to make key science measurements for a variety of planetary targets. SHS could be implemented on a dedicated SmallSat or ISS that can sit and stare at its target for long duration of time that cannot be done from the ground or on big missions. SmallSats are lower cost, faster to build, relatively easy to correct and upgrade. For UV observation, currently HST is the only telescope capable of collecting the necessary observations and the next major UV space telescope might be able to fly in 10 years or more. SHS instrument can quickly fill the technology gap for UV space spectrometers.

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123.62 – A Novel Miniature Wide-band Radiometer for Space Applications

Design, development and testing of a novel miniaturised infrared radiometer is described. The instrument opens up new possibilities in planetary science of deployment on smaller platforms – such as unmanned aerial vehicles and microprobes – to enable study of a planet's radiation balance, as well as terrestrial volcano plumes and trace gases in planetary atmospheres, using low-cost long-term observations. Thus a key enabling development is that of miniaturised, low-power and well-calibrated instrumentation.
The paper reports advances in miniature technology to perform high accuracy visible / IR remote sensing measurements. The infrared radiometer is akin to those widely used for remote sensing for earth and space applications, which are currently either large instruments on orbiting platforms or medium-sized payloads on balloons. We use MEMS microfabrication techniques to shrink a conventional design, while combining the calibration benefits of large (>1kg) type radiometers with the flexibility and portability of a <10g device. The instrument measures broadband (0.2 to 100um) upward and downward radiation fluxes, with built-in calibration capability, incorporating traceability to temperature standards such as ITS-90. The miniature instrument described here was derived from a concept developed for a European Space Agency study, Dalomis (Proc. of 'i-SAIRAS 2005', Munich, 2005), which involved dropping multiple probes into the atmosphere of Venus from a balloon to sample numerous parts of the complex weather systems on the planet. Data from such an in-situ instrument would complement information from a satellite remote sensing instrument or balloon radiosonde. Moreover, the addition of an internal calibration standard facilitates comparisons between datasets.
One of the main challenges for a reduced size device is calibration. We use an in-situ method whereby a blackbody source is integrated within the device and a micromirror switches the input to the detector between the measured signal and the calibration target. Achieving two well-calibrated radiometer channels within a small (<10g) payload is made possible by using micromachining techniques.

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123.63 – Target Analysis for the Twinkle Space Mission

Twinkle is a dedicated exoplanet space mission planned for launch in 2019 to observe and characterize the atmospheres of planets around F, G, K, and M type stars. By obtaining high-resolution near-infrared transit spectra (0.5 – 4.5 microns), Twinkle will identify molecules of interest within planetary atmospheres. Twinkle will provide critical data for the characterization of individual exoplanets, leading to an improved understanding of planetary systems as a whole.
In this study, we provide an analysis of potential targets for the Twinkle space mission, and we find that the spacecraft will be capable of observing a wide range of planet types, including Earths, Super Earths, Sub Neptunes, Large Neptunes, and Hot Jupiters. We discuss the population distribution of observable targets in terms of planet temperature and radius, host star temperature, and observation time necessary to achieve the desired signal-to-noise ratios. We also include sample Twinkle spectra from a simulated data set, as well as an example retrieval using the TauRex program to retrieve molecules in these simulated spectra. We conclude with a discussion of these results and their implications for the Twinkle mission.

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Contributing team(s): The Twinkle Consortium

123.64 – LEAF Entry eXperiement (LEX)

Northrop Grumman has been developing the Lifting Entry Atmospheric Flight (LEAF) system. The LEAF is a lifting, hypersonic entry, maneuverable platform capable of performing long-term (~year) in situ and remote measurements at any solar system body with an atmosphere. The Venus application is Venus Atmospheric Maneuverable Platform (VAMP) and the Titan version, T-LEAF. LEAF's ultra-low ballistic coefficient combined with a lifting entry presents an innovative way to enter the atmosphere from space. Benefits of LEAF's entry are 1) large PL capacity achieved by re-allocating the mass made available by the elimination of a heavy aeroshell, 2) reduced mission risk and critical events by fully deploying in space and gently entering the atmosphere, and 3) benign entry loads (both thermal and structural) allowing use of a lightweight, flexible thermal protection system and readily available avionics and instruments.
Earth atmosphere presents an ideal environment in which to validate lifting entry. The LEAF Entry eXperiment (LEX) will be performed with an 8.5m wingspan vehicle. Many options are being considered to place the LEX vehicle in space, including sounding rockets, secondary payload launch manifests and SpaceX's Dragon trunk. The ISS may also be a suitable platform from which the LEX vehicle could be released. Specific launch opportunities will be studied and finalized as the LEX vehicle is matured. Similar to the LEAF system concept, the vehicle will be deployed in space, prior to re-entry. To assure success, a series of Ground Deployment Demonstrations (GDDs) are planned prior to the LEX Earth re-entry flight demo.
The anticipated re-entry conditions for the LEX are entry velocity (v)=7.33km/s, altitude (h)=152km, and entry flight path angle (g)=-1.4°. The expected LEX entry loads are Q_{dot}=30W/cm^2, $T_{max\ stag}$=1796K, and g_{max}=2.9g compared to Q_{dot}=15W/cm^2, $T_{max\ stag}$=1319

K, and g_{max}=2.5g for VAMP. Hence it is expected that the LEX would be a representative demonstration of lifting entry for VAMP.
In this presentation, we discuss the plans and progress for LEX, including the GDD of the 8.5m vehicle. We also discuss the overall LEX concept of operations and the aero-thermal design.

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Institution(s): *1. Northrop Grumman*
Contributing team(s): Linden Bolisay, Ron Polidan

123.65 – Titan Lifting Entry & Atmospheric Flight (T-LEAF) Science Mission

Northrop Grumman has been developing the Titan Lifting Entry & Atmospheric Flight (T-LEAF) sky rover to roam the lower atmosphere and observe at close quarters the lakes and plains of Saturn's ocean moon, Titan. T-LEAF also supports surface exploration and science by providing precision delivery of *in-situ* instruments to the surface of Titan.
T-LEAF is a highly maneuverable sky rover and its aerodynamic shape (*i.e.*, a flying wing) does not restrict it to following prevailing wind patterns on Titan, but allows mission operators to chart its course. This freedom of mobility allows T-LEAF to follow the shorelines of Titan's methane lakes, for example, or to target very specific surface locations.
We will present a straw man concept of T-LEAF, including size, mass, power, on-board science payloads and measurement, and surface science dropsonde deployment CONOPS. We will discuss the various science instruments and their vehicle level impacts, such as meteorological and electric field sensors, acoustic sensors for measuring shallow depths, multi-spectral imagers, high definition cameras and surface science dropsondes. The stability of T-LEAF and its long residence time on Titan will provide for
- time to perform a large aerial survey of select prime surface targets,
- deployment of dropsondes at selected locations,
- surface measurements that are coordinated with on-board remote measurements,
- communication relay capabilities to orbiter (or Earth).
In this context, we will specifically focus upon key factors impacting the design and performance of T-LEAF science:
- science payload accommodation, constraints and opportunities,
- characteristics of flight, payload deployment and measurement CONOPS in the Titan atmosphere.
This presentation will show how these factors provide constraints as well as enable opportunities for novel long duration scientific studies of Titan's surface.

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Institution(s): *1. Northrop Grumman*

123.66 – Titan LEAF: A Sky Rover Granting Targeted Access to Titan's Lakes and Plains

Northrop Grumman, in collaboration with L'Garde Inc. and Global Aerospace Corporation (GAC), has been developing the Titan Lifting Entry Atmospheric Flight (T-LEAF) sky rover to roam the atmosphere and observe at close quarters the lakes and plains of Titan. T-LEAF also supports surface exploration and science by providing precision delivery of in situ instruments to the surface.
T-LEAF is a maneuverable, buoyant air vehicle. Its aerodynamic shape provides its maneuverability, and its internal helium envelope reduces propulsion power requirements and also the risk of crashing. Because of these features, T-LEAF is not restricted to following prevailing wind patterns. This freedom of mobility allows it be commanded to follow the shorelines of Titan's methane lakes, for example, or to target very specific surface locations.
T-LEAF utilizes a variable power propulsion system, from high power at ~200W to low power at ~50W. High power mode uses the propellers and control surfaces for additional mobility and maneuverability. It also allows the vehicle to hover over specific locations for long duration surface observations. Low power mode utilizes GAC's Titan Winged Aerobot (TWA) concept, currently being developed with NASA funding, which achieves guided flight without the use of propellers or control surfaces. Although slower than high powered flight, this mode grants increased power to science instruments while still maintaining control over direction of travel. Additionally, T-LEAF is its own entry vehicle, with its leading edges protected by flexible thermal protection system (f-TPS) materials already being tested by NASA's Hypersonic Inflatable Aerodynamic Decelerator (HIAD) group. This f-TPS technology allows T-LEAF to inflate in space, like HIAD, and then enter the atmosphere fully deployed. This approach accommodates entry velocities from as low as ~1.8 km/s if entering from Titan orbit, up to ~6 km/s if entering directly from Saturn orbit, like the Huygens probe.
This presentation will discuss each of these topic areas, showing that a sky rover like T-LEAF is an ideal option for exploration of both the surface and atmosphere of Titan.

Author(s): Floyd Ross[3], Greg Lee[3], Daniel Sokol[3], Benjamin Goldman[1], Linden Bolisay[2]
Institution(s): *1. Global Aerospace Corporation, 2. L'Garde Inc., 3. Northrop Grumman*

200 – Centaurs/Kuiper III

200.01 – Planet Nine From Outer Space

All known Kuiper belt objects with orbital periods longer than 4,000 years have orbits that are clustered in physical space. Statistically, the chances of such alignment being coincidental are smaller than a hundredth of a percent. In this talk, we show that the observed clustering of Kuiper belt orbits can be explained by a distant, eccentric, Neptune-like planet, whose orbit lies in approximately the same plane as those of the distant Kuiper belt objects, but whose perihelion is 180° away from the perihelia of the minor bodies. In addition to accounting for the observed grouping of orbital trajectories, the existence of such a planet naturally explains the presence of high-perihelion Sedna-like objects, as well as the known collection of high semi-major axis objects with inclinations between 60° and 150°.

Author(s): Konstantin Batygin[1], Michael E. Brown[1]
Institution(s): *1. California Institute of Technology*

200.02 – The Search for Planet Nine

We use an extensive suite of numerical simulations to constrain the mass and orbit of Planet Nine, and we use these constraints to begin the search for this newly proposed planet in new and in archival data. Here, we compare our simulations to the observed population of aligned eccentric high semimajor axis Kuiper belt objects and determine which simulation parameters are statistically compatible with the observations. We find that only a narrow range of orbital elements can reproduce the observations. In particular, the combination of semimajor axis, eccentricity, and mass of Planet Nine strongly dictates the semimajor axis range of the orbital confinement of the distant eccentric Kuiper belt objects. Allowed orbits, which confine Kuiper belt objects with semimajor axis beyond 380 AU, have perihelia roughly between 150 and 350 AU, semimajor axes between 380 and 980 AU, and masses between 5 and 20 Earth masses. Orbitally confined objects also generally have orbital planes similar to that of the planet, suggesting that the planet is inclined approximately 30 degrees to the ecliptic. We compare the allowed orbital positions and estimated brightness of Planet Nine to previous and ongoing surveys which would be sensitive to the planet's detection and use these surveys to rule out approximately two-thirds of the planet's orbit. Planet Nine is likely near aphelion with an approximate brightness of 22<V<25. At opposition, its motion, mainly due to parallax, can easily be detected within 24 hours. We discuss the state of our current and archival searches for this newly predicted planet.

Author(s): Michael E. Brown[1], Konstantin Batygin[1]
Institution(s): *1. Caltech*

200.03 – Solar Obliquity Induced by Planet Nine

The six-degree obliquity of the sun suggests that either an asymmetry was present in the solar system's formation environment, or an external torque has misaligned the angular momentum vectors of the sun and the planets. However, the exact origin of this obliquity remains an open question. Batygin and Brown (2016) have recently shown that the physical alignment of distant Kuiper Belt orbits can be explained by a $m_9 = 10\text{-}20\ m_{Earth}$ planet on a distant, eccentric, and inclined orbit, with an approximate perihelion distance of $q_9 \sim 250$ AU. Using an analytic model for secular interactions between Planet Nine and the remaining giant planets, here we show that a planet with similar parameters can naturally generate the observed obliquity as well as the specific pole position of the sun's spin axis. Thus, Planet Nine offers a testable explanation for the otherwise mysterious spin-orbit misalignment of the solar system.

Author(s): Elizabeth Bailey[1], Konstantin Batygin[1], Michael E. Brown[1]
Institution(s): *1. California Institute of Technology*

200.04 – Corralling a distant unseen planet with extreme resonant Kuiper belt objects

Several recent studies have appealed to the clustering of the angular orbital elements of very distant, extreme Kuiper belt objects (eKBOs) to argue for the existence of a large planet in the distant solar system. We identify other properties of eKBOs that may support the existence of such an unseen planet. We observe that several eKBOs have orbital periods close to integer ratios with each other. These would be dynamically significant only if the eKBOs are in mean motion resonances (MMRs) with an unseen massive planet. If such MMRs are true, then their resonant dynamics can provide constraints on the planet's parameters and its current location in its orbital path. We calculate that a hypothetical planet with orbital period ~17,117 years (semimajor axis ~665 AU), could have small integer period ratios (of the form N/1 or N/2) with the four longest period eKBOs. Our calculations suggest two possibilities for the planet's orbit plane: a plane moderately close to the ecliptic (i~18°) or an inclined plane (i~48°). The former offers dynamical stability of the high-eccentricity eKBOs by means of libration of the relative longitudes, and the latter offers enhanced dynamical stability by means of additional libration of the argument of perihelion, ω. Standard theory of MMRs breaks down for the extremely high orbital eccentricities (~0.7–0.9) of the eKBOs. We developed asymptotic analytical approximations, supported by numerical analysis of the circular restricted three body problem, to estimate that a planet of mass >~10 $M_{♀}$ has MMR widths large enough that the current orbital uncertainties of the eKBOs allow libration in the hypothesized MMRs, as well as libration of ω in the inclined planet case. Our calculations indicate that the planet's orbital eccentricity is unlikely to exceed ~0.3 for stable resonant librations of the eKBOs. Libration of critical resonant angles of the hypothesized MMRs of the eKBOs define exclusion zones of the current location of the planet in its orbital path; these exclude just over half of the orbital path. (For additional details, please see Malhotra et al 2016 ApJ 824 L22.) RM and KV acknowledge NASA grant NNX14AG93G.

Author(s): Renu Malhotra[1], Kathryn Volk[1], Xianyu Wang[1]
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200.05D – The Observable Effects of a Planet 9 on the Distant TNOs

We explore the 9th planet hypothesis by integrating the large a, large q TNOs in the presence of the giant planets and a variety of external perturbers whose orbits are consitent with the eccentric and inclined 9th planet proposed in Batygin & Brown 2016.
We find a generic outcome of such evolutions is that the known TNOs evolve to large q, large i orbits, removing them from the volume detectable by observation on relatively short timescales. Although some orbits retain confinement in longitude of pericentre, most cycle through i, q values that imply that the currently detected sample is only a small fraction of the population that the presence of a 9th planet would require.
Some of the highly inclined orbits produced by the examined perturbers may actually be inside of the orbital parameter space probed by prior surveys, implying a missing signature of the 9th planet scenario.

Author(s): Cory Shankman[3], JJ Kavelaars[1], Michele T Bannister[3], Samantha Lawler[1], Brett Gladman[2]
Institution(s): *1. National Research Council of Canada, 2. University of British Columbia, 3. University of Victoria*

200.06 – Observational Constraints on Planet Nine

Recent publications from Batygin & Brown have rekindled interest in the possibility that there is a large (~10 Earth-Mass) planet lurking unseen in a distant (a~500 AU) orbit at the edge of the Solar System. Such a massive planet would tidally distort the orbits of the other planets in the Solar System.
These distortions can potentially be measured and/or constrained through precise observations of the orbits of the outer planets and distant trans-Neptunian objects. I will discuss our recent (and ongoing) attempts to observationally constrain the possible location of Planet Nine via (a) measurements of the orbit of Pluto, and (b) measurements of the orbit of Saturn derived from the Cassini spacecraft.

Author(s): Matthew John Payne[1], Matthew J. Holman[1]
Institution(s): *1. Harvard-Smithsonian*

200.07 – The structure of the distant Kuiper belt in a Nice model scenario

By utilizing a well-sampled migration model and characterized survey detections, we demonstrate that the Nice-model scenario results in consistent populations of scattering trans-Neptunian objects (TNOs) and several resonant TNO populations, but fails to reproduce the large population of 5:1 resonators discovered in surveys. We examine in detail the TNO populations implanted by the Nice model simulation from Brasser and Morbidelli (2013, B&M). This analysis focuses on the region from 25-155 AU, probing the classical, scattering, detached, and major resonant populations. Additional integrations were necessary to classify the test particles and determine population sizes and characteristics. The classified simulation objects are compared to the real TNOs from the Canada-France Ecliptic Plane Survey (CFEPS), CFEPS high latitude fields, and the Alexandersen (2016) survey. These surveys all include a detailed characterization of survey depth, pointing, and tracking efficiency, which allows detailed testing of this independently produced model of TNO populations. In the B&M model, the regions of the outer Solar System populated via capture of scattering objects are consistent with survey constraints. The scattering TNOs and most *n*:1 resonant populations have consistent orbital distributions and population sizes with the real detections, as well as a starting disk mass consistent with expectations. The B&M 5:1 resonators have a consistent orbital distribution with the real detections and previous models. However, the B&M 5:1 Neptune resonance is underpopulated by a factor of ~100 and would require a starting proto-planetesimal disk with a mass of ~100 Earth masses. The large population in the 5:1 Neptune resonance is unexplained by scattering capture in a Nice-model scenario, however this model accurately produces the TNO subpopulations that result from scattering object capture and provides additional insight into sub-population orbital distributions.

Author(s): Rosemary E. Pike[4], Samantha Lawler[3], Ramon Brasser[2], Cory Shankman[4], Mike Alexandersen[1], J. J. Kavelaars[3]
Institution(s): *1. Academia Sinica Institute of Astronomy and Astrophysics, 2. Earth Life Science Institute, Tokyo Institute of Technology, 3. National Research Council of Canada, Herzberg, 4. University of Victoria*

200.08 – Let's Dense - Modifying densities and compositions through collisions of Kuiper belt objects

Ice-rock bodies in the outer solar system preserve crucial information on past dynamical and physical conditions, through compositions and structure. Known dwarf planets have a large range of ice/rock ratios and maintain diverse satellite counterparts. Specific modification processes have not yet been demonstrated numerically and identification of intermediate evolution stages is lacking in simulations and observations.
Barr & Schwamb (2016) hypothesized on how to interpret densities in the Kuiper belt according to different collision conditions, pointing to a two-mode process. We show how to reconstruct their distribution of primary density and satellite-to-total mass ratio, as a function of varying collision regimes, in similar and marginally-similar-sized collisions (dependent on target/impactor mass ratio). We varied the initial mass ratios, impact velocities and angles and differentiation state of large and mid-sized (300-1200 km in radius) colliding objects, in SPH-based shock physics simulations (using GADGET2 with EOS implementation). Fully, partial and non-differentiated initial configurations of each object are derived from a consistent calculation of thermal evolution histories and a pre-selected range in initial compositions and material properties.
We will discuss the scaling of these simulations, as it informs our predictions for the survival and current presence of water and other volatile ice species. Intermediate-size KBOs (radii ~300-500 km) should be most amenable for buried ices to be resurfaced by impacts. A preliminary scaling relation between collision conditions and global shock processed state of the ice (H2O) and rock (silicate, serpentine) components will be discussed as well. We also predict the satellite-to-total mass ratio and primary density of objects that have not yet been observed to maintain a stable satellite system. These would be observations of massive satellites around ice-rich bodies. The predicted collision regime, between disruption and partial merging, is erosive Hit-and-Run, characterized by large ejected mass, but small velocities relative to the mutual escape velocity of the system.

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200.09 – New Extreme Trans-Neptunian Objects: Towards A Super-Earth In Our Solar System Beyond A Few Hundred AU

We are conducting the widest and deepest survey ever obtained for extreme distant solar system objects. Our goal is to increase understanding of the origin of extremely high perihelion objects like Sedna and 2012 VP113. We also want to determine if the extreme trans-Neptunian objects cluster in their orbital angles, which would be an indication of a yet unobserved massive shepherding planet in the distant solar system, as first shown in Trujillo and Sheppard (2014). Our survey, started in 2012, has covered about 2000 square degrees to over 24th magnitude using the wide-field imagers on the Subaru 8 meter and CTIO 4 meter telescopes. We have found several new extreme solar system objects and inner Oort cloud objects as well as discovered the first outer Oort cloud object with a perihelion beyond Neptune. We will discuss these objects along with several other interesting objects discovered in our ongoing survey.

Author(s): Scott S. Sheppard[1], Chadwick A. Trujillo[2], David J. Tholen[3]
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201 – Comets: 67P-CG II: Summary Results and Basic Characterization

201.01 – The Dust and Gas Outburst of Comet 67P/C-G on 19 February 2016, as Seen at Millimeter and Submillimeter Wavelengths by the MIRO Instrument

The Microwave Instrument for the Rosetta Orbiter (MIRO) is a U.S. instrument with French, German, and Taiwanese participation. It is on the European Space Agency's Rosetta spacecraft which, from August 2014 through September 2016, was flying along side comet 67P/Churyumov-Gerasimenko. MIRO is designed to study the nucleus and coma of the comet as a coupled system. It makes broad-band continuum measurements of the thermal emission of the nucleus at 190 and 563 GHz (1.6 and 0.5 mm) which probe the thermal and dielectric properties of the nucleus as a function of depth from ~1 mm to ~10 cm. When looking off the nucleus, continuum emission from dust can be used to constrain the abundance and size distribution of particles. In addition to its continuum channels, MIRO has a high resolution (44 kHz) spectrometer fixed tuned to submillimeter lines of H_2O, $H_2{}^{17}O$, $H_2{}^{18}O$, CO, NH_3, and three CH_3OH transitions, allowing us to determine the abundance, velocity, and temperature of these species in the coma. This presentation will provide an overview of the instrument, and then focus on measurements made during an outburst from the comet on 19 February 2016. At that time, the spacecraft was 35 km from the nucleus. The first indication of the main outburst was a cloud of dust rising from the nucleus, seen by the OSIRIS camera and Alice UV spectrometer (see Alice presentations by Stern et al., Noonan et al., and Steffl et al. at this conference). After several minutes, MIRO observed the rotational temperature of water in the coma near the spacecraft start to rise from about 20 to 50 K. Several minutes after the temperature started to increase, the ROSINA-COPS instrument recorded a sharp rise in gas density at the spacecraft. A possible explanation for this sequence of events is a landslide or collapse on the nucleus which first raises dust. The dust then heats the coma, after which nucleus ices, newly exposed or brought near-surface by the landslide, begin sublimating and increasing coma gas density. This and other interpretations will be discussed.

Author(s): Mark D. Hofstadter[3], Nicolas Biver[5], Seungwon Lee[3], Paul von Allmen[3], Dominique Bockelee-Morvan[5], F. Peter Schloerb[6], Bjorn Davidsson[3], Samuel Gulkis[2], Gerard Beaudin[5], Mathieu Choukroun[3], Jacques Crovisier[5], Pierre Encrenaz[5], Therese A. Encrenaz[5], Margaret Frerking[3], Paul Hartogh[4], Wing-Huen Ip[1], Michael A. Janssen[3], Christopher Jarchow[4], Emmanuel Lellouch[5], Cedric Leyrat[5], Ladislav Rezac[4], Thomas R. Spilker[2]
Institution(s): *1. Inst. Ast. Space Sci., 2. JPL Retired, 3. JPL/Caltech, 4. Max Planck, 5. Obs. Paris, 6. Univ. Mass.*

201.02 – Comet 67P as seen by Rosetta/OSIRIS

In September 2016, the ESA Rosetta mission will come to its ending. Having escorted comet 67P for more than two years, the scientific

camera system OSIRIS onboard Rosetta witnessed all important milestones of the mission: after the first characterization and the Philae landing we saw the comet's activity increasing while it was approaching the Sun. During the peak of activity around perihel in August 2015, the spacecraft had to retreat to a safe distance but we witnessed strong but predictable jet activity and, at the same time, short lived eruptions, some of these being big outbursts. When the activity declined post perihelion and allowed the spacecraft to go back closer, comparison with the early characterization revealed numerous morphologic changes on the surface, which can be attributed to the strong activity during perihelion passage.
The paper will give an overview of latest OSIRIS science and discoveries including the morphology, activity, and surface changes mentioned above. Implications on the nature of the comet and its mechanisms will be drawn from these. The current plan for the mission is to go to very close distances in August and September 2016 and finally land the spacecraft on 67P.
Acknowledgements: OSIRIS was built by a consortium led by the Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, in collaboration with CISAS, University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Scientific Support Office of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universität Braunschweig, Germany.
We thank the Rosetta Science Ground Segment at ESAC, the Rosetta Mission Operations Centre at ESOC and the Rosetta Project at ESTEC for their outstanding work enabling the science return of the Rosetta Mission.
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Institution(s): *1. Aix Marseille Université, CNRS, LAM, 2. Centro de Astrobiología, CSIC-INTA, 3. European Space Research and Technology Centre/ESA, 4. Max Planck Institute for Solar System Research, 5. University of Padova, 6. Uppsala University*
Contributing team(s): The OSIRIS Team

201.03 – "Back fall" dust controls seasonal erosion and composition measurements of 67P

Seasonal effects of 67P's activity are very pronounced due to the strong insolation during southern summer when the comet is near its perihelion. About ¾ of the overall gas and dust production are released from the southern hemisphere when large parts of the surface near the north pole are in polar night (Keller et al. 2015). This leads to a dichotomy of the hemispheres. The southern regions show rough consolidated material whereas the northern plain surfaces are covered by what looks like dust (El Maary et al 2015). Recent close up observations of the northern territories show a granularity near the resolution limit of the images. This is comparable to the sizes of particles (10-20 cm) seen to cross the coma at velocities comparable to or below the escape speed from the nucleus around perihelion. These large particles are deprived from super volatiles but maintain their water ice content. A major part will cover the northern hemisphere as "back fall" over the aphelion passage and will lead to water controlled activity from the northern hemisphere during the next cometary approach. New dune-like features (Thomas et al. 2015) have been recently observed in the gravitational low *Hapi* region. Philae ROLIS images show wind tails and moats around obstacles, all oriented in a south-north direction, that are well modelled by abrasion by impinging back fall from the south (Mottola et al. 2015). Consequently activity from the northern hemisphere during the early Rosetta mission revealed mainly water molecules (Fougere et al. to be submitted) originating from back fall and not from the original consolidated surface, that was widely isolated by the cover of back fall. Hence more volatile compounds such as CO_2 and CO are not reached by insolation. Composition measurements of the northern hemisphere are strongly influenced by the back fall cover and do not reflect the original composition of the nucleus. A further consequence is that erosion of the nucleus of 67P takes place predominantly on the south. The liberation of large (water active) particles probably requires activity driven by super volatiles (CO_2 and CO). Back fall was also suggested for comet 103P (A'Hearn et al. 2011).
Author(s): Horst Uwe Keller[3], Stubbe F. Hviid[1], Stefano Mottola[1], Jessica Agarwal[2]
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Contributing team(s): OSIRIS

201.04D – Formation of the dumbbell-like nucleus of a comet by sublimation

The nucleus of the comet 67P/Churyumov-Gerasimenko is an elongated body with a deep groove around the middle. There are also other comets that look like dumbbells (e.g. 103P/Hartley 2, 19P/Borrelly, 1P/Halley). Two most probable interpretations are discussed in the scientific society. The first hypothesis explains the creation of such an object as sticking of two cometesimals during the process of formation. The second one suggests that the sublimation process can change the nucleus shape and make a groove in the middle.
In this work we consider the second hypothesis. It was assumed that the spin axis of the nucleus is perpendicular to the plane of the cometary orbit and that initially the nucleus shape is a sphere. Thus, the problem is represented as a differential equation, which describes the change of the cometary nucleus. We solved this equation analytically. It was shown that initially a convex cometary nucleus (e.g. a sphere), consisting of homogeneous material, can not be transformed into a dumbbell-like body by the influence of sublimation. However, assuming that the density in the centre of the nucleus is less than on the surface, a groove can arise on the equator of the cometary nucleus as a result of sublimation.
Author(s): Dmitrii Vavilov[2], Yurii Medvedev[2], Pavel Zatitskiy[1]
Institution(s): *1. Chebyshev Lab, 2. Institute of Applied Astronomy of the Russian Academy of Science*

201.05 – Direct measurement of grain acceleration in the near-surface coma of comet 67P/Churyumov-Gerasimenko with Rosetta/OSIRIS

We for the first time directly measure the acceleration of individual fragments in the inner coma (<2 km) of a comet, and discover the ejection of the material that is thought to subsequently cover large parts of the northern hemisphere as airfall (Thomas et al., 2015).
In early 2016, the OSIRIS Narrow Angle Camera on board the Rosetta spacecraft observed fountains of decimeter-sized fragments emerging from confined regions on the surface of comet 67P/Churyumov-Gerasimenko. We trace the motion of individual fragments through images obtained at high cadence over an interval of 2 hours, and measure their projected velocities as a function of time. The fragments are accelerated at a constant rate either away from the nucleus or towards it, and to both directions in the horizontal dimension. The magnitude of the acceleration is compatible with both gas drag and rocket force induced by the

sublimation of ice contained in the material, but approximately one order of magnitude larger than the local gravity. Some of these fragments are likely to escape from the gravitational field of the nucleus and feed the comet's debris trail, while others will fall back to the surface or senter orbit. A significant fraction of the comet's northern hemisphere is thought to be covered by such airfall material (Thomas et al., 2015). This paper describes our images and trajectory analysis, discusses the implications for fragment ejection and acceleration mechanisms, and the expected fate of the fragments.

References: N. Thomas et al. (2015), A&A 583, A17.

Author(s): Jessica Agarwal[1], Michael F. A'Hearn[2], Carsten Guettler[1], Sebastian Hoefner[1], Holger Sierks[1], Cecilia Tubiana[1], Jean-Baptiste Vincent[1]

Institution(s): *1. Max Planck Institute for Solar System Research, 2. University of Maryland*

Contributing team(s): OSIRIS-Team

201.06D – Interpretation of surface properties of comet 67P/Churyumov-Gerasimenko using bidirectional reflectance studies of laboratory cometary analogs

The European Space Agency's Rosetta mission has been orbiting the nucleus of comet 67P/Churyumov-Gerasimenko (67P) for more than 2 years. An enormous quantity of surface data at variable spatial resolution and over a wide range of the electromagnetic spectrum has been acquired by a series of complementary instruments during this period. The long accompany time allowed characterization and comparison of spectrophotometric properties in the pre- and post-perihelion phase.

A profound knowledge of laboratory analogues of cometary surfaces is essential for interpreting remote sensing data. The LOSSy laboratory (Laboratory for Outflow Studies of Sublimating Materials) at the University of Bern was set up to study the spectrophotometric properties of ice-bearing cometary nucleus analogs. The laboratory is equipped with two instruments: the PHIRE-2 radio-goniometer [2], designed to measure the bidirectional visible reflectance of samples under a wide range of geometries and the SCITEAS simulation chamber [3], designed to study the evolution of icy samples subliming under low pressure/temperature conditions by hyperspectral imaging in the VIS-NIR range.

We present reflectance data of various well characterized and reproducible mixtures of fine grained ice particles, tholins, and carbonaceous compounds that we systematically compare to the phase curves, albedo, spectrum and phase reddening observed by Rosetta at 67P [4].

Our results allow us setting a lower limit of a few micrometers on the dust particle size and demonstrate that meter-sized bright patches have to be relatively dust free at small scale. Further we show that the most porous samples ($p \approx 80\%$) best match the phase curve of 67P.

[1] Keller, H. U., et al., 2007, Space Sci. Rev. 128, 26

[2] Jost, B., et al., 2016. Icarus 264, 109-131.

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[4] Fornasier, S., et al., 2015. A&A 583, A30.

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201.07 – H $_2$O and O $_2$ Absorption-Line Abundances in the Coma of Comet 67P/Churyumov-Gerasimenko Measured by the R-Alice Ultraviolet Spectrograph

The Alice far-UV spectrograph, aboard the ESA *Rosetta* spacecraft, has observed emissions in the wavelength range 800-2000 Å from the coma of Comet 67P/Churyumov-Gerasimenko since before orbital insertion in September 2014. We present novel observations of the cometary coma in absorption against the stellar continuum of UV-bright stars that were targeted or serendipitously observed near the comet's nucleus between April 2015 and February 2016 at heliocentric radii ranging from 1.2 to 2.4 AU. These spectra show clear signatures of absorption from gaseous H_2O and O_2. The observed H_2O column densities agree well with values found by *Rosetta*'s VIRTIS instrument (Bockelée-Morvan et al. 2015, A&A, 583, A6) and can be reasonably described by a simple Haser model. However, the absorption-derived O_2/H_2O ratio is somewhat larger than the 1-10% range reported by *Rosetta*'s ROSINA mass spectrometer (Bieler et al. 2015, Nature, 526, 678) from September 2014 through March 2015 at heliocentric radii of 2.1-3.2 AU. We explore potential causes for this discrepancy, including systematic biases in the absorption-line measurements and seasonal variations in O_2/H_2O as the comet approaches perihelion.

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201.08 – MIRO Observations of Millimeter-wave Emission from Large Dust Particles in the Coma of 67P/Churyumov-Gerasimenko

We present observations of dust emission from comet 67P/Churyumov-Gerasimenko obtained by the Microwave Instrument for the Rosetta Orbiter (MIRO). MIRO is a millimeter-wave instrument with two continuum channels at wavelengths of 0.53 mm and 1.59 mm. The instrument has a 30cm-diameter antenna which provides resolution of about 217m and 690m at the respective wavelengths for a spacecraft-comet distance of 100km. During the months around the August 2015 perihelion of comet 67P, a small continuum emission excess was observed above the sunlit limb of the comet. The excess emission extends many beam widths off the dayside limb and is a persistent feature for months of observations. No excess above the noise limit of the instrument is observed above the nightside limb, and given the known strong day-night asymmetry of gas production from the nucleus, we interpret the observed continuum excess on the day side to result from thermal emission from dust. Typical antenna temperatures of the emission over the day side at a distance of 4 km from the center of the nucleus (approximately 2 km above the surface) are approximately 1K in both the submillimeter-wave (0.53 mm) and millimeter-wave (1.59 mm) channels, corresponding to likely dust column densities of ~0.1 kg m^{-2}. The typical relative brightness of the 0.53 mm emission to the 1.59 mm emission is approximately 1.2. This result is most consistent with particle size distributions which extend up to radii of at least several centimeters and/or flatter particle size distributions than those often attributed to cometary dust. Maps of the emission show that the column density of dust decreases with distance from the nucleus following a power law with $b^{-1.6} – b^{-2.0}$, where b is the impact parameter of the beam with respect to the nucleus. Models of dust outflow, in which particles are accelerated by the drag force of the outflowing gas, predict a column density falloff according to $b^{-1.2}$. We find that to achieve the observed exponents between -1.6 and -2.0 would require the large particles observed by MIRO to disappear on time scales of 20,000-80,000 seconds.

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201.09 – The heliocentric variation of the outgassing rate and molecular abundances in the coma of 67P as seen by MIRO

During the two years around the Aug. 2015 perihelion, the MIRO instrument on board the Rosetta spacecraft has been regularly mapping the emission of 8 molecular lines around 560 GHz (H_2O and its isotopes, CO, NH_3 and CH_3OH) in the inner coma of comet 67P/Churyumov-Gerasimenko. We have used those observations to estimate the mean outgassing rates as a function of time in 2014-2016 and heliocentric distance (Rh=1.2-4 AU). The peak outgassing rate of water (~10^{28} molec./s), based on maps of $H_2{}^{18}O$ was reached slightly after perihelion. We have also measured the evolution of the abundances relative to water of CO, CH_3OH and NH_3. The abundances of CH_3OH and CO significantly increased around and after perihelion time when most of the outgassing was coming from the illuminated southern pole. We have also retrieved the 3-D outgassing patterns, which enabled us to track the location of the bulk of outgassing for each molecule.

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Contributing team(s): The MIRO team

202 – Extrasolar Planets: Giant Planet Atmospheres I

202.01 – HAT-P-26b: A Neptune-mass Exoplanet with Primordial Solar Heavy Element Abundance

A trend in giant planet mass and atmospheric heavy elemental abundance was first noted last century from observations of planets in our own solar system. These four data points from Jupiter, Saturn, Uranus, and Neptune have served as a corner stone of planet formation theory. Here we add another point in the mass-metallicity trend from a detailed observational study of the extrasolar planet HAT-P-26b, which inhabits the critical mass regime near Neptune and Uranus. Neptune-sized worlds are among the most common planets in our galaxy and frequently exist in orbital periods very different from that of our own solar system ice giants. Atmospheric studies are the principal window into these worlds, and thereby into their formation and evolution, beyond those of our own solar system. Using the Hubble Space Telescope and Spitzer, from the optical to the infrared, we conducted a detailed atmospheric study of the Neptune-mass exoplanet HAT-P-26b over 0.5 to 4.5 µm. We detect prominent H2O absorption at 1.4 µm to 525 ppm in the atmospheric transmission spectrum. We determine that HAT-P-26b's atmosphere is not rich in heavy elements (≈1.8×solar), which goes distinctly against the solar system mass-metallicity trend. This likely indicates that HAT-P-26b's atmosphere is primordial and obtained its gaseous envelope late in its disk lifetime with little contamination from metal-rich planetesimals.

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202.02D – Blind extraction of exoplanetary spectra

In the last decade, remote sensing spectroscopy enabled characterization of the atmospheres of extrasolar planets. Transmission and emission spectra of tens of transiting exoplanets have been measured with multiple instruments aboard Spitzer and Hubble Space Telescopes as well as ground-based facilities, revealing the presence of chemical species in their atmospheres, and constraining their temperature and pressure profiles.
Early analyses were somehow heuristic, leading to some controversies in the literature.
A photometric precision of 0.01% is necessary to detect the atmospheric spectral modulations. Current observatories, except Kepler, were not designed to achieve this precision. Data reduction is necessary to minimize the effect of instrument systematics in order to achieve the target precision. In the past, parametric models have extensively been used by most teams to remove correlated noise with the aid of auxiliary information of the instrument, the so-called optical state vectors (OSVs). Such OSVs can include inter- and intra-pixel position of the star or its spectrum, instrument temperatures and inclinations, and/or other parameters. In some cases, different parameterizations led to discrepant results.
We recommend the use of blind non-parametric data detrending techniques to overcome those issues. In particular, we adopt Independent Component Analysis (ICA), i.e. a powerful blind source separation (BSS) technique to disentangle the multiple instrument systematics and astrophysical signals in transit/eclipse light curves. ICA does not require a model for the systematics, thence it can be applied to any instrument with little changes, if any. ICA-based algorithms have been applied to Spitzer/IRAC and synthetic observations in photometry (Morello et al. 2014, 2015, 2016; Morello 2015) and to Hubble/WFC3, Hubble/NICMOS and Spitzer/IRS and Hubble/WFC3 in spectroscopy (Damiano, Morello et al., in prep., Waldmann 2012, 2014, Waldmann et al. 2013) with excellent results. In this conference, I will illustrate the detrending algorithms optimized to specific instruments and the results obtained over new observations, not yet published at the time of abstract submission.

Author(s): Giuseppe Morello[1], Ingo Waldmann[1], Mario Damiano[1], Giovanna Tinetti[1]
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202.03 – Determining the role of TiO/VO in hot exoplanet atmospheres

The role of TiO and VO in ultra hot (>2000K) gas giant atmospheres is a major unresolved issue in the exoplanet field. At these temperatures, TiO and VO are known to be important absorbers in the atmospheres of M/L dwarfs and have been theorized to play an important role in irradiated gas giants. To date, however, TiO/VO has not been securely detected in a planetary atmosphere, despite numerous searches. One possibility is that the upper atmospheres of highly irradiated planets are typically depleted of TiO/VO by cold-trapping at lower altitudes or rain-out on the relatively cool nightside. Using WFC3 G141 and ground-based photometry, we have recently published a transmission spectrum for WASP-121b (T~2400K) showing new evidence for absorption by TiO/VO. Our observations also yielded a high confidence (5.4 sigma) detection of the 1.4 micron H2O absorption band. The TiO/VO claim, however, remains tentative, as it currently hinges upon broadband photometry measurements obtained from the ground at relatively low signal-to-noise. If TiO/VO is present it will have significant implications for the overall physics and chemistry of the atmosphere, including the likely production of a strong thermal inversion in the upper atmosphere. I will describe the follow-up observations we are currently pursuing in order to confirm or rule out TiO/VO in the atmosphere of WASP-121b and in doing so address a long-standing mystery of exoplanet atmospheres.

Author(s): Thomas Evans[1]
Institution(s): *1. University of Exeter*

202.04 – VLT FORS2 comparative transmission spectral survey of clear and cloudy exoplanet atmospheres

Transmission spectroscopy is a key to unlocking the secrets of close-in exoplanet atmospheres. Observations have started to unveil a vast diversity of irradiated giant planet atmospheres with clouds and hazes playing a definitive role across the entire mass and temperature regime. We have initiated a ground-based, multi-object transmission spectroscopy of a hand full of hot Jupiters, covering the wavelength range 360-850nm using the recently upgraded FOcal Reducer and Spectrograph (FORS2) mounted on the Very Large Telescope (VLT) at the European Southern Observatory (ESO). These targets were selected for comparative follow-up as their transmission spectra showed evidence for alkali metal absorption, based on the results of Hubble Space Telescope (HST) observations. This talk will discuss the first results from the programme, demonstrating excellent agreement between the transmission spectra measured from VLT and HST and further reinforce the findings of clear, cloudy and hazy atmospheres. More details will be discussed on the narrow alkali features obtained with FORS2 at higher resolution, revealing its high potential in securing optical transmission spectra. These FORS2 observations are the first ground-based detections of clear, cloudy and hazy hot-Jupiter atmosphere with a simultaneous detections of Na, K, and H2 Rayleigh scattering. Our program demonstrates the large potential of the instrument for optical transmission spectroscopy, capable of obtaining HST-quality light curves from the ground. Compared to HST, the larger aperture of VLT will allow for fainter targets to be observed and higher spectral resolution, which can greatly aid comparative exoplanet studies. This is important for further exploring the diversity of exoplanet atmospheres and is particularly complementary to the near- and mid-IR regime, to be covered by the upcoming James-Webb Space Telescope (JWST) and is readily applicable to less massive planets down to super-Earths.

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202.05 – Spectroscopic observations of Hot-Jupiters with the Hubble WFC3 camera

Thousands of exoplanets have been discovered with a huge range of masses, sizes and orbits. The next step to characterize them is to study their atmosphere. The atmospheres of giant planets are mostly made of hydrogen and helium. The relevant questions therefore concern the amounts of all elements other than hydrogen and helium, i.e. the heavy elements, that are present.
The atmospheres of hot Jupiters present a critical advantage compared to the planets of the Solar System: their high temperature.
Unlike Jupiter and Saturn, there is no cold trap in their atmosphere for species such as H2O, CH4, NH3, CO2 etc., which condense at much colder temperatures. Observations of hot gaseous exoplanets can therefore provide a unique access to their elementary composition (especially C, O, N, S) and enable the understanding of the early stage of planetary and atmospheric formation during the nebular phase and the following few millions years.
Here we present new spectroscopic observations of hot-Jupiters' atmospheres obtained with the WFC3 camera. In our presentation we will focus on the data reduction method used and on the interpretation of the results through state of the art spectral retrieval models.

Author(s): Mario Damiano[1], Giuseppe Morello[1], Angelos Tsiaras[1], Tiziano Zingales[1], Giovanna Tinetti[1]
Institution(s): *1. UCL*
Contributing team(s): ExoLights, ExoMol

202.06 – Evidence for the Direct Detection of the Thermal Spectrum of the Non-Transiting Hot Gas Giant HD 88133 b

We target the thermal emission spectrum of the non-transiting gas giant HD 88133 b with high-resolution near-infrared spectroscopy, by treating the planet and its host star as a spectroscopic binary. For sufficiently deep summed flux observations of the star and planet across multiple epochs, it is possible to resolve the signal of the hot gas giant's atmosphere compared to the brighter stellar spectrum, at a level consistent with the aggregate shot noise of the full data set. To do this, we first perform a principal component analysis to remove the contribution of the Earth's atmosphere to the observed spectra. Then, we use a cross-correlation analysis to tease out the spectra of the host star and HD 88133 b to determine its orbit and identify key sources of atmospheric opacity. In total, six epochs of Keck NIRSPEC L band observations and three epochs of Keck NIRSPEC K band observations of the HD 88133 system were obtained. Based on an analysis of the maximum likelihood curves calculated from the multi-epoch cross correlation of the full data set with two atmospheric models, we report the direct detection of the emission spectrum of the non-transiting exoplanet HD 88133 b and measure a radial projection of its Keplerian orbital velocity, its true mass, its orbital inclination, and dominant atmospheric species. This, combined with eleven years of radial velocity measurements of the system, provides the most up-to-date ephemeris for HD 88133.

Author(s): Danielle Piskorz[1], Nathan R. Crockett[1], Alexandra Lockwood[1], Björn Benneke[1], Geoffrey A. Blake[1], Travis S. Barman[5], Chad F. Bender[4], Marta Bryan[1], John S Carr[3], Debra Fischer[8], Andrew Howard[7], Howard T. Isaacson[6], John A. Johnson[2]
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202.07 – Jupiter's Phase Variations from Cassini: a testbed for future direct-imaging missions

Phase curves are important for our understanding of the energy balance and scattering behavior of an exoplanet's atmosphere. In preparation for future direct-imaging missions of Jupiter-like planets, we present phase curves of Jupiter from 0--150 degrees as measured in multiple optical bandpasses by Cassini/ISS during the Millennium flyby of Jupiter in late 2000 to early 2001. We demonstrate and confirm that Jupiter is not well represented by a Lambertian phase function and that its color is more variable with phase angle than predicted by Jupiter-like models. This indicates that a Jupiter-twin observed near quadrature may not be as straightforward to classify as a Jupiter-like planet.

Author(s): Laura Mayorga[4], Jason Jackiewicz[4], Kathy Rages[5], Robert West[2], Ben Knowles[1], Mark Marley[3], Nikole Lewis[6]

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202.08 – Reflected Light Curves, Spherical and Bond Albedos of Jupiter- and Saturn-like Exoplanets

Reflected light curves observed for exoplanets indicate that a few of them host bright clouds. We estimate how the light curve and total stellar heating of a planet depends on forward and backward scattering in the clouds based on Pioneer and Cassini spacecraft images of Jupiter and Saturn. We fit analytical functions to the local reflected brightnesses of Jupiter and Saturn depending on the planet's phase. These observations cover broad bands at 0.59–0.72 and 0.39–0.5 µm, and narrow bands at 0.938 (atmospheric window), 0.889 (CH_4 absorption band), and 0.24–0.28 µm. We simulate the images of the planets with a ray-tracing model, and disk-integrate them to produce the full-orbit light curves. For Jupiter, we also fit the modeled light curves to the observed full-disk brightness. We derive spherical albedos for Jupiter and Saturn, and for planets with Lambertian and Rayleigh-scattering atmospheres. Jupiter-like atmospheres can produce light curves that are a factor of two fainter at half-phase than the Lambertian planet, given the same geometric albedo at transit. The spherical albedo is typically lower than for a Lambertian planet by up to a factor of ∼1.5. The Lambertian assumption will underestimate the absorption of the stellar light and the equilibrium temperature of the planetary atmosphere. We also compare our light curves with the light curves of solid bodies: the moons Enceladus and Callisto. Their strong backscattering peak within a few degrees of opposition (secondary eclipse) can lead to an even stronger underestimate of the stellar heating. This work is published: Dyudina, U.,et al., 2016: ApJ, 822, 76, http://arxiv.org/abs/1511.04415.

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202.09 – Multi-band Emission Light Curves of Jupiter: Insights on Brown Dwarfs and Directly Imaged Exoplanets

Many brown dwarfs exhibit significant infrared flux variability (e.g., Artigau et al. 2009, ApJ, 701, 1534; Radigan et al. 2012, ApJ, 750, 105), ranging from several to twenty percent of the brightness. Current hypotheses include temperature variations, cloud holes and patchiness, and cloud height and thickness variations (e.g., Apai et al. 2013, ApJ, 768, 121; Robinson and Marley 2014, ApJ, 785, 158; Zhang and Showman 2014, ApJ, 788, L6). Some brown dwarfs show phase shifts in the light curves among different wavelengths (e.g., Buenzli et al. 2012, ApJ, 760, L31; Yang et al. 2016, arXiv:1605.02708), indicating vertical variations of the cloud distribution. The current observational technique can barely detect the brightness changes on the surfaces of nearby brown dwarfs (Crossfield et al. 2014, Nature, 505, 654) let alone resolve detailed weather patterns that cause the flux variability. The infrared emission maps of Jupiter might shed light on this problem. Using COMICS at Subaru Telescope, VISIR at Very Large Telescope (VLT) and NASA's Infrared Telescope Facility (IRTF), we obtained infrared images of Jupiter over several nights at multiple wavelengths that are sensitive to several pressure levels from the stratosphere to the deep troposphere below the ammonia clouds. The rotational maps and emission light curves are constructed. The individual pixel brightness varies up to a hundred percent level and the variation of the full-disk brightness is around several percent. Both the shape and amplitude of the light curves are significantly distinct at different wavelengths. Variation of light curves at different epochs and phase shift among different wavelengths are observed. We will present principle component analysis to identify dominant emission features such as stable vortices, cloud holes and eddies in the belts and zones and strong emissions in the aurora region. A radiative transfer model is used to simulate those features to get a more quantitative understanding. This work provides rich insights on the relationship between observed light curves and weather on brown dwarfs and perhaps on directly imaged exoplanets in the future.

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203 – Planetary Rings III: Modeling and Other Ring Systems

203.01 – New Horizons Imaging of Jupiter's Main Ring

New Horizons took roughly 520 visible-light images of Jupiter's ring system during its 2007 flyby, using the spacecraft's Long-Range Reconnaissance Imager (LORRI). These observations were taken over nine days surrounding Jupiter close-approach. They span a range in distance of 30 - 100 RJ, and a phase angle range of 20 - 174 degrees. The highest resolution images -- more than 200 frames -- were taken at a resolution approaching 20 km/pix.

We will present an analysis of this dataset, much of which has not been studied in detail before. Our results include New Horizons' first quantitative measurements of the ring's intrinsic brightness and variability. We will also present results on the ring's azimuthal and radial structure. Our measurements of the ring's phase curve will be used to infer properties of the ring's dust grains.

Our results build on the only previous analysis of the New Horizons Jupiter ring data set, presented in Showalter et al (2007, Science 318, 232-234), which detected ring clumps and placed a lower limit on the population of undetected ring-moons.

This work was supported by NASA's OPR program.

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Contributing team(s): New Horizons Science Team

203.02 – On the Extraordinary Propagation of the Janus 2:1 Density Wave: Synergy between Density Waves and Viscous Overstability

The effective damping produced by particle collisions prevents most spiral density waves in Saturn's rings from propagating more than about 100 km from their resonance location. The Janus 2:1 density wave defies the usual behavior and appears to alternatively grow and decay in amplitude repeatedly as it propagates into regions of larger mean optical depth before finally disappearing over 500 km from the resonance location. Borderies et al. (1985) suggested that the effective viscous coefficients in dense rings might lead to wave growth rather than damping. Salo et al. (2001) used N-body simulations to constrain the surface density dependence of the shear and bulk viscosity in the rings and applied them to the study of axisymmetric viscous overstable waves. We modify the formalism used by Latter and Ogilvie (2009) to model the nonlinear propagation of viscous overstable waves and apply it to model the propagation of the Janus 2:1 density wave. Normal optical depth

profiles obtained from Cassini UVIS observations of stellar occultations are used to constrain the mean optical depth variation with ring radius as well as the variation of the wave amplitude. We find that the viscous overstability can indeed explain how the wave amplitude can alternately grow and decay repeatedly as the wave propagates into higher optical depth regions. Detailed modeling of the Janus 2:1 density wave profile should allow us to place new constraints on the viscous properties of Saturn's inner B ring.
Author(s): Glen R. Stewart[1], Nicole Albers[1], Larry W Esposito[1]
Institution(s): *1. LASP/Univ. of Colorado*

203.03 – On the Janus-Epimetheus Ring

Cassini spacecraft found a new and unique ring to share a trajectory with Janus and Epimetheus, co-orbital satellites of Saturn. Analyzing Cassini images, we found that the Janus-Epimetheus ring is a continuous and smooth ring, which can only be seen by Cassini's camera at very high phase angles, not being observed at other geometries, as a `firefly' behavior. We also found a very short mean lifetime for the ring particles, less than a couple of decades. Consequently, the ring needs to be constantly replenished. Using a collisional model of micrometeoroids on the satellites' surfaces we found that it produces a faint ring that is fully compatible with the Janus-Epimitheus ring. We also verified that the steady state of the generated particles distribution corresponds to that of the light scattering regime responsible for the `firefly' behavior.
Author(s): Othon Winter[2], Alexandre Souza[2], Rafael Sfait[2], Silvia Giuliatti Winter[2], Decio Mourão[2], Dietmar Foryta[1]
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203.04 – Global viscous overstabilities in narrow rings

Local viscous overstabilities have been the focus of a number of theoretical analyses in the last decades due to the rôle they are believed to play in the creation of the small scale structure of broad ring systems (Saturn, Uranus). Global viscous overstabilities have also been investigated in the 1980s and 1990s as a potential source of narrow ring eccentricities (Longaretti and Rappaport, *1995, Icarus*, **116**, 376).
An important feature of global viscous overstabilities is that they produce slow relative librating or circulating motions of narrow ring edges; they may also produce slowly librating or circulating components of edge modes. This process is potentially relevant to explain the occurrence of unusually large apsidal shifts observed in some saturnian ringlets and may also explain the existence of the free m=2 B ring edge mode that is slowly circulating with respect to the component forced by Mimas.

The time-scale of such motions is primarily controlled by the ring self-gravity and can be analytically quantified in a two-streamline analysis which yields a characteristic libration/circulation frequency $\Omega_l = (n/\pi)(M_r/M_p)(a/\delta a)^2 H(q^2)$ where n is the mean motion, M_r the ringlet or pertubed region mass, M_p the planet mass, a the semi-major axis, δa the narrow ringlet or pertubed region width and $H(q^2)$ a dimensionless factor of order unity that depends on the streamline compression parameter q. The related time-scale is of the order of a few years to a few tens of years depending on the surface density and ringlet/perturbed region geometry. Preliminary data analyzes indicate that the Maxwell and Huyghens ringlets are probably librating with periods consistent with this two-streamline estimate. The talk will briefly present the physics of global viscous overstabilities as well as more detailed applications to narrow rings, and if time permits, to edge modes.
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203.05 – Reinterpreting the Sharp Edges of Planetary Rings

Narrow ringlets are found throughout the Solar System and are typically 1-100 km wide. Angular momentum, L, is the key to understanding how narrow rings remain confined; $L^2 \propto a(1 - e^2)$ for semimajor axis a and eccentricity e. In a circular ring, L conservation demands that the ring quickly spread apart when some colliding particles lose energy while others gain it. By contrast, in an eccentric ring, energy loss and the associated decay of the average semi-major axes can be offset by a decrease in the average eccentricity. We argue that a ring's lifetime can be greatly extended if particles arrange themselves in this way (Borderies et al. 1984). The key difference of our model, however, is that rings need not be shepherded and can confine themselves provided they are sufficiently eccentric. Satellites merely extend the rings' lifespans by pumping up their eccentricities.
This confinement mechanism can explain the existence and longevity of narrow ringlets in a variety of contexts. Saturn's Titan ringlet, which is quite circular, may nevertheless be able to confine itself indefinitely if its eccentricity decay is balanced by the increase from the resonance with Titan. Preliminary simulations presented by Rimlinger et al. at this year's DDA Conference have verified that this ring can self-confine even in the absence of any satellite; we update these findings with new results that include the effects of Titan. Furthermore, Mimas' resonance with the edge of the B ring may excite its higher order modes to similar effect. We update the findings of Hahn and Spitale (2013), who used artificial forces to confine the B ring's edge, and suggest that with a suitable viscosity and density, no such forces will be needed to keep the edge sharp. Finally, a ring that is "born" with a sufficiently high eccentricity may live for hundreds of millions or even billions of years in isolation if the rate of decay is slow enough. We present simulations exploring such a scenario.
Author(s): Thomas Rimlinger[2], Douglas P. Hamilton[2], Joseph M. Hahn[1]
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203.06 – Chariklo's ring system 1. Structure of the ring system from stellar occultations

Two dense and narrow rings around Chariklo (the largest centaur object known to date) were discovered by stellar occultation on June 3, 2013 (Braga-Ribas et al., Nature 508, 72, 2014). The main and larger ring is called C1R, while the faintest one is called C2R. Here we report six others occultations by Chariklo's ring system observed on February 16, March 16, April 29, June 28, 2014 and April 26, May 12, 2015. They provide a total of fifteen ring profiles, among which are four resolved profiles of C1R.
The latter exhibits a W-shape profile that is essentially opaque at the edges. Its width varies from 4.8 to 7.7 km over the available longitude range. Those caracteristics have been detected in Uranus elliptic rings. The equivalent width W_e (normal opacity x physical radial width) of C1R is 2 km with typical rms of 1 km, while C2R has W_e of 0.2 km (rms ~ 0.1 km). None of the rings exhibits variation of W_e with longitude.
Assuming the rings are circular, we can exhibit a pole which is compatible with the two multi-chord ring detections (June 3, 2013 and April 29, 2014): α_p=151.4° and δ_p=41.5°. We will then estimate an upper limit of a possible ring eccentricity based on those two observations.
Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR").

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203.07 – Chariklo's ring system 2. Main body physical constraints

We report the observation of two multi-chord stellar occultation by the Centaur object (10199) Chariklo on 29 April 2014 and 28 June 2014. From these and a previously published observation on 3 June 2013 (Braga-Ribas et al 2014) we estimate Chariklo's size, shape and density using a Bayesian approach. Assuming an homogeneous body in hydrostatic equilibrium we consider two possible models. For a Maclaurin spheroid model, topographic features of 8 km are needed to fit all the events and a density of 1.29 (+2.28-0.18) g cm^{-3} is found with equatorial radius of a = b = 133 ±5 km and polar radius c=110±10 km. For a Jacobi ellipsoid model, topographic features of 5 km are needed to fit all the events and a density of 0.81 ± 0.01 g cm^{-3} is found with semi major axes of a = 167 ± 5 km, b = 133 ±5 km and c = 86±2 km. The mass for the Maclaurin model is 1.72 (+1.64 -0.49) × 10^{19} kg and for the Jacobi model is 1.08± 0.01 × 10^{19} kg.
Considering a ring at an orbital radius of 400 km (the average radius of Chariklo's rings) we determine a Roche critical density limit for the ring particles of 0.44 g cm^{-3} and 0.20 g cm^{-3} for the Maclaurin and Jacobi model respectively.
In a companion abstract we discuss possible resonance effects between Chariklo's spin period and ring particle orbital motion.
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**Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR").
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203.08 – Chariklo's ring system 3. Exploration of possible Chariklo spin/ring orbit resonances

Two dense and narrow rings orbit the Centaur object Chariklo at respective radii of 391±3 and 405±3 km (Braga-Ribas *et al.*, Nature 508, 72, 2014).
With a rotation period of P_C = 7.004 ± 0.036 h (Fornasier *et al.* A.&A. 568, L11, 2014), Chariklo may adopt either a MacLaurin spheroid or a Jacobi ellipsoid shape, depending on density (and assuming hydrostatic equilibrium). Moreover, being a small icy body, Chariklo is prone to topographic features at several-kilometer scales.
Meanwhile, scarce information on Chariklo's size and shape is presently available from occultation works, as only five chords have been obtained during three occultations that have been observed in 2013 and 2014. Those data are consistent with a MacLaurin shape with axes *a, b, c* ~ 133x133x110 km and mass M_C ~ (1-2)x10^{19} kg, or with a Jacobi shape with *a, b, c* ~ 167x133x124 km and M_C ~ 0.6-0.7x10^{19} kg, see the companion paper by Leiva *et al*.
Those values imply a corotation radius between 190 and 280 km, depending on the adopted value of M_C. This is well inside the ring radii, ruling out the corotation resonance as the main driver for the ring orbital dynamics.
The ring orbital period could lie between *Pr* ~12 and 22 h, depending on M_C, thus allowing possible resonances with Chariklo's spin rate Ω_C. Two models will be explored. One model assumes a MacLaurin shape with a topographic feature of mass *m* that acts as perturbing satellites with orbital radius and period *a* and P_C, respectively. This creates 1^st^order Linblad-type resonances of the kind $Pr/P_C = m+1/m$ (*m* integer) whose possible effects on the ring structure will be evaluated.
The other model assumes a Jacobi shape that creates a perturbing potential GM_c/r^3 $[(A+B-2C)2 + (3/2)(A-B).cos(2\vartheta)]$ with $\vartheta= \lambda-\Omega_C.t$ in Chariklo's equatorial plane, where *A, B, C*are the moments of inertia around *a, b, c*, respectively, and λ is the mean longitude. This creates q^{th} order Linblad-type resonances of the kind $Pr/P_C = q+2/q$ (*q* integer) that will also be discussed.
Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR").
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203.09 – Hubble Observations of the Ongoing Evolution of Neptune's Ring-Moon System

We report on a new analysis of Hubble Space Telescope (HST) images of the Neptune system spanning 2004 to 2016. This expands upon an initial analysis we presented in 2013 (Showalter et al., DPS Meeting #45, abstract 206.01), based on HST images from 2004-2009. At that time we reported (1) the discovery of Neptune's fourteenth moon, S/2004 N 1, which orbits between Proteus and Larissa; (2) the recovery of Naiad, Neptune's innermost moon, although at an orbital longitude 90 degrees away from its prediction; and (3) the disappearance of the leading arcs in the Adams Ring, along with a marked decrease in the brightness of the trailing two arcs. Recent HST images extend the time baseline of the system by seven additional years, allowing us to expand upon prior results. We will report on our progress in refining the orbit, size and shape of S/2004 N 1, on understanding the orbital dynamics of Naiad, and on determining the ongoing evolution of the arcs and rings.
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204 – Akatsuki, Atmospheric Dynamics, and Spin

204.01 – Initial Results of Ultraviolet Imager on AKATSUKI

The UV images of the Venusian cloud top were obtained by several Venus spacecrafts such as Mariner 10 [Bruce et al., 1974], Pioneer Venus [Travis et al., 1979; Rossow et al., 1980], Galileo [Belton et al., 1991], Venus Express [Markiewicz et al., 2007; Titov et al., 2008]. Those previous instruments have taken images at the wavelength around 365-nm, but what material distribution reflects the contrasting density has been unknown yet. There is the SO2

absorption band around the 283-nm wavelength, and the 283-nm images clarify the distribution of SO2. The ultraviolet imager (UVI) on the AKATUSKI satellite takes ultraviolet images of the solar radiation scattered at the Venusian cloud top level at the both 283- and 365-nm wavelengths. There are absorption bands of SO2 and unknown absorber in these wavelength regions. The UVI carries out the measurements of the SO2 and the unknown absorber distributions, and the sequential images lead to understand the velocity vector of the wind at the cloud top altitude.
The UVI is equipped with fast off-axial catadioptric optics, two bandpass filters and a diffuser installed in a filter wheel moving with a stepping motor, and a high-sensitive CCD devise with a UV coating. The UVI takes images of the ultraviolet solar radiation scattered from the Venusian cloud top in two wavelength ranges at the center of 283nm and 365nm with bandpass of 15 nm. A back illuminated type of a frame-transfer CCD with a UV sensitive coating is adopted. Its effective area is 1024 x 1024 pixels. UVI has 12-deg field-of-view, so the angular resolution is 0.012 deg/pix. The nominal exposure time is 125 msec and 46 msec at the observations of the 283- and 365-nm wavelengths, respectively. CCD has no mechanical shutter, so a smear noise in transferring from the image area to the storage area degrades the signal-to-noise ratio of the signal image especially in the short exposure operation. The images have a signal-to-noise ratio of over 100 after desmearing of onboard data processing. The cooling radiator for the CCD device cools down the instrument temperature below 9C in the observation mode to reduce the dark current. The UVI nominally take one image of the Venus cloud top level every two hours.

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204.02 – A bow-shaped thermal structure traveling upstream of the zonal wind flow of Venus atmosphere

The Longwave Infrared Camera (LIR) onboard the Japanese Venus orbiter Akatsuki acquires a snap shot of Venus in the middle infrared region, and provides a brightness temperature distribution at the cloud-top altitudes of about 65 km. Hundreds of images taken by LIR have been transferred to the ground since the successful Venus orbit insertion of Akatsuki on Dec. 7, 2015. Here we report that a bow shaped thermal structure extending from the northern high latitudes to the southern high latitudes was found in the brightness temperature map on Dec. 7, 2015, and that it lasted for four days at least surprisingly at almost same geographical position. The bow shape structure looks symmetrical with the equator, and consists of a high temperature region in east or upstream of the background strong westward wind or the super rotation of the Venus atmosphere followed by a low temperature region in west with an amplitude of 5 K. It appeared close to the evening terminator in the dayside, and seems not to have stayed in the same local time rather to have co-rotated with the slowly rotating ground where the western part of Aphrodite Continent was below the center of the bow shape. Meridionally aligned dark filaments similar to the bow shape structure in shape but in much smaller scale were also identified in the brightness temperature map on Dec. 7, and they propagated upstream of the zonal wind as well. The bow shape structure disappeared when LIR observed the same local time and longitude in the earliest opportunity on Jan. 16, 2016. Similar events, though their amplitudes were less than 1 K, were found on Apr. 15 and 26, 2016, but they appeared in different local times and longitudes. A simulation of a gravity wave generated in the lower atmosphere and propagating upward reproduces the observed bow shape structure. The bow shape structure could be a signature of transferring momentum from the ground to the upper atmosphere.

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Contributing team(s): Akatsuki Science Team

204.03 – Initial Results of Radio Science in Akatsuki mission

The Radio Science experiment (RS) in the Akatsuki mission of JAXA aims to determine the vertical structure of the Venus atmosphere, thereby complementing the imaging observations by onboard instruments. The physical quantities to be retrieved are the vertical distributions of the atmospheric temperature, the electron density, the sulfuric acid vapor density, and small-scale density fluctuations. The uniqueness of Akatsuki RS is quasi-simultaneous observations with multi-band cameras dedicated to meteorological study; the cameras can observe the locations probed by RS a short time before or after the occultations.
An ultra-stable oscillator (USO) provides a stable reference frequency, which is used for the X-band downlink signal. The signal traverses the Venusian atmosphere near the limb and reaches the ground station, where it is sampled using an open-loop recording system. In the first radio occultation season of March-July, 2016, we plan 8 Venus occultation experiments in total (6 experiments have been done successfully till June). The temperature profiles cover the altitude region of 40-90 km, which enables studies of vertical coupling among different altitude levels and studies of the cloud system.
Another target of Akatsuki RS is solar corona. During solar conjunction periods, the downlink signal that traverses the solar corona is recorded at the ground station. The data yields information on the solar wind velocity, plasma density fluctuations, and magnetic field fluctuations from Faraday rotation measurement. In the solar conjunction period of May-June, 2016, 11 occultation experiments were conducted.

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204.04 – Structure and dynamical effects of the thermal tide in the Venus atmosphere

We investigate structure and dynamical effects of the thermal tide in the Venus atmosphere by using a general circulation model (GCM). The thermal tide is important for the Venus atmospheric dynamics (Fels and Lindzen, 1974; Plumb, 1975; Newman and Leovy, 1992; Takagi and Matsuda, 2007). However, its three-dimensional structure has not been fully investigated so far. It is expected that detailed wind distributions of the thermal tide will be obtained by the Venus Climate Orbiter Akatsuki in the near future. It is necessary to investigate its structure so that the observational results can be interpreted in terms of dynamics. The GCM used in the present study is AFES for Venus (Sugimoto et al., 2014a, b). The resolution is set to T64L120. The model atmosphere extends from the ground to ~120 km. The infrared radiative transfer process is simplified by the

Newtonian cooling approximation. See Sugimoto et al. (2014a, b) for more model details. The initial state is an idealized superrotating flow in solid body rotation. The GCM is integrated for 5 Earth years. The result shows that the semidiurnal and diurnal tides are predominant in low and high latitudes poleward of 60 degrees, respectively. The diurnal tide is trapped at 55-75 km levels; the phase is almost unchanged in the vertical direction. This result indicates that the subsolar-antisolar (SS-AS) circulation is predominant at these levels. The strong upward wind is located at early afternoon and near the morning and evening terminators. The vertical velocity of the SS-AS circulation is 0.04 m/s, which is ~10 times as fast as that of the mean meridional circulation (MMC). Titov et al. (2012) pointed out that dark regions are observed in the evening region, suggesting that the dark material is transported from below. These results suggest that the SS-AS circulation is quite important to the material transport at the cloud levels in the Venus atmosphere. The preliminary analysis also shows that the MMC at 50-90 km levels is strongly affected by the thermal tide. In order to elucidate the dynamical balance, the EP-flux and the residual MMC of the thermal tide are investigated in detail.

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204.05 – Venusian Polar Vortex reproduced by a general circulation model

Unlike the polar vortices observed in the Earth, Mars and Titan atmospheres, the observed Venus polar vortex is warmer than the mid-latitudes at cloud-top levels (~65 km). This warm polar vortex is zonally surrounded by a cold latitude band located at ~60 degree latitude, which is a unique feature called 'cold collar' in the Venus atmosphere [e.g. Taylor et al. 1980; Piccioni et al. 2007]. Although these structures have been observed in numerous previous observations, the formation mechanism is still unknown. In addition, an axi-asymmetric feature is always seen in the warm polar vortex. It changes temporally and sometimes shows a hot polar dipole or S-shaped structure as shown by a lot of infrared measurements [e.g. Garate-Lopez et al. 2013; 2015]. However, its vertical structure has not been investigated. To solve these problems, we performed a numerical simulation of the Venus atmospheric circulation using a general circulation model named AFES for Venus [Sugimoto et al. 2014] and reproduced these puzzling features.And then, the reproduced structures of the atmosphere and the axi-asymmetirc feature are compared with some previous observational results.
In addition, the quasi-periodical zonal-mean zonal wind fluctuation is also seen in the Venus polar vortex reproduced in our model. This might be able to explain some observational results [e.g. Luz et al. 2007] and implies that the polar vacillation might also occur in the Venus atmosphere, which is silimar to the Earth's polar atmosphere. We will also show some initial results about this point in this presentation.

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204.06 – A density-driven separation of CO_2 and N_2 in the deep atmosphere of Venus

The deepest 12 kilometers of Venus' atmosphere, characterized by supercritical conditions for the major constituent CO_2, is largely unknown. The only available and reliable temperature profile reaching to the surface was acquired by the Soviet Vega-2 probe in 1985. The planetary boundary layer interacting with the surface plays a key role in the exchanges of energy and angular momentum between Venus' atmosphere and surface. To characterize this layer, we report here a new interpretation of the Vega-2 probe temperature profile, in particular why it is significantly steeper than the adiabatic lapse rate below the altitude of 7 km. It reveals a non-homogeneous layer, close to neutral stability, wherein the abundance of N_2, the second most abundant constituent of the atmosphere with a mixing ratio of 3.5%, gradually decreases to reach a value close to zero near the surface. The implementation of these characteristics of the Venusian air in the LMD Venus General Circulation Model predicts the vertical structure and properties of the deepest atmospheric layers everywhere on Venus.

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204.07 – Equatorial cloud level convection on Venus

In the equatorial region on Venus, a clear cloud top morphology difference depending on solar local time has been observed through UV images. Laminar flow shaped clouds are shown on the morning side, and convective-like cells on the afternoon side (Titov et al. 2012). Baker et al. (1998) suggested that deep convective motions in the low-to-middle cloud layers at the 40–60 km range can explain cellular shapes. Imamura et al. (2014), however argued that this cannot be a reason, as convection in the low-to-middle cloud layers can be suppressed near sub solar regions due to a stabilizing effect by strong solar heating. We suggest that the observed feature may be related to strong solar heating at local noon time (Lee et al. 2015). Horizontal uneven distribution of an unknown UV absorber and/or cloud top structure may trigger horizontal convection (Toigo et al. 1994). In order to examine these possibilities, we processed 1-D radiative transfer model calculations from surface to 100 km altitude (SHDOM, Evans 1998), which includes clouds at 48-71 km altitudes (Crisp et al. 1986). The results on the equatorial thermal cooling and solar heating profiles were employed in a 2D fluid dynamic model calculation (CReSS, Tsuboki and Sakakibara 2007). The calculation covered an altitude range of 40-80 km and a 100-km horizontal distance. We compared three conditions; an 'effective' global circulation condition that cancels out unbalanced net radiative energy at equator, a condition without such global circulation effect, and the last condition assumed horizontally inhomogeneous unknown UV absorber distribution. Our results show that the local time dependence of lower level cloud convection is consistent with Imamura et al.'s result, and suggest a possible cloud top level convection caused by locally unbalanced net energy and/or horizontally uneven solar heating. This may be related to the observed cloud morphology in UV images. The effective global circulation condition, however, can "remove" such cloud top level convection. The later one consists with measured high static stability at the cloud top level from radio occultation measurement.

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204.08 – High-resolution numerical simulation of Venus atmosphere by AFES (<u>A</u>tmospheric general circulation model <u>F</u>or the <u>E</u>arth<u>S</u>imulator)

We have developed an atmospheric general circulation model (AGCM) for Venus on the basis of AFES (AGCM For the Earth Simulator) and performed a high-resolution simulation (e.g., Sugimoto et al., 2014a). The highest resolution is T639L120; 1920 times 960 horizontal grids (grid intervals are about 20 km) with 120 vertical layers (layer intervals are about 1 km). In the model, the atmosphere is dry and forced by the solar heating with the diurnal and semi-diurnal components. The infrared radiative process is

simplified by adopting Newtonian cooling approximation. The temperature is relaxed to a prescribed horizontally uniform temperature distribution, in which a layer with almost neutral static stability observed in the Venus atmosphere presents. A fast zonal wind in a solid-body rotation is given as the initial state.
Starting from this idealized superrotation, the model atmosphere reaches a quasi-equilibrium state within 1 Earth year and this state is stably maintained for more than 10 Earth years. The zonal-mean zonal flow with weak midlatitude jets has almost constant velocity of 120 m/s in latitudes between 45°S and 45°N at the cloud top levels, which agrees very well with observations. In the cloud layer, baroclinic waves develop continuously at midlatitudes and generate Rossby-type waves at the cloud top (Sugimoto et al., 2014b). At the polar region, warm polar vortex surrounded by a cold latitude band (cold collar) is well reproduced (Ando et al., 2016). As for horizontal kinetic energy spectra, divergent component is broadly (k > 10) larger than rotational component compared with that on Earth (Kashimura et al., in preparation). We will show recent results of the high-resolution run, e.g., small-scale gravity waves attributed to large-scale thermal tides.

Sugimoto, N. et al. (2014a), Baroclinic modes in the Venus atmosphere simulated by GCM, Journal of Geophysical Research: Planets, Vol. 119, p1950-1968.
Sugimoto, N. et al. (2014b), Waves in a Venus general circulation model, Geophysical Research Letters, Vol. 41, p7461–7467.
Ando, H., Sugimoto, N. et al. (2016), The puzzling Venusian polar atmospheric structure reproduced by a general circulation model, Nature Communications, Vol. 7, 10398, p1-8

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204.09 – Space-based and Earth-based Prospects for Measuring the Moment of Inertia of Venus

The moment of inertia is an essential integral constraint on models of planetary interiors. Our ignorance about Venus's moment of inertia prevents us from obtaining definite answers to key questions related to the size of the core, the thermal evolution history of the planet, the absence of a global magnetic field, and the evolution of the spin state. The technical challenge and cost of Venus landers make a direct measurement of the core size with seismology unlikely in the near future. For the same reasons, lander-based measurements of the spin precession rate, which yields the moment of inertia, are improbable in the near term. Tracking of the spin axis orientation with spacecraft or Earth-based radar over a decade or more offers more promising avenues. We use a precession model and the characteristics of existing data sets to quantify measurement prospects. The best Magellan estimates of the pole orientation have uncertainties of ~15 arcseconds (Konopliv et al., 1999) and an epoch that corresponds to the mid-point of the observations (~Oct. 1993). We describe achievable measurement uncertainties for a variety of scenarios including an additional spacecraft data point (e.g., at epoch 2023) with comparable or better precision than that of Magellan. Our 14 existing Earth-based radar observations obtained in 2006-2014 are sufficient to improve upon the best Magellan values and to unambiguously detect Venus's spin precession. We describe these results and quantify the uncertainties achievable on spin precession rate and moment of inertia with additional observations in the 2016-2023 interval. The Earth-based radar technique yielded a measurement of the spin axis orientation of Mercury with <5 arcsecond precision (Margot et al., 2012) that was later validated to <1 arcsecond level agreement with an independent, MESSENGER-based estimate (Stark et al., 2015).

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205 – Mission Showcase: New Horizons at Pluto Results

205.01 – Geology and Composition of Pluto and Charon from New Horizons

Data gathered by New Horizons during its July 2015 flyby has revolutionized our understanding of the geology and surface composition of Pluto and Charon. While much of Pluto's ice shell is ancient and rigid, as evinced by locally high crater densities and deep graben, much of the surface has been reworked, up to the present day, by a bewildering variety of geological processes. These include deposition and erosion of kilometers of mantle material, sublimation, apparent cryovolcanism, chaotic breakup of the crust to form rugged mountains, erosion and creation of channel networks by probable glacial action, and active glaciation. Pluto's anti-Charon hemisphere is dominated by 1000 km wide field of actively convecting nitrogen and other ices, informally called Sputnik Planum, occupying a large depression of probable impact origin. Color and composition is very varied, and is dominated by dark red tholins and N_2, CH_4, and CO ices, with H_2O ice bedrock also exposed in many places. Apart from Sputnik Planum, color and composition is strongly correlated with latitude, showing the importance of insolation in controlling ice distribution.
Charon shows pervasive extensional tectonism and locally extensive cryovolcanic resurfacing, both dating from early in solar system history. Its color and surface composition, dominated by H_2O ice plus NH_3 hydrate, is remarkably uniform apart from a thin deposit of dark red material near the north pole which may be due to cold-trapping and radiolysis of hydrocarbons escaping from Pluto.
Neither Pluto nor Charon is likely to have experienced tidal heating during the period when observable landforms were created. Charon's surface shows resurfacing comparable in extent and age to many Saturnian and Uranian satellites such as Dione or Ariel, suggesting that observed activity on these satellites may not necessarily be tidally-driven. Pluto demonstrates that resurfacing on small volatile-rich icy bodies can be powered for at least 4.5 Ga by ongoing radiogenic and residual early heat alone, though the fact that Triton shows much more pervasive resurfacing than Pluto provides some evidence that Triton, unlike Pluto, has access to an additional heat source, presumably tidal.

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Contributing team(s): The New Horizons Geology/Geophysics and Composition Theme Teams

205.02 – New Horizons: Gas and Plasma in the Pluto System

NASA's New Horizons mission gave us information about gas and plasma in the Pluto system from Pluto's surface up to a distance of ~200,000 km beyond Pluto. This review will give an overview of our current theories and observations of the near-surface atmospheric structure; the properties, production and settling of Pluto's ubiquitous haze; the minor atmospheric species and atmospheric chemistry; the energetics and high-altitude thermal structure; the escape rate and the pickup of methane ions; the effect of methane impacting Charon; and Pluto's heavy-ion tail. Details are given in other presentations at this conference.
This work was supported by NASA's New Horizons project.

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Contributing team(s): New Horizons Atmospheres Science Theme Team, New Horizons Particles and Plasma Science Theme Team

205.03 – Spectroscopy of Pluto's Small Satellites

On July 14, 2015, *New Horizons* made its closest approach to the Pluto system. Among its many tasks were spectroscopic observations of Nix, Hydra and Kerberos using LEISA (Linear Etalon Imaging Spectral Array), the near infrared imaging spectrograph, and component of the Ralph instrument (Reuter, D.C., Stern, S.A., Scherrer, J., et al. 2008, Space Sci. Rev. 140, 129). Shapes and composition inferred from images were discussed in Weaver et al. (2016, Science, 351). Styx was not observed with LEISA because it was too distant and faint.
Observations of Nix were made at 60,000 and 162,000 km from *New Horizons.* At best, Nix filled ~130 LEISA pixels. At the continuum level, the disk integrated spectrum has an*I/F*~0.4 and a blue slope. Evident in the spectrum are deep bands at 1.5, 1.65 and 2.0 µm, indicating crystalline H_2O-ice. At band minimum, the *I/F*~0.1 and 0.05 for the 1.5 and 2.0 µm bands, respectively. These nearly saturated bands suggest that H_2O-ice is either large grained or very pure. We also see an absorption band at 2.21 µm that well matches NH_3-hydrate.
Observations of Hydra were made at 240,000 and 370,000 km from *New Horizons.* Hydra was barely resolved and covered ~3-5 LEISA pixels. Hydra's spectrum has a continuum*I/F*~0.35, a blue slope weaker than Nix's, crystalline H_2O-ice and the 1.5 and 2.0 µm bands have minimum *I/F*~0.12 and 0.07, respectively. Since the bands on Hydra are slightly weaker, the H_2O-ice grains are either smaller or contaminated by a greater fraction of dark material. Hydra's spectrum also shows the NH_3-hydrate absorption at 2.21 µm, but like the H_2O-ice bands, it too appears weaker on Hydra than Nix.
Finally, *New Horizons* made a LEISA observation of Kerberos at 394,000 km distance. At a scale of 24 km/pix, Kerberos fills ~40% of a LEISA pixel. The signal-to-noise of the data is low. Nonetheless, we attempt to extract the spectrum.
At DPS, we will present spectra of all three objects, examine the disk resolved spectra of Nix, present Hapke models and discuss why the H_2O and NH_3-hydrate bands appear deeper on Nix and Hydra than on Charon.
This work was supported by NASA's New Horizons project.
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Contributing team(s): the New Horizons Surface Composition Theme Team

205.04 – Sputnik Planum, Pluto: Composition, Geology, and Origin

Large-grained nitrogen ice dominates Sputnik Planum (SP, all names herein being informal), both spectroscopically and rheologically, but spectroscopic evidence also exists for a considerable volume fraction of methane ice (Protopapa *et al.*, *Icarus*, submitted). If true, this considerably broadens the range of possible viscosity contrasts controlling cellular convection within SP (see McKinnon *et al.*, *Nature 2016*), while potentially complicating buoyancy arguments regarding the numerous "icebergs," especially for those at the western margin where the Hillary and Norgay Montes sources must be predominantly water-ice owing to their great topographic heights (Moore *et al.*, *Science* 2016). Bergs carried into SP by glacial flow from the Tombaugh Regio uplands to the east must themselves also be erodible at the downwelling margins of convection cells, for otherwise the entire planum surface would become choked, Sargasso-like, over geologic time. Within SP, the cellular pattern loses its distinctive trough-bounded topographic signature towards the northwest, which is apparently not simply a solar incidence angle effect; this transition coincides with a lower surface N_2 and greater CH_4 abundance. Towards the south, the cellular pattern ceases, presumably due to a shallowing of the nitrogen-rich layer (which decreases the Rayleigh number, or convective drive), and which is consistent with the water-ice basement topography expected from an oblique, basin-forming impact on a sphere. The "stability" of the southern SP surface apparently promotes development of pits by sublimation, but both relict cell boundaries and pit ensembles show evidence of shear flow to the south. Upwelling centers within cells also show photometric evidence for elongation to the south, meaning these cells are not simply plumes, but longitudinal convective rolls. Simple scaling arguments suggest surface velocities on the order of 1 cm/yr to the south. This suggests a surface age for southern SP in excess of 10 Myr, but likely consistent with an impactor population deficient in smaller crater-forming bodies (see talk by Singer *et al.*, this meeting).
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206 – Comets: Physical Characterization (Coma): Outbursts, Dust, and Gas

206.01 – Dust grains in the coma of 67P/Churyumov-Gerasimenko – link with surface properties and cometary activity

The imaging spectrometer VIRTIS and the dust analyzer GIADA, onboard Rosetta, made an extensive observation of the dust particles in the coma of the comet 67P/Churyumov-Gerasimenko. From the analysis of GIADA data, two different kind of particles have been revealed, compact and fluffy with different compositions and dynamical properties. Compact particles are characterized by densities of about 10^3 kg/m^3, while fluffy particles have an almost fractal nature, with densities less than 1 kg/m^3.
In this work we present the initial results of a model linking the dust flux distribution, as obtained from a theoretical thermal nucleus model, with a model describing the dynamics of aspherical grains in the coma. The results are discussed in the context of the latest observations from VIRTIS and GIADA instruments.
The 2D nucleus thermal model, when applied to the real shape of the comet, provides the size distribution and physical properties of the emitted grains at different times and location on the surface. The thermal model can simulate grains of various size distribution, composition and physical properties. This information is used as an input for the dust dynamical model that follows the emitted

particles in the coma. The main source of heating is the solar illumination. In the dust dynamical model, the grain trajectory of emitted particles remains in a plane perpendicular to the rotational axis and the direction of illumination is taken to be in the same plane (i.e. does not cause transversal forces). The dust particles are assumed to be isothermal convex bodies and temperature changes only induce modest changes in the aerodynamic force (twice higher temperature changes aerodynamic force less than ~30%). This study reviews the theoretical values at which temperature difference starts to play a role on the dynamics. We discuss to what extent the particle's temperature affects the terminal velocities of the dust grains in the 67P coma in dependence on their mass and temperature constrained by the observations.

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Contributing team(s): VIRTIS, GIADA

206.02 – Characterizing the Large (cm-size) Grains Around Comet 103P/Hartley 2

During the flyby of comet 103P/Hartley 2, two populations of bright grains were identified in the coma. Small, 1 µm-sized, water ice-rich grains were observed near the small end of the nucleus that were dragged from the interior by CO_2 gas emissions. At closest approach a population of larger grains was clearly seen in visible images off the large lobe. The estimated brightness of the isolated grains suggests that they are likely cm-sized particles and likely water ice-rich. Both sets of grains were simultaneously observed in visible images, at two different resolutions, and by Deep Impact infrared spectrometer. However, because of the difficulty in finding isolated grains in the infrared slit, the population of larger grains has not previously been characterized. Doing so allows us to determine both the reflected and thermal properties of the grains, which when compared to visible images can be used to constrain the size of the grains. Their spectral properties can also be used to definitively detect water ice as has been assumed from visible albedos. In addition, the infrared spectra can be used estimate the relative abundance and particle sizes of ice and non-ice components. The velocity and dynamics of these larger grains can also be characterized. These data will be compared with those of the population of smaller grains emanated directly from the nucleus. Funding from NASA'S Discovery Data Analysis Program (NNX16AJ93G) is greatfully acknowledged.

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206.03 – Characterization of Comet 252P/LINEAR during its 2016 Earth Encounter

Comet 252P/LINEAR had a close encounter to Earth at 14 lunar distances in March 2016, representing one of the closest encounters of known comets in history and a good opportunity to measure its nucleus size and to resolve its inner coma. Observations from previous apparitions suggested a small nucleus of about or less than 1 km, and very weak activity for this comet. The similarity between the orbits of 252P and P/2016 BA16 suggests that they might be a pair of fragments from one common parent comet. We imaged 252P with the Hubble Space Telescope Wide Field Camera 3 through r'- and V-band filters over ~45 min on March 14 and over ~8 hours on April 4, 2016 at pixel scales down to 1.4 km/pix. The dust coma shows a strong enhancement in the sunward direction within about 1".5 (about 100 km at the comet) for both epochs. Image enhancement with 1/rho normalization shows that the sunward feature moves about the nucleus for ~60 deg in the second epoch, consistent with a ~7.35-hr period. The r'-band partial lightcurve measured in the April 4 images in a 0".2-radius aperture shows variability of about 0.14 mag or larger. This partial lightcurve is not consistent with the 7.35-hr period, but is consistent with a periodicity of ~5.5 hr or its multiples. The r'-band mean value of Afrho is 13 cm for March 14 and 46 cm for April 4 in a 0".2-radius aperture. We will also measure the nucleus size of this comet, and discuss its implications about the evolutionary state of the comet.

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206.04 – Recent Cryovolcanic Activity of Comet 29P/Schwassmann-Wachmann 1

The centaur Comet 29P/SW1 is a large 60-km object which appears to be uniquely active, almost certainly as a consequence of an extremely slow (57-d) rotation rate of its nucleus. It exhibits outbursts, which are explosive by nature and some of which appear to be associated with enduring cryovolcanoes. High-cadence precision photometry during 2014-2016 has quantified its recent behaviour in unprecedented detail. Photometry of the inner coma showing more than 20 discrete outbursts will be presented and discussed in relation to a gas-exsolution mechanism involving sub-crustal liquid phases. The results to be shown confirm earlier findings that a single outburst can trigger one or more follow-up outbursts from other sources within a few days of the initial event. Given that this object is most probably a recent interloper into the inner solar system, having originated from the trans-Neptunian region, it is a worthy target for further investigation. Its large nucleus and Hill sphere radius of ~30000 km would facilitate an orbiting probe, and with an escape velocity of ~20 m/s, its inner coma would be expected to clear relatively rapidly during quiescent intervals that can last for several months. Given its likely provenance as a TNO, prompt ground-based spectroscopic observation of its expanding coma following bright outbursts, which appear to arise from various locations on its nucleus, is to be encouraged.

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Contributing team(s): Las Cumbres Observatory Global Telescope team

206.05 – The outburst sequence of 67/P on 2015 September 13 as seen by VIRTIS/Rosetta

On 13 September, 2015, the Visual, Infrared and Thermal Imaging Spectrometer (VIRTIS) onboard Rosetta observed strong, anomalous activity of the coma of 67P/Churyumov-Gerasimenko starting at 13:40 UTC, in a range of latitude between -26° and -40° and longitude between 265° and 280°. VIRTIS is an imaging spectrometer in the spectral range 0.25-1 mm (VIRTIS- M) and a high-resolution spectrometer in the range 2-5 mm (VIRTIS- H) on board the Rosetta spacecraft. The instrument observed one large outburst followed by two mini-outbursts that occurred approximately one hour thereafter. This is probably the highest temporally resolved dataset available from a remote sensing instrument of an outburst observed

on 67P. The data cover the full spectral range of the two channels and allow studying both dust and gas properties to derive information on the underlying physical mechanism driving the outbursts.
The preliminary results of the outburst sequence indicate that they occur on the daylight side of the nucleus. They are characterized by a short duration and decay that lasts typically 15 minutes for the large outburst and 5 minutes for the two mini outbursts. The spatial and temporal distribution of the dust indicates a complex light curve for each event showing internal structures. The large outburst shows a bluer color than the background coma in the range of 2-2.5mm with a value around 1% per 100 nm, which can be interpreted as a change of dust properties and perhaps the presence of icy grains. However, the spectral signature of water ice at 3 mm is not detected in the outburst material, or in the background coma. In the range of 0.45-0.75 mm, the spectral slope shows a redder value in the outburst material (15 % per 100 nm) than in the background (12 % per 100 nm).The dust temperature, measured by fitting the thermal continuum, is much higher for the outburst material than for the background coma. No significant increase in CO2 or H2O production is detected. Both the bluer color in the IR and the higher temperature suggest that the outburst material is dominated by small dust particles. Further analysis will be presented during the congress.

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Contributing team(s): VIRTIS-Team

206.06 – Are Comet Outbursts the Result of Avalanches?

Recently, Rosetta became the first spacecraft to make high-resolution observations of a comet outburst (a rapid, ephemeral increase in dust production) emerging from the surface of a comet nucleus. These outbursts occurred near perihelion, lasted only a few minutes, and produced a highly collimated outburst plume without any corresponding increase in H2O or CO2 gas production (See abstract by Rinaldi et al.). These observations cannot be explained by proposed driving outburst mechanisms (such as crystallization of amorphous ice, cryovolcanic gas exsolution, or explosive outgasing of subsurface chambers), all of which are driven by gas, and would therefore lead to an increase in the gas production.
We propose instead that the observed outbursts on Comet 67P/Churyumov-Gerasimenko (hereafter 67P) are the result of cometary avalanches. The surface of 67P contains many cliffs and scarps, with dusty surface layers blanketing the shallower slopes above and below these steep surfaces. The Rosetta spacecraft returned clear evidence of mass wasting, which form icy talus fields that are the source of much of 67P's cometary activity. Additionally, Rosetta observed morphological changes over time in the shallower, dusty surface layers above these steep slopes, which suggest that avalanches periodically release dusty materials onto these active talus fields.
Here we present the results of a numerical simulation of dusty material avalanching into an active area (active talus field). These simulations show that such avalanches will generate a transient, highly collimated outburst plume that closely matches the observed morphology of the outbursts emanating from the surface of 67P. This mechanism predicts that cometary outbursting should not be directly associated with any increase in gas production, consistent with observations. Additionally, we show that regions of the nucleus that have sourced outburst plumes contain steep surfaces (above the angle of repose), which is required for the generation of avalanches and the viability of this mechanism.

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206.07 – Small is different: RPC observations of a small scale comet interacting with the solar wind

Rosetta followed comet 67P from low activity at more than 3 AU heliocentric distance to peak activity at perihelion and then out again. We study the evolution of the dynamic plasma environment using data from the Rosetta Plasma Consortium (RPC). Observations of cometary plasma began in August 2014, at a distance of 100 km from the comet nucleus and at 3.6 AU from the Sun. As the comet approached the Sun, outgassing from the comet increased, as did the density of the cometary plasma. Measurements showed a highly heterogeneous cold ion environment, permeated by the solar wind. The solar wind was deflected due to the mass loading from newly added cometary plasma, with no discernible slowing down. The magnetic field magnitude increased significantly above the background level, and strong low frequency waves were observed in the magnetic field, a.k.a. the "singing comet". Electron temperatures were high, leading to a frequently strongly negative spacecraft potential. In mid to late April 2015 the solar wind started to disappear from the observation region. This was associated with a solar wind deflection reaching nearly 180°, indicating that mass loading became efficient enough to form a solar wind-free region. Accelerated water ions, moving mainly in the anti-sunward direction, kept being observed also after the solar wind disappearance. Plasma boundaries began to form and a collisionopause was tentatively identified in the ion and electron data. At the time around perihelion, a diamagnetic cavity was also observed, at a surprisingly large distance from the comet. In late 2016 the solar wind re-appeared at the location of Rosetta, allowing for studies of asymmetry of the comet ion environment with respect to perihelion. A nightside excursion allowed us to get a glimpse of the electrodynamics of the innermost part of the plasma tail. Most of these phenomena are dependent on the small-scale physics of comet 67P, since for most of the Rosetta mission the solar wind - comet atmosphere interaction region is smaller than the pickup ion gyroradius in the undisturbed solar wind.

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Contributing team(s): Rosetta Plasma Consortium Team

206.08 – Investigating the correlations between water coma emissions and active regions in comet 67P/ Churyumov-Gerasimenko

Vibrational emission lines of H_2O and CO_2 at 2.67 and 4.27 µm, respectively, were identified by the VIRTIS spectrometer (Bockelée-Morvan et al., 2015; Migliorini et al., 2016; Fink et al., 2016) and mapped from the surface up to about 10 km altitude with a spatial resolution on the order of tens of meters per pixel (Migliorini et al., 2016).
Data acquired in April 2015 with the VIRTIS spectrometer on board the Rosetta mission, provided information on the possible

correlation between the H_2O emission in the inner coma and the exposed water deposits detected in the Hapi region on the 67P/Churyumov-Gerasimenko surface (Migliorini et al., 2106; De Sanctis et al., 2015). Further bright spots attributed to exposed water ice have been identified in other regions by OSIRIS at visible wavelengths (Pommerol, et al., 2015) and confirmed in the infrared by VIRTIS-M in the Imothep region (Filacchione et al., 2016). The small dimensions of these icy spots - approximately 100x100 m (Filacchione et al., 2016) – and the relatively small amount of water ice (about 5%) make uncertain the correlation with the strong emissions in the coma.
However, VIRTIS data show that the distribution of jet-like emissions seems to follow the distribution of cliffs and exposed areas identified in the North hemisphere with OSIRIS camera (Vincent et al., 2015). These areas are mainly concentrated in correspondence of comet's rough terrains, while a lack of active regions is observed in the comet's neck. Nevertheless, strong H_2O emission is observed above the neck with VIRTIS. This might be a consequence of gas jets that are originated in the surrounding of the neck but converging towards the neck itself. This gaseous activity is the main driver of the dust upwelling (Migliorini et al, 2016; Rinaldi et al., in preparation)
In this paper, we investigate the relationship between H_2O vapour observed with VIRTIS within 5 km from the 67P/C-G nucleus and the exposed regions identified by OSIRIS on the surface (in the timeframe March to April 2015) with an attempt to address possible variations with the heliocentric distance.
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Contributing team(s): VIRTIS Team

206.09 – Investigation into the disparate origin of CO_2 and H_2O outgassing for comet 67P

We present an investigation of the emission intensity of CO_2 and H_2O and their distribution in the coma of 67P/ Churyumov-Gerasimenko obtained by the VIRTIS-M imaging spectrometer on the Rosetta mission. We analyze 4 data cubes from Feb. 28, and 7 data cubes from April 27, 2015. For both data sets the spacecraft was at a sufficiently large distance from the comet to allow images of the whole nucleus and the surrounding coma.
We find that unlike water which has a reasonably predictable behavior and correlates well with the solar illumination, CO_2 outgasses mostly in local regions or spots. Furthermore for the data on April 27, the CO_2 evolves almost exclusively from the southern hemisphere, a region of the comet that has not received solar illumination since the comet's last perihelion passage. Because CO_2 and H_2O have such disparate origins, deriving mixing ratios from local column density measurements cannot provide a meaningful measurement of the CO_2/H_2O ratio in the coma of the comet. We obtain total production rates of H_2O and CO_2 by integrating the band intensity in an annulus surrounding the nucleus and obtain pro-forma production rate CO_2/H_2O mixing ratios of ~5.0% and ~2.5% for Feb. 28 and April 27 respectively. Because of the highly variable nature of the CO_2 evolution we do not believe that these numbers are diagnostic of the comets bulk CO_2/H_2O composition. We believe that our investigation provides an explanation for the large observed variations reported in the literature for the CO_2/H_2O production rate ratios. Our mixing ratio maps indicate that, besides the difference in vapor pressure of the two gases, this ratio depends on the comet's geometric shape, illumination and past orbital history.
Our annulus measurement for the total water production for Feb. 28 at 2.21AU from the sun is $2.5x10^{26}$ molecules/s while for April 27 at 1.76 AU it is $4.65x10^{26}$. We find that about 83% of the H_2O resides in the illuminated portion of our annulus and about 17% on the night side. A rough estimate of the water surface evaporation rate of the illuminated nucleus for April 27 yields about $5x10^{19}$ molecules/s m^2.
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Contributing team(s): VIRTIS team

207 – Extrasolar Planets: Giant Planet Atmospheres II

207.01 – Optical phase curves of exoplanets at small and large phase angles

Phase curves and secondary eclipses provide key information on exoplanet atmospheres. Indeed, recent work on close-in giant planets observed by Kepler has shown that it is possible to constrain various reflecting, dynamical and thermal properties of their atmospheres from the analysis of the planets' phase curves. This presentation discusses new diagnostic possibilities for the characterization of exoplanet atmospheres with optical phase curves. These possibilities benefit from the fact that at optical wavelengths the signal from the planet is either partly or mostly determined by scattering of starlight within its atmosphere, which entails that the structure of the planet's phase curve mimics to some extent the optical properties of the atmospheric medium. In particular, we will show how cloud properties such as the particle size or the atmospheric scale height might be constrained through observations at small (i.e. near transit) and large (i.e. near occultation) phase angles. We will emphasize how the interpretation of optical phase curves differs from the interpretation of phase curves obtained at longer wavelengths. The conclusions are relevant to the study of Kepler planets, but also to the investigation of phase curves to be delivered by upcoming space missions such as CHEOPS, JWST, PLATO and TESS.
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207.02 – Transiting Exoplanet Studies and Community Targets for JWST's Early Release Science Program

The James Webb Space Telescope (JWST) will likely revolutionize transiting exoplanet atmospheric science; however, it is unclear precisely how well it will perform and which of its myriad instruments and observing modes will be best suited for transiting exoplanet studies. We will describe a prefatory JWST Early Release Science (ERS) Cycle 1 program that focuses on testing specific observing modes to quickly give the community the data and experience it needs to plan more efficient and successful transiting exoplanet characterization programs in later cycles. We will also present a list of "community targets" that are well suited to achieving these goals. Since most of the community targets do not have well-characterized atmospheres, we have initiated a preparatory HST + Spitzer observing program to determine the presence of obscuring clouds/hazes within their atmospheres. Measurable spectroscopic features are needed to establish the optimal resolution and wavelength regions for exoplanet characterization. We will present preliminary results from this preparatory observing program and discuss their implications on the pending JWST ERS proposal deadline in mid-2017.
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Contributing team(s): "Enabling Transiting Exoplanet Science with JWST" workshop attendees

207.03 – Beginning a new chapter in the characterization of directly imaged exoplanets: the science of MIRI

The next major space facility to characterize the atmosphere of exoplanets will be the JWST. Among its instruments the Mid-Infrared instrument (MIRI) will perform the first ever characterization of young giant exoplanets observed by direct imaging in the 5 -28 microns wavelength range.

Retrieving the precise set of parameters of these objects, such as luminosity, temperature, surface gravity, mass, and age is extremely important as it supplies information about the initial entropy of the planets and hence it allows us to shed light on their formation mechanism.

The new extreme adaptive optic cameras (e.g. SPHERE, GPI) are already providing excellent constraints on these parameters, but the spectral window in which they are operating is limited to near IR so that the uncertainties are still significant. Therefore, since observations taken on a longer wavelength range are mandatory for reducing them, MIRI will be playing a key role in this new chapter of exoplanetary characterization.

Furthermore, MIRI will give us the opportunity to probe for the first time the presence of ammonia in the atmosphere of the coldest known young giants (T < 1000 K). Notice that the ammonia spectral signature is a further useful indicator of equilibrium and temperature in the planetary atmosphere.

In this work we have used the Exoplanet Radiative-convective Equilibrium Model (Exo-REM), developed by Baudino et al. (2015) and tailored for directly imaged exoplanets, to quantify the constraints on the planetary parameters that MIRI will bring.

We simulated the MIRI coronographic and Low-resolution spectrometer observations for a set of 13 known directly imaged exoplanetary systems. Subsequently, taking into account various source of noise and the photometric precision, we show to which accuracy the exoplanetary parameters (temperature, gravity, chemical composition) can be determined when adding MIRI observations, and we provide the significance of the ammonia detection.

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207.04D – Investigating Metal-Enrichment, Tidal Heating, and Clouds in the Emission and Transmission Spectra of GJ 436b

One of the legacies of the Kepler mission is the preponderance of planets between Earth and Neptune in radius; a major goal of atmospheric studies is to characterize planets spanning this size range. What is the range of compositions of these objects, and does these compositions correlate with planet mass (or some other property)? Do they have clouds and/or hazes in their atmospheres? How do atmospheric dynamics shape our observations? The Neptune-mass GJ 436b is one of the most-studied transiting exoplanets to date, with repeated measurements of both its thermal emission and transmission spectra. I will discuss new observations of GJ 436b's thermal emission at 3.6 and 4.5 µm, which reduce the uncertainties in estimates of GJ 436b's flux at those wavelengths and demonstrate consistency between *Spitzer* observations spanning more than 7 years. For the first time, we analyze the *Spitzer* thermal emission photometry and *Hubble* WFC3 transmission spectrum in tandem. I will show how we use a powerful dual-pronged modeling approach, comparing these data to both self-consistent and retrieval models. We vary the metallicity, intrinsic luminosity from tidal heating, disequilibrium chemistry, and heat redistribution. We also study the potential effect of both clouds and photochemical hazes on the spectra, but do not find strong evidence for either. The self-consistent and retrieval modeling combine to suggest that GJ 436b has a high atmospheric metallicity, with best fits at or above several hundred times solar metallicity, tidal heating warming its interior with best-fit intrinsic effective effective temperatures around 300–350 K, and disequilibrium chemistry. We suggest that Neptune-mass planets may be a more diverse class than previously imagined, with a range of metal-enhancements spanning over an order of magnitude from 50–100 to perhaps over 1000× solar metallicity. High fidelity observations with instruments like JWST will be critical for characterizing this diversity.

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207.05 – Exploring the Relationship Between Planet Mass and Atmospheric Metallicity for Cool Giant Planets

Measurements of the average densities of exoplanets have begun to help constrain their bulk compositions and to provide insight into their formation locations and accretionary histories. Current mass and radius measurements suggest an inverse relationship between a planet's bulk metallicity and its mass, a relationship also seen in the gas and ice giant planets of our own solar system. We expect atmospheric metallicity to similarly increase with decreasing planet mass, but there are currently few constraints on the atmospheric metallicities of extrasolar giant planets. For hydrogen-dominated atmospheres, equilibrium chemistry models predict a transition from CO to CH_4 below ~1200 K. However, with increased atmospheric metallicity the relative abundance of CH_4 is depleted and CO is enhanced. In this study we present new secondary eclipse observations of a set of cool (<1200 K) giant exoplanets at 3.6 and 4.5 microns using the Spitzer Space Telescope, which allow us to constrain their relative abundances of CH_4 and CO and corresponding atmospheric metallicities. We discuss the implications of our results for the proposed correlation between planet mass and atmospheric metallicity as predicted by the core accretion models and observed in our solar system.

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207.06 – A Predictive Theory for the Atmospheric Circulation of Hot Jupiters

The atmospheres of extremely close in extrasolar giant planets, or "hot Jupiters," are beginning to be analyzed as a population. Synthesizing observations of many different planets provides insight into the nature of the atmospheric circulation of these objects. Notably, the dayside-to-nightside brightness temperature difference of these tidally locked objects has been found to increase with increasing incident stellar flux in all observed infrared wavelength bands. Additionally, there is an eastward infrared phase shift on these planets, which shows tentative evidence of decreasing longitudinal offset from the substellar point with increasing day-to-night temperature differences and hence increased stellar flux. Motivated by these observations, we developed an analytic theory from first principles that predicts dayside-nightside temperature differences and horizontal and vertical wind speeds as a function of incident stellar flux, rotation rate, atmospheric composition, potential frictional drag strength, and pressure level in the atmosphere. We find that our analytic theory captures well the observed trend of increasing dayside-nightside temperature difference with increasing incident stellar flux. When applied to individual planets, the theory matches well the dayside-nightside temperature difference for planets with large incident stellar flux, but under-predicts the dayside-nightside temperature difference for planets with lower incident stellar flux. We interpret this as due to nightside clouds obscuring the nightside infrared radiation, causing an increase in the day-night temperature contrast. Assuming an eastward equatorial jet speed, we can also use this theory to estimate the infrared phase offset. We find that our theory can match all but one of the observed phase offsets with varying drag strength. Lastly, to understand how atmospheric circulation varies with incident stellar flux and drag strength, we perform three-dimensional numerical simulations including a double-grey radiative transfer scheme. Using these simulations, we confirm our theoretically predicted trends of increasing day-night temperature difference and decreasing infrared phase offset with increasing stellar flux.

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207.07 – Cloud and Haze in the Atmospheres of Wide-Separation Exoplanets

Imaging and characterizing wide-separation exoplanets with spaceborne coronagraph will write a new chapter of exoplanet science. Most of the exoplanets to be observed by coronagraph will be located further away from their parent stars than is Earth from the Sun. These "cold" exoplanets have atmospheric environments conducive for the formation of water and/or ammonia clouds by condensation. Above the condensation clouds, photochemical processes driven by UV irradiation can lead to formation of haze particles. Understanding the cloud and haze in the atmosphere of wide-separation exoplanets is essential, because they determine the planets' spectral signal and how well we can measure the planets' atmospheric abundances. Using atmospheric chemistry and radiative transfer models, I find that the mixing ratio of methane and the pressure level of the uppermost cloud deck on these planets can be uniquely determined from their reflection spectra, if a strong band and a weak band of methane are measured at moderate spectral resolutions. This determination can however be biased by a haze layer above the cloud. To constrain the uncertainty, atmospheric photochemistry models are used to estimate the amount of haze particles.

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207.08 – Atmospheric circulation of brown dwarfs and directly imaged extrasolar giant planets with active clouds

Observational evidence have suggested active meteorology in the atmospheres of brown dwarfs (BDs) and directly imaged extrasolar giant planets (EGPs). In particular, a number of surveys for brown dwarfs showed that near-IR brightness variability is common for L and T dwarfs. Directly imaged EGPs share similar observations, and can be viewed as low-gravity versions of BDs. Clouds are believed to play the major role in shaping the thermal structure, dynamics and near-IR flux of these atmospheres. So far, only a few studies have been devoted to atmospheric circulation and the implications for observations of BDs and directly EGPs, and yet no global model includes a self-consistent active cloud formation. Here we present preliminary results from the first global circulation model applied to BDs and directly imaged EGPs that can properly treat absorption and scattering of radiation by cloud particles. Our results suggest that horizontal temperature differences on isobars can reach up to a few hundred Kelvins, with typical horizontal length scale of the temperature and cloud patterns much smaller than the radius of the object. The combination of temperature anomaly and cloud pattern can result in moderate disk-integrated near-IR flux variability. Wind speeds can reach several hundred meters per second in cloud forming layers. Unlike Jupiter and Saturn, we do not observe stable zonal jet/banded patterns in our simulations. Instead, our simulated atmospheres are typically turbulent and dominated by transient vortices. The circulation is sensitive to the parameterized cloud microphysics. Under some parameter combinations, global-scale atmospheric waves can be triggered and maintained. These waves induce global-scale temperature anomalies and cloud patterns, causing large (up to several percent) disk-integrated near-IR flux variability. Our results demonstrate that the commonly observed near-IR brightness variability for BDs and directly imaged EGPs can be explained by the typical cloud-induced turbulent circulation, and in particular, the large flux variability for some objects can be attributed to the global-scale patterns of temperature anomaly and cloud formation caused by atmospheric waves.

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207.09 – Estimating mixing in hot Jupiter atmospheres

Ground- and space-based observations of exoplanets have shown that like solar system planets and brown dwarfs, clouds are ubiquitous in exoplanet atmospheres. However, the dynamics that underpin their formation and transport are still poorly understood. In order to further elucidate the three-dimensional mixing in exoplanet atmospheres, we present a generalized study comparing the dynamics of exoplanets to brown dwarfs and solar system planets. We utilize previously published hot Jupiter GCMs to estimate the microphysical timescales that dictate cloud formation and calculate horizontal and vertical wind profiles, and compare those to these other classes of substellar objects. In doing so, we can provide a framework for which to explain the small cloud particle sizes observed in hot Jupiters, and create a generalized profile for vertical mixing in hot Jupiter atmospheres.

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208 – Trojan Asteroids

208.01 – Rotation Properties of Small Jovian Trojan Asteroids

Jovian Trojan asteroids are of interest both as objects in their own right (we have no spectral analogs among meteorite samples) and as possible relics of Solar System formation. Asteroid lightcurves can give information about processes that have affected a group of asteroids; they can also give information about the density of the objects when enough lightcurves have been collected. We have been carrying out a survey of Trojan lightcurve properties for comparison with small asteroids and with comets. In a recent paper (French*et al.* 2015) we presented evidence that a significant number of Trojans have rotation periods greater than 24 hours. We will report our latest results and compare them with results of sparsely-sampled lightcurves from the Palomar Transient Factory (Waszczak *et al.* 2015). LF, RS, and DR were visiting astronomers at Cerro Tololo Interamerican Observatory, operated by AURA under contract with the NSF, and with the SMARTS Consortium at CTIO. This research was sponsored by NSF Planetary Astronomy grant 1212115.
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Waszczak, A. *et al.* 2015. *A.J.* **150**, Issue 3, I.D. 35.
Author(s): Linda M. French[3], Robert D. Stephens[1], David James[2], Daniel R Coley[1], Brian D. Warner[1], Derrick Rohl[3]
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208.02 – Observations of Candidate Binary Asteroids in the Jovian Trojan and Hilda Populations

Jovian Trojans (hereafter, Trojans) are asteroids in stable orbits at Jupiter's L4 and L5 Lagrange points, and Hilda asteroids are inwards of the Trojans in 3:2 mean-motion resonance with Jupiter. Due to their special dynamical properties, observationally constraining the formation location and dynamical histories of Trojans and HIldas offers key input for giant planet migration models. A fundamental parameter in assessing formation location is the bulk density - with low-density objects associated with an ice-rich formation environment in the outer solar system and high-density objects typically linked to the warmer inner solar system. Bulk density can only be directly measured during a close fly-by or by determining the mutual orbits of binary asteroid systems. With the aim of determining densities for a statistically significant sample of Trojans and Hildas, we are undertaking an observational campaign to confirm and characterize candidate binary asteroids published in Sonnett et al. (2015). These objects were flagged as binary candidates because their large NEOWISE brightness variations imply shapes so elongated that they are not likely explained by a singular equilibrium rubble pile and instead may be two elongated, gravitationally bound asteroids. We are obtaining densely sampled rotational light curves of these possible binaries to search for light curve features diagnostic of binarity and to determine the orbital properties of any confirmed binary systems by modeling the light curve. We present preliminary results from the follow-up campaign of these candidates, including estimates on the densities of objects that appear to be in binary systems and the binary fraction for Trojans and Hildas.
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208.03D – Colors and Properties of Jupiter's Greeks and Trojans

In this Ph.D. talk, I will present the colors and properties of Jupiter Trojan asteroids examined in my dissertation research. The Jupiter Trojan asteroids are minor bodies that orbit 60 degrees in front and 60 degrees behind Jupiter. Because these orbits are stable over the lifetime of the Solar System, the properties of these objects may inform us about the conditions under which the Solar System formed. We present $BVR_{KC}I_{KC}$ photometry for over 100 of the intrinsically brightest and presumably largest members of the L4 and L5 Jupiter Trojans. We use a new principal color component derived by Chatelain et al. 2016 that is indicative of taxonomic types relevant to the Jupiter Trojan asteroids. We previously found that 76% of the largest L5 Jupiter Trojans are consistent with a D-type classification, while 24% show shallower slopes more consistent with X-type and C-type classifications. Here we extend this study to the L4 cloud and compare the two populations, as well as include findings about specific objects that have resulted from these data. Specifically, multiple photometric observations hint at color variation in some objects, and our richest datasets allow for the determination of phase curves and shapes for a handful of the most compelling asteroids including a new shape model and pole solution for 1173 Anchises. Our goal is to use this study to shed light on these fascinating objects and to place the Trojans in context in the larger Solar System.
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208.04 – Ground-based characterization of Eurybates and Orus, two fly-by targets of the Lucy Discovery mission

Lucy is a proposed NASA Discovery mission designed to perform close fly-bys with six Jupiter Trojan asteroids. The mission, which is currently in the Phase A development phase, is planned to launch in 2021 and arrive at the Trojan L4 cloud in 2027.
We report on ground-based light curve observations of two of Lucy's fly-by target candidates: (3548) Eurybates and (21900) Orus. The goal is to characterize their shape, spin state and photometric properties both to aid in the planning of the mission, and to complement the space-borne data.
Each object has been observed over 5 apparitions in a wide range of geocentric ecliptic longitudes. Shape and spin state modeling was performed by using the convex shape inversion method (Kaasalainen, Mottola & Fulchignoni, 2002). Eurybates is a retrograde rotator with a sidereal rotation P_{sid}=8.702724±0.000009 h. It has a moderately elongated shape with equivalent axial ratios a/b=1.08, b/c=1.16. No obvious signs of global non-convexities and/or albedo variegation are detected in its light curves. Orus is also a retrograde rotator with a period P_{sid}=13.48617±0.00007 h. Its approximate axial ratios are a/b=1.14, b/c=1.12. The presence of a large, planar facet in the proximity of the model's North Pole suggests the presence of a large polar crater.
Author(s): Stefano Mottola[1], Simone Marchi[3], Marc W. Buie[3], Stephan Hellmich[1], Mario Di Martino[2], Gerrit Proffe[1], Harold F. Levison[3], Amanda Marie Zangari[3]
Institution(s): *1. DLR - German Aerospace Center, 2. INAF - Osservatorio Astrofisico di Torino, 3. Southwest Research Institute*

208.05 – HST Observations of a Large-Amplitude, Long-Period Trojan: (11351) Leucus

(11351) Leucus (1997 TS25) is a Trojan that is notable for having one of the longest known rotation periods of any small body, T=514 h. A possible cause for this long period would be the existence of a tidally locked binary similar to the already-known long period binary Trojan, (617) Patroclus. If this were the case, the system would become tidally circularized in a time short compared to the age of the solar system. In such a case, the components would be separated by ~0.18 arcsec at lightcurve maximum, resolvable by WFC3. We carried out observations in June 2016, coordinated with groundbased observations to schedule near a maximum to test whether (11351) Leucus is binary. We describe the results of these observations.
Observations of (11351) Leucus are of particular interest because it is a target of the Lucy mission, a Discovery mission currently in phase A and one of five that may be selected in early 2017. Searches for binary Trojans also offer multiple scientific benefits independent of mission status. Orbit-derived mass and density can be used to constrain planetary migration models. Low density is characteristic of bodies found in the dynamically cold Kuiper Belt, a remnant of the solar system's protoplanetary disk. Only one undisputed density has been measured in the Trojans, that of the binary (617) Patroclus, which has a low density of 0.8 g/cm3, similar to the low densities found in the Kuiper Belt. Slow rotators offer a set of targets that are

tidally evolved systems and therefore are among the most attractive potential targets for an HST search.

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208.06 – Ground-based characterization of Leucus and Polymele, two fly-by targets of the Lucy Discovery mission

Lucy is a proposed NASA Discovery mission designed to perform close fly-bys with six Jupiter Trojan asteroids. The mission, which is currently in the Phase A development phase, is planned to launch in 2021 and arrive at the L4 Trojan cloud in 2027. We report on the results of an observational campaign of (11351) Leucus and (15094) Polymele conducted this year. The goal is to characterize their shape, spin state and photometric properties to aid in mission planning and to complement the mission data. Leucus was previously observed by French et al (2013) where they reported a 514 hour rotation period with a lightcurve amplitude as high as 1 magnitude. Our data confirm a long-period and high-amplitude lightcurve but with a period closer to 440 hours. The lightcurve shape has a symmetric double-peaked shape with a ~0.7mag peak-to-peak amplitude. Initial results for Polymele indicate a low-amplitude lightcurve at or below 0.1 mag with a period near 4 hours. Thus, the Lucy target sample includes bodies with among the slowest and fastest rotation rates. Additional observations will be required to further refine the period and pole orientation for both bodies. This year's data are especially challenging due to observing at low galactic latitude. We will report on final results of this year's campaign along with our methods for removing field confusion using optimal image subtraction and photometric calibration based on the new APASS catalog (Henden et al, 2012).

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209 – Asteroid Interiors

209.01 – Fast Prediction of Blast Damage from Airbursts: An Empirical Monte Carlo approach

The February 15, 2013 Chelyabinsk airburst was the first modern bolide whose associated shockwave caused blast damage at the ground (Popova et al., 2013). Near-Earth Object (NEO) impacts in the Chelyabinsk-size range (~20 m) are expected to occur every few decades (Boslough et al., 2015) and therefore we expect ground damage from meteoric airbursts to be the next planetary defense threat to be confronted. With pre-impact detections of small NEOs certain to become more common, decision makers will be faced with estimating blast damage from impactors with uncertain physical properties on short timescales.
High fidelity numerical bolide entry models have been developed in recent years (eg. Boslough and Crawford, 2008; Shuvalov et al., 2013), but the wide range in a priori data about strength, fragmentation behavior, and other physical properties for a specific impactor make predictions of bolide behavior difficult. The long computational running times for hydrocode models make the exploration of a wide parameter space challenging in the days to hours before an actual impact.
Our approach to this problem is to use an analytical bolide entry model, the triggered-progressive fragmentation model (TPFM) developed by ReVelle (2005) within a Monte Carlo formalism. In particular, we couple this model with empirical constraints on the statistical spread in strength for meter-scale impactors from Brown et al (2015) based on the observed height at maximum bolide brightness. We also use the correlation of peak bolide brightness with total energy as given by Brown (2016) as a proxy for fragmentation behaviour. Using these constraints, we are able to quickly generate a large set of realizations of probable bolide energy deposition curves and produce simple estimates of expected blast damage using existing analytical relations.
We validate this code with the known parameters of the Chelyabinsk airburst and explore how changes to the entry conditions of the observed bolide may have modified the blast damage at the ground. We will also present how this approach could be used in an actual short-warning impact scenario.

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209.02 – Seismic wave propagation in granular media

Asteroids and small bodies of the Solar System are thought to be agglomerates of irregular boulders, therefore cataloged as granular media. It is a consensus that many asteroids might be considered as rubble or gravel piles.
Impacts on their surface could produce seismic waves which propagate in the interior of these bodies, thus causing modifications in the internal distribution of rocks and ejections of particles and dust, resulting in a cometary-type comma.
We present experimental and numerical results on the study of propagation of impact-induced seismic waves in granular media, with special focus on behavior changes by increasing compression. For the experiment, we use an acrylic box filled with granular materials such as sand, gravel and glass spheres. Pressure inside the box is controlled by a movable side wall and measured with sensors. Impacts are created on the upper face of the box through a hole, ranging from free-falling spheres to gunshots. We put high-speed cameras outside the box to record the impact as well as piezoelectic sensors and accelerometers placed at several depths in the granular material to detect the seismic wave.
Numerical simulations are performed with ESyS-Particle, a software that implements the Discrete Element Method. The experimental setting is reproduced in the numerical simulations using both individual spherical particles and agglomerates of spherical particles shaped as irregular boulders, according to rock models obtained with a 3D scanner. The numerical experiments also reproduces the force loading on one of the wall to vary the pressure inside the box.
We are interested in the velocity, attenuation and energy transmission of the waves. These quantities are measured in the experiments and in the simulations. We study the dependance of these three parameters with characteristics like: impact speed, properties of the target material and the pressure in the media.
These results are relevant to understand the outcomes of impacts in rubble/gravel pile asteroids.

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209.03 – Geostability of Didymos, the target of the AIDA mission

As the target of the proposed Asteroid Impact & Deflection Assessment (AIDA) mission [1, 2], the near-Earth binary asteroid 65803 Didymos represents a special class of binary asteroid, those whose primaries are at risk of rotational disruption [3]. To support the AIDA mission and gain a better understanding of these binary systems, we investigate the structural stability and dynamic behavior of the Didymos primary and the orbital stability of the secondary using a Soft-Sphere Discrete Element Method (SSDEM)

[4]. The primary and the secondary are modeled as granular assemblies. In the first step of this study, the primary is artificially spun up to the current spin period of 2.26 h using a quasi-static spin-up procedure without considering the secondary [5]. The effects of arrangement and size distribution of constituent particles, bulk density, spin-up path, interparticle friction, and cohesion strength on the dynamic behavior of self-gravitating aggregates are numerically explored. The results show that the strength and stability of a spinning self-gravitating aggregate depend strongly on its internal configuration and material parameters, while its failure mode and mechanism are affected by its internal configuration and the cohesion strength. When cohesion is not included, the Didymos primary rubble-pile model can maintain its shape at the current observed spin rate within the uncertainty of the observed bulk density (< 2.7 g/cc) using material parameters with friction angle of ~30°, which most cohesionless sands can sustain. In the second step, the effect of the secondary on the stability of the primary is studied. The secondary can stably orbit the primary without including cohesion. The results show that the presence of the secondary will slightly reduce the stability of the primary. Our study provides some constraints on the possible physical properties of the Didymos primary.

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210 – The Dynamical Martian Atmosphere

210.01 – Surface Wind Stresses and Triggering of Global Dust Storms on Mars

Global dust storms on Mars occur during summer in the southern hemisphere, but their occurrence in some years and not in others has stubbornly eluded explanation. Shirley (2016, in review, and at arxiv.org/abs/1605.02707) and Mischna and Shirley (2016, in revision, and at arxiv.org/abs/1602.09137) have demonstrated the role of a so-called “coupling term acceleration” (CTA) in modifying the Mars global circulation through potential exchange of Mars' orbital and rotational momenta. The CTA has been incorporated into the MarsWRF general circulation model (GCM), which reveals distinct changes to the circulation due to the CTA, leading to conditions favorable to GDS formation in all years in which perihelion season GDS were observed, and conditions unfavorable in nearly all other years. These circulation changes reveal themselves, in part, through changes in surface wind stress, which is a strong function of near-surface wind speed. We present additional analysis of these results for the past years with perihelion season GDS (7 in total) showing commonalities in the evolution of surface stresses in the season leading up to GDS initiation. Specifically, the enhancement of surface stress during this pre-storm season, arising from the orbit-spin coupling in years with perihelion season storms, presents some common patterns. Among these are the rate and duration of increase of wind stress, and the minimum level of enhancement from the CTA that is apparently required in these years prior to initiation of a GDS. Previously we assessed changes in surface stress using a simple, dust-free model atmosphere. Here, further, we perform parallel simulations for MY 24-27 using realistic dust profiles from TES limb observations. The inclusion of dust in the GCM modifies atmospheric opacity and will alter global atmospheric temperatures leading to a markedly different atmospheric state. We find that the inclusion of dust in the atmosphere reduces the magnitude of surface stresses as compared to our dust-free simulations. The relationship of dust and the CTA will be addressed, in terms of its potential impact on the duration and strength of the modeled GDS.

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210.02 – Winds measured by the Rover Environmental Monitoring Station (REMS) during Curiosity's Bagnold Dunes Campaign

Curiosity's damaged wind sensor has trouble measuring winds coming from behind the rover, due to the loss of its side-pointing boom during landing. During the Bagnold Dunes Campaign, however, the rover was turned to permit measurements of winds from missing directions, capturing upslope/downslope day-night flow on the slopes of Aeolis Mons and blocking of wind in the lee of a dune.

The rover's heading is generally determined by the drive direction and often varies little over many tens of sols. Good wind measurements are made when the wind comes from the hemisphere to the front of the rover, but there are sometimes long periods during which winds from certain directions (i.e., at certain times of sol) are largely missed. Since rover turns are often precluded by rover safety and other operational constraints, it is usually not possible to turn to measure such winds properly.

During the Bagnold Dunes Campaign, wind measurements were prioritized to provide context for aeolian dune studies. Rover headings were optimized for three wind investigations covering a period of about 90 sols. The first investigation characterized the wind field on approach to the dunes, with the rover turned to face two unusual headings for several sols each and monitoring focused on the ‘missing' winds / times of sol. This confirmed the expected primary wind pattern of daytime roughly upslope winds (from ~NW/N) and nighttime downslope winds (from ~S/SE) on the slopes of Aeolis Mons, with significant sol-to-sol variability in e.g. the timing of the reversals. Comparison with the previous year suggests an increasingly upslope-downslope pattern as Curiosity approached the slope.

The second investigation studied changes to the wind pattern in the lee of the Namib Dune. This revealed the blocking of northerly winds by the large dune, leaving primarily a westerly component to the daytime winds with weaker wind speeds.

The third investigation characterized the wind field at the side of Namib Dune. The rover heading was chosen to optimize daytime winds, in support of ‘change detection' experiments that were designed to correlate strong winds with changes in surface grain positions imaged over periods ranging from a few hours to several sols.

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210.03 – Interannual, seasonal and diurnal Mars surface environmental cycles observed from Viking to Curiosity

We analyze in-situ environmental data from the Viking landers to the Curiosity rover to estimate atmospheric pressure, near-surface air and ground temperature, relative humidity, wind speed and dust opacity with the highest confidence possible. We study the interannual, seasonal and diurnal variability of these quantities at the various landing sites over a span of more than twenty Martian years to characterize the climate on Mars and its variability.

Additionally, we characterize the radiative environment at the various landing sites by estimating the daily UV irradiation (also called insolation and defined as the total amount of solar UV energy received on flat surface during one sol) and by analyzing its interannual and seasonal variability.
In this study we use measurements conducted by the Viking Meteorology Instrument System (VMIS) and Viking lander camera onboard the Viking landers (VL); the Atmospheric Structure Instrument/Meteorology (ASIMET) package and the Imager for Mars Pathfinder (IMP) onboard the Mars Pathfinder (MPF) lander; the Miniature Thermal Emission Spectrometer (Mini-TES) and Pancam instruments onboard the Mars Exploration Rovers (MER); the Meteorological Station (MET), Thermal Electrical Conductivity Probe (TECP) and Phoenix Surface Stereo Imager (SSI) onboard the Phoenix (PHX) lander; and the Rover Environmental Monitoring Station (REMS) and Mastcam instrument onboard the Mars Science Laboratory (MSL) rover.
A thorough analysis of in-situ environmental data from past and present missions is important to aid in the selection of the Mars 2020 landing site. We plan to extend our analysis of Mars surface environmental cycles by using upcoming data from the Temperature and Wind sensors (TWINS) instrument onboard the InSight mission and the Mars Environmental Dynamics Analyzer (MEDA) instrument onboard the Mars 2020 mission.
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210.04 – Weather and Large-Scale Dust Activity during Martian Northern Spring and Summer

Observations from MCS, TES and THEMIS now span the northern spring and summer seasons (Ls 0° to 180°) of 10 consecutive Mars Years (MY 24 through MY 33). These observations show very similar behavior each year. However, there are also noticeable differences and clear signs of inter-annual variability. To best study the three datasets, we examine zonal mean observations of the lower atmosphere (50 Pa, or ~25 km). This region was selected to provide the best quality from all three instruments. We separate the daytime (afternoon) and nighttime (early morning) data in the analysis.
The climate at these seasons is dominated by the aphelion cloud belt, and 50 Pa is often close to the peak opacities in the clouds. There is also a strong diurnal thermal tide signature throughout the season at this altitude. The overall behavior is a rapid cooling at the start of the year (as the dust from the dusty season sediments out of the atmosphere) over the the first ~30° of Ls. The coldest temperatures then last until about the solstice and are followed by a slow warming trend through most of the rest of the season. The last ~30° prior to the fall equinox show a more rapid warming trend and significant inter-annual variability.
In about half of the years, there is a warming event of the 50 Pa temperatures in the second half of northern summer. The warming is the signature of dust being lofted above the boundary layer, into the lower atmosphere. Due to the relatively clear atmosphere overall, even modest amounts of dust will create noticeable temperature changes. The temperature signature of the dust is more pronounced in the northern hemisphere.
Author(s): David M. Kass[2], Armin Kleinboehl[2], Daniel J. McCleese[2], John Tim Schofield[2], Michael D. Smith[3], Nicholas Heavens[1]
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210.05 – Planetary-scale hydraulic jumps and transonic jet-streaks in the MACDA reanalysis of the Martian atmosphere: a comparison with Earth's lower mesosphere

We have analyzed the Mars MACDA V1.0 global reanalysis on potential-temperature surfaces, θ, over the range θ = 400 to 900 K (~30 to ~60 km). The strongest seasonal wind, the northern-winter polar jet, exhibits two intriguing features: i) transonic jet streaks and ii) the juxtaposition of regions of shooting and tranquil flow, in the sense of Froude-number hydraulics, which suggests a planetary-scale hydraulic jump. Mesoscale bores have been studied on Mars, but to our knowledge the above two features have not been reported elsewhere. To characterize the basic state, we examine scatter plots of Ertel potential vorticity, Q, versus Bernoulli streamfunction, B, and fit the linear model $Q/Q_0 = 1 - \mu_0 (B-B_0)$. In autumn, winter and spring, the nondimensionalized correlation parameter, $\mu'_0 = (NH)^2 \mu_0$, in mid-latitudes is positive and nearly constant in time. Its value is close to unity at the bottom of the study region and gradually decreases with increasing θ (increasing altitude). In northern summer it swings negative. These attributes match Earth's lower mesosphere (θ = 2000 to 3000 K; ~48 to ~62 km). In southern summer, L_s ~ 270°, a hypsometric flaring of the θ layers, which is not seen in northern summer, is associated with the previously reported reduction of Q to approximately zero across the entire southern hemisphere and northern tropics. Between each winter polar jet and pole, especially in the north, there is a large spread of Q over a small domain of B, which is unlike Earth and may be related to the aforementioned hydraulic jump. We are currently examining 3D Lagrangian fluid trajectories to better characterize the rotating hydraulics of the system as a function of season.
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210.06D – The Energetics of Transient Eddies in the Martian Northern Hemisphere

The energetics of northern hemisphere transient waves in the Mars Analysis Correction Data Assimilation is analyzed. Three periods between the fall and spring equinoxes (L_s=200°-230°, 255°-285°, and 330°-360°) during three Mars Years are selected to exemplify the fall, winter, and spring wave activity. Fall and spring eddy energetics is similar with some inter-annual and inter-seasonal variability, but winter eddy kinetic energy and its transport are strongly reduced in intensity as a result of the solsticial pause in eddy activity. Barotropic energy conversion acts as a sink of eddy kinetic energy throughout the northern hemisphere eddy period with little reduction in amplitude during the solsticial pause. Baroclinic energy conversion acts as a source in fall and spring but disappears during the winter period as a result of the stabilized vertical shear profile of the westerly jet around winter solstice.
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210.07D – Using data assimilation to compare models of Mars and Venus atmospheres with observations

Data assimilation is a technique that optimally reconstructs a best estimate of the atmospheric state by combining observations and an *a priori* provided by a numerical model. The aim of data assimilation is to extrapolate in space and time observations of the atmosphere with the means of a model in order to recover the state of the atmosphere as completely and as accurately as possible.
In this work, we employ a state-of-the-art Martian Global Climate Model to assimilate vertical profiles of atmospheric temperature, airborne dust, and water ice clouds retrieved from observations of the Mars Climate Sounder onboard the Mars Reconnaissance Orbiter. The assimilation is carried out using an Ensemble Kalman Filter technique, that maps covariances between model variables. Therefore, observations of one variable (e.g. temperature) can be used to estimate other unobserved variables (e.g. winds), using covariances constructed from an ensemble of model simulations for which initial states slightly differ. Using this method, one can estimate dust from temperature observations only, confirming the presence of detached layers of dust in the atmosphere from their thermal signature. Then, the joint assimilation of temperature, dust, and water ice clouds shows that the performance of the assimilation is limited due to model biases, such as an incorrect phasing of the thermal tide and observed dust diurnal variations unexplained by a model. However, dust estimation makes possible the predictability of the atmosphere, up to around ten days in the most favorable cases, a great improvement over previous studies.
Future developments for an improved assimilation strongly suggest to assimilate model parameters, such as the ones for the representation of parameterized atmospheric gravity waves.
Also, in the light of the recent global observations of the Venusian atmosphere from the Akastuki spacecraft, the case for the first-ever assimilation of Venus will be made.

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210.08 – Global distribution of gravity wave fields and their seasonal dependence in the Martian atmosphere simulated in a high-resolution general circulation model

Gravity waves (GWs) are small-scale atmospheric waves generated by various geophysical processes, such as topography, convection, and dynamical instability. On Mars, several observations and simulations have revealed that GWs strongly affect temperature and wind fields in the middle and upper atmosphere. We have worked with a high-resolution Martian general circulation model (MGCM), with the spectral resolution of T106 (horizontal grid interval of ~67 km), for the investigations of generation and propagation of GWs. We analyzed for three kinds of wavelength ranges, (1) horizontal total wavenumber s=21-30 (wavelength λ~700-1000 km), (2) s=31-60 (λ~350-700 km), and (3) s=61-106 (λ~200-350 km). Our results show that shorter-scale harmonics progressively dominate with height during both equinox and solstice. We have detected two main sources of GWs: mountainous regions and the meandering winter polar jet. In both seasons GW energy in the troposphere due to the shorter-scale harmonics is concentrated in the low latitudes in a good agreement with observations. Orographically-generated GWs contribute significantly to the total energy of disturbances, and strongly decay with height. Thus, the non-orographic GWs of tropospheric origin dominate near the mesopause. The vertical fluxes of wave horizontal momentum are directed mainly against the larger-scale wind. Mean magnitudes of the drag in the middle atmosphere are tens of $m\ s^{-1}\ sol^{-1}$, while instantaneously they can reach thousands of $m\ s^{-1}\ sol^{-1}$, which results in an attenuation of the wind jets in the middle atmosphere and in tendency of their reversal.

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210.09D – Escape of Hydrogen from the Exosphere of Mars

After decades of exploration, the martian neutral hydrogen exosphere has remained largely uncharacterized even today. In my dissertation I have attempted to constrain the characteristics of the martian hydrogen exosphere using Hubble Space Telescope observations obtained during October-November 2007 and 2014. These observations reveal short-term seasonal changes exhibited by the martian hydrogen exosphere that are inconsistent with the diffusion-limited escape scenario. This seasonal behavior adds a new element towards backtracking the history of water loss from Mars. Modeling of the data also indicates the likely presence of a superthermal population of hydrogen created by non-thermal processes at Mars, another key element to understand the present-day escape. Exploration of the latitudinal symmetry of the martian exosphere indicates that it is symmetric above 2.5 martian radii and asymmetric below this altitude, which could be due to temperature differences between the day and night sides. Finally, the large uncertainties in determining the characteristics of the martian exosphere after decades of exploration is due to various assumptions about the intrinsic characteristics of the martian exosphere in the modeling process, degeneracy in the two modeling parameters temperature and density of the hydrogen atoms, unaccounted seasonal effects, and uncertainties introduced from spacecraft instrumentation as well as their viewing geometry.

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211 – Comets: 67P-CG III: Implications and Explanations

211.01 – High Resolution Optical Spectroscopy of Rosetta Target 67P/Churyumov-Gerasimenko Using Keck HIRES

We present high spectral resolution optical spectroscopy of Rosetta target 67P/Churyumov-Gerasimenko obtained on UT Dec 26 and 27, 2015 using the HIRES instrument on Keck I when the comet was at a heliocentric distance of approximately 2 AU post-perihelion. The spectra cover a spectral range of 3500-10000 Angstroms at a spectral resolution of 67,000. These observations aim to provide high spectral resolution, large projected field of view context for the high spatial resolution and small projected field of view observations obtained from the Rosetta instrument suite. We report detections of CN, NH_2, and [OI] emission. From the [OI]6300 emission we derive a water production rate of approximately 2 x 10^{27} mol/s. Production rates (or upper limits) for other species will be presented and placed in context with recent results from Rosetta. We will also present results pertaining to the [OI]5577 line, which combined with the [OI]6300 emission can be used as a proxy for CO_2. We will compare our results to observations obtained by Rosetta as well as NEOWISE and Spitzer.

Author(s): Adam McKay[7], Anita L. Cochran[7], Dennis Bodewits[6], Michael F. A'Hearn[6], Kathrin Altwegg[5], Samuel Gulkis[2], Colin Snodgrass[3], Miguel de Val Borro[4], Michael S. Kelley[6], Lori M. Feaga[6], Diane H. Wooden[1], James M. Bauer[2], Emily A. Kramer[2]
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211.02 – Cosmochemical implications of CONSERT permittivity characterization of 67P/C-G

Unique information about the internal structure of the nucleus of comet 67P/C-G was provided by the CONSERT bistatic radar on-board Rosetta and Philae [1]. Analysis of the propagation of its signal throughout the small lobe indicated that the real part of the permittivity at 90 MHz is of (1.27±0.05). The first interpretation of this value using dielectric properties of mixtures of dust and ices (H_2O, CO_2), led to the conclusion that the comet porosity ranges between 75–85%. In addition, the dust/ice ratio was found to range between 0.4-2.6 and the permittivity of dust (including 30% of porosity) was determined to be lower than 2.9.

The dust permittivity estimate is now reduced by taking into account the updated values of nucleus density and of dust/ice ratio, in order of providing further insights into the nature of the constituents of comet 67P/C-G [2]. We adopt a systematic approach: i) determination of the dust permittivity as a function of the ice (I) to dust (D) and vacuum (V) volume fraction; ii) comparison with the permittivity of meteoritic, mineral and organic materials from literature and laboratory measurements; iii) test of several composition models of the nucleus, corresponding to cosmochemical end members of 67P/C-G. For each of these models the location in the ternary I/D/V diagram is calculated based on available dielectric measurements, and confronted to the locus of 67P/C-G. The number of compliant models is small and the cosmochemical implications of each are discussed [2]. An important fraction of carbonaceous material is required in the dust in order to match CONSERT permittivity observations, establishing that comets represent a massive carbon reservoir.

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[1] Kofman et al., Science, 349, 6247, aaa0639, 2015. [2] Herique et al., MNRAS, submitted, 2016.

Author(s): A. Levasseur-Regourd[5], Alain Hérique[2], Wlodek Kofman[2], Pierre Beck[2], Lydie Bonal[2], Ilaria Buttarazzi[1], Essam Heggy[4], Jeremie Lasue[3], Eric Quirico[2], Sonia Zine[2]

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211.03 – The distribution of gas and ions in the inner coma of 67P/Churyumov-Gerasimenko between 3 AU before and after its perihelion

Rosetta explored a regime not accessible before: the inner coma of a low-activity comet at a large range of heliocentric distances. The Wide Angle Camera (WAC) of the OSIRIS instrument on board the *Rosetta* spacecraft is equipped with several narrowband filters that are centered on the emission lines and bands of various molecules and ions. These filters center on fragment species that are relatively bright and that have been used for numerous comet studies from the ground (e.g. A'Hearn et al. 1995). Surprisingly, we found that outside 2 AU pre-perihelion, the emission in the filters was dominated by emission from dissociative electron impact excitation (Bodewits et al. 2016). Closer to perihelion, higher gas densities reduced electron temperatures in the inner coma and photo-processes drove much if not most of the emission from the comet. Our observations allowed us to study changes in the physical environment of the inner coma, and Rosetta's excursions as far as 1000 km from the surface allowed us to study different regions of the coma.In this contribution, we will summarize the results of our OSIRIS observations from approximately 3 AU before to 3 AU after perihelion.

Author(s): Dennis Bodewits[5], Luisa Lara[4], Fiorangela La Forgia[1], Michael F. A'Hearn[5], Jörg Knollenberg[2], Monica Lazzarin[1], Zhong-Yi Li[3]

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Contributing team(s): Osiris team

211.04 – Comet 67P/Churyumov-Gerasimenko, is the pristine material present anywhere close to the surface?

Observations of the nucleus of comet 67P/Churyumov-Gerasimenko indicate high complexity of the topography (Thomas et al., 2015). Presence of numerous pits, and depressions, as well as scarps suggests complex evolution of the nucleus. This in turn makes uncertain presence of the pristine material anywhere close to the surface. However, non-uniformity of the mechanical strength of the nucleus suggests, that in some locations material can retain initial structure. This should be expected neither in the final Philae landing site Abydos, where the compressive strength of the material is about 2 MPa (Spohn et al., 2015), neither in the location of the first touch down, where beneath a layer of unconsolidated material possibly is a hard material (Biele et al., 2015). Both locations are at low latitudes, where the flux of solar energy is much higher than northern parts of the lobes, illuminated when the comet is far form perihelion. Groussin et al. (2015) investigated what inclination of slopes corresponds to the presence of falling-out boulders and have found, that the average strength is probably lower than 1.5 kPa.

I attempted to answer the question, whether in poorly illuminated regions of the nucleus of comet 67P/Churyumov-Gerasimenko are possible thermal conditions suitable for preservation of a pristine unconsolidated ice-dust material. For this purpose I calculated evolution of the temperature and structure of the material versus depth in selected locations in region Ma'at. This region is in general smooth (El-Maary et al., 2015), which may indicate presence of a loose dust mantle on the surface. The applied shape model is SHAP4s v1.0 (Preuskner et al., 2015). The performed simulations indicate, that in Scenario A preservation of low uni-axial compressive strength is possible, but only in shadowed locations, beneath a dust mantle of low thermal conductivity, at least few centimeters thick.

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211.05 – A Creaking and Cracking Comet

Since the middle of 2014 the OSIRIS cameras on the ESA Rosetta mission have been monitoring the evolution of the comet 67P/Churyumov-Gerasimenko as it passed through perihelion. During the perihelion passage several change events have been observed on the nucleus surface. For example existing large scale cracks have expanded and new large scale cracks have been created. Also several large scale "wave pattern" like change events have been observed in the Imhotep and Hapi regions. These are events not directly correlated with any normal visible cometary activity. One interpretation is that these are events likely caused by "seismic" activity. The seismic activity is created by the self-gravity stress of the non-spherical comet nucleus and stress created by the non-gravitational forces acting on the comet. The non-gravitational forces are changing the rotation period of the comet (~20min/perihelion passage) which induces a changing mechanical stress pattern through the perihelion passage. Also the diurnal cycle with its changing activity pattern is causing a periodic wobble in the stress pattern that can act as a trigger for a comet quake. The stress pattern has been modeled using a finite element model that includes self-gravity, the comet spin and the non-gravitational forces based on a cometary activity model. This paper will discuss what can be learned about the comet nucleus structure and about the cometary material properties from these events and from the FEM model.

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Contributing team(s): OSIRIS Team

211.06 – Comet 67P Nucleus Water Ice Distribution and Evolution Inferred from Inner Coma Structure Seen by Rosetta/MIRO

The spatial structure and temporal evolution of the inner coma of Comet 67P have been observed by Microwave Instrument on Rosetta Orbiter (MIRO) since the Rosetta Orbiter has rendezvoused with Comet 67P in August 2014. Among the several cometary gas emission lines that the MIRO spectrometer is tuned to, the water isotopologue $H_2^{18}O$ line is optically thin and is used to probe the inner coma structure as the MIRO beam scans the space near the comet nucleus. The water line area/strength shows clearly that the day side of coma has a lot more gas than the night side of coma and the summer hemisphere side of coma has a lot more gas than the winter hemisphere side of coma. These diurnal and seasonal dependencies strongly suggest that the water gas in the coma is from the sublimation of ice in the nucleus, where its rate greatly depends on the thermal condition of surface and near-surface governed by the sun illumination condition. In addition to the sun illumination condition, the water ice distribution on 67P nucleus affects the inner coma structure. We model the inner coma structures with various ice distributions and compare them with the observation. The comparison undoubtedly shows that the ice is not uniformly distributed on 67P nucleus. The observation favors the model with the ice distributed only in polar caps in both poles. The observation also shows the evidence of temporal evolution of the ice distribution. The southern polar ice cap was less active a few months before the perihelion (August 2015), became more active near the perihelion, and became less active a few months after the perihelion. Note that the ice cap activity change due to the temperature-dependent sublimation rate change is already taken into account, and does not explain the temporal variation of the inner coma structure. This result indicates that there was a change of ice distribution (polar cap size) or ice location near the surface (how deep the dust layer covers the ice).

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Contributing team(s): The MIRO Team

211.07D – Study of cliff activity dominating the gas and dust comae of comet 67P/Churyumov-Gerasimenko during the early phase of the Rosetta mission using ROSINA/COPS and OSIRIS data

The study by [1] has proposed the idea that the cometary dust jets in the northern hemisphere of comet 67P/Churyumov-Gerasimenko arise mainly from rough cliff like terrain. Using our 3D gas and dust dynamics coma model [2] we have run simulations targeting the question whether areas with high gravitational slopes alone can indeed account for both the ROSINA/COPS and the OSIRIS data obtained for mid August to end October 2014.
The basis of our simulations is the shape model "SHAP4S" of [3]. Surface temperatures have been defined using a simple 1-D thermal model (including insolation, shadowing, thermal emission, sublimation but neglecting conduction) computed for each facet of the shape model allowing a consistent and known description of the gas flux and its initial temperature. In a next step we use the DSMC program PDSC++ [4] to calculate the gas properties in 3D space. The gas solution can be compared with the in situ measurements by ROSINA/COPS. In a subsequent step dust particles are introduced into the gas flow to determine dust densities and with a column integrator and Mie theory dust brightnesses that can be compared to OSIRIS data.
To examine cliff activity we have divided the surface into two sets. One with gravitational slopes larger than 30° which we call cliffs and one with slopes less than 30° which we shall call plains. We have set up two models, "cliff only" and "plains only" where the respective set of areas are active and the others inert. The outgassing areas are assumed to be purely insolation driven. The "cliffs only" model is a statistically equally good fit to the ROSINA/COPS data as the global insolation driven model presented in [2]. The "plains only" model on the other hand is statistically inferior to the "cliffs only" model. We found in [2] that increased activity in the Hapi region (called inhomogeneous model) of the comet improves the fit of the gas results significantly. We can show in this study that a "cliffs + Hapi" model fits the ROSINA/COPS data equally well as the inhomogeneous model. These results are consistent with OSIRIS data.

[1] Vincent et al., 2016, A&A, 587, A14
[2] Marschall et al., 2016; A&A, 589, A90
[3] Preusker et al., 2015, A&A 583, A33
[4] Su, C. C., 2013

Author(s): Raphael Marschall[3], Cheng-Chin Su[2], Ying Liao[3], Martin Rubin[3], Jong-Shinn Wu[2], Nicolas Thomas[3], kathrin altwegg[3], Holger Sierks[1]
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Contributing team(s): OSIRIS, ROSINA

211.08D – Sulfides and refractory organic matter at the surface of 67P/Churyumov-Gerasimenko: evidence from VIRTIS data and laboratory measurements

From Aug. 2014 to Sept. 2016, Rosetta has been orbiting comet 67P and has obtained informations on the origin and evolution of comets. The imaging spectrometer VIRTIS collected reflectance spectra of the surface within the range 0.25-5.1 µm that revealed a low albedo and a homogeneous surface (Capaccioni et al., 2015; Ciarniello et al., 2015). The spectra are also characterized by red slopes in the visible and in the near infrared. These properties have been interpreted to be due to the presence of an organic polyaromatic material mixed with opaque minerals, presumably troilite-like sulfides according to the composition of presumed cometary grains (Quirico et al., 2016).
In order to test this proposition, we have run a series of experimental measurements of granular mixtures of an analog of cometary polyaromatic organic matter (an immature coal) and different sulfides (pyrite, pyrrhotite and troilite). Bi-directional reflectance spectra were obtained at IPAG in the range 0.4-4 µm and under a range of viewing geometries. For the first time we are performing measurements on materials with sub-micrometer grains relevant to what is expected for cometary grains. Produced with a planetary grinder operating on colloidal solutions, these grains were

characterized with SEM, X-ray diffraction and an electronic microprobe.
The experiment confirms that the low albedo in the near infrared is controlled by the abundance of pyrrhotite or troilite, while pyrite is not a viable candidate. These sulfides also account very well for the red slopes in the visible and the near infrared ranges. Excellent match with VIRTIS spectra is obtained for coal+pyrrhotite mixtures with a pyrrhotite abundance ranging from 30 to 50 wt%. Although the cometary grains composition include silicates and other organic compounds (see IDPs and Wild2 samples analysis), these results offer another interpretation of the reddish nature of some small bodies' surfaces, which has been interpreted so far as the presence of red organics or the consequence of space weathering. Finally, the suggestion that sulfides are major contributors to 67P dust might be generalized to other cometary nuclei that have similar VNIR spectra, as well as to P & D type asteroids.

Author(s): Batiste Rousseau[5], Stéphane Érard[5], Pierre Beck[3], Eric Quirico[3], Bernard Schmitt[3], Lydie Bonal[3], German Montes-Hernandez[4], Lyuba Moroz[6], David Kappel[1],Kathrin Markus[1], Gabriele Arnold[1], Mauro Ciarniello[2], Andrea Raponi[2], Andrea Longobardo[2], Fabrizio Capaccioni[2], Gianrico Filacchione[2], Dominique Bockelee-Morvan[5], Cedric Leyrat[5]
Institution(s): *1. German Aerospace Center (DLR), 2. IAPS - INAF, 3. IPAG - Universite Grenoble Alpes, CNRS, 4. ISTerre - Université Grenoble Alpes, 5. LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, Univ. Paris Diderot, Sorbonne Paris Cité, 6. University of Postdam*
Contributing team(s): Rosetta VIRTIS Team

211.09 – Observations of Post-Perihelion Outbursts Around Comet 67P/Churyumov-Gerasimenko with the R-Alice Ultraviolet Spectrograph

The *Rosetta* Alice (R-Alice) ultraviolet spectrograph on the European Space Agency *Rosetta* spacecraft, currently escorting the comet 67P/Churyumov-Gerasimenko in its orbit around the Sun, has observed the activity of the comet since just before entering orbit in August 2014. Fortuitous observations taken in October and November 2015, two and three months after perihelion respectively, show large, short timescale primary and secondary increases in the Lyman-ß, OI 1304, CII 1335, OI] 1356, and CI 1657 atomic emission lines that indicate gas outbursts. The data are compared to lab measured electron impact cross sections and line ratios to put constraints on outburst composition. Analysis of these emission lines and their ratios indicate that each primary outburst was driven by molecular oxygen (O_2), supporting the R-Alice results of Feldman et al. 2016 (Accepted for publication in ApJ Letters, arXiv:1606.05249). In both cases the secondary outburst contained a different mixing ratio of CO_2 or H_2O than in the primary outburst. These observations also corroborate *Rosetta* mass spectrometer findings by Bieler et al. 2015 (Nature, 526, 678) and are compared against the *Rosetta* mass spectrometer interpretations of Mousis et al. 2016a (ApJ Letters, 819, 2) and Mousis et al. 2016b (ApJ Letters, 823, 2).

Author(s): John Noonan[3], Eric Schindhelm[3], Paul D. Feldman[4], Joel Wm Parker[3], S. Alan Stern[3], Harold A. Weaver[1], Andrew Steffl[3], Michael F. A'Hearn[5], Lori M. Feaga[5],Jean-Loup Bertaux[2]
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211.10 – How primordial is the structure of comet 67P/C-G (and of comets in general)?

Several properties of the comet 67P-CG suggest that it is a primordial planetesimal. On the other hand, the size-frequency distribution (SFD) of the craters detected by the New Horizons missions at the surface of Pluto and Charon reveal that the SFD of trans-Neptunian objects smaller than 100km in diameter is very similar to that of the asteroid belt. Because the asteroid belt SFD is at collisional equilibrium, this observation suggests that the SFD of the trans-Neptunian population is at collisional equilibrium as well, implying that comet-size bodies should be the product of collisional fragmentation and not primordial objects. To test whether comet 67P-CG could be a (possibly lucky) survivor of the original population, we conducted a series of numerical impact experiments, where an object with the shape and the density of 67P-CG, and material strength varying from 10 to 1,000 Pa, is hit on the "head" by a 100m projectile at different speeds. From these experiments we derive the impact energy required to disrupt the body catastrophically, or destroy its bi-lobed shape, as a function of impact speed. Next, we consider a dynamical model where the original trans-Neptunian disk is dispersed during a phase of temporary dynamical instability of the giant planets, which successfully reproduces the scattered disk and Oort cloud populations inferred from the current fluxes of Jupiter-family and long period comets. We find that, if the dynamical dispersal of the disk occurs late, as in the Late Heavy Bombardment hypothesis, a 67P-CG-like body has a negligible probability to avoid all catastrophic collisions. During this phase, however, the collisional equilibrium SFD measured by the New Horizons mission can be established. Instead, if the dispersal of the disk occurred as soon as gas was removed, a 67P-CG-like body has about a 20% chance to avoid catastrophic collisions. Nevertheless it would still undergo 10s of reshaping collisions. We estimate that, statistically, the last reshaping collision should have happened 250My-1Gy ago, implying that the actual morphology of 67P-CG should be younger than this age.

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211.11 – Formation of bi-lobed 67P/C-G-like shapes by sub-catastrophic collisions

Small bodies with a bi-lobe shape such as comet 67P/C-G have been argued to form as the result of low velocity ($v \approx v_{esc}$) collisional mergers of similar-sized bodies very early on in the history of the solar system [1]. However, the recent analysis of the subsequent collisional survival of the global structure and shape of comet 67P/C-G strongly suggests that such a structure will not survive until today [2]. Hence, the comet must have acquired its present characteristics as a result of a collision occurring at later time when the relative velocities between small bodies are much higher ($v >> v_{esc}$).
One possible scenario would be that 67P/C-G-like bi-lobe structures form as the result of collisional disruptions of larger parent bodies [3]. Whether the internal properties of such larger parent bodies, the timing of such a collision, and the subsequent survival of the shape produced is compatible with observations will remain to be seen.
Here, we propose a scenario in which the final bi-lobe shapes result from low-energy, sub-catastrophic impacts. We start with bodies of about the same mass as comet 67P/C-G, which are rotating and are slightly elongated (i.e., with properties which are consistent with the outcome of the disruptions of larger bodies). We use a SPH shock physics code to model the impacts, the subsequent re-accumulation of material and the reconfiguration into a stable final shape. Our modelling results suggest that these kind of collisions result in "splitting" events which frequently lead to formation of bi-lobe

67P/C-G-like shapes.
The frequency of such small-scale impact events is consistent with a young (less than 1 Gy) age of the shape of comet 67P/C-G [2].
Equally important, the probability for such a shape-forming event to take place without a subsequent shape-destroying event occurring until today is reasonably high.
Although the collisions considered in this work can alter the global shape, their respective energy is small enough not to lead to any substantial global-scale heating or compaction, consistent with the observed primordial characteristics of comets.
[1] Jutzi&Asphaug, 2015, Science 348. [2] Jutzi et al., submitted. [3] Schwartz et al., in prep.
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211.12 – Disruptive collisions as the origin of 67P/C-G and small bilobate comets

Images of comets sent by spacecraft have shown us that bilobate shapes seem to be common in the cometary population. This has been most recently evidenced by the images of comet 67P/C-G obtained by the ESA Rosetta mission, which show a low-density elongated body interpreted as a contact binary. The origin of such bilobate comets has been thought to be primordial because it requires the slow accretion of two bodies that become the two main components of the final object. However, slow accretion does not only occur during the primordial phase of the Solar System, but also later during the reaccumulation processes immediately following collisional disruptions of larger bodies. We perform numerical simulations of disruptions of large bodies. We demonstrate that during the ensuing gravitational phase, in which the generated fragments interact under their mutual gravity, aggregates with bi-lobed or elongated shapes formed form by reaccumulation at speeds that are at or below the range of those assumed in primordial accretion scenarios [1]. The same scenario has been demonstrated to occur in the asteroid belt to explain the origin of asteroid families [2] and has provided insight into the shapes of thus-far observed asteroids such as 25143 Itokawa [3]. Here we show that it is also a more general outcome that applies to disruption events in the outer Solar System. Moreover, we show that high temperature regions are very localized during the impact process, which solves the problem of the survival of organics and volatiles in the collisional process. The advantage of this scenario for the formation of small bilobate shapes, including 67P/C-G, is that it does not necessitate a primordial origin, as such disruptions can occur at later stages of the Solar System. This demonstrates how such comets can be relatively young, consistent with other studies that show that these shapes are unlikely to be formed early on and survive the entire history of the Solar System [4].
[1] Schwartz, S.R. et al. 2016, in preparation; [2] Michel, P. et al. 2001, Science 294, 1696; [3] Michel, P., Richardson, D.C. 2013, A&A 554, L1; [4] Jutzi, M. et al. 2016 submitted to A&A.
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212 – Extrasolar Planets: Giant Planet Atmospheres III

212.01 – Lucifer's Planet: Photolytic Hazes in the Atmosphere of 51 Eri b

The star 51 Eridani is a pre-main-sequence F dwarf that is only 20 million years old. Direct-imaging observations with GPI (Gemini Planet Imager) reveal that the star is orbited by a self-radiant young Jupiter, designated 51 Eri b, that emits with an effective temperature on the order of 700 K (Macintosh et al (2015) Science 350, 64). Thermal evolution models predict that the planet has Jupiter's radius and twice its mass.
We use a 1D model to address photochemistry and possible haze formation in the irradiated atmosphere of 51 Eri b (2016arXiv160407388Z). The intended focus was to have been on carbon and organic hazes, but sulfur photochemistry turns out to be interesting and possibly more important. The case for organic photochemical hazes is intriguing but falls short of being compelling. If organic hazes form abundantly, they are likeliest to do so if vertical mixing in 51 Eri b is weaker than in Jupiter, and they would be found below the altitudes where methane and water are photolyzed. The more novel result is that photochemistry turns H2S into elemental sulfur, here treated as S8. In the cooler models, S8 is predicted to condense in optically significant clouds of solid sulfur particles, whilst in the warmer models S8 remains a vapor along with several other sulfur allotropes that are both visually striking and potentially observable. For 51 Eri b, the division between models with and without condensed sulfur is at an effective temperature of 700 K, which is within error its actual effective temperature; the local temperature where sulfur condenses is between 280 and 320 K. The sulfur photochemistry we discuss is quite general and ought to be found in a wide variety of worlds over a broad temperature range, both colder and hotter than the 650-750 K range studied here, and we show that products of sulfur photochemistry will be nearly as abundant on planets where the UV irradiation is orders of magnitude weaker than it is on 51 Eri b.
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212.02 – Transitions in the cloud composition of hot Jupiters

Over a large range of equilibrium temperatures, clouds shape the transmission spectrum of hot Jupiter atmospheres, yet their composition remains unknown. Recent observations show that the Kepler lightcurves of some hot Jupiters are asymmetric: for the hottest planets, the lightcurve peaks before secondary eclipse, whereas for planets cooler than 1900K, it peaks after secondary eclipse. We use the thermal structure from 3D global circulation models to determine the expected cloud distribution and Kepler lightcurves of hot Jupiters. We demonstrate that the change from an optical lightcurve dominated by thermal emission to one dominated by scattering (reflection) naturally explains the observed trend from negative to positive offset. For the cool planets the presence of an asymmetry in the Kepler lightcurve is a telltale sign of the cloud composition, because each cloud species can produce an offset only over a narrow range of effective temperatures. By comparing our models and the observations, we show that the cloud composition of hot Jupiters likely varies with equilibrium temperature. We suggest that a transition occurs between silicate and manganese sulfide clouds at a temperature near 1600K, analogous to the L/T transition on brown dwarfs. The cold trapping of cloud species below the photosphere naturally produces such a transition and predicts similar transitions for other condensates, including TiO. We predict that most hot Jupiters should have cloudy nightsides, that partial cloudiness should be common at the limb and that the dayside hot spot should often be cloud-free.
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212.03 – The impact of non-uniform thermal structure on the interpretation of exoplanet emission spectra

Observations and models have revealed the complex and dynamic states of exoplanetary atmospheres. In particular, the atmospheres of warm and hot gas giants have opened the doors to physical and chemical regimes unseen in our solar system. To understand their thermal structures and chemical abundances, the field has been moving towards inverse models, or ``retrievals.'' Traditionally, one retrieves what are supposed to be 1D hemispheric average atmospheric conditions. However, the real spectra are produced by 3D structures that feature hot and cool spots, chemical gradients, clouds, etc. How well does a 1D retrieval represent, or misrepresent, a complex reality?

Here, we investigate the biases accompanying the 1D interpretation of retrievals by putting more complex retrieval scenarios to the test on emission spectra. Our first scenario is the emission from a hypothetical HD 189733b-like planet at first or third quarter phase, featuring a ``hot'' dayside and ``colder'' nightside thermal profile. We simulate JWST and WFC3+IRAC data and compare the results of retrieving for 1 profile (1 T-Ps) and abundances versus for 2 profiles (2 T-Ps) and abundances. We also examine the effects of increasing contrast between the two profiles. We find that, for both JWST and WFC3+IRAC, when the contrast is large (80% difference between the temperatures at the top of the atmosphere), the 1 T-P approach shows well constrained abundances -- but the retrieved values are inaccurate. When we apply the 2 T-P approach, we better recover the true value. We also demonstrate the effect on real WASP-43b HST+Spitzer phase curve data: invoking a second profile indeed reveals that 1 T-P returns a well-constrained, but likely false, abundance of methane. We also quantify which wavelengths are more sensitive to temperature profile differences. Our work is greatly complementary to observational studies.

In the future, we will expand to retrieve from spectra at different phases and the study of dayside hot-spots, patchy clouds, and chemical gradients. These studies have broad applicability to transiting and imaged gas giants, as well as the atmospheres of smaller worlds.

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212.04 – Dreaming of Atmospheres

Radiative transfer retrievals have become the standard in modelling of exoplanetary transmission and emission spectra. Analysing currently available observations of exoplanetary atmospheres often invoke large and correlated parameter spaces that can be difficult to map or constrain.

To address these issues, we have developed the Tau-REx (tau-retrieval of exoplanets) retrieval and the RobERt spectral recognition algorithms. Tau-REx is a bayesian atmospheric retrieval framework using Nested Sampling and cluster computing to fully map these large correlated parameter spaces. Nonetheless, data volumes can become prohibitively large and we must often select a subset of potential molecular/atomic absorbers in an atmosphere.

In the era of open-source, automated and self-sufficient retrieval algorithms, such manual input should be avoided. User dependent input could, in worst case scenarios, lead to incomplete models and biases in the retrieval. The RobERt algorithm is build to address these issues. RobERt is a deep belief neural (DBN) networks trained to accurately recognise molecular signatures for a wide range of planets, atmospheric thermal profiles and compositions. Using these deep neural networks, we work towards retrieval algorithms that themselves understand the nature of the observed spectra, are able to learn from current and past data and make sensible qualitative preselections of atmospheric opacities to be used for the quantitative stage of the retrieval process.

In this talk I will discuss how neural networks and Bayesian Nested Sampling can be used to solve highly degenerate spectral retrieval problems and what 'dreaming' neural networks can tell us about atmospheric characteristics.

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212.05 – Tests of Exoplanet Atmospheric Radiative Transfer Codes

Atmospheric radiative transfer codes are used both to predict planetary spectra and in retrieval algorithms to interpret data. Observational plans, theoretical models, and scientific results thus depend on the correctness of these calculations. Yet, the calculations are complex and the codes implementing them are often written without modern software-verification techniques. In the process of writing our own code, we became aware of several others with artifacts of unknown origin and even outright errors in their spectra. We present a series of tests to verify atmospheric radiative-transfer codes. These include: simple, single-line line lists that, when combined with delta-function abundance profiles, should produce a broadened line that can be verified easily; isothermal atmospheres that should produce analytically-verifiable blackbody spectra at the input temperatures; and model atmospheres with a range of complexities that can be compared to the output of other codes. We apply the tests to our own code, Bayesian Atmospheric Radiative Transfer (BART) and to several other codes. The test suite is open-source software. We propose this test suite as a standard for verifying current and future radiative transfer codes, analogous to the Held-Suarez test for general circulation models. This work was supported by NASA Planetary Atmospheres grant NX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

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212.06 – Comparative exoplanetology with consistent retrieval methods

The number of hot Jupiters with broad wavelength spectroscopic data has finally become large enough to make comparative planetology a reasonable proposition. New results presented by Sing et al. (2016) showcase ten hot Jupiters with spectra from the Hubble Space Telescope and photometry from Spitzer, providing insights into the presence of clouds and hazes.

Spectral retrieval methods allow interpretation of exoplanet spectra using simple models, with minimal prior assumptions. This is particularly useful for exotic exoplanets, for which we may not yet fully understand the physical processes responsible for their atmospheric characteristics. Consistent spectral retrieval of a range of exoplanets can allow robust comparisons of their derived atmospheric properties.

I will present a retrieval analysis using the NEMESIS code (Irwin et al. 2008) of the ten hot Jupiter spectra presented by Sing et al. (2016). The only distinctive aspects of the model for each planet are the mass and radius, and the temperature range explored. All other a priori model parameters are common to all ten objects. We test a range of cloud and haze scenarios, which include: Rayleigh-dominated and grey clouds; different cloud top pressures; and both vertically extended and vertically confined clouds.

All ten planets, with the exception of WASP-39b, can be well represented by models with at least some haze or cloud. Our analysis of cloud properties has uncovered trends in cloud top pressure, vertical extent and particle size with planet equilibrium temperature. Taken together, we suggest that these trends indicate condensation and sedimentation of at least two different cloud species across planets of different temperatures, with condensates forming higher up in hotter atmospheres and moving progressively further down in cooler planets.

Sing, D. et al. (2016), Nature, 529, 59
Irwin, P. G. J. et al. (2008), JQSRT, 109, 1136

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212.07 – A Bayesian Atmospheric Retrieval Performed on HAT-P-16b and WASP-11b/HAT-P-10b

HAT-P-16b is a hot (equilibrium temperature 1626 ± 40 K, assuming zero Bond albedo and efficient energy redistribution), 4.19 ± 0.09 Jupiter-mass exoplanet orbiting an F8 star every 2.775960 ± 0.000003 days (Buchhave et al 2010). WASP-11b/HAT-P-10b is a cooler (1020 ± 17 K), 0.487 ± 0.018 Jupiter-mass exoplanet orbiting a K3 star every 3.7224747 ± 0.0000065 days (Bakos et al. 2009, co-discovered by West et al. 2008). We observed secondary eclipses of both planets using the 3.6 µm and 4.5 µm channels of the Spitzer Space Telescope's Infrared Array Camera (program ID 60003). We applied our Bayesian Atmospheric Radiative Transfer (BART) code to constrain the temperature-pressure profiles and atmospheric molecular abundances of the two planets. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

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212.08 – Bayesian Inference of the Composition and Inflation Power of Hot Jupiters

The radius of a planet for a given mass is the result of its composition and thermal evolutionary history. For cooler giants, where thermal evolution is relatively well-understood, we can infer a planet's bulk composition from its mass, radius, stellar insolation and age, since all being equal, more metal-rich planets are smaller and denser. For inflated hot giants, there is a degeneracy between inferred composition and inflation power. Within a Bayesian framework we examine both groups, beginning with the cool giant planets. Among these, we observe that the internal heavy-element mass correlates well with the total planet mass, and the metal enrichment relative to the parent star is correlated negatively with planet mass. However, it appears that there is not a simple relation between the planet heavy-element mass and stellar metallicity. These fundamental "mass-metallicity" results are consistent with the core accretion model of planet formation. For the hotter inflated gas giants, we estimate the functional dependence of inflation power on stellar insolation by demanding that the same metal to mass relation applies to both cold and hot gas giants. We consider various forms for this relation and the resulting outliers. This inflation power result is robust to assumptions about metal placement within the planet and equation of state because it relies only on matching the two groups of planets. These results serve as a new way to connect models of planet inflation to existing observations of giant planets.

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Institution(s): *1. UC Santa Cruz*

212.09 – The Dependence of the Kepler Planet Population on Host Star Properties

The Kepler spacecraft has monitored stars with a wide range of masses and metallicities for transiting planets. These stellar properties trace the conditions in the protoplanetary disk at the time of planet formation, and leave an imprint on the exoplanet population. We derive planet occurrence rates as a function of stellar mass and metallicity. In contrasts to giant planets, whose occurrence scales positively with both quantities, the occurrence of super-earths is anti-correlated with stellar mass and does not depend on metallicity except at orbital periods less than 10 days. The higher average mass of planetary systems around low-mass M dwarfs compared to sun-like stars indicates migration of planetary building blocks is stellar-mass dependent and plays a prominent role in the planet formation process. The excess of hot super-earths around metal-rich stars implies they either share a formation mechanism with hot Jupiters, or trace a planet trap at the protoplanetary disk inner edge which is metallicity-dependent.

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212.10 – Stellar Variability Effects on Transit Spectroscopy

Stellar variability caused by surface magnetic activity poses a great challenge to accurately and precisely characterize the atmospheres of transiting exoplanets. We present a preliminary analysis of the effects of unocculted star spots at IR wavelengths on planetary transmission and emission spectra. We will explore how stellar variability changes the derived exoplanet atmospheric parameters inferred through retrievals for a group of exoplanetary hosts stars. Our study includes stars ranging in activity levels from an inactive sun to a very active late-type star, and a range of planetary masses from super-Earths to Jupiters. These effects will be especially important for the high precision measurements (<100 ppm) needed to characterize the atmospheric composition of smaller planets. This work is critical for optimizing the exoplanet observing program of JWST, which will study known habitable zone transiting planets as well as new ones found by TESS orbiting nearby M dwarfs, which are more active than solar-type stars.

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212.11 – Polarization in Thermal Emission from Hot Jupiters: Preliminary Studies

Scattering of thermal emission from a deep, hot region by high altitude atmospheric particles induces polarization in the scattered light. However, symmetries on a spherical planet with a uniform spatial distribution of scattering particles usually result in zero net polarization. If the symmetry is broken, either by rotation induced oblateness or by spatially inhomogeneous cloud or haze particle distributions, polarization may become observable. Additionally, variation of temperatures across the planetary disc could also contribute to asymmetries, giving us a new way to measure the day-night temperature contrast on hot exoplanets. We perform modeling studies using a multiple scattering, radiative transfer model for polarized light to understand how to distinguish between various symmetry breaking phenomena and map an observed polarization to a specific atmospheric state. The models can be used to predict the most suitable candidates for observation, and once observations are available, to retrieve various parameters of interest.

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212.12 – Accurately Modelling the Absorption of a Mixture of Gases at Low- to Medium-resolution in Exoplanetary and Brown Dwarf Atmospheric Radiative Transfer Calculations

Exoplanetary and brown dwarf atmospheres are extremely diverse environments ranging over many different temperatures, pressures, and compositions. In order to model the spectra produced by the these objects, a commonplace approach in exoplanetary science is to use cross-sections of individual gases to quickly calculate the atmospheric opacities. However, when combining multiple gases with non-monochromatic absorption coefficients, the multiplication property of transmission does not hold. The resulting spectra are hence unreliable. Extensive work was carried out on Solar System radiative transfer models to find an efficient alternative to line-by-line calculations of opacity which was more accurate than combining cross-sections, resulting in many band models and the correlated-*k* method. Here we illustrate the effect of using cross-sections to model typical brown dwarf and exoplanetary atmospheres (e.g. HD189733b), and compare them to the spectra calculated using the correlated-*k* method. We verify our correlated-*k* method using a line-by-line model. For the same objects, we also present the effects of pressure broadening on the resulting spectra. Considering both the method of calculation (i.e. cross-section or correlated-*k*) and the treatment of pressure broadening, we show that the differences in the spectra are immediately obvious and hugely significant. Entire spectral features can appear or disappear, changing the morphology of the spectra. For the inspected brown dwarfs, these spectral features can vary by up to three orders of magnitude in luminosity. For our exoplanets, the transit depth can vary by up to 1%. We conclude that each effect would change the retrieved system parameters (i.e. temperature and abundances) considerably.

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213 – Geology of Pluto: Sputnik Planitia at the Heart

213.01 – Kepler K2 Precision Lightcurve Observations of Pluto: Preliminary Results

Pluto is a key object in the third zone of our Solar System and provides important insight into formation and collisional processes that were at work in the early solar system. In July 2015 the New Horizons spacecraft successfully obtained high resolution fly-by clear filter imaging observations of the Pluto system. We report on our continued monitoring of the Pluto system from October-December 2015 using the Kepler spacecraft's imaging photometer during Campaign 7 of the K2 extended mission (Howell et al. 2014). We obtained an unprecedented 83-day nearly continuous lightcurve with measurements every 30 minutes using Kepler's long cadence sampling. The result was 3,980 discrete, unresolved measurements of the combined Pluto system. The 3-month baseline allowed us to sample rotational variations and solar phase angles ranging from 1.1°-1.7° during the period of observation. This dataset is a key baseline for advancing the study of Pluto's actively evolving surface-atmosphere interaction as revealed by the surface geomorphology discovered by New Horizons. Our challenge is to gain an understanding of the ways in which Pluto's surface can be evolving as it recedes from the Sun, and of the influence of Pluto and Charon on each other. In this paper, we present our preliminary results from our K2 dataset. We describe the challenges in reducing the K2 lightcurve data for a target moving across the K2 FOV, and our progress in understanding the lightcurve's variability, which in our current reduction is due to a combination of systematics in the K2 dataset and inherent characteristics of the Pluto system's rotation and changing orbital geometry wrt the Sun and the Earth.
This work was supported by NASA's K2 and New Horizons missions.

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Contributing team(s): New Horizons Science Team

213.02 – The Pluto System At Small Phase Angles

Hubble Space Telescope observations of the Pluto system acquired during the New Horizons encounter epoch (HST Program 13667, M. Buie, PI) span the phase angle range from 0.06 to 1.7 degrees, enabling the measurement and characterization of the opposition effect for Pluto and its satellites at 0.58 microns using HST WFC3/UVIS with the F350LP filter, which has a broadband response and a pivot wavelength of 0.58 microns. At these small phase angles, differences in the opposition effect width and amplitude appear. The small satellites Nix and Hydra both exhibit a very narrow opposition surge, while the considerably larger moon Charon has a broader opposition surge. Microtextural surface properties derived from the shape and magnitude of the opposition surge of each surface contain a record of the collisional history of the system. We combine these small phase angle observations with those made at larger phase angles by the New Horizons Long Range Reconnaissance Imager (LORRI), which also has a broadband response with a pivot wavelength of 0.61 microns, to produce the most complete disk-integrated solar phase curves that we will have for decades to come. Modeling these disk-integrated phase curves generates sets of photometric parameters that will inform spectral modeling of the satellite surfaces as well as terrains on Pluto from spatially resolved New Horizons Ralph Linear Etalon Imaging Spectral Array (LEISA) data from 1.2 to 2.5 microns. Rotationally resolved phase curves of Pluto reveal opposition effects that only appear at phase angles less than 0.1 degree and have widths and amplitudes that are highly dependent on longitude and therefore on Pluto's diverse terrains. The high albedo region informally known as Sputnik Planum dominates the disk-integrated reflectance of Pluto on the New Horizons encounter hemisphere. These results lay the groundwork for observations at true opposition in 2018, when the Pluto system will be observable at phase angles so small that an Earth transit across the solar disk will be visible from Pluto and its satellites.

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Contributing team(s): New Horizons Science Team

213.03 – The Extraordinary Albedo Variations on Pluto Detected by *New Horizons* and Implications for Dwarf Planet Eris

The *New Horizons* mission returned stunning observations of active geology on the surface of Pluto (Stern et al., 2015, *Science* **350**, 292). One of the markers for activity on planets or moons is normal

albedos approaching 1.0, as is the case for Enceladus (Buratti et al., 1984, *Icarus* **58**, 254; Verbiscer et al., 2005, *Icarus* **173,** 66). When all corrections for viewing geometry are made for Pluto, it has normal albedos that approach unity in the regions that show evidence for activity by a lack of craters, notably the region informally named Sputnik Planum. On the other hand, Pluto also has a very dark (normal albedo ~0.10) equatorial belt.
The geometric albedo of Eris, another large dwarf planet in the Kuiper Belt, is 0.96 (Sicardy et al., 2011, *Nature* **478**, 493), close to that of Enceladus. Coupled with a high density of 2.5 gm/cc (Sicardy et al., ibid.), implying an even larger amount of radiogenic heating than that for Pluto (with a density near 1.9 gm/cc), we find it highly likely that Eris is also active with some type of solid state convection or cryovolcanism on its surface. Alternate explanations such as complete condensation of methane frost onto its surface in the colder environment at nearly 100 AUs would not lead to the high albedo observed.
Another implication of the extreme albedo variations on Pluto is that the temperature varies by at least 20K on its surface, spawning possible aeolian processes and associated features such as wind streaks and dunes, which are currently being sought on *New Horizons* images. Finally, low albedo regions on Pluto, with normal reflectances less than 0.10, provide possible evidence for dust in the Kuiper Belt that is accreting onto the surface of Pluto. Another - or additional - explanation for this low-albedo dust is native material created in Pluto's hazy atmosphere.
New Horizons funding by NASA is gratefully acknowledged.
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213.04 – The structure and temperature of Pluto's Sputnik Planum using 4.2 cm radiometry

New Horizons measured the radiometric brightness temperature of Pluto at 4.2 cm, during the encounter with two scans of the spacecraft's high gain antenna shortly after closest approach. The Pluto mid-section scan included the region informally known as Sputnik Planum, now understood to be filled with nitrogen ice. The mean radiometric brightness temperature at 4.2 cm, obtained in this region is 25 K, for both Right Circular Polarization (RCP) and Left Circular Polarization (LCP), well below the sublimation temperature for nitrogen ice. Sputnik Planum was near the limb and the termination of the radiometric scan. Consequently, the thermal emission was measured obliquely over a wide range of emission angles. This geometry affords detailed modeling of the angular dependence of the thermal radiation, incorporating surface and subsurface electromagnetic scattering models as well as emissivity models of the nitrogen ice. In addition, a bistatic radar measurement detected the scattering of a 4.2 cm uplink transmitted from Earth. The bistatic specular point was within Sputnik Planum and the measurements are useful for constraining the dielectric constant as well as the surface and subsurface scattering functions of the nitrogen ice. The combination of the thermal emission's angular dependence, RCP and LCP polarization dependence, and the bistatic scattering, yields estimates of the radiometric thermal emissivity, nitrogen ice temperature and spatial correlation scales.
This work is supported by the NASA New Horizons Mission.
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213.05 – Geomorphological Mapping of Sputnik Planum on Pluto

The New Horizons flyby of Pluto in July 2015 provided extensive high-resolution coverage of its encounter hemisphere. The most prominent surface feature in this hemisphere is the high albedo region informally named Tombaugh Regio, the western portion of which is represented by the expansive nitrogen ice plains informally named Sputnik Planum. A large fraction of Sputnik Planum displays a distinct cellular pattern, with individual cells typically displaying ovoid planforms and shallow pitting on a scale of a few hundred meters. Troughs with medial ridges define the boundaries between cells. Prior studies have argued that this pattern is indicative of solid-state convection occurring within the nitrogen ice. The southern non-cellular plains are either featureless or display dense fields of often elongate and aligned pits typically reaching a few km across, which are interpreted to have formed via sublimation.
The mapping that will be presented at DPS focuses on identifying the different plains units that compose Sputnik Planum and defining the boundaries between them, which aids in assessing their time sequencing and correlation to one another. The cellular plains are divided into bright and dark units; the nature of the contact between the two indicates that ice of the bright plains, interpreted to have been recently emplaced via glacial flow from the highlands to the east of Sputnik Planum, is overlying ice of the dark plains, interpreted to be an older ice mass with a higher abundance of entrained dark material. Reconciling the seemingly contradictory models of a layered and also convecting Sputnik Planum requires consideration of the timescale of lateral flow of the bright plains ice relative to the timescale of convective overturn. The non-cellular plains are universally bright and display evidence for southwards flow of the ice, based on the orientations of elongate sublimation pits as well as the presence of 'extinct cells' that appear to have migrated away from the zone of active convection. The larger pits that occur within the non-cellular plains imply that these plains are older than the cellular plains, where resurfacing via convection limits the maximum size attainable by sublimation pits.
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213.06 – An Expanded Analysis of Nitrogen Ice Convection in Sputnik Planum

The New Horizons close-encounter flyby of Pluto revealed 20-35 km scale ovoid patterns on the informally named Sputnik Planum. These features have been recently interpreted and shown to arise from the action of solid-state convection of (predominantly) nitrogen ice driven by Pluto's geothermal gradient. One of the major uncertainties in the convection physics centers on the temperature and grain-size dependency of nitrogen ice rheology, which has strong implications for the overturn times of the convecting ice. Assuming nitrogen ice in Sputnik Planum rests on a passive water ice bedrock that conducts Pluto's interior heat flux, and, given the uncertainty of the grain-size distribution of the nitrogen ice in Sputnik Planum, we examine a suite of two-dimensional convection models that take into account the thermal contact between the nitrogen ice layer and the conducting water-ice bedrock for a given emergent geothermal flux. We find for nitrogen ice layers several km deep, the emerging convection efficiently cools the nitrogen-ice water-ice bedrock interface resulting in temperature differences across the convecting layer of 10-20 K (at most) regardless of layer depth. For grain sizes ranging from 0.01 mm to 5 mm the resulting horizontal size to depth ratios of the emerging convection patterns go from 4:1 up to 6:1, suggesting that the nitrogen ice layer in Sputnik Planum may be anywhere between 3.5 and 8 km deep. Such depths are consistent with Sputnik Planum being a large impact basin (in a relative sense) analogous to Hellas on Mars. In this grain-size range we also find, (i) the calculated cell overturn times are anywhere from 1e4 to 5e5 yrs and, (ii) there is a distinct transition from steady state to time dependent convection.

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213.07D – Investigating the present and past glacial and frost activity on Pluto with a volatile transport model

The high obliquity and eccentricity of the orbit of Pluto induce seasonal cycles of condensation and sublimation of the main volatile ices: N_2, CH_4, and CO. The New Horizons spacecraft, which flew by Pluto in July 2015, revealed a complex surface composition including a thousand-kilometre nitrogen glacier in the "Sputnik Planum" plain near the Anti-Charon longitude, extensive methane frosts at mid and high latitudes, and equatorial ice-free regions. We present numerical simulations designed to model the evolution of Pluto's volatiles over thousands of years on the basis of straightforward universal physical equations.

Our results explain the observed distribution of ices on the surface and the quantities of volatiles in the atmosphere. In particular the model predicts the N_2 ice accumulation in the deepest low-latitude basin and the 3-fold increase of pressure observed to occur since 1988. This points to atmospheric-topographic processes at the origin of the Sputnik Planum's nitrogen glacier. The same simulations also show frosts of methane, and sometimes nitrogen, that seasonally cover the mid and high latitudes, explaining the bright northern polar cap reported in the 1990s and the observed ice distribution in 2015. The model also predicts that most of these seasonal frosts should disappear in the next decade, and thus could be tested observationally in the near future.

Using prior orbital parameters of Pluto and a realistic glacial flow parametrization, we also simulate past climates of Pluto. The results show that Pluto undergoes cycles of glacial activity (over timescales of few million years) that may explain the rugged eroded-mountain landscapes surrounding Sputnik Planum and the “bladed” methane terrains east of “Tombaugh Regio”.

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213.08 – Volatile Transport in Pluto’s Super Seasons

The data returned from NASA’s New Horizons’ reconnaissance of the Pluto system shows striking albedo variations from polar to equatorial latitudes as well as sharp boundaries for longitudinal variations. Pluto has a high obliquity (currently around 119 degrees) which varies by more than 23 degrees (between roughly 103 and 127 degrees) over a period of less than 3 million years. These obliquity properties, combined with Pluto’s orbital regression in longitude of perihelion (360 degrees over 3.7 million years), create epochs of “Super Seasons” on Pluto. A “Super Season” occurs, for example, when Pluto happens to be pole-on towards the Sun at the same time as perihelion. In such a case, one pole experiences a short, intense summer (relative to its long-term average) followed by a longer than average period of winter darkness. By complement, the other pole experiences a much longer, but less intense summer and short winter season. We explore the relationship between albedo variations and volatile transport for the current epoch as well as historical epochs during which Pluto experienced these “Super Seasons”. Our investigation suggests Pluto’s orbit creates the potential for runaway albedo variations, particularly in the equatorial region, which would create and support stark longitudinal contrasts like the ones we see between the informally named Tombaugh and Cthulhu Regios.

This work was supported by the NASA New Horizons mission.

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213.09D – Pluto followed its heart: reorientation and faulting of Pluto due to volatile loading in Sputnik Planum

The *New Horizons* flyby of Pluto revealed the dwarf planet to be a strikingly diverse, geologically active world. Perhaps the most intriguing feature on the *New Horizons* encounter hemisphere is Sputnik Planum—a 1000 km diameter, probable impact basin, filled with several kilometers of actively convecting volatile ices (N2, CH4, CO). One salient characteristic of Sputnik Planum is its curious alignment with the Pluto-Charon tidal axis. The alignment of large geologic features with principal axis of inertia (such as the tidal axis) is the hallmark of global reorientation, i.e. true polar wander. Here we show that the present location of Sputnik Planum is a natural consequence of loading of 1-2 km of volatile ices within the Sputnik Planum basin. Larger volatile ice thicknesses (like those inferred from studies of ice convection within Sputnik Planum) betray an underlying negative gravity anomaly associated with the basin. As Pluto reoriented in response to the loading of volatile ices within Sputnik Planum, stresses accumulated within the lithosphere (as each geographic location experiences a change in tidal/rotational potential). These reorientation stresses, coupled with loading stresses, and stresses from the freezing of a subsurface ocean resulted in the fracturing of Pluto’s lithosphere in a characteristic, global pattern of extensional faults. Our predicted pattern of extensional faults due to this reorientation closely replicates the observed distribution of faults on Pluto (more so than global expansion, orbit migration, de-spinning, or loading alone). Sputnik Planum likely formed ~60° northwest of its present location, and was loaded with volatile ices over millions of years due to seasonal volatile transport cycles. This result places Pluto in a truly unique category of planetary bodies where volatiles are not only controlling surface geology and atmospheric processes, but they are also directly controlling the orientation of the entire dwarf planet. Pluto's past, present, and future orientation is controlled by complicated feedbacks between volatile transport, insolation, and interior structure.

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213.10 – Landslides on Charon and not on Pluto

Landslide features are observed on Charon but not on Pluto. This observation is another that reinforces the different strength regime of surface materials on the two bodies. Pluto's surface, although underlain by strong water ice, is primarily mantled with a variety of geologically weak ice species. Observations of these features indicate that they flow and move, but do so in a manner similar to glacial flow, and the strength and steepening required to precipitate a landslide simply isn't present in these materials under the pressure and temperature conditions on Pluto's surface. There are certainly areas of local mass-wasting, but no substantial landslide deposits. There are some locations on Pluto, notably along the fossae walls, and perhaps on the steeper montes surfaces that could have fostered landslides, but no landslide deposits have been observed nor are there obvious landslide alcoves that would have sourced them. The resolution of observations along the fossae may prevent identification there, and the toes of the steeper montes are embayed by geologically recent plains material which could be overlaying any landslide deposits.
Charon, however, has a water-ice surface which exhibits many strength-dominated geologic features, and also exhibits landslide deposits. There are not many of these features and they are confined to the informally named Serenity Chasma, which has relatively steep, tall slopes, perfect for landslide initiation. We will discuss the physical characteristics of these landslide deposits and their context amongst other landslide features in the solar system.

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213.11 – Bladed Terrain on Pluto: Possible Origins and Evolutions

Pluto's Bladed Terrain (centered roughly 20°N, 225°E) covers the flanks and crests of the informally named Tartarus Dorsa with numerous roughly aligned blade-like ridges oriented ~North-South; it may also stretch considerably farther east onto the non-close approach hemisphere but that inference is tentative. Individual ridges are typically several hundred meters high, and are spaced 5 to 10 km crest to crest, separated by V-shaped valleys. Many ridges merge at acute angles to form Y-shape junctions in plan view. The principle composition of the blades themselves we suspect is methane or a methane-rich mixture. (Methane is spectroscopically strongly observed on the optical surfaces of blades.) Nitrogen ice is very probably too soft to support their topography. Cemented mixtures of volatile and non-volatile ices may also provide a degradable but relief supporting "bedrock" for the blades, perhaps analogous to Callisto. Currently we are considering several hypotheses for the origins of the deposit from which Bladed Terrain has evolved, including aeolian disposition, atmospheric condensation, updoming and exhumation, volcanic intrusions or extrusions, crystal growth, among others. We are reviewing several processes as candidate creators or sculptors of the blades. Perhaps they are primary depositional patterns such as dunes, or differential condensation patterns (like on Callisto), or fissure extrusions. Or alternatively perhaps they are the consequence of differential erosion (such as sublimation erosion widening and deepening along cracks), variations in substrate properties, mass wasting into the subsurface, or sculpted by a combination of directional winds and solar isolation orientation. We will consider the roles of the long-term increasing solar flux and short periods of warm thick atmospheres. Hypotheses will be ordered based on observational constrains and modeling to be presented at the conference.

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213.12 – Impact Craters on Pluto and Charon Indicate a Deficit of Small Kuiper Belt Objects

The impact craters observed during the New Horizons flyby of the Pluto system currently provide the most extensive empirical constraints on the size-frequency distribution of smaller impactors in the Kuiper belt. These craters also help us understand the surface ages and geologic evolution of the Pluto system bodies. Pluto's terrains display a diversity of crater retention ages and terrain types, indicating ongoing geologic activity and a variety of resurfacing styles including both exogenic and endogenic processes. Charon's informally named Vulcan Planum did experience early resurfacing, but crater densities suggest this is also a relatively ancient surface. We will present and compare the craters mapped across all of the relevant New Horizons LOng Range Reconnaissance Imager (LORRI) and Multispectral Visible Imaging Camera (MVIC) datasets of Pluto and Charon.
We observe a paucity of small craters on all terrains (there is a break to a shallower slope for craters below 10 km in diameter), despite adequate resolution to observe them. This lack of small craters cannot be explained by geological resurfacing alone. In particular, the main area of Charon's Vulcan Planum displays no obviously embayed or breached crater rims, and may be the best representation of a production population since the emplacement of the plain. The craters on Pluto and Charon are more consistent with Kuiper belt and solar system evolution models producing fewer small objects.
This work was supported by NASA's New Horizons project.

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214 – Enceladus

214.01 – The heterogeneous ice shell thickness of Enceladus

Saturn's moon Enceladus is the smallest Solar System body that presents an intense geologic activity on its surface. Plumes erupting from Enceladus' South Polar terrain (SPT) provide direct evidence of a reservoir of liquid below the surface. Previous analysis of gravity data determined that the ice shell above the liquid ocean must be 30-40 km thick from the South Pole up to 50° S latitude (Iess et al., 2014), however, understand the global or regional nature of the ocean beneath the ice crust is still challenging. To infer the thickness of the outer ice shell and prove the global extent of the ocean, we used the self-similar clustering method (Bonnet et al., 2001; Bour et al., 2002) to analyze the widespread fractures of the Enceladus's surface. The spatial distribution of fractures has been analyzed in terms of their self-similar clustering and a two-point correlation method was used to measure the fractal dimension of the fractures population (Mazzarini, 2004, 2010). A self-similar clustering of fractures is characterized by a correlation coefficient with a size range defined by a lower and upper cut-off, that represent a mechanical discontinuity and the thickness of the fractured icy crust, thus connected to the liquid reservoir. Hence, this method allowed us to estimate the icy shell thickness values in different regions of Enceladus from SPT up to northern regions.
We mapped fractures in ESRI ArcGis environment in different regions of the satellite improving the recently published geological map (Crow-Willard and Pappalardo, 2015). On these regions we have taken into account the fractures, such as *wide troughs* and *narrow troughs*, located in well-defined geological units. Firstly, we analyzed the distribution of South Polar Region fracture patterns finding an ice shell thickness of ~ 31 km, in agreement with gravity measurements (Iess et al., 2014). Then, we applied the same approach to other four regions of the satellite inferring an increasing of the ice shell thickness from 31 to 70 km from the South Pole to northern regions. By these findings, we prove the global extent of the ocean underneath the ice crust of the satellite.

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214.02 – True Polar Wander of Enceladus From Topographic Data

Besides the relative motion of lithospheric plates, the Earth as a whole moves with respect to its rotation pole, as shown by paleomagnetic, astrometric and geodetic measurements [1]. Such so-called *true polar wander* (TPW) occurs because our planet's moments of inertia change temporally owing to internal thermal convection and to the redistribution of surficial mass during ice ages. Thus, to conserve angular momentum while losing rotational energy, Earth's axis of maximum moment of inertia aligns with its spin axis. Theoreticians suspect similar reorientations of other celestial bodies but supporting evidence is fragmentary, at best [2]. Here we report the discovery of a global series of topographic lows on Saturn's satellite Enceladus indicating that this synchronously locked moon has undergone reorientation by ~55°. We use improved topographic data from spherical harmonic expansion of Cassini limb [3,4,5] and stereogrammetric [5,6,7] measurements to characterize regional topography over the surface of Enceladus. We identify a group of nearly antipodal basins orthogonal to a topographic basin chain tracing a non-equatorial circumglobal belt across Enceladus' surface. We argue that the belt and the antipodal regions are fossil remnants of old equator and poles, respectively. These lows are argued to arise from isostasic compensation [7,8] with their pattern reflecting variations in internal dynamics of the ice shell. Our hypothesis is consistent with many geological features visible in Cassini images [9].

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214.03 – Enceladus' tidal dissipation revisited

A series of chemical and physical evidence indicates that the intense activity at Enceladus' South Pole is related to a subsurface salty water reservoir underneath the tectonically active ice shell. The detection of a significant libration implies that this water reservoir is global and that the average ice shell thickness is about 20-25km (Thomas et al. 2016). The interpretation of gravity and topography data further predicts large variations in ice shell thickness, resulting in a shell potentially thinner than 5 km in the South Polar Terrain (SPT) (Cadek et al. 2016). Such an ice shell structure requires a very strong heat source in the interior, with a focusing mechanism at the SPT. Thermal diffusion through the ice shell implies that at least 25-30 GW is lost into space by passive diffusion, implying a very efficient dissipation mechanism in Enceladus' interior to maintain such an ocean/ice configuration thermally stable.
In order to determine in which conditions such a large dissipation power may be generated, we model the tidal response of Enceladus including variable ice shell thickness. For the rock core, we consider a wide range of rheological parameters representative of water-saturated porous rock materials. We demonstrate that the thinning toward the South Pole leads to a strong increase in heat production in the ice shell, with a optimal thickness obtained between 1.5 and 3 km, depending on the assumed ice viscosity. Our results imply that the heat production in the ice shell within the SPT may be sufficient to counterbalance the heat loss by diffusion and to power eruption activity. However, outside the SPT, a strong dissipation in the porous core is required to counterbalance the diffusive heat loss. We show that about 20 GW can be generated in the core, for an effective viscosity of 10^{12} Pa.s, which is comparable to the effective viscosity estimated in water-saturated glacial tills on Earth. We will discuss the implications of this revisited tidal budget for the activity of Enceladus and the long-term evolution of its interior.

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214.04D – The role of turbulent dissipation in planetary fluid interiors driven by tidal and librational forcing

The turbulent fluid motions generated in the liquid metal cores and oceans of planetary bodies can have profound effects on energy dissipation and magnetic field generation. An important driver of such fluid motions is mechanical forcing from precession, libration, and tidal forcing. On Earth, the dissipation of energy through tidal forcing occurs primarily in the oceans and may be due, in part, to nonlinear tidally forced resonances. However, the role that such nonlinear resonances play are not generally considered for other planetary bodies also possessing oceans and liquid metal cores. Recent laboratory experimental and numerical studies of Grannan *et al.* 2014 and Favier *et al.* 2015 have shown that nonlinear fluid resonances generated by sufficiently strong librational forcing can drive turbulent flows in ellipsoidal containers that mimic gravitational deformations. In Grannan *et al.* 2016, similar results were found for strong tidal forcing. Thus, a generalized scaling law for the turbulent r.m.s. velocity is derived, $U \sim \varepsilon\beta E^{-\alpha}$, where ε is the dimensionless amplitude of the tidal or librational forcing, β is the dimensionless tidal deformation of the body, E is the dimensionless Ekman number characterizing the ratio of viscous to Coriolis forces, and α is a varying exponent.
Using planetary values for tidal and librational forcing parameters, the turbulent dissipation is estimated for multiple bodies. For the subsurface oceans of Europa and Enceladus, the amount of nonlinear dissipation is comparable to the dissipation generated from linear resonances of the fluid layer and from upper bounding estimates of the tidal dissipation in the solid icy shell. In addition, our estimates of this turbulent dissipation provide bounds for the stratification in these subsurface oceans. Finally we find that dissipation from these nonlinear resonances in the liquid metal cores of the the early and present Earth, Io, and several exoplanets may help drive the dynamos in these bodies. Thus, the impact of these nonlinear resonances may play an important role in several planetary processes and may extend to more geophysically relevant models that including fluid stratification and ellipsoidal shell geometries.

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214.05 – Effect of the tiger stripes on the tidal deformation of Enceladus

The south polar region of Saturn's moon Enceladus has been subjected to a thorough scientific scrutiny since the Cassini mission discovery of an enigmatic system of fractures informally known as “tiger stripes”. This fault system is possibly connected to the internal water ocean and exhibits a striking geological activity manifesting itself in the form of active water geysers on the moon's surface.
The effect of the faults on periodic tidal deformation of the moon has so far been neglected because of the difficulties associated with the implementation of fractures in continuum mechanics models.
Employing an open source finite element FEniCS package, we provide a numerical estimate of the maximum possible impact of the tiger stripes on the tidal deformation and the heat production in Enceladus's ice shell by representing the faults as narrow zones with negligible frictional and bulk resistance passing vertically through the whole shell.
For a uniform ice shell thickness of 25 km, consistent with the recent estimate of libration, and for linear elastic rheology, we demonstrate that the faults can dramatically change the distribution of stress and strain in Enceladus's south polar region, leading to a significant increase of the heat flux and to a complex deformation pattern in this area. We also present preliminary results studying the effects of (i) variable ice-shell thickness, based on the recent topography, gravity and libration inversion model by Čadek et al. (2016) and (ii) Maxwell viscoelastic rheology on the global tidal deformation of the ice shell.
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214.06 – Enceladus Plumes: Causes of Decadal Variability

The Enceladus plumes have decreased over the decade that Cassini has been observing them. This long-term variation is superposed on the much shorter-term variation tied to the position of Enceladus in its orbit around Saturn. The observations are ISS and VIMS images, which reveal the particles in the plumes but not the gas. The decadal variability largely consists of a 2-fold decline in the mass of plume material, but there is a hint of a recent turnaround. Here we offer three hypotheses, each with its strengths and weaknesses, to explain the long-term variability. The first is seasonal change, from summer to fall in the southern hemisphere. The loss of sunlight could increase the build-up of ice around the tiger stripes. The weakness is that the sunlight is likely to have a small effect, e.g., decreasing the sublimation rate of the ice by only ~1 cm/year. The second hypothesis is a statistical fluctuation in the number of active plumes, which tend to turn themselves off due to build-up of ice at the throat of the vent. The weakness is that the plumes are likely to fluctuate independently, and if there are ~100 plumes, their sum will only fluctuate by 10%. The third hypothesis is that the variation is part of a well-known decadal cycle of orbital eccentricity, which varies by ±2.5% around a mean of 0.0047. The peak eccentricity occurred in 2009-2010, and the minimum occurred in 2015. Since eccentricity controls the short-term orbital cycle variations, it could also control the longer-term decadal variations. The weakness is that the eccentricity variation is small, from 0.0046 to 0.0048. It is not certain that such a small variation could cause a 2-fold variation in the strength of the plumes. An independent study, still in its infancy, is the possibility that liquid water reaches the surface during part of the orbital cycle.

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214.07 – Enceladus' Supersonic Gas Jets' Role in Diurnal Variability of Particle Flux

Introduction: The Cassini Ultraviolet Imaging Spectrograph (UVIS) has observed 6 occultations of stars by Enceladus’ plume from 2005 to 2011 [1]. Supersonic gas jets were detected, imbedded in the overall expulsion of gas at escape velocity along the tiger stripe fissures that cross Enceladus’ south pole [2]. The gas flux can be calculated [1], and is observed to vary just 15% in over 6 years, representing a steady output of ~200 kg/sec. In contrast, the brightness of the particle jets, a proxy for the amount of particles expelled, varies 3x with orbital longitude [3], implicating tidal stresses. This is not necessarily inconsistent with the steady gas flux, which had not been measured at apokrone until now.
2016 epsilon Orionis Occultation: In order to investigate whether gas flow increases dramatically at apokrone an occultation observation was inserted into the Cassini tour on March 11, 2016 on

orbit 233. Enceladus was at a mean anomaly of 208 at the time of the occultation. Using the same methodology as previously employed the column density has been determined to be 1.5 x 10^{16} cm^{-2}, giving a gas flux of 250 kg/sec. This value is 20% higher than the average 210 kg/sec, but only 15% higher than the occultations at a mean anomaly of 236; i.e. higher than the others but not by a factor of 2 or 3. The overall expulsion of gas from the south pole of Enceladus thus does not seem to change dramatically with orbital position.

Jets: The line of sight to the star pierced the Baghdad I gas jet. The jet data, in contrast to the integrated plume, look significantly different in this dataset. The column density of the jet is higher than observed in previous occultations. The collimation of the jet is more pronounced and from that we derive a mach number of 8-9, compared to a previous value for this jet of 6. We conclude that the higher velocity and increased quantity of gas in the jet close to apokrone indicate that the jets are the primary contributors to the increased particle flux observed at apokrone.

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214.08 – Comparing different Ultraviolet Imaging Spectrograph (UVIS) occultation observations using modeling of water vapor jets

Motivation: On March 11, 2016 the Cassini UVIS observed its 6th star occultation by Enceladus' plume. This observation was aimed to determine variability in the total gas flux from the Enceladus' southern polar region. The analysis of the received data suggests that the total gas flux is moderately increased comparing to the average gas flux observed by UVIS from 2005 to 2011 [1]. However, UVIS detected variability in individual jets. In particular, Baghdad 1 is more collimated in 2016 than in 2005, meaning its gas escapes at higher velocity.

Model and fits: We use 3D DSMC model for water vapor jets to compare different UVIS occultation observations from 2005 to 2016. The model traces test articles from jets' sources [2] into space and results in coordinates and velocities for a set of test particles. We convert particle positions into the particle number density and integrate along UVIS line of sight (LoS) for each time step of the UVIS observation using precise observational geometry derived from SPICE [3]. We integrate all jets that are crossed by the LoS and perform constrained least-squares fit of resulting modeled opacities to the observed data to solved for relative strengths of jets. The geometry of each occultation is specific, for example, during solar occultation in 2010 UVIS LoS was almost parallel to tiger stripes, which made it possible to distinguish jets venting from different tiger stripes. In 2011 Eps Orionis occultation LoS was perpendicular to tiger stripes and thus many of the jets were geometrically overlapping. Solar occultation provided us with the largest inventory of active jets – our model fit detects at least 43 non-zero jet contributions. Stellar occultations generally have lower temporal resolution and observe only a sub-set of these jets: 2011 Eps Orionis needs minimum 25 non-zero jets to fit UVIS data. We will discuss different occultations and models fits, including the most recent Epsilon Orionis occultation of 2016.

[1] Hansen et al., DPS 48, 2016 [2] Porco et al. 2014 The Astronomical Journal 148, 4 [3] Acton, C.H., 1996 PSS 44, 65-70

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214.10 – Cassini VIMS Spectra of the Thermal Emission from Hot Spots Along Enceladus South Pole Fissures

Most of the south pole fissure region has not been directly illuminated by sunlight since the sub-solar point moved into the northern hemisphere in 2009, thereby eliminating the background of reflected sunlight at VIMS wavelengths and making the fissure thermal emission readily measureable. Since then, VIMS has measured spectra of at least 11 hot spots along the fissures. Most of these measurements were acquired in ride-along mode with CIRS as the prime instrument. During at least 2 encounters, VIMS and CIRS acquired simultaneous or near-simultaneous spectra of the same fissure location. VIMS spectra include multiple hot spots along Damascus, Baghdad, Cairo, and a likely hot spot on Alexandria.

All of the VIMS spectra examined to date are consistent with this scenario of a self-regulating fissure maximum T~200 K with brighter VIMS emissions corresponding to fissures up to ~20 m wide. Emission from the warm fissure interior walls dominate the VIMS spectra with <15% contributed by conductive heating of the adjacent terrain at VIMS wavelengths.

CIRS spectra report slightly cooler T's due to CIRS increased sensitivity to lower T emission at longer wavelengths and averaging over contributions from both the hottest and cooler areas.

Combined analysis of the CIRS and VIMS spectra spanning 3 to 500 micron wavelengths promises to reveal the distribution of [T, area] near the fissures that cannot be spatially resolved. This [T, area] distribution holds the key to understanding how heat is transferred to the surface within a few 100 m of the fissures.

The VIMS-detected emission is concentrated in localized hot spots along the fissures and does not seem to be distributed continuously along them. CIRS spectra suggest a more continuous distribution of the emission along the fissure length. Jets locations also are distributed along the fissure length and it appears that the VIMS-detected hot spots in general correlate with jet locations, but not all of the jet locations have been seen as VIMS hot spots.

Acknowledgement: This research was conducted at the Jet Propulsion laboratory, California Institute of Technolgy, Pasadena, CA.

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Contributing team(s): Cassini VIMS Team

214.11 – Thermal, dielectric and structural properties of Enceladus' leading face

The Cassini RADAR was initially designed to examine the surface of Titan through the veil of its optically-opaque atmosphere. However, it is occasionally used to observe airless Saturn's moons from long range and, less frequently, during targeted flybys. In particular, the 16th targeted encounter of Enceladus (Nov. 6, 2011, flyby E16) was dedicated to the RADAR instrument which then acquired data for over 4 hours. This paper focuses on the mid-resolution (0.1-$0.6R_{Enceladus}$) and low-resolution polarized data (0.6-$1.0R_{Enceladus}$) collected during the E16 flyby in the radiometry mode of the RADAR, mainly on the leading side of the moon.

In its passive mode, the RADAR records the thermal emission at 2-cm wavelength from, likely, the first meters of an icy surface. Ries and Janssen (2015) first analyzed the E16 mid-resolution radiometry observation and reported on a large-scale emissivity anomaly, possibly associated with the seemingly young tectonized Leading Hemisphere Terrain mapped by Crow-Willard and Pappalardo (2015). With the goal of further investigating the extension of the anomaly region and providing constrains on the thermal, dielectric

and structural properties of Enceladus' near surface, we have re-examined this dataset as well as observations acquired in two orthogonal polarizations with the help of a thermal model. This thermal model accounts for both diurnal and seasonal variations of the incident flux, including eclipses which is of importance for the E16 observations partially occurred during a solar eclipse by Saturn. Preliminary results suggest that the average thermal inertia of the near surface of Enceladus' leading face is relatively low, as low as 40 $Jm^{-2}K^{-1}s^{-1/2}$. This value does not depart much from the one inferred from measurements in the IR suggesting that the surface of Enceladus is covered by a very porous regolith, at least a few meters thick. In agreement, with this interpretation, the degree of volume scattering (i.e., high-order scattering by voids/heterogeneities in the subsurface) was found to be high, especially in the anomaly region where it is of same order of magnitude of the anomalously radar-bright terrains on Titan (Janssen et al., 2011).
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214.12 – Enceladus and Tethys: Ultraviolet clues to surface composition & surface processing

Cassini's Ultraviolet Imaging Spectrograph (UVIS) is sensitive to the uppermost portion of the regoliths of the icy Saturnian moons, where interactions with E-ring grains and plasma processing are important. Organics are present in at least 30% of E ring grains (Postberg et al., 2008) and are likely transported to the surfaces of the satellites orbiting Saturn within the E ring. Plasma bombardment on the trailing hemispheres of the satellites can further process these organic species. Enceladus' surface exhibits visible color variations (Schenk et al., 2011), evidence of plume fall-out zones and zones where plume fall-out is not as heavy (and where E ring grain bombardment dominates). In this study, we investigate far-UV spectral and photometric differences in the Enceladus plume fallout and non-fallout regions to study compositional and structural differences, and we also study compositional and photometric variations in regions on Tethys' trailing and leading hemispheres to understand spectral effects of organics, E ring bombardment and plasma bombardment.
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215 – Moon: Atmosphere and Surface

215.01 – The Outsized Influence of a Primordial Lunar Atmosphere

Immediately following formation of the moon, its surface was subject to radiative influences from the Lunar Magma Ocean, an early Earth that radiated like a mid type M Dwarf Star, and the early Sun. These contributions have been hypothesized to have produced a vapor pressure atmosphere on the Moon. We model the early atmosphere of the Moon using an atmospheric model originally developed for Io. We also use a magma ocean crystallization model that finds that heating from the early Earth delays crystallization of the Lunar Magma Ocean and contributes to a moderate pressure and collapsing metal-dominated atmosphere on the earthside of the Moon until lid formation. The atmosphere is characterized by maximum pressures ~1 bar and strong horizontal supersonic winds that decreased as the Moon's orbital separation increased. Crustal and other compositional asymmetries may have been influenced by this atmosphere. The atmosphere transported significant amounts of mass horizontally and may have been a source for present day depletions and heterogeneities of moderately volatile elements on the lunar surface.
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215.02 – Exospheres from Asteroids to Planets

The study of exospheres can help us understand the long-term loss of volatiles from planetary bodies due to interactions of planets, satellites, and small bodies with the interplanetary medium (solar wind, meteors, and dust), solar radiation, internal forces including diffusion and outgassing, and surface effects like sticking and chemistry. Recent evidence for water and OH on the moon has spurred interest in processes involving chemistry and sequestration of volatile species at the poles and in voids. In recent years, NASA has sent spacecraft to asteroids including Vesta and Ceres, and ESA sent Rosetta to the asteroids Lutetia and Steins. OSIRIS-REX will return a sample from a primitive asteroid, Bennu, to Earth. It is possible that a Phobos-Deimos flyby will be a precursor to a manned mission to Mars. Exospheric particles are derived from the surface and to some extent from interplanetary dust and meteoroids. By comparing the exospheric compositions before and after major meteor shower events it may be possible to determine the extent to which the exosphere reflects the surface composition. Observation of an escaping exosphere, termed a corona, is challenging. We therefore have embarked on a parametrical study of exospheres as a function of basic controlling parameters such as the mass of the primary object, mass of the exospheric species, heliocentric distance, rotation rate of the primary, composition of the body (asteroid type or icy body). These parameters will be useful for mission planning as well as quick look data to determine the size and location of bodies likely to retain their exospheres and observability of exospheric species. We will also consider the sizes of small clusters that may be gravitationally bound to small bodies such as Phobos. In addition, it is of interest to be able to determine the extent of contamination of the pristine exosphere due to the spacecraft sent to make measurements, and the effect on the measurements of outgassing in the instruments.
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Contributing team(s): DREAM2

215.03D – Thermally induced stresses in boulders on airless body surfaces: Implications for breakdown

We investigate the role of thermally induced rock breakdown in the evolution of airless body surfaces. This process is driven by the propagation of microcracks due to stress caused by changes in temperature. Here we model the thermomechanical response of spherical lunar boulders of varying size to diurnal thermal forcing. Exploring the magnitude and distribution of induced stresses reveals a bimodal response. During sunrise, high stresses occur in the boulders' interiors that are associated with large-scale temperature gradients (developed due to overnight cooling). During sunset, high stresses occur at the boulders' exteriors due to the cooling and contraction of the surface. Both kinds of stresses are on the order of 10 MPa in 1 m boulders and decrease for smaller radii, suggesting that larger boulders break down more quickly. Boulders ≤30 cm exhibit a weak response to thermal forcing, suggesting a boulder-size threshold below which crack propagation may not occur. Boulders of any size buried by regolith are shielded from thermal breakdown.

As boulders increase in size (>1 m), stresses increase to several 10s of MPa as the behavior of their surfaces approaches that of an infinite halfspace. The rate of stress-increase is rapid until the boulder reaches ~5 times the skin depth (~4 m) in size. Above this size, stresses only slowly increase as the surface loses thermal contact with the boulder center. Boulders between 3 m and 7 m have less volume of material to erode than larger boulders (> 10 m) but only moderately lower stresses, suggesting they may be preferentially broken down by this process.

Stress orientations can yield insight into how breakdown may occur. Interior stresses act on a plane perpendicular to the path of the sun, driving the propagation of surface-parallel cracks and contributing to exfoliation of planar fragments. Exterior stresses act parallel to the boulder surface driving the propagation of surface-perpendicular cracks and contributing to granular disintegration. These two mechanisms likely work together to hasten disaggregation of the near-surface.

We will present results for boulder stresses on the Moon and other airless bodies, and discuss implications for breakdown on these surfaces.

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215.04 – Rock infromation of the moon revealed by multi-channel microwave radiometer data

Rock abundance on lunar surface is an important consideration for understanding the physical properties of the Moon. With the deeper penetration power of the microwave, data from Chang'E (CE) multichannel (3.0-, 7.8-, 19.35-, and 37-GHz) microwave radiometer (MRM) are used to constrain the rock distribution on the Moon. The contrasting thermo-physical properties between rocks and regolith fines cause multiple brightness temperature (TB) to be present within the field of view of CE microwave data. But these variations could be easily masked by the more significant effect of ilmenite on TB, especially in the mare regions which are rich in ilmenite.

To highlight the rock effect in TB, the diurnal TB difference, which has the effect of enlarging the TB difference caused by the rock abundance and reducing the absolute error of the CE microwave data, is considered here. The rock information in TB data is distinguished from the ilmenite effect by comparing the diurnal TB difference with a statistical TB model of the mare regions which are relatively low in rock abundance. The employed statistical TB model is a polynomial fitting formula between the selected CE TB data from mare regions and the corresponding TiO_2 content data from Clementine UVVIS data. The correlation coefficients of the polynomial fit between TB and TiO_2 content are 0.94 at lunar daytime and 0.84 at lunar nighttime, respectively. This polynomial fit forms an approximated relationship between the TiO_2 content and TB when rock abundance is zero, with a standard error determined from the regression procedure.

Based on the TiO_2 map retrieved from Clementine UVVIS data, the TB map that is deflated to a lower TiO_2 content shows a distribution trend similar to the rock abundance map retrieved by LRO data, except for the mare regions at the nearside of the Moon. The bigger diurnal TB difference in the mare regions could be either caused by the rich ilmenite rocks or the smaller rocks which cannot be recognized by the LRO data.

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Contributing team(s): This work is supported by Science and Technology Development Fund in Macao SAR 048/2012/A2 and 039/2013/A2, and the NSFC program (41490633). The CE data was supported by the Key Laboratory of Lunar and Deep Space Exploration (2013DP173157), National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China.

215.05 – Lunar cold spots and crater production on the Moon

A new class of small, fresh impact craters has been recently identified on the Moon through the systematic mapping of lunar surface temperatures by the Diviner Lunar Radiometer instrument aboard the Lunar Reconnaissance Orbiter [1]. These craters are distinguished by anomalously low nighttime temperatures at distances ~10–100 crater radii. This thermal behavior indicates that impacts modify the surrounding regolith surfaces making them highly insulating with little evidence for either significant deposition or erosion of surface material [2]. These thermophysically distinct surfaces, or "cold spots", appear to be common to all recent impacts and provide a means of uniquely identifying the most recent impact craters on the Moon. We have conducted a survey of the crater population associated with cold spots. Comparison with existing crater chronology models [e.g., 3] constrains the retention-age of the cold spots to ~200,000 yr with a size-frequency distribution (SFD) slope that is consistent with the modeled production function. This implies the rate at which cold spots fade to background levels is independent of initial cold spot size and that the SFD of crater production in the last 200 ka is similar to the long-term average used to establish modeled production functions, though the rate of cratering may have varied [4]. In addition, we observe a longitudinal heterogeneity in cold spot crater density that is consistent with that predicted to occur as a result of the Moon's synchronous rotation [5] and has been observed in the rayed crater population [6], with the cold spot density at the apex of motion (90°W) nearly twice that observed at the antapex (90°E).

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215.06 – Crater shapes in transition – classification of lunar impact craters in the 5 km to 20 km size range

Lunar craters transition from simple to complex morphology in the diameter range 10 - 20 km. This transition is reflected in the crater topography and is indicative of an energy threshold and gravity [1]. The change in shapes of craters in the 10 km to 20 km transition range is investigated in this work by performing topography-based classification of 19335 lunar craters in the size range 5 km to 20 km. A global database of lunar craters (location and approximate diameter) with diameters (D) between 5 km to 20 km (±60° latitude) was constructed [2] from Lunar Reconnaissance Orbiter Wide Angle Camera global mosaic and stereo topography (GLD100). In this work we extract topographic information from each crater in this global database by using the GLD100 and classify them based on their depth-to-diameter ratio, observed central uplift activity, flatness of the floor, radial variations in crater wall slopes. Shapes of craters are also characterized using a Chebyshev polynomial [3] based representation for crater topographic profile.

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characterization of impact crater topography." *Icarus* 241 (2014): 114-129.
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215.07 – Spatial distribution of steep lunar craters may be linked to size-dependent orbital distribution of impactors

The depth/diameter (d/D) ratio of simple lunar craters (D<15km) is known to be ~0.2 at the time of formation; larger complex craters (D>15km) have smaller d/D ratios. We examine the spatial distribution of high d/D ratio (>0.18) craters using LU60645GT catalogue (Salamunićcar et al. 2012). We select craters larger than 8km for which the census is known to be almost complete over the whole lunar surface. We find that the number density of steep craters in maria is significantly lower than in highlands, which may be explained by the age differences of the background surfaces. We also find that the spatial density of steep craters in the equatorial region is lower than in the polar region. On the contrary, higher cratering flux on the lunar equator has been claimed: from the numerical calculations with the orbital distribution of observed Earth Crossing Objects (ECOs) larger than 1km (Le Feuvre & Wieczorek 2008; Ito & Malhotra 2010) and from the distribution of steepest slopes at a 25m baseline (Kreslavsky & Head, 2016). In order to reconcile our findings with previous observations, we hypothesize that the cratering rate at low latitudes has been higher for meter to decameter size ECOs than for kilometer size objects since the Late Imbrian epoch; smaller objects have triggered more frequent mass wasting on the pre-existing large steep craters (D>8km, d/D>0.18) at low latitudes, thereby reducing the surviving number of steep craters. Our hypothesis is supported by the finding that the power-law slope in the H magnitude distribution for the low inclination ECOs (i<15 deg) is steeper than for the high inclination objects. Renu Malhotra acknowledges research support from NSF (grant AST-1312498).
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215.08 – Topographic erosion by meteroid bombardment results in non-classical diffusion

Here we develop a new Monte Carlo method for modeling meteoroid erosion in which local diffusivity is treated as a superposition of diffusivities whose values are determined by Poisson's distribution. We use numerical experiments to determine the effective diffusivity of a crater of a given size. We demonstrate that this Monte Carlo diffusion model can successfully explain the crater count equilibrium level observed on heavily-cratered terrains throughout the solar system. However, we find that the equilibrium level that we produce in our model is sensitive to how the local slope at the point of impact affects the final morphology of the resulting crater. Our model also explains the increase in the apparent erosion rate with increasing feature age and the increase in the apparent erosion rate with increasing feature size.
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215.09 – Photometric Characteristics of Lunar Terrains

The photometric properties of the lunar depend on albedo, surface roughness, porosity, and the internal/external structure of particles. Hapke parameter maps derived using a bidirectional reflectance model [Hapke, 2012] from Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) images demonstrated the spatial and spectral variation of the photometric properties of the Moon [Sato et al., 2014]. Using the same methodology, here we present the photometric characteristics of typical lunar terrains, which were not systematically analyzed in the previous study.

We selected five representative terrain types: mare, highland, swirls, and two Copernican (fresh) crater ejecta (one mare and one highlands example). As for the datasets, we used ~39 months of WAC repeated observations, and for each image pixel, we computed latitude, longitude, incidence, emission, and phase angles using the WAC GLD100 stereo DTM [Scholten et al., 2012]. To obtain similar phase and incidence angle ranges, all sampling sites are near the equator and in the vicinity of Reiner Gamma. Three free Hapke parameters (single scattering albedo: ***w***, HG2 phase function parameter: ***c***, and angular width of SHOE: ***hs***) were then calculated for the seven bands (321-689 nm). The remaining parameters were fixed by simplifying the model [Sato et al., 2014].

The highlands, highland ejecta, and swirl (Reiner Gamma) showed clearly higher ***w*** than the mare and mare ejecta. The derived ***c*** values were lower (less backscattering) for the swirl and higher (more backscattering) for the highlands (and ejecta) relative to the other sites. Forward scattering materials such as unconsolidated transparent crystalline materials might be relatively enriched in the swirl. In the highlands, anorthositic agglutinates with dense internal scattering could be responsible for the strong backscattering. The mare and mare ejecta showed continuously decreasing ***c*** from UV to visible wavelengths. This might be caused by the FeO-rich pyroxene and glass in the mare becoming more translucent at longer wavelengths.
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215.10 – Optical Maturity on the Walls of Lunar Craters

Recent studies found that the optical maturity (OMAT) and the mean grain size <d> of the lunar regolith have latitude dependences, probably because of the reduced flux of space-weathering agents at high latitudes. Here we extend our previous work (Jeong et al.) to the inner walls of lunar impact craters, dividing the wall into four quadrants. We consider the ~3000 craters whose latitude is between -58° and +58° and whose diameter is between 5 km and 120 km in the Lunar Impact Crater Database 2015 from the LPI. We adopt the topography-corrected OMAT data from the Kaguya/MI observations. The OMAT differences between the northern and southern walls are insignificant near the equator, but at high latitudes, the equator-facing walls have generally smaller (more mature) OMAT values than the pole-facing walls. This is consistent with the global latitudinal dependence of the OMAT and <d> values found in previous researches. The overall mean value curve of [OMAT(E) - OMAT(W)] has a minimum and maximum near longitudes -60° and +60°, respectively. This is thought to be due to the shielding of solar wind particles during the Moon's passage through the Earth's magneto-tail. Further analyses on the longitudinal dependencies of OMAT and <d> will give us insights on the relative importance of solar wind particles and micrometeoroids on the space weathering of the lunar regolith grains.
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215.11 – Young Lunar Volcanic Features: How Did They Form?

Irregular mare patches (IMPs) on the Moon are younger than 100 Myr [1, 2], but their formation mechanism is unknown. Previous work has suggested caldera collapse [3], explosive outgassing [2], pyroclastic eruptions [4], basaltic lava flows [1, 5], and regolith drainage into graben [6]. Here we present observations from the Lunar Reconnaissance Orbiter (LRO) Diviner thermal radiometer of the four largest IMPs. These observations suggest that the surfaces of the IMPs are on average only slightly rockier than the surrounding regolith. The nighttime cooling curves of the IMPs and the surrounding regolith do not intersect, which suggests that there is no layering in the top 5-10 cm of the IMPs. We also measure the thermal inertia (parameterized through the "H-parameter" [7]) of the IMPs. We find that the thermal inertia of Sosigenes is higher than that of the surrounding regolith (probably due to mass wasting), the thermal inertia of Cauchy-5 and Maskelyne is not significantly different from the surrounding regolith, and the thermal inertia of the largest smooth mound in Ina is significantly lower than the surrounding regolith. Only some IMPs are in topographic depressions or associated with graben, so neither caldera collapse nor drainage into graben can explain the formation of all IMPs. It is unlikely that basaltic lava flows would lead to a thermal inertia lower than that of lunar regolith. Therefore, of the formation mechanisms proposed to date, pyroclastic eruptions or another type of explosive outgassing [e.g. 2] possibly accompanied by basaltic lava flows or drainage into graben best explain the available observations of IMPs.

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Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

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215.12 – Development of a Gamma-Ray Spectrometer for Korean Pathfinder Lunar Orbiter

Korea is preparing for a lunar orbiter mission (KPLO) to be developed in no later than 2018. Onboard the spacecraft is a gamma ray spectrometer (KLGRS) allowing to collect low energy gamma–ray signals in order to detect elements by either X-ray fluorescence or by natural radioactive decay in the low as well as higher energy regions of up to 10 MeV. Scientific objectives include lunar resources (water and volatile measurements, rare earth elements and precious metals, energy resources, major elemental distributions for prospective in-situ utilizations), investigation of the lunar geology and studies of the lunar environment (mapping of the global radiation environment from keV to 10 MeV, high energy cosmic ray flux using the plastic scintillator).

The Gamma-Ray Spectrometer (GRS) system is a compact low-weight instrument for the chemical analysis of lunar surface materials within a gamma-ray energy range from 10s keV to 10 MeV. The main $LaBr_3$ detector is surrounded by an anti-coincidence counting module of BGO/PS scintillators to reduce both low gamma-ray background from the spacecraft and housing materials and high energy gamma-ray background from cosmic rays. The GRS system will determine the elemental compositions of the near surface of the Moon.

The GRS system is a recently developed gamma-ray scintillation based detector which can be used as a replacement for the HPGe GRS sensor with the advantage of being able to operate at a wide range of temperatures with remarkable energy resolution. $LaBr_3$ also has a high photoelectron yield, fast scintillation response, good linearity and thermal stability. With these major advantages, the $LaBr_3$ GRS system will allow us to investigate scientific objectives and assess important research questions on lunar geology and resource exploration.

The GRS investigation will help to assess open questions related to the spatial distribution and origin of the elements on the lunar surface and will contribute to unravel geological surface evolution and elemental distributions of potential lunar resources.

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Contributing team(s): GRS Team

216 – Venus Posters

216.01 – Access to VIRTIS / Venus-Express post-operations data archive

All data acquired during the Venus-Express mission are publicly available on ESA's Planetary Science Archive (PSA). The PSA itself is being redesigned to provide more comprehensive access to its content and a new interface is expected to be ready in the coming months.

However, an alternative access to the VIRTIS/VEx dataset is also provided in the PI institutes as part of the Europlanet-2020 European programme. The VESPA user interface (http://vespa.obspm.fr) provides a query mechanism based on observational conditions and instrument parameters to select data cubes of interest in the PSA and to connect them to standard plotting and analysis tools. VESPA queries will also identify related data in other datasets responsive to this mechanism, e. g., contextual images or dynamic simulations of the atmosphere, including outcomes of the EuroVenus programme funded by the EU. A specific on-line spectral cube viewer has been developed at Paris Observatory (http://voplus.obspm.fr/apericubes/js9/demo.php). Alternative ways to access the VIRTIS data are being considered, including python access to PDS3 data (https://github.com/VIRTIS-VEX/VIRTISpy) and distribution in NetCDF format on IAPS website (http://planetcdf.iaps.inaf.it). In the near future, an extended data service will provide direct access to individual spectra on the basis of viewing angles, time, and location.

The next step will be to distribute products derived from data analysis, such as surface and wind maps, atmospheric profiles, movies of the polar vortices or O_2 emission on the night side, etc. Such products will be accessed in a similar way, and will make VIRTIS results readily available for future Venus studies. Similar actions are taken in the frame of Europlanet concerning atmospheric data from the Mars-Express mission and Cassini observations of Titan.

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216.02 – The Variability of the Nightside Venusian Ionosphere and its Connection to Solar Storms

Observations of ionospheric electron density profiles and auroral emission on the nightside of planetary atmospheres allow for the study between the solar wind and the upper atmosphere of a planet. The interaction between the solar wind and Venus is unique given Venus' thick atmosphere and lack of an intrinsic magnetic field. Here, we study the variability of the Venusian nightside ionosphere and its connection to the solar wind (particularly after solar storms) and observed auroral-type emission of the OI 5577.7 oxygen green line.
The Venusian ionosphere has two distinct electron density peaks, the V1 and V2 peaks located near 125 and 150 km, respectively. They are known to be highly variable on the nightside and are even observed to "disappear" during periods of increased solar wind dynamic pressure (Cravens et al. 1982). However, using data from the Electron Spectrometer onboard Venus Express (VEX), Gray et al. 2016 (submitted) have shown an increase in the V1 peak density and a decrease in the V2 peak density during three separate CME passages which also coincided with observed green line emission. Here, we compare electron density profiles collected during solar minimum and maximum from VEX between 2006 – 2009 to determine if the variations observed by Gray et al (2016) are typical of solar storm passages or are due to normal variations in the Venusain nightside. We propose that this behavior is not typical and is due to a combination of increased solar wind dynamic pressure and particle precipitation from solar storms.

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216.03 – Multiple signal propagation at the tropopause of the Venusian atmosphere: new insights from the Radio Science Experiment (VeRa) onboard Venus Express

The rapid change of the refractive index over a short altitude range in a planetary atmosphere can lead to multi-path effects when sounding the atmosphere with radio waves. The Radio Science Experiment (VeRa) [1,2] onboard Venus Express sounded the Venusian atmosphere from 90 km downward to 40 km altitude[3,4]. More than 800 profiles of temperature, pressure and neutral number density could be retrieved which cover almost all local times and latitudes. A specially developed analysis method based on the VeRa open loop receiving technique deciphers the multi-path effect and identifies an inversion layer near the tropopause at an altitude of about 60km. This layer is of particular interest - it separates the stratified troposphere from the highly variable mesosphere and can be a likely location for the formation of gravity waves [5]. The new retrieval method shows an inversion layer up to 15 K colder than commonly thought. Local time and latitude dependence including the influence of the spacecraft trajectory on this effect will be discussed. These results will contribute to a consistent picture of the Venus' thermal atmosphere structure and therefore help to improve atmospheric models.

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216.04 – Gravity Waves in the Atmospheres of Mars and Venus

Gravity waves are ubiquitous in all stably stratified planetary atmospheres and play a major role in the redistribution of energy and momentum. Gravity waves can be excited by many different mechanisms, e.g. by airflow over orographic obstacles or by convection in an adjacent layer.
Gravity waves on Mars were observed in the lower atmosphere [1,2] but are also expected to play a major role in the cooling of the thermosphere [3] and the polar warming [4]. They might be excited by convection in the daytime boundary layer or by strong winter jets in combination with the pronounced topographic diversity on Mars.
On Venus, gravity waves play an important role in the mesosphere above the cloud layer [5] and probably below. Convection in the cloud layer is one of the most important source mechanisms but certain correlations with topography were observed by different experiments [6,7,8].
Temperature height profiles from the radio science experiments on Mars Express (MaRS) [9] and Venus Express (VeRa) [10] have the exceptionally high vertical resolution necessary to study small-scale vertical gravity waves, their global distribution, and possible source mechanisms.
Atmospheric instabilities, which are clearly identified in the data, can be investigated to gain further insight into possible atmospheric processes contributing to the excitation of gravity waves.

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216.05 – Analysis of Venusian Zonal Winds Using Venus Express Data

We measure the zonal mean wind structure of Venus between 2006 and 2013 in the ultraviolet images captured by the Venus Monitoring Camera (VMC) onboard the ESA Venus Express spacecraft. Our wind measurements employ the digital two-dimensional Correlation Imaging Velocimetry method to track cloud motions. Our current focus is on understanding the short- and long-term dynamics of Venus's atmospheric superrotation, in which the equatorial atmosphere rotates with a period of approximately 4-5 days (~60 times faster than the solid planet). The Venusian atmospheric superrotation's forcing and maintenance mechanisms remain to be explained. A number of studies have been published on the cloud-tracking wind measurements on Venus, however, those different measurements have not reached a consensus on the temporal evolution of the zonal wind structure (e.g., Kouyama et al 2013, Khatuntsev et al 2013, Patsaeva et al. 2015). Temporal evolution of the zonal wind could reveal the transport of energy and momentum and eventually shed a light on mechanisms that maintain the superrotation. Our first goal is to characterize the temporal dynamics of Venus's zonal wind profile and two-dimensional wind field, in which we will search for equatorial waves (in particular the so-called "Y-feature") that may force the Venusian atmospheric superrotation.

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216.06 – VIRTIS on Venus Express thermal emission spectra near 1µm

Thermal emission from the surface of Venus is observable through narrow spectral windows close to 1µm. Surface temperature is strongly constrained by surface elevation, due to the thick and dense atmosphere. The data from Visible and InfraRed Thermal Imaging Spectrometer VIRTIS on Venus Express together with altimetry constrain surface emissivity. In VIRTIS observations at 1.02µm, strongly deformed highland plateaus (tesserae) appear to have a lower emissivity consistent with continental crust, an interpretation that implies existence of an early ocean. Comparison between the Magellan stereo digital elevation model (DEM) and altimetry shows that the altimetry height error in rough tesserae greatly exceeds the formal error. In the one tesserae outlier covered by altimetry, DEM, and VIRTIS, the height error could account for the observed emissivity variation. The radiances observed at 1.10 and 1.18µm have a different response to topography, mostly due to spectrally varying absorption in the overlying atmospheric column. Thus if the tesserae have the same emissivity as volcanic plains, its spectrum should be the same as that of plains of the correct surface elevation. In order to investigate this statistically, we create a database of all long exposure duration VIRTIS spectra in the range of 1 – 1.4µm. The spectra are corrected for the ubiquitous straylight from the dayside, based on analysis of spectra showing deep space. Because the 1.10 and 1.18µm peaks are narrow compared to the variation of instrument spectral registration, we fit each spectrum with a synthetic spectrum from an atmospheric radiative transfer model, using wavelength offset and bandwidths as parameters in addition to atmospheric variables. This dataset of ~28 million thermal emission spectra spans a wide range of southern latitudes and night local times, and thus may be useful for studies beyond the question of surface emissivity. A portion of this research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

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216.07 – VERITAS (Venus Emissivity, Radio Science, InSAR, Topography And Spectroscopy): A Proposed Discovery Mission

VERITAS addresses one of the most fundamental questions in planetary evolution: How Earth-like is Venus? These twin planets diverged down different evolutionary paths, yet Venus may hold lessons for past and future Earth, as well as for Earth-sized exoplanets. VERITAS will search for the mineralogical fingerprints of past water, follow up on the discoveries of recent volcanism and the possible young surface age, and reveal the conditions that have prevented plate tectonics from developing. Collectively these questions address how Venus ended up a sulfurous inferno while Earth became habitable.
VERITAS carries the Venus Interferometric Synthetic Aperture Radar (VISAR) and the Venus Emissivity Mapper (VEM), plus a gravity science investigation.
The VISAR X-band radar produces: 1) a global digital elevation model (DEM) with 250 m postings, 5 m height accuracy, 2) Synthetic aperture radar (SAR) global imaging with 30 m pixels, 3) SAR imaging at 15 m for targeted areas, and 4) surface deformation from repeat pass interferometry (RPI) at 2 mm height precision for targeted, potentially active areas.
VEM [see Helbert abstract] will measure surface emissivity, look for active volcanic flows and outgassing of water over ~78% of the surface using 6 NIR surface bands within 5 atmospheric windows and 8 bands for calibration of clouds, stray light, and water vapor.
VERITAS uses Ka-band uplink and downlink to create a global gravity field with 3 mgal accuracy and 145 km resolution (130 spherical harmonic degree and order or d&o) and providing a significantly higher resolution field with much more uniform resolution than that available from Magellan.
VERITAS will create a rich data set of high resolution topography, imaging, spectroscopy, and gravity. These co-registered data sets will be on par with those acquired for Mercury, Mars and the Moon that have revolutionized our understanding of these bodies. VERITAS would be a valuable asset for future lander or probe missions, collecting the data needed to select landing or entry sites. VERITAS also provides a baseline for future missions to detect surface change, and contributes to our ability to predict the nature of Earth-sized exoplanets.

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Contributing team(s): VERITAS Science Team

216.08 – EnVision M5 Venus Orbiter Proposal: Opportunities and Challenges

The core goal of EnVision is to detect activity and measure rates of change on Venus, including geological and geochemical cycles involving the interior, surface and atmosphere.It will observe >20% of the surface with all instruments and will obtain gravity and emissivity data globally. The instrument suite for M5 is under review but will likely comprise the same three instruments as at M4: VenSAR, VEM and SRS.
VenSAR. The largest payload instrument is a phased array S-band radar, developed from the UK's low-cost NovaSAR-S instrument optimized for Venus. Use of spacecraft pointing for side-looking,

instead of a fixed slant, simplifies the observation strategy to three pairs of ~9 minute/orbit (~36° latitude, ~3800 km) pass-to-pass InSAR swaths, two ~9 minute/orbit multipolar (HH-HV-VV) swaths at lower incidence angle for stereo mapping, two ~3 minute/orbit (~12° latitude, ~1300 km) high resolution swath and 1 to 2 S-band emissivity swaths per day plus 50 km^2 ~1 m resolution sliding spotlight images. In addition, InSAR will be acquired along a narrow equatorial strip and across the North Pole to measure variability in the spin rate and axis.
VEM. The Venus Emissivity Mapper suite comprises two UV and IR spectrometer channels in addition to the VEM-M IR mapping. A filter array provides wavelength stability and maximizes signal to the focal plane array (FPA). VEM-H is high-resolution, nadir-pointing, infrared spectrometer, the ideal instrument to enable characterization of volcanic plumes released from the surface of Venus by observing SO_2, H_2O and HDO through the 1 µm, 1.7 µm, and 2-2.3 µm atmospheric windows. Specifically, VEM-H is a redesign of the LNO (Limb, Nadir and Occultation) channel of NOMAD, retaining much heritage from the original with minor modifications to meet the science objectives of the M5 EnVision mission. The third channel, VEM-UV is an upper-atmosphere UV spectrometer dedicated to global SO_2 & sulfur cycles.
SRS. The Subsurface Radar Sounder will image faults, stratigraphy and weathering in the upper ~100 m of the areas mapped by VenSAR, to identify structural relationships and geological history.
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216.09 – The Venus Emissivity Mapper
The permanent cloud cover of Venus prohibits observations of the surface with traditional imaging techniques over the entire visible spectral range. Fortunately, Venus' atmospheric gases are largely transparent in narrow spectral windows near 1 mm. Ground observers were the first to successfully use these windows, followed by spacecraft observations during the flyby of the Galileo mission on its way to Jupiter and most recently from Venus orbit by ESA's Venus Express with the VMC and VIRTIS instruments. Analyses of VIRTIS measurements have successfully demonstrated that surface information can be extracted from these windows, but the design of the instrument limited its use for more in-depth surface investigations.
Based on experience gained from using VIRTIS to observe the surface of Venus and new high temperature laboratory experiments currently performed at the Planetary Spectroscopy Laboratory of DLR, we have designed the multi-spectral Venus Emissivity Mapper (VEM). Observations from VIRTIS have revealed surface emissivity variations correlated with geological features, but existing data sets contain only three spectral channels. VEM is optimized to map the surface composition and texture, and to search for active volcanism using the narrow atmospheric windows, building on lessons from prior instrumentation and methodology. It offers an opportunity to gain important information about surface mineralogy and texture by virtue of having six different channels for surface mapping.
VEM is focused mainly on observing the surface, mapping in all near-IR atmospheric windows using filters with spectral characteristics optimized for the wavelengths and widths of those windows. It also observes bands necessary for correcting atmospheric effects; these bands also provide valuable scientific data on composition as well as altitude and size distribution of the cloud particles, and on H_2O vapor abundance variations in the lowest 15 km of the atmosphere. In combination with a high-resolution radar mapper that provides accurate topographic data as planned for the NASA VERITAS mission or for the ESA EnVision mission, VEM will provide new insights into current properties and the geologic evolution of Venus
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216.10 – Atmosperic Science with VEM on board *Veritas*
Thermal brightness on Venus' night side is mainly modulated by the lower cloud layer extending from about 45 to 60 km in altitude, the most recent observations being the outstanding 2.3 µm images recorded by the IR2 camera onboard *Akatsuki* [Gibney, 2016]. The VEM multispectral imager (P.I.: J. Helbrt, DLR) onboard the proposed NASA*VERITAS* orbiter (P.I.: S. Smrekar, JPL) has the capability to observe these lower clouds. The VEM filter bands at 1.195, 1.310 and 1.510 µm will acquire very accurate images of the clouds: resolution in Phase II orbit after spatial binning will be about 20 km, which is close to the atmospheric blurring limit. This will lead to the acquisition of a large data set that allows for the study of the lower cloud morphology and climatology with good coverage in latitude, planetocentric longitude and local solar time.
On the other hand, variations in the ratios of these three bands would help in constraining changes in composition, altitude and/or size distribution of the lower cloud particles [Barstow et al., 2012; Haus et al., 2014, 2015]. Such observations at small horizontal scales would be of great importance to microphysical models of Venus' clouds and haze system [McGouldrick et al., 2007]. Previous (*Venus Express*) or present (*Akatsuki*) observations of the lower clouds have proven the validity of these methods, but VEM onboard *VERITAS*will give an unprecedented coverage of the lower cloud horizontal structure on scales between 20 and 200 km in terms of spatial and temporal sampling, wavelength stability and signal-to-noise ratio.
Tracking lower cloud motions as a proxy for wind measurements at a high spatial resolution would also be of great interest to mesoscale and general circulation models. Such a study is made challenging due to the fast zonal super-rotation so that clouds that are visible in the field of view usually cannot be observed 90 min later when *VERITAS* flies over the same region in its next orbit. However, the super-rotation breaks down for latitudes higher than 80°, so that cloud tracking would be possible in both north and south polar dipoles [Piccioni et al., 2007] well known for their complex and ever-changing dynamics.
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216.11 – Tidal constraints on the interior of Venus
As a prospective study for a future exploration of Venus, we propose to systematically investigate the signature of the internal structure in the gravity field and the rotation state of Venus, through the determination of the moment of inertia and the tidal Love number. We test various mantle compositions, core size and density as well as temperature profiles representative of different scenarios for formation and evolution of Venus. The mantle density ρ and seismic vP and vS wavespeeds are computed in a consistent manner from

given temperature and composition using the Perple X program. This method computes phase equilibria and uses the thermodynamics of mantle minerals developped by Stixrude and Lithgow-Bertelloni (2011).
The viscoelastic deformation of the planet interior under the action of periodic tidal forces are computed following the method of Tobie et al. (2005).
For a variety of interior models of Venus, the Love number, k2, and the moment of inertia factor are computed following the method described above. The objective is to determine the sensitivity of these synthetic results to the internal structure. These synthetic data are then used to infer the measurement accuracies required on the time-varying gravitational field and the rotation state (precession rate, nutation and length of day variations) to provide useful constraints on the internal structure.
We show that a better determination of k2, together with an estimation of the moment of inertia, the radial displacement, and of the time lag, if possible, will refine our knowledge on the present-day interior of Venus (size of the core, mantle temperature, composition and viscosity). Inferring these quantities from a future ex- ploration mission will provide essential constraints on the formation and evolution scenarios of Venus.
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216.12 – MAD-VenLA: a microphysical modal representation of clouds for the IPSL Venus GCM

Venus is enshrouded by 20km-thick clouds, which are composed of sulfuric acid-water solution droplets. Clouds play a crucial role on the climate of the planet. Our goal is to study the formation and evolution of Venusian clouds with microphysical models. The goal of this work is to develop the first full 3D microphysical model of Venus coupled with the IPSL Venus GCM and the photochemical model included (Lebonnois et al. 2010, Stolzenbach et al. 2016).
Two particle size distribution representations are generally used in cloud modeling: sectional and modal. The term 'sectional' means that the continuous particle size distribution is divided into a discrete set of size intervals called bins. In the modal approach, the particle size distribution is approximated by a continuous parametric function, typically a log-normal, and prognostic variables are distribution or distribution-integrated parameters (Seigneur et al. 1986, Burgalat et al. 2014). These two representations need to be compared to choose the optimal trade-off between precision and computational efficiency. At high radius resolution, sectional models are computationally too demanding to be integrated in GCMs. That is why, in other GCMs, such as the IPSL Titan GCM, the modal scheme is used (Burgalat et al. 2014).
The Venus Liquid Aerosol cloud model (VenLA) and the Modal Dynamics of Venusian Liquid Aerosol cloud model (MAD-VenLA) are respectively the sectional and the modal model discussed here and used for defining the microphysical cloud module to be integrated in the IPSL Venus GCM. We will compare the two models with the key microphysical processes in 0D setting: homogeneous and heterogeneous nucleation, condensation/evaporation and coagulation. Then, MAD-VenLA will be coupled with the IPSL VGCM. The first results of the complete VGCM with microphysics coupled with chemistry will be presented.
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216.13 – Simulations of the Solar Wind Interaction with the Atmosphere/Ionosphere of Venus

The latest results of high resolution 3-D hybrid particle code simulations of the solar wind interacting with the atmosphere/ionosphere of Venus will be presented. The research is focused on understanding the how the solar wind interaction with Venus results in the subsequent ionospheric losses. In addition, the simulations focus on structures caused by the interaction particularly on the pole of the planet where the convection electric field points. A variety of simulation results will be presented each with varying solar wind parameters. The hybrid particle code HALFSHEL contains a variety of physical and chemical models which will also be discussed. These include a chemistry package that produces the ionosphere on grid resolution of 10 km altitude, atmospheric densities and dynamics from the VTGCM code and the Hall and Pedersen conductivities associated with plasma neutral collisions. The specific simulations to be presented trace solar wind protons, and ionospheric O+ and O2+.
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216.14 – High dispersion spectroscopy of Venus at 1.0 µm using WINERED at Koyama Astronomical Observatory

We obtained high dispersion near-infrared (NIR) spectra from the sunlit dayside hemisphere of Venus using a NIR high resolution spectrograph, WINERED, attached to the 1.3-m Araki telescope at Koyama Astronomical Observatory. The observation was carried out on 3 October 2015, and the cross-dispersed spectra cover the wavelength range of 0.9 - 1.1 µm with sperctral resolution of $\lambda/\Delta\lambda$ ~50,000. Absorption lines of Venusian $^{12}CO_2$ from the triad of (ν_1, ν_2, ν_3) = (2,0,3), (1,2,3), and (0,4,3) bands are observed at 1.038, 1.051, and 1.065 µm, respectively. In addition, the hot band lines of (1,3,1) - (0,1,0) are also clearly seen in the measured spectra.
Assuming the equivalent width of a CO_2 line varies with respect to some power of the line intensity, we can derive the rotational temperature from the curve of growth. The derived rotational temperature from the 1.051 µm band is ~246 K, which agrees with early ground-based studies reported in 1970's. We present the detailed analysis of these high dispersion CO_2 lines with the use of a radiative transfer model developed for the Venusian atmosphere.
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216.15 – Temperature and Wind Measurements in Venus Lower Thermosphere between 2007 and 2015

The structure of Venus atmosphere and its thermal and dynamical behavior was intensely studied during the past decade by groundbased and the space mission Venus Express. A comprehensive understanding of the atmosphere, however, is still missing. Direct measurements of atmospheric parameters on various time scales and at different locations across the planet are essential for better understanding and to validate global circulation

models. Line-resolved spectroscopy of infrared CO_2 transitions provides a powerful tool to accomplish measurements of temperature and wind speed within the neutral atmosphere, using Doppler line-broadening and Doppler shift. Temperature is the motor to drive circulation, and wind speed is the result. Measuring both provides both the basis and an empirical test for circulation models. Non-LTE emission lines at 10 µm that originate from a pressure level of 1µbar, ~110 km altitude, probe the lower thermosphere and are measurable at high spectral resolution using the infrared heterodyne spectrometers THIS (University of Cologne), HIPWAC (NASA GSFC) and MILAHI (Tohoku University).
Thermal and dynamical structures on the Venus day side are retrieved using a newly developed method that considers the influence of the spectrometer field-of-view (FoV) and the dispersion of spectral properties across the FoV. New conclusions from the ground-based observing campaigns between 2007 and 2015 will be presented based on this retrieval methodology. The spatial resolution on the planetary disk is different for each campaign, depending on the apparent diameter of the planet and the diffraction-limited FoV of the telescope. Previously, a comparison of the observing campaigns was limited due to the difference in spatial resolution. The new retrieval method enables comparing observations with different observing geometry. The observations yield a large quantity of temperature and wind measurements at different positions on the planetary disk, which supports mapping most of the dayside of Venus. A detailed study of the interesting area close to the terminator will be given, a region which is not well understood, including the general behavior of the temperature and differences between both terminators.
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216.16 – General circulation and thermal structure simulated by a Venus AGCM with a two-stream radiative code

Atmospheric general circulation model (AGCM) is expected to be a powerful tool for understanding Venus climate and atmospheric dynamics. At the present stage, however, the full-physics model is under development. Ikeda (2011) developed a two-stream radiative transfer code, which covers the solar to infrared radiative processes due to the gases and aerosol particles. The radiative code was applied to Venus AGCM (T21L52) at Atmosphere and Ocean Research Institute, Univ. Tokyo. We analyzed the results in a few Venus days simulation that was restarted after nudging zonal wind to a super-rotating state until the equilibrium. The simulated thermal structure has low-stability layer around 10^5 Pa at low latitudes, and the neutral stability extends from $\sim 10^5$ Pa to the lower atmosphere at high latitudes. At the equatorial cloud top, the temperature lowers in the region between noon and evening terminator. For zonal and meridional winds, we can see difference between the zonal and day-side means. As was indicated in previous works, the day-side mean meridional wind speed mostly corresponds to the poleward component of the thermal tide and is much higher than the zonal mean. Toward understanding dynamical roles of waves in UV cloud tracking and brightness, we calculated the eddy heat and momentum fluxes averaged over the day-side hemisphere. The eddy heat and momentum fluxes are poleward in the poleward flank of the jet. In contrast, the fluxes are relatively weak and equatorward at low latitudes. The eddy momentum flux becomes equatorward in the dynamical situation that the simulated equatorial wind is weaker than the midlatitude jet. The sensitivity to the zonal flow used for the nudging will be also discussed in the model validation.
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216.17 – The impact of planetary-scale waves upon Venus' thermal structure in the thermosphere based upon VTGCM simulation

Observations of the Venusian thermal structure have been conducted by Venus Express (VEx) and its multiple instruments (i.e. SOIR, SPICAV, and VIRTIS). These VEx observations are being combined with ground based observations to create a single comprehensive database. Thus far, these observations are continuing to reveal the significant variability of Venus' upper atmosphere structure, thereby motivating an analysis of the driver(s) of this variability. A likely driver of this variability is wave deposition. Evidence of waves has been observed, but these waves have not been completely analyzed to understand how and where they are important.
The Venus Thermospheric General Circulation Model (VTGCM) will be utilized to examine the role planetary-scale waves play in driving Venus' thermosphere structure and variability (~80 – 200 km). Planetary-scale waves (Kelvin and Rossby waves) have been incorporated at the lower boundary of the VTGCM. The atmospheric response to these waves will be analyzed and presented. Specifically, the simulated thermal structure will be presented with and without planetary scale waves (e.g. Kelvin and Rossby waves) to (1) characterize the magnitude of change; structural change; and location of greatest impact and (2) compare with VEx and ground based observations. Since the thermal structure is strongly dependent on the global circulation, the corresponding wind and density distributions (e.g. CO_2 and CO) will also be presented.
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216.18 – Three-dimensional turbulence-resolving modeling of the Venusian cloud layer and associated gravity waves

One of the main questions that remains unclear about the dynamics of the atmosphere of Venus and its interaction with the photochemistry is the characterization of the cloud convective layer which mixes momentum, heat, chemical species and generates gravity waves observed by Venus Express. This dynamical forcing induced by the cloud layer has been proposed as a significant contribution to the maintenance of the super-rotation. However these waves develop from regional to local scales and can not be resolved by global circulation models (GCM) developed insofar. Therefore we developed an unprecedented 3D Venusian mesoscale model based on the Martian mesoscale model using the Weather Research and Forecast terrestrial model. We report the first application of this model : simulating convection in the Venusian cloud layer and associated gravity waves by 3D turbulent-resolving simulations (Large-Eddy Simulations). The model employs an offline radiative forcing based on heating rates extracted from the LMD Venus GCM consisting of three distinct kind of rates. Two radiative ones for short wave (solar) and long wave (IR) and one for the adiabatic cooling/warming due to the global dynamics of the atmosphere (mainly the Hadley cell) with 2 different cloud models. Therefore we are able to characterize the convection and associated gravity waves in function of latitude and local time. To assess the impact of the general circulation on the convection we ran simulations with forcing from a 1D radiative model.

The resolved convective layer takes place between 1.0 10^5 and 3.8 10^4 Pa with vertical wind between ± 3 m/s, is organized as polygonal closed cells of about 8x8km^2, and emits gravity waves on either side with temperature perturbations of about 0.5 K with vertical wavelength of 1 km and horizontal wavelength from 1 to almost 20 km. The order of magnitude of the resolved plumes is consistent with observations though underestimated.
We are working on coupling the model with a complete radiative scheme to resolve radiative-photochemical feedbacks in order to study the Planetary Boundary Layer, the convective layer and the gravity waves, their possible link with topography as well as their role in maintaining the superrotation.
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216.19 – Constraints on Lithospheric Rheology from Observations of Coronae on Venus

Coronae are enigmatic, quasi-circular features found in myriad geological environments. They are primarily distinguished as rings of concentric fractures superimposed on various topographic profiles with at least small-scale volcanism. Mantle plumes may produce coronae with interior rises, whereas coronae with central depressions are often attributed to downwellings like Rayleigh-Taylor instabilities. For almost three decades, modelers have attempted to reproduce the topographic and gravity profiles measured at coronae. Until recently, few studies also considered tectonic deformation and melt production. In particular, "Type 2" coronae have complete topographic rims but arcs of fractures extending less than 180°, signifying both brittle and ductile deformation. Only a narrow range of rheological parameters like temperature and volatile content may be compatible with these observations. Ultimately, identifying how lithospheric properties differ between Earth and Venus is critical to understanding what factors permit plate tectonics on rocky, Earth-sized planets.
Here we present a hierarchical approach to study the formation of coronae. First, we discuss an observational survey enabled by a new digital elevation model derived from stereo topography for ~20% of the surface of Venus, which offers an order-of-magnitude improvement over the horizontal resolution (10 to 20 kilometers) of altimetry data from NASA's Magellan mission. Next, we search this new dataset for signs of lithospheric flexure around small coronae. Simple, thin-elastic plate models were fit to topographic profiles of larger coronae in previous studies, but data resolution impeded efforts to apply this method to the entire coronae population. Finally, we show simulations of the formation of coronae using Underworld II, an open-source code adaptable to a variety of geodynamical problems. We benchmark our code using models of pure Rayleigh-Taylor instabilities and then investigate the influence of realistic rheology and three-dimensional effects on the topography, tectonics, and magmatism.
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216.20 – Monitoring the thermal structure and minor species of Venus mesosphere with ALMA submm observations

Submillimeter observations obtained with the Atacama Large Millimeter Array (ALMA) allowed to monitoring the temporal evolution of temperature, sulfur species and water in the upper atmosphere of Venus. We observed the upper atmosphere of Venus with ALMA on November 14, 15, 26 and 27, 2011 during the first ALMA Early Science observation cycle. These observations targeted CO, SO, HDO and SO_2 transitions around 345 GHz during four sequences of 30 minutes each. The disk of Venus was about 11" with an illumination factor of 90%, so that mostly the dayside of the planet was mapped.
Thanks to the imaging capabilities of ALMA, we could obtain instantaneous maps of temperature, SO and HDO for the four days of observations. Assuming a nominal dayside CO abundance profile adapted from Clancy et al. 2012, we retrieved vertical temperature profiles between 60-100 km of altitude over the entire disk as a function of latitude and local time for the four days of observation. Temperature profiles were later used to derive the abundances of minor species (SO and HDO) in each pixel of the disk in order to study their spatial and temporal variability. Moreover, we plan to analyze the SO_2 disk-averaged spectra to study its temporal variability.
Temperature profiles show at all latitudes and local times a similar behavior with a constant decrease of temperature up to an altitude of about 80-100 km, depending on the local time, followed by a constant increase of temperature. Up to about 90 km temperatures increase from the morning side towards the evening terminator, this trend is inverted above 90 km. The thermal structure does not show strong temporal variations from one day to another. An exception is the thermal structure of the November 27: compared to the first day of observation, temperatures change of more than 15 K.
SO exhibits a strong spatial and temporal variability with a mixing ratio ranging from 0 to 15 ppb. It presents also a clear cutoff around 89 km. HDO is detected uniformly all over the Venus disk.
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216.21 – Infrasound as a Geophysical Probe Using Earth as a Venus Analog

JPL is in a process of developing an instrument to measure seismic activity on Venus by detecting infrasonic waves in the atmosphere. The overall objective of this research is to demonstrate the feasibility of using sensitive barometers to detect infrasonic signals from seismic and explosive activity on Venus from a balloon platform. Because of Venus' dense atmosphere, seismic signatures from even small quakes (magnitude ~3) are effectively coupled into the atmosphere. The seismic signals are known to couple about 60 times more efficiently into the atmosphere on Venus than on Earth. It was found that almost no attenuation below 80 km on Venus for frequency less than 1Hz. Whereas wind noise is a major source of background noise for terrestrial infrasonic arrays, it is expected that a balloon platform, which drifts with winds will be capable of very sensitive measurements with low noise.
In our research we will demonstrate and apply techniques for discriminating upward propagating waves from a seismic event by making measurements with two or more infrasonic sensors using very sensitive barometers on a tether deployed from the balloon in a series of earth-based tests. We will first demonstrate and validate the technique using an artificial infrasound source in a deployment from a hot air balloon on Earth and then extend it with longer duration flights in the troposphere and stratosphere.
We will report results on the first flight experiment that will focus on using the barometer instruments on a tethered helium-filled balloon. The balloon flight will be conducted in the vicinity of a known seismic source generated by a seismic hammer. Earlier tests conducted by Sandia National Laboratory demonstrated that this is a highly reproducible source of seismic and acoustic energy using infrasound sensors. The results of the experiments are intended to validate the two-barometer signal processing approach using a well-characterized point signal source.

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216.22 – The main layers of the ionosphere of Venus as seen by Pioneer Venus Orbiter radio occultations

Pioneer Venus Orbiter (PVO) performed numerous atmospheric experiments from 1978 to 1992. Radio occultation measurements were used to create vertical ionospheric electron density profiles extending as low as 100 km altitude; yielding data coverage across the V1 and V2 layers of the Venusian ionosphere, 125 and 140 km respectively. The PVO data give us a unique look at the ionosphere during solar maximum compared to later Venus missions. However, none of these ionospheric profiles were archived at the PDS nor have been available for comparison to Venus Express observations. We have extracted 120 PVO radio occultation profiles from published papers using a program to digitally read data from graphical images. Additionally, the NSSDC had 94 profiles, 63 of which were added to our dataset. The data from both sources were used in conjunction to analyze trends between solar activity and the characteristics of the V1 and V2 layers. The V1 layer, created by soft x-rays, should react more to changes in solar activity than the EUV created V2 layer. We intend to archive this data at the PDS so that the community can easily access digital measurements of the Venusian ionosphere at solar maximum.

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217 – Comets: Physical Characterization (Coma): Outbursts, Dust, and Gas Posters

217.01 – Observation of the activity of selected Oort Cloud comets with perihelia at large distances from the Sun

Many comets exhibit considerable level of activity at large distances from the Sun, where sublimation of crystalline water ice cannot account for observable comae. Different patterns of physical activity already observed at large heliocentric distances may be related to the primordial differences in the composition of comet nuclei. Therefore, monitoring of physical activity in the wide range of heliocentric distances can potentially contribute to understanding of internal structure of comet-like bodies. We have observed ten long periodic comets with orbital perihelia lying beyond the "water ice sublimation zone" to quantify the level of physical activity in the wide range of heliocentric distances. Pre-perihelion observations were made when targets moved between 16.7 and 6.5 au from the Sun; post perihelion activity was monitored between 5.2 and 10.6 au. The bulk of the data were gathered with the 2-m Robotic Liverpool Telescope (Observatorio del Roque de Los Muchachos, La Palma, Spain). Some targets were observed with the 2-m RC Telescope located at Peak Terskol Observatory and the 6-m Telescope of the Special Astrophysical Observatory (Northern Caucasus, Russia). Since most of recently obtained spectra of distant active objects are continuum dominated, we use B, V, R images to estimate dust production rates, an upper limit on nucleus radii, and color indices of near nucleus region. The comets C/2005 L3 (McNaught) and C/2006 S3 (Boattini), which exhibit the considerable level of activity, have been repeatedly observed. This enables us to infer the heliocentric dependence of dust production rates, perihelion brightness asymmetries, and color variations over the comae caused possibly by small changes in dust particle properties.

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217.02 – Observations of comet 252P/LINEAR during its historically close approach to Earth in 2016 from Lowell Observatory

We report on imaging and photometry of comet 252P/LINEAR acquired at Lowell Observatory during 2016 February-April. 252P passed 0.036 AU from Earth on March 21, among the closest passages on record. Its southern declination and the full moon made observations during the close encounter impractical from Lowell Observatory, but we observed 252P on one night each in February and early March, and on 13 nights from April 2-21 using the 4.3-m Discovery Channel Telescope, Hall 1.1-m, and 0.8-m. According to reports by other observers, the comet brightened significantly beginning in late-February and, coupled with the extreme close approach, was highly extended during our April observations. Narrowband photometry revealed a typical gas composition and an extremely low dust-to-gas ratio. The ratios remained essentially unchanged between late-February and April, e.g., during and after the extended "outburst" reported by other observers. 252P exhibited distinctly different coma morphology between dust and gas species. Enhanced images revealed a short sunward dust feature and the dust tail. Enhanced CN and C3 images exhibited a tilted spiral that was seen partially edge on approximately in the north-south directions. Enhanced OH images were also brightest along this direction but with considerably more material in the tailward hemisphere, potentially implying icy grains subject to radiation pressure. The CN coma morphology varied smoothly during a night and repeated every ~22 hr, implying a period of ~22 hr or a sub-multiple. There was also a repetition of features after ~95.5 hr, implying that the actual period is 7.35 +/- 0.05 hr. The repetition of features was most consistent April 2-7; the morphology diverged during later later nights, with the apparent spiral seen earlier separating into two or more distinct jet features. We will discuss these results as well as the results of our ongoing analyses. These studies were supported by NASA Planetary Astronomy grant NNX14AG81G.

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217.03 – Near-Infrared high resolution spectral survey of comets with GIANO/TNG: The CN red-system at 1.1 µm

High-resolution spectroscopy in the near-infrared spectral range is a powerful tool to investigate chemical composition and isotopic fractionation.

Comets are the best preserved relic of the enfant stages of the solar system. By targeting biologically relevant species in cometary comae and retrieving isotopic (e.g. D/H) and spin isomeric (e.g., ortho- and para- water) ratios, we can study the formation and evolution of solar system matter, address the origin of Earth's oceans and characterize the delivery of organic matter that was essential for the appearance of life on early Earth. We initiated the first high resolution spectral survey of comets ever conducted in the 0.9-2.5 µm range, targeting C/2014 Q2 (Lovejoy), C/2013 US10 (Catalina) and C/2013 X1 (Panstarrs) with GIANO - the near-IR high resolution spectrograph on Telescopio Nazionale Galileo (TNG). In comet Lovejoy, we detected eight ro-vibrational bands of H2O (Faggi et al., 2016, ApJ in press), emission from the red-system of CN, and many other emission lines whose precursors are now being identified. In this talk we will present a new quantum mechanical solar fluorescence model for the CN red system and the retrievals obtained with it from our cometary spectra. These observations open new pathways for cometary science in the near-infrared spectral range (0.9-2.5 µm) and establish the feasibility of astrobiology-related scientific investigations with future high resolution IR spectrographs on 30-m class telescopes, e.g., the HIRES spectrograph on the E-ELT telescope. This work is part of Sara Faggi's Ph.D. thesis project. NASA's Planetary Astronomy Program supported GLV and MJM through funding awarded under proposal 11-PAST11-0045 (M. J. Mumma, PI).

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217.04 – A Diversity of Dust In Oort Cloud Comets

Oort cloud comet nuclei, especially their interiors, have remained cool enough to retain highly volatile molecules such as CO_2, CO, and CH_4. At these low temperatures the composition of comet dust remains stable. Thus, observations of comet dust may reveal information on cometary origins, including dust formation processes and the spatial distribution of refractory materials in the early outer Solar System. We examine IRTF/BASS, IRTF/MIRSI, Gemini/T-ReCS, and VLT/VISIR mid-infrared spectra of six Oort cloud comets: C/2004 Q2 (Machholz), C/2009 P1 (Garradd), C/2011 L4 (Pan-STARRS), C/2012 F6 (Lemmon), C/2013 US_{10} (Catalina) (from Woodward et al. in prep.), and C/2014 Q1 (Pan-STARRS). The shapes of their 10-µm silicate bands are similar, trapezoidal with a crystalline silicate peak at 11.2 to 11.3 µm. However, there are some differences on the short-wavelength end of the spectrum, and the relative strengths of the silicate bands vary from 12% to 45% above the pseudo continuum. These variations are due to dust grain size, porosity, and composition. We fit each spectrum with our comet dust thermal model to quantify the relative amounts of the major dust species: "amorphous" silicates, crystalline silicates, and low albedo (e.g., carbonaceous) dust. These results are presented, and comapred to other Oort cloud comets already modeled in the literature in order to better understand the distribution of dust in the comet formation zone.

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217.05 – A new 3D multi-fluid model: a study of kinetic effects and variations of physical conditions in the cometary coma

Physics-based numerical coma models are desirable whether to interpret the spacecraft observations of the inner coma or to compare with the ground-based observations of the outer coma. In this work, we develop a multi-neutral-fluid model based on BATS-R-US in the University of Michigan's SWMF (Space Weather Modeling Framework), which is capable of computing both the inner and the outer coma and simulating time-variable phenomena. It treats H_2O, OH, H_2, O, and H as separate fluids and each fluid has its own velocity and temperature, with collisions coupling all fluids together. The self-consistent collisional interactions decrease the velocity differences, re-distribute the excess energy deposited by chemical reactions among all species, and account for the varying heating efficiency under various physical conditions. Recognizing that the fluid approach has limitations in capturing all of the correct physics for certain applications, especially for very low density environment, we applied our multi-fluid coma model to comet 67P/Churyumov–Gerasimenko (CG) at various heliocentric distances and demonstrated that it is able to yield comparable results as the Direct Simulation Monte Carlo (DSMC) model, which is based on a kinetic approach that is valid under these conditions. Therefore, our model may be a powerful alternative to the particle-based model, especially for some computationally intensive simulations. In addition, by running the model with several combinations of production rates and heliocentric distances, we can characterize the cometary H_2O expansion speeds and demonstrate the nonlinear effect of production rates or photochemical heating. Our results are also compared to previous modeling work (e.g., Bockelee-Morvan & Crovisier 1987) and remote observations (e.g., Tseng et al. 2007), which serve as further validation of our model. This work has been partially supported by grant NNX14AG84G from the NASA Planetary Atmospheres Program, and US Rosetta contracts JPL #1266313, JPL #1266314 and JPL #1286489.

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217.06 – Using Spectroscopic Profiles to Study the Morphology of Comets

We have used the integral-field unit spectrograph (the George and Cynthia Mitchell Spectrograph) on the 2.7m Harlan J. Smith telescope at McDonald Observatory to obtain spectroscopic images of the comae of several comets. The images were obtained for various radical species (C2, C3. CH, CN, NH2). Radial and azimuthal average profiles of the radical species were created to enhance any observed cometary coma morphological features. We compare the observed coma features across the observed species and over the different observation periods in order to constrain possible rotational states of the observed comets. We will present results for several comets, including 2009P1 (Garradd). This work was funded by NASA's Planetary Atmospheres program (Award No. NNX14AH186).

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217.07 – Variation of the water production rate of comet C/2013 X1 (PanSTARRS) from SOHO/SWAN observations throughout its apparition

The all-sky hydrogen Lyman-alpha camera, SWAN (Solar Wind ANisotropies), on the SOlar and Heliospheric Observatory (SOHO) satellite makes observations of the hydrogen coma of comets. Most water vapor produced by comets is ultimately photodissociated into two H atoms (in addition to one O atom) producing a huge atomic hydrogen coma that is routinely observed in the daily full-sky SWAN images in comets of sufficient brightness. Water production rates are calculated using our time-resolved model (Mäkinen & Combi, 2005, Icarus 177, 217), typically yielding about 1 observation every 2 days on the average over an apparition. Here we describe the analysis of observations of bright comet C/2013 X1 (PanSTARRS) observed during 2016. C/2013 X1 reached a perihelion distance of 1.314278 AU on 20.72 April 2016. Its brightening toward the end of June 2016 is influenced by a somewhat close geocentric distance of 0.64 AU. A status update on the entire SOHO/SWAN archive of water production rates in comets will also be given. Support from grants NNX15AJ81G from the NASA Solar System Observations Planetary Astronomy Program and NNX13AQ66G from the NASA Planetary Mission Data Analysis Program are gratefully acknowledged, as is support from CNRS, CNES, and the Finnish Meteorological Institute (FMI).

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217.08 – MESSENGER's special delivery: Comets 2P/Encke and C/2012 S1 (ISON) at small heliocentric distances

Observations of comets when they are close to the Sun can potentially reveal interesting aspects of their behavior thanks to the rapid change of both seasons on the nucleus and the local insolation environment. However this is typically the most difficult time to make observations from Earth because the solar elongation is small, so studies of comets that are near the Sun generally require special facilities. In autumn 2013, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft observed comets 2P/Encke and C/2012 S1 (ISON) from its orbital perch around Mercury when both comets were poorly located for most Earth-based telescopes. The observations included visible-wavelength, multi-filter imaging as well as ultraviolet spectroscopy. Both comets were observed down to about 0.3 AU from the Sun; in Encke's case it was followed through perihelion, which has rarely been done before. The data provide us with a look at the behavior of the dust and gas (e.g., OH, CO, OI, CI, SI, HI) production rates over several weeks, and we can investigate how the rates change with time, rotational phase, and heliocentric distance. In this poster we will present preliminary analyses of the time-series photometry and spectroscopy of these MESSENGER-observed comets, and place their behaviors into context.

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217.09 – Modeling CO $_2$ and CO dissociation scale lengths in NEOWISE comets

NEOWISE images of comets provide important constraints on CO and CO_2 dissociation scale lengths, as well as gas production rates for these rarely-observed species. Radial profiles constructed from mid-infrared images are compared to Monte Carlo simulations to investigate extended volatile source regions. In addition, NEOWISE observations of comet 67P/Churyumov-Gerasimenko provide a link to the larger-scale behavior of the Rosetta mission target. CO_2 gas production rates, as observed by NEOWISE, are consistent with those observed during the previous perihelion passage. We will present initial results of our modeling efforts on gas species in 67P and other comets.

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217.10 – Results from Modeling CN Jets in Comet Lulin (C/2007 N3)

We present results from Monte Carlo modeling of the CN jets on dynamically new Comet Lulin (C/2007 N3). Our model is based on 16 nights of narrowband imaging obtained with Lowell Observatory's 1.1-m Hall Telescope from 2009 January 30 through April 1, an interval during which our viewing orientation varied by more than 120 degrees. Following basic image enhancement by removing median radial profiles, two opposite pointing corkscrew jets were revealed, and a rotation period of 42 +/- 0.5 hr was determined (Knight & Schleicher 2009; IAU Circular #9025). The presence of these two distinct, non-overlapping jets, combined with the large change in aspect angle, made Lulin an excellent candidate for detailed 3-D jet modeling, allowing us to test a number of physical properties of outgassing which can eventually be utilized for other comets. We successfully reproduced Lulin's CN morphology using a nucleus having a tightly constrained obliquity of 95 deg with the axis pointing toward RA = 90 deg and Dec = +27 deg. The jet towards the west is centered at ~65 deg latitude and has a radius of ~25 deg, while the east jet is centered near -75 deg latitude and has a radius of ~15 deg. The longitudes differ by about 120 deg. The rotation axis crossed the plane of the sky on Feb 22, coincidently just prior to opposition. Our modeling shows that at this heliocentric distance of 1.4 AU, the CN gas continued to accelerate away from the nucleus out to a distance of about 20,000 km, reaching a velocity of 0.48 km/s. We also significantly improved the period determination since the model compensates for the rapidly changing viewing geometry, obtaining a sidereal period of 42.0 +/- 0.2 hr. We see a strong seasonal change in activity consistent with the variation in the sub-solar latitude from January until April as the CN jets change in brightness relative to each other. These and other results will be presented. Support is provided by NASA Planetary Atmospheres Grant NNX14AH32G.

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217.11 – Polarization of large cometary dust aggregates: computations with FaSTMM

We model light scattering by cometary dust with a special emphasis on polarization effects of large aggregated non-spherical dust particles. The contribution of large aggregates to the scattering characteristics of cometary dust is not well studied due to the rapid growth of computational time with respect to the number of grains in an aggregate when modelled by conventional numerical techniques (Mackowski, Mishchenko, JQSRT, 112(13), 2182-2192, 2011). To speed up computations, we apply our novel Fast Superposition T-Matrix Method (FaSTMM) that can deal with aggregates consisting of large numbers of non-spherical inhomogeneous grains.

The FaSTMM is based on two individual solvers. First, the so-called T-matrices of the grains in an aggregate are determined by the method-of-moments solution of the Maxwell equations based on the volume-integral-equation approach. Once the T-matrices have been computed and stored, the second solver, i.e., the superposition T-matrix method, accelerated by the multilevel-fast-multipole algorithm (MLFMA), is employed to solve for the scattering properties of the entire aggregate consisting of arbitrarily rotated grains whose T-matrices had been computed by the first solver. Such an approach allows for efficient computations of ensample-averaged light-scattering features of aggregated dust particles. The MLFMA acceleration works especially well for sparse, fractal-like aggregates within a large volume. The method is exact in the sense that no approximation is made for the physics described by the classical electromagnetic scattering theory.

As a dust model, we use porous aggregates with non-spherical grains consisting of a silicate core covered by organic refractory mantle. Thus, the dust particle model is consistent with the cometary dust formation model by Greenberg (Greenberg, Hage, Astrophys. J. 361, 260-274, 1990).

Acknowledgments. Research supported by the European Research Council (ERC, grant Nr. 320773).

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217.12 – Dynamics of Cometary Dust Particles in Electromagnetic Radiation Fields

The formation of cometary dust tails and comae is based on solar radiation pressure. The pressure effects of electromagnetic radiation were originally conceptualized in Kepler's observations of the tails of comets and formulated mathematically by Maxwell in 1873. Today, the dynamics of cometary dust are known to be governed by gravity, electromagnetic forces, drag, solar wind, and solar radiation pressure.

Solar radiation pressure has its roots in absorption, emission, and scattering of electromagnetic radiation. Due to modern advances in so-called integral equation methods in electromagnetics, a new approach of studying the effect of radiation pressure on cometary dust dynamics can be constructed. We solve the forces and torques due to radiation pressure for an arbitrarily shaped dust particle using volume integral equation methods.

We then present a framework for solving the equations of motion of cometary dust particles due to radiative interactions. The solution is studied in a simplified cometary environment, where the radiative effects are studied at different orbits. The rotational and translational equations of motion are solved directly using a quaternion-based integrator. The rotational and translational equations of motion affect dust particle alignment and concentration. This is seen in the polarization of the coma. Thus, our direct dynamical approach can be used in modelling the observed imaging photo-polarimetry of the coma.

In future studies, the integrator can be further extended to an exemplary comet environment, taking into account the drag, and the electric and magnetic fields. This enables us to study the dynamics of a single cometary dust particle based on fundamental physics.

Acknowledgments. Research supported, in part, by
the European Research Council (ERC, grant Nr. 320773).

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217.13 – Characterization of Continuum Coma features in Comets

We will present the results of an analysis of continuum coma features of comets belonging to different dynamical classes at geocentric distances less than 1.5 AU. Our analysis focusses on groundbased visible observations of over a dozen comets. The position angles of the continuum features close to the nucleus, the curvatures, and extents of radial features will be determined, and the dynamics of dust grains will be investigated. We will also use the change in position angles (if relevant) to place constraints on the periodicity of the repeatability of the features. The prevalence of the features in the sunward direction compared to other orientations will be investigated. We will further compare continuum features with CN features when available. This investigation will eventually lead to the discrimination between hemispherical and localized outgassing for the sunward continuum features seen in comets.

We acknowledge support from the NASA SSW and PAST programs.

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217.14 – The Amateur Observers' Program for 46P/Wirtanen

Comets 1P/Halley, 9P/Tempel 1, 103P/Hartley 2, C/2012 S1 (ISON), C/2013 A1 (Siding Spring), and 67P/Churyumov-Gerasimenko are some of the many comets that have been intensely studied by professional and amateur ground-based observers in collaboration with NASA and ESA missions. With the upcoming favorable apparition in 2018 for comet 46P/Wirtanen, the University of Maryland Comet Group is organizing an observing campaign to study this potential spacecraft target. The original target of Rosetta and the proposed target of the Comet Hopper Discovery Phase A mission proposal, Wirtanen will be bright enough, possibly naked-eye, to allow another wonderful opportunity for professionals to collaborate with the amateur astronomy community and engage the public. This Wirtanen campaign is utilizing the Amateur Observers' Program (AOP) that successfully supported the Deep Impact and EPOXI projects over 10 years in collecting amateur data of Tempel 1 and Hartley 2, as well as supporting other projects in more recent initiatives. We present the resources and capabilities of the AOP in the context of the Wirtanen observing campaign.

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218 – Comet Dynamics Posters

218.01 – What do comets 252P/LINEAR and P2016 BA14 have in common?

Automated surveys of NEOs continue to discover objects in cometary-like orbits that are likely candidate parent bodies [1]. Some of them unexpectedly produce a comet-like comae and tails [2, 3]. Here, we study one such case, namely asteroid 2016 BA14 recently discovered by the Pan-STARRS survey, which shows cometary appearance and has a Tisserand parameter of 2.8. Moreover, the orbital similarly between P/2016 BA14 and comet 252P/LINEAR was pointed. If those JFCs split in the past, significant dust would have been released. We present a survey of results dealing with investigating the association of comets P/2016 BA14 and 252P/LINEAR with meteor showers observed on Earth. We carry out a further search to investigate the possible genetic relationship between the comets themselves too. To confirm the reality of the relation between a comet and a meteoroid stream it is necessary to investigate the evolution of their orbits. The model of generation and evolution of meteoroid stream in the solar system is taken from Vaubaillon et al. [4]. The ejections of meteoroids from the possible parent body surface took place when it was passing its perihelion between 1700 A.D. and 2016 A.D. Next, the orbits of ejected meteoroids were integrated to year 2079. We will show the similarities and differences of the two streams, and will conclude regarding the possible relationship between P/2016 BA14 and 252P/LINEAR.

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[2] Jewitt, D., AJ, 143, 66, 2012
[3] Jewitt, D. and Li, J., AJ, 140, 1519, 2010
[4] Vaubaillon, J., Colas, F. Jorda, L., A&A, 439, 751, 2005

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218.02 – A (revised) confidence index for the forecasting of the meteor showers

The prediction of meteor shower is known to provide several quality results depending on how it is performed. As a consequence it is hard to have an idea of how much one can trust a given prediction. In this paper I will present a revised confidence index, aiming to provide users with information regarding the way the prediction was performed. An effort to quantify the influence of close encounters

with the parent body of a meteor shower is part of this confidence index. In fine, a single code will be provided for each prediction of meteor showers at any planet with a focus on Earth, Mars and Venus.
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219 – Comet Physical Characteristics: Surfaces Posters

219.01 – Force Survey and Statics of Structures on a Two-Lobed Comet

In recent years, Scheeres and coworkers have shown the value of surveying the forces at work on the surface of small asteroids. From this analysis, it has been shown that cohesion dominates the behavior of surficial regolith on small bodies and may enable the existence of fast-rotating asteroids. The recent Rosetta mission to comet 67P/Churyumov-Gerasimenko (67P) observed surface structures, specifically clumps and spires, indicating that cohesion is also likely to drive regolith behavior on this body. We will present a survey of forces present at the surface of a simplified two-lobed comet (elliptical lobes with size and rotation state inspired by 67P), considering shape-dependent gravity, rotation, cohesion, and gas drag. We will also present the statics of a sample spire, indicating the level of cohesion required to stabilize this type of formation. This analysis will provide a preliminary indication of the significance of forces present on the surface of a 67P-like comet.
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Institution(s): *1. University of Maryland*

219.02 – Mapping of thermal properties of comet 67P/C-G and temporal variations

The long-term evolution of the surfaces of comets depends mainly on the erosion rate that is driven by the thermal properties of the regolith and the sub-surface material. Following the diurnal and the seasonal thermal cycles, dust and gas are released progressively, increasing the erosion process. The amount of dust released depends on the surface and subsurface temperatures and thus on thermal inertia and bulk composition.
The ESA's Rosetta spacecraft has followed the comet 67P/Churyumov-Gerasimenko over several months from 4 AU to 1.28 AU heliocentric distance, and the VIRTIS/Rosetta imaging infrared spectrometer was capable of detecting the thermal emission of the surface longward of 3 microns.
The surface temperature was mapped over a large fraction of the nucleus and was previously used to derive thermal inertia of the main geomorphological units.
In this presentation, we now focus on two different aspects: (1) We aim to present a complete detailed map of the thermal inertia by combining measurements of similar areas obtained at different viewing angles ; and (2) we track the evolution of the local thermal properties derived over months when the comet was moving towards perihelion. We then discuss and compare our results with the textural features observed at the surface.
Author(s): Cedric Leyrat[4], Federico Tosi[1], Fabrizio Capaccioni[1], Stéphane Érard[4], Batiste Rousseau[4], Gianrico Filacchione[1], Maria Teresa Capria[1], Maria Cristina De Sanctis[1],Dominique Bockelee-Morvan[4], Ekkehard Kührt[3], Bernard Schmitt[2], Alessandra Migliorini[1], David Kappel[3]
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Contributing team(s): VIRTIS/Rosetta Team

219.04 – Rotation Rates and Spin Changes of Jupiter Family Comet Nuclei: New optical lightcurves and an update on the population properties.

In this work, we revise the physical characteristics of Jupiter family comets (JFCs) by expanding the sample of nuclei with known rotational and shape properties.
The study provides a review of the properties of all JFCs with known rotation rates derived from optical, radar or spacecraft measurements. This sample is complemented by newly obtained lightcurves of eight comets which are used to improve the precision of some known spin rates as well as to add new objects to the sample. We derive the new lightcurves from archival data partially taken within the framework of the Survey of Ensemble Physical Properties of Cometary Nuclei (SEPPCoN) and from devoted phase function observing campaigns. The lightcurves are produced with a specially-developed pipeline which enables data from various instruments at different epochs and geometries to be analyzed together. All lightcurves are absolutely calibrated using PanSTARRs photometric standards. Combining photometric measurements from different epochs allows us to achieve high precision in the period determinations and to constrain the phase functions of the comets. For three of the comets - 8P/Tuttle, 110P/Hartley 3 and 162P/Siding Spring - we obtain well-sampled phase functions which we compare to these of other well-studied JFCs.
The newly added data provide us with a better-constrained sample which we use to compare JFC characteristics with the rotation rates, shapes and surface properties of other small-body populations.
A special focus is put on the handful of JFCs which are known to demonstrate spin changes on orbital timescales. We are expanding this sample by adding new lightcurves derived from archival data as well as from our targeted survey using 2-4m telescopes. The rotational changes are obtained by comparison of the comets' current spin rates to those from previous apparitions. Using the new extended sample, we study the relation between the measured period changes and the physical properties of the nuclei.
Author(s): Rosita Kokotanekova[1], Colin Snodgrass[2], Pedro Lacerda[1], Simon F. Green[2]
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219.05 – High-resolution Goldstone radar imaging of comet P/2016 BA14 (Pan-STARRS)

Comet P/2016 BA14 (Pan-STARRS) was discovered by Pan-STARRS on January 21, 2016 and approached Earth within 0.024 astronomical units (9.2 lunar distances) on March 22. It was originally classified as an asteroid but subsequent observations (Knight et al., CBET 4257, 2016) showed the presence of a faint, short tail suggesting that the object is a comet. The similarity of its orbit to that of comet 252P/LINEAR led to speculation of a common origin.
We observed 2016 BA14 with radar using the 70-m DSS-14 (8560 MHz, 3.5 cm) and 34-m DSS-13 (7190 MHz, 4.2 cm) antennas at Goldstone as transmitters and the 100-m Green Bank Telescope in West Virginia as a receiver on four days spanning one week around close approach. The best images have range resolutions of 7.5 m/pixel and are the finest resolution comet images ever obtained at Goldstone. The maximum visible extent of the nucleus in the radar images is about 900 m, strongly implying that the diameter is more than 1 km. Its absolute magnitude of 19.5 and a diameter of at least 1 km imply an optical albedo of < 3%. The echo bandwidth is ~2.5 Hz, which suggests a slow rotation period of about 40 h that is consistent with the rotation evident in images obtained on each day. There are no obvious signatures of a coma in the radar data. The appearance of the leading edge of the nucleus varies significantly as

it rotates: there are facets hundreds of meters in length, angular junctions between facets, depressions, and rounded regions. The radar images lack any prominent high-contrast surface features, but there are subtle signatures of linear ridges, concavities, and a raised region casting a radar shadow.

Author(s): Shantanu P Naidu[1], Lance A. M. Benner[1], Marina Brozovic[1], Jon D. Giorgini[1], Joseph S Jao[1], Clement G Lee[1], Martin A. Slade[1], Lawrence G Snedeker[1], Michael W. Busch[3], Frank D. Ghigo[2]
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220 – Mars Atmosphere Posters

220.01 – A Comparison between 3D Model Predictions for Martian Exospheric Hot Oxygen and MAVEN IUVS observations: Sensitivity to Model Parameters

Earlier observations have suggested that the current deficiency of water and CO_2 is due to various mechanisms driven from the surface, atmosphere and surroundings over geologic time. Understanding the nature of the loss processes at the current epoch is critical for evaluating both the global atmospheric loss rate and the time-dependent volatile inventory, and in turn for unraveling the evolution of the Martian atmosphere. At the current epoch, the main photochemical mechanism that induces the escape of atomic O is suggested to be dissociative recombination of O_2^+, which also produces the extended hot O corona in the upper thermosphere and exosphere. To understand the loss via this process quantitatively, it is important to constrain the model by characterizing the structure and variability of the hot O corona in accordance with the observed features of the atmosphere. Here, we present our 3D model predictions for the Martian hot O corona compared with the OI 130.4 nm emission observed by Imaging Ultraviolet Spectrograph (IUVS) onboard Mars Atmosphere and Volatile EvolutioN (MAVEN). The hot O corona has been simulated by the coupled framework between our Mars application of the 3D Adaptive Mesh Particle Simulator (M-AMPS) and the Mars Global Ionosphere Thermosphere Model (M-GITM), based completely on our best pre-MAVEN understanding of the 3D structure of the thermosphere and ionosphere. Among important model parameters, we have chosen appropriate seasonal and solar activity parameters, which are approximately equivalent to the conditions during each observation. We have also examined the sensitivity of the resulting hot O density to the elastic collision cross sections for the hot O collisions with the background atmospheric species. We present the importance of these key parameters by comparing measurements with the model predictions for the altitude variation of the hot O density and the spatial variation of the dayside-dominated corona. Any discrepancies between the model predictions and IUVS data require further analysis of the MAVEN measurements for constraining of our M-AMPS and M-GITM models. The MAVEN mission has been funded by NASA through the Mars Exploration Program.

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220.02 – Oxygen emission line properties from analysis of MAVEN-IUVS Echellograms of the Martian atmosphere

The high resolution echelle mode of the Mars Atmosphere and Volatile Evolution (MAVEN) mission Imaging Ultraviolet Spectrograph (IUVS) instrument has been used to spectrally image the sunlit limb of Mars during the spacecraft periapse orbital segments. When multiple images are co-added over a few hours, there are detectable spectral emission features that have been identified to originate from atomic and molecular neutral species such as H, D, N, O, CO as well as from C^+ ions. The echelle detector has a localized spectral resolution of ~0.008 Angstrom and is therefore capable of spectrally resolving the oxygen resonant triplet (130.217, 130.486 and 130.603 nm) and forbidden doublet (135.560 and 135.851 nm) emission lines. The brightness of each of these emission lines has been determined and will be compared with detected brightnesses of other species. The emission line integrated brightness ratios are being analyzed for insights into the abundance, excitation, and variability of oxygen in the martian atmosphere.

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Contributing team(s): IUVS Team

220.03 – A study of ion emissions in MAVEN/IUVS data

The Imaging Ultraviolet Spectrograph (IUVS) instrument on the Mars Atmosphere and Volatile EvolutionN (MAVEN) mission is designed to measure radiances of several of the most abundant species present in Mars' atmosphere. Many spectral features are associated with ions; one of the most prominent spectral features in the mid-ultraviolet region is the CO_2^+ Ultraviolet Doublet (UVD) at 289 nm. However this emission, and many others, results from several radiative processes, some of which originate from the ionization process and is therefore not diagnostic of the ion densities. Several other emissions are diagnostic of ion densities, especially at high altitudes, and therefore lend themselves to density retrievals based on inclusion of all radiative processes. The most promising of these is the Fox-Duffendack-Barker (FDB) (3,0) band at 314 nm, near the long-wavelength limit of the IUVS instrument. We report on a new process for performing density retrievals of CO_2^+ with particular attention to the credibility of high-altitude signal in the FDB bands as well as the associated uncertainties. We also investigate the feasibility of C^+ and other ion density retrievals.

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220.04 – Pick-up Ion Sputtering of Mars' Atmosphere: Analysis of MAVEN Data and Simulations

One of the ways hot oxygen escapes the exosphere of Mars is through sputtering caused by the precipitation of, primarily, O+ pickup ions. This process is thought to have been particularly important early in martian history, as it is correlated with increased solar activity (Luhmann 1992). With ion precipitation data from the MAVEN mission for a variety of solar conditions (Leblanc 2015), we can potentially see the effect of atmospheric sputtering. To determine if this process is apparent in MAVEN data, we first model the thermosphere and exosphere with an O and CO2 Direct Simulation Monte Carlo model. We then introduce a heat flux representative of the energy deposited by pickup ions for a variety solar conditions and look for the resulting signatures in the in situ neutral and ion atmospheric data from the NGIMS instrument available on the PDS. Preliminary simulations and data analysis are suggestive. Analysis of the simulations and the data analysis will be presented.

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220.05 – Characteristic of Ion loss as determined by hybrid simulations

One of the major objectives of the MAVEN mission is to determine the loss rate of oxygen ions from the atmosphere of Mars. It is thought that the oxygen ion loss represents a conduit for the loss of water from Mars. However, the actual measurements and estimates of global loss rates are very difficult because one needs an average over many orbits and full coverage of the loss regions of Mars; something that MAVEN will only accomplish with an extended mission. In the meantime global kinetic simulations are an avenue to gain further insight into the loss process and perhaps offer insight into the data analysis that will be performed on the MAVEN data. Hybrid particle codes provide self-consistent simulations of the ion dynamics occurring when the solar wind interacts with Mars.
This paper reports the results of HALFSHEL hybrid code simulations of the solar wind interaction with Mars and the subsequent loss of oxygen ions in the form of O^+ and O_2^+. Four simulations were performed representing different orientations of the crustal magnetic fields with the subsolar regions using a solar EUV flux representative of the moderate solar activity experienced by MAVEN. Loss rates will be presented as will evaluations of the distribution functions of the various loss ion species as accumulated at roughly 2 R_m for each of the four simulations. The results will be presented as faces on a box surrounding Mars so that one can evaluate regions such as that of the measured plasma plume. The plume feature has now been measured and is often seen in simulations. Finally, the losses and the subsequent velocity distributions will be compared between the various crustal magnetic field orientations.
In summary, results from the HALFSHEL hybrid code will be presented. These results will address characteristics of the oxygen ions lost from Mars as a function of crustal magnetic field orientation. Further, they will be compared with respect to the regions surrounding Mars and the associated velocity distribution functions.

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220.06 – Charge Balance in the Martian Ionosphere

We present empirical models of the Martian ionosphere in conjunction with data from the Langmuir Probe and Waves (LPW), Neutral Gas and Ion Mass Spectrometer (NGIMS), and Extreme Ultraviolet Monitor (EUVM) instruments aboard the Mars Atmosphere and Volatile Evolution mission (MAVEN) spacecraft. Among the data provided by MAVEN are electron densities and temperatures, ion and neutral densities, and solar extreme ultraviolet (EUV) flux. We explore a number of contributors to the CO_2 photoionization rate, with a specific focus on the role of electron temperatures, which, prior to MAVEN, were not well-known. We compare our results with expectations of the ionospheric structure and behavior to confirm our understanding of the basic structure of the Martian ionosphere in the photochemical region. We show that the ionosphere of Mars is well matched by photochemical equilibrium to within the accuracy of the measurements. These results will aid in the development of more complex ionospheric and escape models and lead to a comprehensive and global scale picture of thermal ion escape on Mars.

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Contributing team(s): MAVEN

220.07 – Comparative Aeronomy: Molecular Ionospheres at Earth and Mars

The ionospheres in our solar system vary not only in their electron densities, but also in the dominance of atomic versus molecular ions at their altitudes of peak plasma density. With the exception of Earth's F-layer composed of atomic oxygen ions and electrons, all other planets have their peak ionospheric layers composed of molecular ions and electrons embedded in a dense neutral atmosphere. At Mars, both of its ionospheric layers have molecular ions, with the M1-layer at a lower altitude than the more robust M2-layer above it. The terrestrial ionosphere has a prominent region of molecular ions (the E-layer) below the dominant F-layer. In this paper, we explore the production and loss of molecular ion layers observed under the same solar irradiance conditions at Mars and Earth. We compare observations of M1 and M2 electron densities with terrestrial ionosonde data for the peak densities of the E- and F-layers during low, moderate and high solar flux conditions. The sub-solar peak densities of molecular ion layers have high correlations at each planet, as well as between planets, even though they are produced by separate portions of the solar spectrum. We use photo-chemical-equilibrium theory for layers produced by soft X-rays (M1 and E) versus the M2-layer produced by extreme ultraviolet (EUV) to identify the key parameters that cause similarities and differences. The yield of our comparative study points to the roles of secondary ionization and temperature dependent plasma recombination rates as areas most in need of further study at each planet.

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220.08 – Model of the dust-loaded ionospheres of Mars and Titan

The ionization of lower atmospheres of celestial bodies and the presence of charged species are fundamental in the understanding of atmospheric electricity phenomena, such as electric discharges, large scale electric currents and Schumann resonances. On January 14, 2005, the Huygens Probe measured the electric conductivity of Titan's atmosphere from 140 km down to the surface. Micro-ARES, the electric field and conductivity sensor on board the ExoMars 2016 Schiaparelli lander, will conduct the very first measurement and characterization of Martian atmospheric electricity. The landing is scheduled for October 19, 2016 and the measurements will be performed over 2-4 sols.
The present photochemical model is developed to compute the concentration of the most abundant charged species (cluster-ions, electrons and charged aerosols) and electric conductivity in the lower atmospheres of Mars (0-70 km) and Titan (0-145 km). For both cases, the main source of ionization is galactic cosmic rays. In addition, during daytime, photoionization of aerosols due to solar UV radiation is important at Mars. Ion and electron attachment to aerosols is another major source of aerosol charging, which can vary between -50 and +200 elementary charges for Mars and -55 and -25 for Titan. The steady state concentration of charged species is computed by solving the respective balance equations, which

include the source and sink terms of the photochemical reactions. Since the amount of suspended dust in the Martian atmosphere can vary considerably and it has an important effect on the atmospheric properties, several dust scenarios, in addition to the day-night variations, are considered to characterize the variability of the concentration of charged species.

The agreement between with the results of the model for Titan and the Huygens data suggests an improvement with respect to previous models. This gives confidence in the results of the model for Mars, which characterize the predicted electric environment in which Micro-ARES will operate, being essential to its data analysis and interpretation.

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220.09 – Non-thermal escape of H_2 and OH from the upper atmosphere of Mars

Two major sources of energetic O atoms in the upper atmosphere of Mars are photochemical production, via dissociative recombination (DR) of O_2^+ and CO_2^+ molecular ions, and energizing collisions with fast energetic neutral atoms (ENA) produced by the precipitating solar wind ions. The non-thermal O atoms can either directly escape to space, forming a hot oxygen corona, or participate in collisions with background thermal atmospheric gases, such as H_2. In this study we present a theoretical analysis of formation and kinetics of hot OH molecules in the upper atmosphere of Mars, produced in reactions of thermal molecular hydrogen and suprathermal oxygen atoms energized by both DR and ENAs. The non-thermal chemical reaction $O + H_2(v',j') \rightarrow H + OH(v',j')$ is described using recent quantum-mechanical state-to-state cross sections[1], which allow us to predict non-equilibrium distributions of excited rotational and vibrational states (v',j') of OH and expected emission spectra for different geometry and solar activity conditions. A potential consequence is appearance or enhancement of faint Meinel bands in the upper atmosphere of Mars. Moreover, a fraction of produced translationally hot H_2 and OH are sufficiently energetic to overcome Mars' gravitational potential and escape into space, contributing to the hot corona. The described non-thermal mechanisms produce estimated total escape fluxes of OH and H_2 from dayside of Mars, for low solar activity conditions, equal to about 5×10^{22} s^{-1} for OH, or about 0.1% of the total escape rate of atomic O and H, and 10^{23} s^{-1} for H_2 [2]. If HD molecules are considered instead of H_2, the non-thermal mechanisms are about 30 times more efficient than Jeans escape, contribute about 5-10% of the total D escape rate, potentially of interest in atmospheric models of water evolution on Mars.

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220.10 – Mars MetNet Mission - Martian Atmospheric Observational Post Network

A new kind of planetary exploration mission for Mars is under development in collaboration between the Finnish Meteorological Institute (FMI), Lavochkin Association (LA), Space Research Institute (IKI) and Institutio Nacional de Tecnica Aerospacial (INTA). The Mars MetNet mission is based on a new semi-hard landing vehicle called MetNet Lander (MNL).

The scientific payload of the Mars MetNet Precursor mission is divided into three categories: Atmospheric instruments, Optical devices and Composition and structure devices. Each of the payload instruments will provide significant insights in to the Martian atmospheric behavior.

The key technologies of the MetNet Lander have been qualified and the electrical qualification model (EQM) of the payload bay has been built and successfully tested.

Full Qualification Model (QM) of the MetNet landing unit with the Precursor Mission payload is currently under functional tests. In the near future the QM unit will be exposed to environmental tests with qualification levels including vibrations, thermal balance, thermal cycling and mechanical impact shock. One complete flight unit of the entry, descent and landing systems (EDLS) has been manufactured and tested with acceptance levels. Another flight-like EDLS has been exposed to most of the qualification tests, and hence it may be used for flight after refurbishments. Accordingly two flight-capable EDLS systems exist.

The eventual goal is to create a network of atmospheric observational posts around the Martian surface. The next step in the MetNet Precursor Mission is the demonstration of the technical robustness and scientific capabilities of the MetNet type of landing vehicle. Definition of the Precursor Mission and discussions on launch opportunities are currently under way. The baseline program development funding exists for the next five years. Flight unit manufacture of the payload bay takes about 18 months, and it will be commenced after the Precursor Mission has been defined.

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220.12 – Phoenix Water Vapor Measurements using the SSI Camera

The Phoenix and Mars Reconnaissance Orbiter (MRO) spacecraft participated together in an observation campaign that was a coordinated effort to study the Martian atmosphere. These coordinated observations were designed to provide near-simultaneous observations of the same column of atmosphere over the Phoenix lander. Seasonal coverage was obtained at L_s=5-10° resolution and diurnal coverage was obtained as often as possible and with as many times of day as possible. One key aspect of this observation set was the means to compare the amount of water measured in the whole column (via the MRO Compact Reconnaissance Imaging Spectrometer for Mars (CRISM; Murchie *et al.*, 2007) and the Phoenix Surface Stereo Imager (SSI) with that measured at the surface (via the Phoenix Thermal and Electrical Conductivity probe (TECP; Zent *et al.*, 2008) which contained a humidity sensor). This comparison, along with the Phoenix LIDAR observations of the depth to which aerosols are mixed (Whiteway *et al.,* 2008, 2009), provides clues to the water vapor mixing ratio profile. Tamppari *et al.* (2009) showed that examination of a subset of these coordinated observations indicate that the water vapor is *not* well mixed in the atmosphere up to a cloud condensation height at the Phoenix location during northern summer, and results indicated that a large amount of water must be confined to the lowest 0.5-1 km. This is contrary to the typical assumption that water vapor is “well-mixed.”

Following a similar approach to Titov et al. (2000), we use the Phoenix SSI camera [Lemmon et al., 2008] filters to detect water vapor: LA = 930.7 nm (broad), R4 = 935.5 nm (narrow), and R5 = 935.7 nm (narrow). We developed a hybrid DISORT-spherical model

(DISORT model, Stamnes et al. 1988) to model the expected absorption due to a prescribed water vapor content and profile, to search for matches to the observations. Improvements to the model have been made and recent analysis using this model and comparisons to earlier results will be presented.

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220.13 – Detection of Northern Hemisphere Transient Baroclinic Eddies in REMS Pressure Data at Gale Crater Mars

Wintertime transient baroclinic eddies in the northern midlatitudes of Mars were identified in Viking Lander 2 (VL2, 48.3N, 134.0E) surface pressure data back in the early 1980s. Here we report the results of an analysis of REMS surface pressure data acquired by the Curiosity Rover in Gale Crater (4.5S, 137.4E) that suggests the meridional scale of these eddies is so large that the disturbances in the surface pressure fields they create extend across the equator and into the southern hemisphere. A power spectrum analysis of the seasonally detrended REMS pressure data from L_s=240-280 shows dominant periods of ~ 6 sols and ~2.2 sols (though with greatly reduced power) which are close the dominant periods of the transient eddies observed by VL2 at this season. Analysis of the surface pressure fields from the Ames Mars GCM for the same season also shows dominant periods at the grid points closest to VL2 and Gale Crater similar to those observed. In the model, the disturbances responsible for these oscillations are eastward traveling baroclinic eddies whose amplitudes are greatest at northern mid latitudes at this season, but whose meridional extent does indeed extend into the low latitudes of the southern hemisphere. REMS appears to be seeing the signature of these eddies, not only for this season but for the early fall and late winter seasons as well. While orbital images of the so called “flushing storms”, which more closely correspond to the shorter period waves, show dust-lifting frontal systems that cross the equator, REMS data - even though acquired at a longitude of comparatively weak storm activity - provide the first in-situ evidence that northern hemisphere transient eddies can be detected at the surface in low latitudes of the southern hemisphere.

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220.14 – A search of dust-devils and convective vortices inside Mars’ Gale crater from REMS data on the MSL rover during 1159 sols

The Mars Science Laboratory (MSL) rover carries a meteorological suite of detectors that constitute the Rover Environmental Monitoring Station (REMS) instrument (Gomez-Elvira et al, 2012). REMS investigates the meteorological conditions at Gale crater with a set of sensors that obtain pressure, air temperature and ground temperature measurements among others. We have run a search of atmospheric warm vortices that could result in dust devils and present a statistical study of the frequency of these events in the REMS pressure and temperature data from its first 1159 sols, from 7 August 2012 (Ls 152) to 10 November 2015 (Ls 67).
A systematic search of short events (time-scales of a few seconds) of pressure drops results in 662 pressure drops with a signal stronger than 0.5 Pa, and with an average duration of 6.4 seconds. Of these events, 404 were diurnal (~61%, with the Sun over the horizon) and 258 were nocturnal. The diurnal pressure drops contains the most intense events and they peak close to noon (12:00-14:00 LMST) extending into the early afternoon hours. The nocturnal sudden pressure drops concentrate in the 20:00-23:00 LMST time interval and present a strong seasonality since they occur only from late spring to early summer. We interpret these nocturnal events not as local warm vortices, but as a consequence of local surface turbulence which is enhanced at Gale crater at summer night-time by the competition between local orographic circulation and global Hadley cell circulation (Rafkin et al, 2016).
A comparison of the REMS diurnal data and similar pressure drop events in other latitudes from previous missions shows that the frequency of these events at Gale crater is significantly lower with less intense events than in other Mars locations explored by Mars Pathfinder and Phoenix. This agrees with the difficulties in finding external evidences of dust devils from MSL images or dust-devil tracks in the surface.

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220.15 – Influence of the atmospheric opacity cycle on the near surface environment of Gale Crater on Mars

The Mars atmospheric dust changes the capacity of the atmosphere to absorb solar radiation or release outgoing thermal infrared radiation. This alters the atmospheric heat exchange fluxes and can interfere with the global circulation. The response of near surface pressure, temperature and winds has been characterized at the higher northern latitudes of 45 degree N at the Viking landing sites. The Rover Environmental Monitoring Station (REMS) on Curiosity allows a similar characterization at near-equatorial latitudes of 4.5 degree S. Using MCAM-880 nm opacities as a measure of local atmospheric dust load, we analyze the response of changes in surface variables measured by REMS and compare to those observed by Viking. As on Viking, diurnal and semidiurnal pressure tide amplitudes track very closely the atmospheric opacity and the mean daily pressure shows the increased wave activity. Temperature tides show a more complex response that combines its sensitivity to changes in dust and cloud opacities. Differences in UV opacities for the REMS set of finite spectral windows are explored during the dust and clear seasons.

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220.16 – Automated detection of Martian water ice clouds: the Valles Marineris

We need to extract water ice clouds from the large number of Mars images in order to reveal spatial and temporal variations of water ice cloud occurrence and to meteorologically understand climatology of water ice clouds. However, visible images observed by Mars orbiters for several years are too many to visually inspect each of them even though the inspection was limited to one region. Therefore, an automated detection algorithm of Martian water ice clouds is necessary for collecting ice cloud images efficiently. In addition, it may visualize new aspects of spatial and temporal variations of water ice clouds that we have never been aware.
We present a method for automatically evaluating the presence of Martian water ice clouds using difference images and cross-correlation distributions calculated from blue band images of the Valles Marineris obtained by the Mars Orbiter Camera onboard the Mars Global Surveyor (MGS/MOC). We derived one subtracted

image and one cross-correlation distribution from two reflectance images. The difference between the maximum and the average, variance, kurtosis, and skewness of the subtracted image were calculated. Those of the cross-correlation distribution were also calculated. These eight statistics were used as feature vectors for training Support Vector Machine, and its generalization ability was tested using 10-fold cross-validation. F-measure and accuracy tended to be approximately 0.8 if the maximum in the normalized reflectance and the difference of the maximum and the average in the cross-correlation were chosen as features.
In the process of the development of the detection algorithm, we found many cases where the Valles Marineris became clearly brighter than adjacent areas in the blue band. It is at present unclear whether the bright Valles Marineris means the occurrence of water ice clouds inside the Valles Marineris or not. Therefore, subtracted images showing the bright Valles Marineris were excluded from the detection of water ice clouds

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220.17 – Assessment of Atmospheric Water Vapor Abundance Above RSL Locations on Mars

The possible signatures of atmospheric water vapor arising from Martian Recurring Slope Lineae (RSLs)[1] are investigated. These RSLs appear during local spring and summer on downward slopes, and have been linked to liquid water which leaves behind streaks of briny material. Viking Orbiter Mars Atmospheric Water Detector (MAWD)[2] and Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES)[3-5] derived water vapor abundance values are interrogated to determine whether four RSL locations at southern mid-latitudes (Palikir Crater, Hale Crater, Horowitz Crater, and Coprates Chasma) exhibit episodic enhanced local water vapor abundance during southern summer solstice (L_s = 270°) and autumnal equinox (L_s = 360°) when RSLs are observed to develop[6,7]. Any detected atmospheric water vapor signal would expand upon current knowledge of RSLs, while non-detection would provide upper limits on RSL water content. Viking Orbiter Infrared Thermal Mapper (IRTM) and MGS TES derived temperature values are also investigated due to the appearance of active RSLs after the surface temperature of the slopes exceeds 250 K[1].
A high spatial resolution Martian atmospheric numerical model will be employed to assess the magnitude and temporal duration of water vapor content that might be anticipated in response to inferred RSL surface water release. The ability of past and future orbiter-based instruments to detect such water vapor quantities will be assessed.

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220.18 – Vertical distribution of ozone at the terminator on Mars

The SPICAM/Mars Express UV solar occultation dataset gives access to the ozone vertical distribution via the ozone absorption in the Hartley band (220–280 nm). We present the retrieved ozone profiles and compare them to the LMD Mars Global Climate Model (LMD-MGCM) results.
Due to the photochemical reactivity of ozone, a classical comparison of local density profiles is not appropriate for solar occultations that are acquired at the terminator, and we present here a method often used in the Earth community. The principal comparison is made via the slant profiles (integrated ozone concentration on the line-of-sight), since the spherical symmetry hypothesis made in the onion-peeling vertical inversion method is not valid for photochemically active species (e.g., ozone) around terminator. For each occultation, we model the ozone vertical and horizontal distribution with high solar zenith angle (or local time) resolution around the terminator and then integrate the model results following the lines-of-sight of the occultation to construct the modeled slant profile. We will also discuss the difference of results between the above comparison method and a comparison using the local density profiles, i.e., the observed ones inverted by using the spherical symmetry hypothesis and the modeled ones extracted from the LMD-MGCM exactly at the terminator. The method and the results will be presented together with the full dataset.
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220.19 – Sensible Ozone on Mars based on 2-D Maps of $O_2(a^1\Delta_g)$ Emission for L_s=102°; Comparison of (0,0) and (1,1) Bands

We report 2-D maps of the $O_2(a^1\Delta_g)$ emission rate (a tracer for high-altitude ozone) taken during early northern summer (L_s=102° on 30 January 2016) using CSHELL at NASA's IRTF. The entrance slit of the spectrometer was positioned N-S on Mars and stepped E-W at 0.5 arc-sec increments. Spectral extracts were taken at 0.6 arc-sec intervals along the slit. We also took data to compare the emission rates of the $O_2(a^1\Delta_g)$ (1-1) band (1.28 µm) to the (0-0) band (1.27 µm) with the entrance slit centered at the sub-Earth point. A model consisting of the solar continuum with Fraunhofer lines, two-way transmission through Mars' atmosphere, and a one-way transmission through the Earth's atmosphere was used to isolate and analyze individual spectral emission lines from Mars. Boltzmann analysis of these lines yielded a rotational temperature (~165 K) that was used to determine the total emission rates for the a-X system from the measured line intensities. The line-of-sight emission rates were converted to vertical emission rates and $O_2(a^1\Delta_g)$ column densities after geometric correction. The sensible O_3 column implied by these data is compared with maps of total O_3 in Mars standard atmosphere models.
The 2-D map shows increased emission in the southern hemisphere when compared to previously reported results taken at earlier seasonal points (L_s=72° on 3 April 2010 and L_s=88° on 10 February 2014). Emission results of the $O_2(a^1\Delta_g)$ (0-0) band (Local Time ~ 14:30) will be compared with MARCI results (LT ~ 15:00, Clancy et al., Icarus 266 (2016) 112-113). We searched for the (1-1) band in two adjacent wavelength ranges; (0-0) emissions were detected at these settings, but no (1-1) emissions were noticed above the noise level. An upper limit will be presented, and implications discussed.
This work was partially funded by grants from NASA's Mars Fundamental Research Program (11-MFRP11-0066) and the NSF-RUI Program (AST-805540). The NASA Astrobiology Institute supported this work through funding awarded to the Goddard Center for Astrobiology under proposal 13-13NAI7-0032. We thank the administration and staff of the NASA-IRTF for awarding observing times and coordinating our observations.

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220.20 – Progress Toward a New/Modern Nonhydrostatic Mars General Circulation Model: Adapting MPAS-A to Study the Atmosphere of Mars

As the database of observations of the Martian atmosphere grows to considerable size and depth, atmospheric modeling becomes more constrained. Improved models and modeling techniques are needed to maintain the scientifically productive interaction between the two specialities. We have begun a process of adapting the nonhydrostatic state-of-the-art atmospheric model for prediction across scales (MPAS-A) to study the atmosphere of Mars. Useful descriptions and references can be found at (https://mpas-dev.github.io/). The key features of this model are: 1) it is global and nonhydrostatic, 2) in its basic configuration it has isotropic spatial resolution that is not hindered by a 'pole problem' as are many GCMs, 3) it is designed to be and is typically run with regions of refined resolution (allowing for true mesoscale simulations, without nest boundary issues, while being forced globally in a fully consistent fashion). Initial testing of the model under Mars conditions has been performed: with Mars topography and surface pressure, at a spatial resolution of ~60 km, and with air temperatures relaxed to a 3-D temperature field for a moderately high dust loading at winter solstice in either hemisphere. Results are fascinatingly complex, and depict a good overall agreement with the expected zonal-mean circulation under these conditions. The model is being run on Pleiades at the NAS supercomputing facility at NASA/Ames, where tests using various numbers of processor cores reveal a near-linear scalability (the decrease in elapsed wall-clock time to the number of cores). Having completed this initial testing phase, we expect to present results where the model is being run: 1) with a simple atmospheric radiation scheme, 2) with realistic surface properties and a soil model, and 3) with a capable PBL scheme. Upon reaching that point in development, we will be able to compare and contrast results from our mission-support modeling efforts for both the Mars 2020 and Insight missions. Looking into the future, we will be adding appropriate physics packages toward the development of a modern GCM, which will be able to simulate the entire atmosphere of Mars consistently across a wide scale range.

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220.21 – Modeling CO_2 ice clouds with a Mars Global Climate Model

Since the first claimed detection of CO2 ice clouds by the Mariner campaign (Herr and Pimentel, 1970), more recent observations and modelling works have put new constraints concerning their altitude, region, time and mechanisms of formation (Clancy and Sandor, 1998; Montmessin et al., 2007; Colaprete et al., 2008; Määttänen et al., 2010; Vincendon et al., 2011; Spiga et al. 2012; Listowski et al. 2014). CO_2 clouds are observed at the poles at low altitudes (< 20 km) during the winter and at high altitudes (60-110 km) in the equatorial regions during the first half of the year. However, Martian CO_2 clouds's variability and dynamics remain somehow elusive. Towards an understanding of Martian CO_2 clouds and especially of their precise radiative impact on the climate throughout the history of the planet, including their formation and evolution in a Global Climate Model (GCM) is necessary.
Adapting the CO_2 clouds microphysics modeling work of Listowski et al. (2013; 2014), we aim at implementing a complete CO_2 clouds scheme in the GCM of the Laboratoire de Météorologie Dynamique (LMD, Forget et al., 1999). It covers CO_2 microphysics, growth, evolution and dynamics with a methodology inspired from the water ice clouds scheme recently included in the LMD GCM (Navarro et al., 2014).
Two main factors control the formation and evolution of CO_2 clouds in the Martian atmosphere: sufficient supersaturation of CO_2 is needed and condensation nuclei must be available. Topography-induced gravity-waves (GW) are expected to propagate to the upper atmosphere where they produce cold pockets of supersaturated CO_2 (Spiga et al., 2012), thus allowing the formation of clouds provided enough condensation nuclei are present. Such supersaturations have been observed by various instruments, in situ (Schofield et al., 1997) and from orbit (Montmessin et al., 2006, 2011; Forget et al., 2009).
Using a GW-induced temperature profile and the 1-D version of the GCM, we simulate the formation of CO_2 clouds in the mesosphere and investigate the sensitivity of our microphysics scheme. First results and steps towards the integration in the 3-D GCM will be presented and discussed at the conference.
This work is funded by the Laboratory of Excellence ESEP.

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220.22 – Synoptic Traveling Weather Systems on Mars: Effects of Radiatively-Active Water Ice Clouds

Atmospheric aerosols on Mars are critical in determining the nature of its thermal structure, its large-scale circulation, and hence the overall climate of the planet. We conduct multi-annual simulations with the latest version of the NASA Ames Mars global climate model (GCM), gcm2.3+, that includes a modernized radiative-transfer package and complex water-ice cloud microphysics package which permit radiative effects and interactions of suspended atmospheric aerosols (e.g., water ice clouds, water vapor, dust, and mutual interactions) to influence the net diabatic heating. Results indicate that radiatively active water ice clouds profoundly affect the seasonal and annual mean climate. The mean thermal structure and balanced circulation patterns are strongly modified near the surface and aloft. Warming of the subtropical atmosphere at altitude and cooling of the high latitude atmosphere at low levels takes place, which increases the mean pole-to-equator temperature contrast (i.e., "baroclinicity"). With radiatively active water ice clouds (RAC) compared to radiatively inert water ice clouds (nonRAC), significant changes in the intensity of the mean state and forced stationary Rossby modes occur, both of which affect the vigor and intensity of traveling, synoptic period weather systems. Such weather systems not only act as key agents in the transport of heat and momentum beyond the extent of the Hadley circulation, but also the transport of trace species such as water vapor, water ice-clouds, dust and others. The northern hemisphere (NH) forced Rossby waves and resultant wave train are augmented in the RAC case: the modes are more intense and the wave train is shifted equatorward. Significant changes also occur within the subtropics and tropics. The Rossby wave train sets up, combined with the traveling synoptic-period weather systems (i.e., cyclones and anticyclones), the geographic extent of storm zones (or storm tracks) within the NH. A variety of circulation features will be presented which indicate contrasts between the RAC and nonRAC cases, and which highlight key effects radiatively-active clouds have on physical and dynamical processes active in the current climate of Mars.

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220.23 – The South Residual CO_2 Cap on Mars: Investigations with a Mars Global Climate Model

The CO_2 cycle is one of the three controlling climate cycles on Mars. One aspect of the CO_2 cycle that is not yet fully understood is the existence of a residual CO_2 ice cap that is offset from the south pole. Previous investigations suggest that the atmosphere could control the placement of the south residual cap (e.g., Colaprete et al., 2005). These investigations show that topographically forced stationary eddies in the south during southern hemisphere winter produce colder atmospheric temperatures and increased CO_2snowfall over the hemisphere where the residual cap resides. Since precipitated CO_2 ice produces higher surface albedos than directly deposited CO_2 ice, it is plausible that CO_2snowfall resulting from the zonally asymmetric atmospheric circulation produces surface ice albedos high enough to maintain a residual cap only in one hemisphere. Our current work builds on these initial investigations with a version of the NASA Ames Mars Global Climate Model (GCM) that includes a sophisticated CO_2 cloud microphysical scheme. Processes of cloud nucleation, growth, sedimentation, and radiative effects are accounted for. Simulated results thus far agree well with the Colaprete et al. study—the zonally asymmetric nature of the atmospheric circulation produces enhanced snowfall over the residual cap hemisphere throughout much of the winter season. However, the predicted snowfall patterns vary significantly with season throughout the cap growth and recession phases. We will present a detailed analysis of the seasonal evolution of the predicted atmospheric circulation and snowfall patterns to more fully evaluate the hypothesis that the atmosphere controls the placement of the south residual cap.

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220.24 – The Mars Analysis Correction Data Assimilation (MACDA): A reference atmospheric reanalysis

The Mars Analysis Correction Data Assimilation (MACDA) dataset version 1.0 contains the reanalysis of fundamental atmospheric and surface variables for the planet Mars covering a period of about three Martian years (late MY 24 to early MY 27). This four-dimensional dataset has been produced by data assimilation of retrieved thermal profiles and column dust optical depths from NASA's Mars Global Surveyor/Thermal Emission Spectrometer (MGS/TES), which have been assimilated into a Mars global climate model (MGCM) using the Analysis Correction scheme developed at the UK Meteorological Office.
The MACDA v1.0 reanalysis is publicly available, and the NetCDF files can be downloaded from the archive at the Centre for Environmental Data Analysis/British Atmospheric Data Centre (CEDA/BADC). The variables included in the dataset can be visualised using an ad-hoc graphical user interface (the "MACDA Plotter") located at the following URL:*http://macdap.physics.ox.ac.uk/*
The first paper about MACDA reanalysis of TES retrievals appeared in 2006, although the acronym MACDA was not yet used at that time. Ten years later, MACDA v1.0 has been used by several researchers worldwide and has contributed to the advancement of the knowledge about the martian atmosphere in critical areas such as the radiative impact of water ice clouds, the solsticial pause in baroclinic wave activity, and the climatology and dynamics of polar vortices, to cite only a few. It is therefore timely to review the scientific results obtained by using such Mars reference atmospheric reanalysis, in order to understand what priorities the user community should focus on in the next decade.
MACDA is an ongoing collaborative project, and work funded by NASA MDAP Programme is currently undertaken to produce version 2.0 of the Mars atmospheric reanalysis. One of the key improvements is the extension of the reanalysis period to nine martian years (MY 24 through MY 32), with the assimilation of NASA's Mars Reconnaissance Orbiter/Mars Climate Sounder (MRO/MCS) retrievals of thermal and dust opacity profiles. MACDA 2.0 is also going to be based on an improved version of the underlying MGCM and an updated scheme to fully assimilate (radiative active) tracers, such as dust.

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Contributing team(s): LMD Team, MGS/TES Team, MRO/MCS Team

220.25 – Developments with the planetWRF and planetMPAS Planetary Atmospheric Models

planetWRF is based upon the NCAR Weather Research and Forecasting (WRF) model and has been applied to Mars, Titan and Pluto. planetWRF offers global-scale, two-way interactive nested mesoscale, and microscale LES simulation of planetary atmospheres using a rectangular grid.
Recently, a fully-coupled dust and water cycle aerosol scheme has been introduced based on Morrison and Gettelman [Lee et al., this conference]. The scheme treats both dust and water ice as two-moment distributions. Significantly, the scheme treats all processes (nucleation, growth, advection, sedimentation, radiation) using the two-moment distributions, with no lossy conversion between spectral and radius-bin representation.
The LES modeing capability has been augmented with the ability to import HiRISE DTMs to allow simulation of small-scale flow over topography including the first order effects of local slope and shadowing. Simulations of Victoria crater (visited by Opportunity) show dramatic variations of surface temperature on scales of a few meters during the morning and distinct changes in the patterns of wind stress as the crater interior is coupled and decoupled from boundary layer convection at different times. The LES has also been augmented to run with dynamically and radiatively interactive dust.
planetMPAS is based upon the NCAR Model for Prediction Across Scales (MPAS), an unstructured mesh model that allows for far more uniform resolution of the whole globe, uses a fully compressible nonhydrostatic dynamical core, and an advanced terrain-following coordinate system. The MPAS model been designed to use WRF physics routines. As such, planetMPAS and planetWRF are alternate dynamical cores within the same modeling system. planetMPAS has major advantages over WRF for certain kinds of global simulations: high-precision tracer problems, e.g. Argon transport on Mars; uniform resolution of polar regions, e.g. water ice cap interactions with the martian global water cycle; and convection-resolving global mesoscale modeling, e.g. Titan methane moist convection. Conversely, for a range of micro- and mesoscale problems, planetWRF retains major advantages over planetMPAS. Simuations from planetWRF and planetMPAS will be shown.

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220.26 – Implications for GCM Modeling of MARCI/TES ACB Optical Depth Differences

The Aphelion Cloud Belt (ACB) is a well-studied phenomenon of Mars. HST violet images and microwave observations [e.g. 1–3] helped characterize its seasonal morphology and measure typical

optical depths. Follow up, long-term studies by orbiting instruments [e.g. 4–6] characterized the growth and decline of the ACB as well as a baseline set of zonally averaged optical depths as a function of latitude and season. All this work provided ground-truth for the assessment and modification of Mars GCMs and current models provide good agreement with observations [e.g. 7–8].
We will present recent analyses of MARCI and TES ACB optical depths that show a wavelength dependance on the timing of the peak zonal-average optical depth that implies a possible evolution in average effective radius of ACB cloud particles as the ACB ages. As we will show, this difference in timing of the optical depth peak between short and long wavelength bands is not seen in the Ames MGCM. In order to begin understanding these differences, we will present retrieved ACB cloud particle sizes from the Ames MGCM to compare to the optical depth observations and calculations and discuss possible model adjustments that may lead to better fits. Aligning model and observation results should lead to a better understanding of what is physically driving the particle size evolution.
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Author(s): David R. Klassen[2], Melinda A. Kahre[1], Michael J. Wolff[3], Robert Haberle[1], Jeffery L. Hollingsworth[1]
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220.27 – Properties of Martian winds as determined from trajectory modelling of jettisoned spacecraft parts

Knowing the properties of the Martian winds, i.e. speed, direction and structure, is important for understanding the global circulation of the atmosphere, dust and water transport and planning the landing of spacecraft. Measurements of wind speed and direction on Mars have previously been limited to near-surface measurements made by landers, imaging of atmospheric features such as clouds and dust and while the lander is on the parachute. The understanding of the Martian environment could therefore benefit from more determinations of wind speed and direction.
The distribution of spacecraft hardware, such as heat shields, parachutes, backshells and landers, on the surface of Mars have been imaged by the HiRISE imager on-board Mars Reconnaissance Orbiter. We analyse these images, and other known properties of a spacecraft's descent, to reconstruct the trajectories of the jettisoned spacecraft components and further constrain wind properties at various lander sites. Interestingly this approach may allow wind property assessments at the landing sites of failed landers assuming their hardware components can be correctly identified in images.
We assess the vertical structure of the wind at selected landing sites of successful spacecraft missions to Mars by comparing our results to mesoscale (MLAM) and 1-D column models of the Martian atmosphere that have been jointly developed by FMI and the University of Helsinki. In addition we compare our wind property findings to published meteorological measurements and modelling. We discuss the implications of our results with respect to slope and crater circulations. The feasibility of imaging spacecraft hardware from orbit of the MetNet vehicle (metnet.fmi.fi) is assessed with space flight visualisation software.
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220.28 – Orbit-Spin Coupling Accelerations and the 2007 Global-Scale Dust Storm on Mars

Global-scale dust storms (GDS) occasionally occur during the southern summer season on Mars. The most recent such storm occurred in 2007 (Mars year 28). We employ a modified version of the MarsWRF global circulation model to simulate atmospheric conditions on Mars leading up to this event. Accelerations due to orbit-spin coupling (arxiv.org/abs/1605.02707) have been incorporated within the dynamical core of the MarsWRF GCM (arxiv.org/abs/1602.09137). We have previously documented an "intensification" of the large scale circulation (as represented in the GCM) due to these accelerations during the dust storm season of MY 28. In this presentation we look more closely at the differences between GCM outcomes for runs performed both with and without the "coupling term accelerations" for this important year. The current version of the GCM has a number of shortcomings; most significantly, we do not yet include radiatively active dust within our simulations. The GCM thus cannot replicate the rapid warming and inflation of the atmosphere that occurs soon after significant dust lifting has commenced; and we do not address specific mechanisms of dust lifting. Nonetheless our model outcomes provide some insight into phenomena such as the variability of global wind systems during intervals leading up to the inception of the global storm. The phasing and amplitude of the orbit-spin coupling accelerations (arxiv.org/abs/1605.01452) for the current Mars year (MY 33) are in some ways similar to those calculated for MY 28. Thus we will also examine and describe MarsWRF model outcomes for the current dust storm season.
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220.29 – Post-impact climate conditions on early Mars: preliminary results from GCM simulations

Observations imply that liquid water was stable on Mars' surface during the late Noachian/early Hesperian era, with valley networks forming roughly 3.5-3.75 billion years ago, possibly from precipitation and runoff (Fassett & Head 2008, Icarus 195, 61; Hynek et al., 2010, JGR Planets, 115, E09008). Climate models, however, struggle to reproduce such warm conditions (Forget et al., 2013, Icarus 21, 81). Volcanism and impacts have been suggested as mechanisms of either inducing a warm and wet environment or causing local melting in a cold and wet environment. Comets and asteroids are capable of injecting into the atmosphere both kinetic energy from the impact and water from the object itself and from vaporized surface and subsurface ice. Segura et al. (2008, JGR Planets 113, E11007) find using a 1-D atmospheric model that significant rainfall and periods of above-freezing temperatures lasting months to years can follow impacts of objects between 30 and 100 km in diameter. We revisit this work utilizing a 3-D global climate model (GCM) to consider the effects of dynamics, topography, global surface ice variations, etc. We present preliminary results from the NASA ARC Mars GCM investigating global temperature and precipitation behavior in a post-impact, early Mars environment.
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220.30 – Ice-Covered Lakes in Gale Crater Mars: The Cold and Wet Hypothesis

Recent geological discoveries from the Mars Science Laboratory provide evidence that Gale crater may have intermittently hosted a fluvio-lacustine environment during the Hesperian, with individual lakes lasting for a period of tens to hundreds of thousands of years. (Grotzinger et al., Science, 350 (6257), 2015). Estimates of the CO2 content of the atmosphere at the time the Gale sediments formed are far less than needed by any climate model to warm early Mars (Bristow et al., Geology, submitted), given the low solar energy input available at Mars 3.5 Gya. We have therefore explored the possibility that the lakes in Gale during the Hesperian were perennially covered with ice using the Antarctic Lakes as an analog. Using our best estimate for the annual mean surface temperature at Gale at this time (~230K) we computed the thickness of an ice-covered lake. These thickness range from 10-30 meters depending on the ablation rate and ice transparency and would likely inhibit sediments from entering the lake. Thus, a first conclusion is that the ice must not be too cold. Raising the mean temperature to 245K is challenging, but not quite as hard as reaching 273K. We found that a mean annual temperature of 245K ice thicknesses range from 3-10 meters. These values are comparable to the range of those for the Antarctic lakes (3-6 m), and are not implausible. And they are not so thick that sediments cannot penetrate the ice. For the ice-covered lake hypothesis to work, however, a melt water source is needed. This could come from subaqueous melting of a glacial dam in contact with the lakes (as is the case for Lake Untersee) or from seasonal melt water from nearby glaciers (as is the case for the Dry Valley lakes). More work is needed to better assess these possibilities. However, the main advantage of the ice-covered lake model (and the main reason we pursued it) is that it relaxes the requirement for a long-lived active hydrological cycle involving rainfall and runoff, which no climate model is able to produce given known constraints on the early Mars environment.

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220.31 – CROSS DRIVE: A New Interactive and Immersive Approach for Exploring 3D Time-Dependent Mars Atmospheric Data in Distributed Teams

Atmospheric phenomena of Mars can be highly dynamic and have daily and seasonal variations. Planetary-scale wavelike disturbances, for example, are frequently observed in Mars' polar winter atmosphere. Possible sources of the wave activity were suggested to be dynamical instabilities and quasi-stationary planetary waves, i.e. waves that arise predominantly via zonally asymmetric surface properties. For a comprehensive understanding of these phenomena, single layers of altitude have to be analyzed carefully and relations between different atmospheric quantities and interaction with the surface of Mars have to be considered. The CROSS DRIVE project tries to address the presentation of those data with a global view by means of virtual reality techniques. Complex orbiter data from spectrometer and observation data from Earth are combined with global circulation models and high-resolution terrain data and images available from Mars Express or MRO instruments. Scientists can interactively extract features from those dataset and can change visualization parameters in real-time in order to emphasize findings. Stereoscopic views allow for perception of the actual 3D behavior of Mars's atmosphere. A very important feature of the visualization system is the possibility to connect distributed workspaces together. This enables discussions between distributed working groups. The workspace can scale from virtual reality systems to expert desktop applications to web-based project portals. If multiple virtual environments are connected, the 3D position of each individual user is captured and used to depict the scientist as an avatar in the virtual world. The appearance of the avatar can also scale from simple annotations to complex avatars using tele-presence technology to reconstruct the users in 3D. Any change of the feature set (annotations, cutplanes, volume rendering, etc.) within the VR is immediately exchanged between all connected users. This allows that everybody is always aware of what is visible and discussed. The discussion is supported by audio and interaction is controlled by a moderator managing turn-taking presentations. A use case execution proved a success and showed the potential of this immersive approach.

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Contributing team(s): CROSS DRIVE Team

220.32 – Quantum yield for O-atom production in the VUV photodissociation of CO $_2$ using the time-sliced velocity-mapped imaging (TS-VMI) method

VUV photodissociation above 10.5 eV is considered the primary region for photochemical destruction of CO_2 by solar radiation. There is enough photon energy in this region so that in addition to ground state $O(^3P_J)$ and $CO(^1\Sigma^+)$ that can be produced during photodissociation excited species such as atomic oxygen $O(^1D)$ and $O(^1S)$, as well as excited carbon monoxide $CO(a^3\Pi, a'^3\Sigma^+)$ also can be formed. Electronic excited oxygen atom and carbon monoxide are the species that are responsible for the airglows in atmospheres of the solar planets and comets. Therefore, detail photodissociation quantum yields for these excited species from CO_2 are critical in interpreting the chemistry in these solar system bodies. We have previously shown that the time-sliced velocity-mapped imaging (TS-VMI) technique can provide detailed branching ratio information about photodissociation of diatomic molecules.[1, 2] However, to date we have not been able to show how this technique can be use to determine absolute quantum yields for the products produced in the VUV photodissociation of CO_2. In this talk we will describe how the known quantum yields for the photodissociation O_2 to $O(^3P_2)$, $O(^3P_1)$, $O(^3P_0)$ and $O(^1D)$ can be used to determine quantum yields of similar products in the photodissociation of CO_2.

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[2] Hong Gao, Yu Song, William M. Jackson and C. Y. Ng, *J. Chem. Phys*, **138**, 191102, 2013.

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220.33 – Oblique echoes at unusually high frequencies in MARSIS-AIS measurements of the topside ionosphere of Mars

The topside plasma density measurements from the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on the Mars Express orbiter have been invaluable for studying the influence of the crustal magnetic fields on the distribution of plasma in the Mars ionosphere. A common feature, especially in the southern crustal field region, is an "oblique echo," or an off-nadir reflection consistent with the spacecraft passing by, or directly above, a localized region with a sharp gradient in electron density. These are often interpreted as regions where the ionosphere is heated by the solar wind fields and plasma which penetrate the ionosphere along vertical field lines.

We present a subset of these oblique echoes which are characterized by reflections at frequencies much higher than those from the nadir ionosphere. If these are interpreted in the same way as typical return signals, where the frequency of the reflected signal is assumed to be the plasma frequency at the point of reflection, then these may be the highest plasma densities reported to date at Mars. In two cases, reflections are detected at the maximum sounding frequency of the instrument, 5.5 MHz, which corresponds to electron densities of 3.75×10^5 cm^{-3}.
These features are associated with strong, vertical magnetic fields, as expected for typical oblique echoes. However, they are only observed in regions where there is also an above-average likelihood of the field lines being open to the solar wind. This is consistent with the interpretation that these cusp-like regions can allow for interaction with the solar wind, but it is not yet clear whether these are an extreme case of "typical" oblique echoes, or whether these high-frequency echoes are caused by a unique physical process or observation geometry.
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220.34 – The effect of solar energetic particles on the Martian ionosphere

The precipitation of Solar Energetic Particles (SEP) into the Martian atmosphere causes several effects, one of the most important of which is ionization. However, the importance of this process to the global structure and dynamics for the Martian ionosphere is currently not well understood. The MAVEN spacecraft carries instrumentation which allow us to examine this process. The Neutral Gas and Ion Mass Spectrometer (NGIMS) measures the densities of planetary ions in the Mars ionosphere (O+,CO2+ and O2+). The Solar Energetic Particle (SEP) detector measures the fluxes of energetic protons and electrons. In this project, we examine the degree to which the density of ions in the Martian ionosphere is affected by the precipitation of energetic particles, under conditions of different SEP ion and electron fluxes and at various solar zenith angles. We will present statistical as well as case studies.
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220.35 – Constraining a Martian general circulation model with the MAVEN/IUVS observations in the thermosphere

The recent measurements of the number density of atomic oxygen by Mars Atmosphere and Volatile EvolutioN/ Imaging UltraViolet Spectrograph (MAVEN/IUVS) have been implemented for the first time into a global circulation model to quantify the effect on the Martian thermosphere. The number density has been converted to 1D volume mixing ratio and this profile is compared to the atomic oxygen scenarios based on chemical models. Simulations were performed with the Max Planck Institute Martian General Circulation Model (MPI-MGCM). The simulations closely emulate the conditions at the time of observations. The results are compared to the IUVS-measured CO2 number density and temperature above 130 km to gain knowledge of the processes in the upper atmosphere and further constrain them in MGCMs. The presentation will discuss the role and importance in the thermosphere of the following aspects: (a) impact of the observed atomic oxygen, (b) 27-day solar cycle variations, (c) varying dust load in the lower atmosphere, and (d) gravity waves.
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220.36 – The Atmosphere of Mars and the MAVEN Mission: Cross-calibrating NGIMS and IUVS

The Mars Atmosphere and Volatile EvolutioN (MAVEN) has two instruments which are used to determine the neutral gas composition of Mars atmosphere: the Imaging UltraViolet Spectrograph (IUVS) and the Neutral Gas and Ion Mass Spectrometer (NGIMS). A detailed comparison between the two is needed in order to verify the integrity of both datasets.Our approach is divided into two stages. First, we compare neutral densities measured by NGIMS in situ and those derived from remote scans of the nearby planetary limb by IUVS, both taken at periapsis. The data resulting from the comparison show that the data is consistent between the two instruments for periapsis near the subsolar point The second stage is to validate the retrievals from the IUVS FUV scans of the Martian disk made from apoapsis by comparing with the NGIMS in situ density measurements. We first process the NGIMS data to be in the same units as the disk scan, i.e. ratios of CO2/CO and CO2/O in the topside column in which the altitude-integrated number density of CO2 is 1016 , cm-2). Since NGIMS is taken at periapsis and IUVS Disk scans are taken at apoapsis, it is not possible to compare data results from the same or nearby orbits. Ideally, it would be best to compare data at the same seasons, however this is not possible because MAVEN has not yet completed a full martian year. Our approach to overcome this obstacle was to review all times where valid data is available and examine data sets occurring at similar environmental conditions. We will present these results.
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221 – Trojan Asteroid Posters

221.01 – Visible spectral slope survey of Jupiter Trojans

Jupiter's Trojans are predicted by the Nice Model [1,2] to be Trans-Neptunian Objects (TNOs) that moved from 30+ AU to 5.2 AU during the early evolution period of the Solar System. This model, predicting giant planet migration and widespread transport of material throughout the Solar System, is however still lacking important constraints. Correlations between the composition, size, and orbital geometry of Jupiter's Trojans can provide additional information to test predicted migration and evolution models.
Two main colour groups have been observed, roughly equivalent to the C (plus low-albedo X) and D classes with distinguishable spectral slopes, and one interpretation is that the two groups have different compositions [3]. Independent compositions together with hints of differing orbital inclination distributions could imply separate formation locations; therefore, determining the relative fractions of C and D asteroids at different sizes would provide a key test for Solar System dynamical models. However, there is a caveat: the distinct colour groups could also arise by other means. Regolith processes or "space weathering" such as micrometeorite impacts and UV irradiation of ice are also plausible explanations for a range of spectrographic slopes from C-like to D-like [4].
Here we report on our latest survey observations at Sutherland, South Africa of approximately 50 Trojan targets using the Sutherland

High Speed Optical Camera (SHOC) [5] on the 74" telescope. These observations are part of a larger multi-telescope survey to determine the spectral slopes (C-like or D-like) for multiple Trojans, focusing on those of small size. These slopes can be used to determine the relative fraction of C+X and D asteroids at different sizes to determine whether what is seen is more consistent with regolith processes or different compositions.

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221.02 – Can Sulfur Explain the Bimodal Color Distribution Observed in the Jupiter Trojans?

We present a series of experiments aimed at exploring the hypothesis that the presence or absence of H_2S ice on the surface of primitive icy bodies in the early solar system is responsible for the bimodal color distribution of the Jupiter Trojans.

Central to our proposed hypothesis is a location-dependent sublimation of ices in the primordial trans-neptunian disk which would have divided objects according to whether they retained H_2S on their surfaces for sufficient time to incorporate their constituents into irradiated organic crusts. The irradiated crusts of objects with and without H_2S would have different chemistry and therefore different optical properties. Dynamical instability models of the early solar system (e.g. Morbidelli *et al*., 2005, Nesvorny *et al*., 2013) predict that Trojans, formed from this primordial population, were later emplaced inward to co-orbit with Jupiter during large-scale rearrangement events. According to our hypothesis, the Trojans today would show evidence of their primordial location with respect to the H_2S sublimation line in the form of a bimodal distribution in surface chemistry, and thus color.

We present laboratory spectroscopy experiments in support of this hypothesis. Numerous thin ice films composed of H_2O, CH_3OH, NH_3, were produced both with and without H_2S. Subsequent processing of these icy bodies was simulated using electron irradiation and heating. Visible reflectance spectra show significant reddening when H_2S is present. Mid-infrared spectra confirm the formation of non-volatile sulfur-containing molecules in the products of H_2S-containing ices. The infrared spectral properties of the organic residues remaining at room temperature show that sulfur significantly changes the chemistry of these irradiation-produced organics. These experiments suggest that the presence of specific sulfur-bearing chemical species may play an important role in the colors of both the KBOs and Trojans today. This testable hypothesis could feed into the design of experiments that might be performed on potential future missions to the Trojans as well as other primitive bodies.

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221.03 – Spectral Emissivity (6 – 38 µm) of Jupiter's Trojan Asteroids

Jovian Trojan asteroids, located in Jupiter's stable Lagrange points, are an extensive population of primitive bodies in the Solar System. Previous work in the visible and NIR shows Trojans have featureless, red-sloped spectra and low albedos, making mineralogical characterization difficult. However, it has been shown that three Trojans exhibit silicate emissivity features in the thermal IR (6 – 38 µm; Emery et al. 2006, Icarus 182). The detected features indicate the presence of fine-grained (micron-sized) silicate dust on the surfaces, and closely resemble spectral features measured of cometary comae. We hypothesize that Trojan surface mineralogy is fairly uniform and is similar to comet dust. The principal goal of this work is, therefore, to derive primary surface mineralogy from thermal emission spectra. We present thermal IR spectra of 12 Trojans observed with NASA's Spitzer space telescope, using the InfraRed Spectrograph (IRS) in Staring Mode from June 2006 to June 2007. Eight objects were observed over the 5.2 – 38 µm spectral range, and four objects over the 7.5 – 38 µm range. Using the NEATM thermal model, we have computed size, albedo, and beaming parameter for the 12 Trojans. Results for these physical parameters are comparable to those derived from WISE data (Grav et al. 2011, ApJ 742 (1); Grav et al. 2012, ApJ 759 (49)). There are, however, some discrepancies, especially with 2797 Teucer. The emissivity spectra fall into groups that directly correlate with the red and less-red spectral slope groupings described in Emery et al. (2011, ApJ, 141(1)). Strong 10 µm emission features appear in each object, suggesting the presence of fine-grained silicates. Features found between 12-13 µm, and 18-19 µm are also observed in all spectra. We will present these new Trojan asteroid data with mineralogical estimates derived from the emissivity spectra.

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221.04 – Near-Infrared Spectroscopy (0.8 to 2.5 µm) of Small Trojan Asteroids

Orbiting the Sun in Jupiter's stable Lagrange regions at 5.2 AU, the Jupiter Trojan asteroids are a large population of primitive bodies distinct from Main Belt asteroids. The Trojan swarms are dominated by bodies with low albedos and red spectral slopes throughout the visible and near-infrared (VNIR; 0.4 – 2.5 µm), characteristic of D and P spectral taxa that are relatively rare in the Main Belt. The absence of absorption band in reflectance spectra of large (D≥75 km) Trojans has enabled the compositions of these bodies to remain a mystery. Because they likely formed beyond the snow line in the solar nebula, it is widely hypothesized that the bulk composition of Trojans includes a large fraction (~50%) of H_2O ice. Low densities of two large binary Trojans support this hypothesis. The low albedos and red spectral slopes are generally hypothesized to be due to the presence of complex organics, although no absorption features supporting this hypothesis have yet been detected. Two VNIR spectral groups exist within the Trojans; ~2/3 of large Trojans form a cluster with very red (D-type-like) spectral slopes, while the other ~1/3 cluster around less-red (P-type-like) slopes. Visible colors of smaller Trojans suggest that the ratio of red to less-red Trojans decreases with decreasing size, from which Wong and Brown (2015; AJ 150:174) suggest that the interiors of all Trojans are represented by the less-red spectral group. In order to further test the hypothesis that Trojans contain H_2O ice and complex organics and to test the result from visible colors that the spectral group ratio changes with size, we have measured near-infrared (0.8 – 2.5 µm) spectra of 35 small (~35 to 75 km) Trojans from both swarms using the SpeX spectrograph at the NASA Infrared Telescope Facility (IRTF). We confirm that the two spectral groups persist to smaller sizes, and we still detect no absorption features that would be diagnostic of composition. Nevertheless, the spectrum of one large Trojan (4709 Ennomos) shows clear evidence of spectral slope variations with rotation. We will present the new spectra and discuss them in the context of Trojan compositions and origins.

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221.05 – Detection of Sulfur Reddening Agents in Irradiated Jupiter Trojans Ice Analogs

Dynamical models, such as the Nice model, suggest that Trojan asteroids are formed out of the same body of material that produced the Kuiper Belt. In addition, telescopic observations show a color bimodality in VNIR spectral slopes of both Trojan asteroids and small KBOs. In one hypothesis, Wong & Brown (AJ, 2016, in revision) interpret the spectrally red and less red Trojans as descendant of sulfur-containing and sulfur-less primordial trans-Neptunian objects that experienced heating and irradiation during their migration inward. A sharp difference in the surface composition (i.e. presence or absence of sulfur) of the common progenitors of KBOs and Trojans would lead to different products of radiation chemistry, which in turn could lead to the observed color bimodality. In this paper, we address the issue of color bimodality through laboratory simulation. Electron irradiation products of ices containing CH_3OH-NH_3-H_2O (without H_2S) and H_2S-CH_3OH-NH_3-H_2O (with H_2S) were examined. Temperature Programmed Desorption (TPD) of the post-irradiation mixtures shows mass spectra corresponding to small red sulfur allotropes (S_2, S_3, S_4) desorbing while heating H_2S-containing films. The production of these small allotropes likely contributes to the reddening slope observed in previously reported “with H_2S” samples (Poston, M., et al. LPSC #2265, 2015) and adds significant soundness to the hypothesis connecting the color bimodality in Jupiter Trojans to sulfur chemistry. These small polymers are reactive and could further polymerize due to thermal processing, producing larger yellow sulfur polymers. We hypothesize that such polymerization would occur as a consequence of heating and increased irradiation experienced by an object as it migrated from the primordial trans-Neptunian disk to the current orbit of Trojans. This could explain the difference in the degree of spectral reddening observed between KBOs and Trojans.
This work has been supported by the Keck Institute for Space Studies (KISS). The research described here was carried out at the Jet Propulsion Laboratory, Caltech, under a contract with the National Aeronautics and Space Administration (NASA) and at the Caltech Division of Geological and Planetary Sciences.
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221.06 – Composition of Irradiation Residue from Jupiter Trojan Laboratory Simulations

Today’s Jupiter Trojan asteroids may have originated in the Kuiper Belt (eg. Morbidelli et al. *Nature* 2005, Nesvorny et al. *ApJ* 2013) and migrated to capture at their present locations. If this is the case, it is expected that their surfaces will contain chemical traces of this history. Our work broadly considers laboratory simulations of this history. In this work we report on the refractory residue left behind when irradiated mixed ice samples were brought to Earth-normal conditions and removed from the vacuum system. Ices that will be discussed include a 3:3:3:1 mixture of H_2S:NH_3:CH_3OH:H_2O; and a 3:3:1 mixture of NH_3:CH_3OH:H_2O. After deposition at 50K, the ices were irradiated with a beam of 10 keV electrons to form a processed crust mixed with unreacted ices. The films were then warmed to 142K under irradiation over several days. After stopping irradiation, the mixtures were slowly heated through the desorption temperatures of the unreacted ices (about 150-180K), leaving only more-stable compounds behind, and up to room temperature. Some of the reaction products were seen to desorb during heating to room temperature, while a significant amount remained as a refractory residue. After backfilling the vacuum system with nitrogen gas, residues were analyzed by Fourier Transform Infrared Spectroscopy, Secondary Ion Mass Spectrometry, and Gas Chromatograph Mass Spectrometry. Results indicate a complex chemistry including aliphatic and aromatic hydrocarbons, and nitrogen and sulfur-containing organics. Notably, when sulfur is not present, a number of nitrogen-containing organic candidates are identified, however, in the mixtures containing sulfur, sulfur-containing compounds appear to dominate the chemistry. While these experiments were conducted with Trojan asteroids in mind, the results are also relevant to comets and other cold locations in the solar system that have experienced large swings in temperature.
This work has been supported by the Keck Institute for Space Studies (KISS). The research described here was carried out at the Jet Propulsion Laboratory, Caltech, under a contract with the National Aeronautics and Space Administration (NASA) and at the Caltech Division of Geological and Planetary Sciences.
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221.07 – A Comparison of Hildas and Jupiter Trojans Using Photometry, Spectroscopy, and Size Distributions

The current paradigm of Solar System evolution describes a scenario in which Jupiter and Saturn crossed their mutual 2:1 mean-motion resonance, leading to a period of dynamical instability and significant restructuring of the orbital architecture throughout the middle and outer Solar System. Simulations have shown that the initial minor body populations in resonance with Jupiter (Hildas and Jupiter Trojans) were first emptied during this chaotic episode, and then replaced primarily with objects scattered inward from the trans-Neptunian region. The major implication of these models is that Kuiper Belt objects, Trojans, and Hildas are expected to share a common progenitor population in the outer Solar System. By comparing the properties of Hildas and Trojans, we can evaluate their similarities and/or differences and thereby empirically test current dynamical instability models.
Our present understanding of Hildas and Trojans reveals many notable similarities. Beyond sharing the general characteristics of reddish colors and very low albedos, both minor body populations have been shown to display a color bimodality. Building on previously published works, we have derived spectral slopes from the Sloan Moving Object Catalog for both Hildas and Trojans, which reveal a robust bifurcation in the optical color distribution over a wide range of sizes and indicate the presence of two classes of objects within the Hildas and Trojans, referred to as the less-red and red sub-populations. We present the first direct comparison between the Hilda and Trojan magnitude distributions, as well as the individual less-red and red population magnitude distributions; we discuss these results in the context of collisional processes and surface properties. We have also obtained new near-infrared spectra of Hildas from the Infrared Telescope Facility and Keck Observatory, covering the wavelength range 0.8–4.0 microns, which supplement previously-obtained spectra for Trojans in the same wavelength range. Taken altogether, these data lend strong support to a common origin for the Hildas and Trojans and serve as the first observational validation of recent models of Solar System evolution.

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222 – Asteroid Physical Characteristics: Interiors Posters

222.01 – Density Distribution of Near Earth Asteroids

The density of near earth asteroids is a fundamental property which can illuminate the structure of the asteroid and is key in assessing the risk of an impact of an NEA with Earth. A low density can be indicative of a rubble pile structure whereas a higher density can imply a monolith and/or a higher metal content. Since the damage resulting from an impact of an asteroid with Earth depends on its interior structure and its total mass, density is a key parameter to understanding the risk of asteroid impact. Unfortunately, measuring the density of asteroids is extremely difficult, has only been attempted for a tiny fraction of NEAs and usually results in measurements with large uncertainties. In the absence of density measurements for a specific object, understanding the range and distribution of likely densities can allow for probabilistic assessment of the ensemble risk of an impact of an NEA and permit estimates of the range of reasonable masses for specific object. We have developed a candidate density distribution for near earth asteroids based on measurements of meteorite densities and an assumed range of macroporosities. Bayesian inference and existing near earth asteroid density measurements are used to develop an updated distribution.

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222.02 – Driving Mechanism of the Brazil Nut Effect in Asteroids

Asteroids are remnant objects from the early planet formation process. Most asteroids are considered rubble-piles since they are likely conglomerates of smaller objects held together by gravity and possibly cohesion. Due to that particular structure, asteroids may be studied using techniques of granular flow. One particular effect called the Brazil Nut Effect (BNE) has previously been proposed to be relevant to asteroids. This effect entails the size-sorting of particles when shaken, where larger particles migrate against the direction of gravity while the smaller particles migrate towards the direction of gravity. Analysis of data from the Hayabusa mission led to asteroid 25143 Itokawa being considered an example where the BNE has occurred bringing large boulders to its surface. Since spacecraft data are limited due to the cost of space missions, there are two other methods of studying this effect: experiments and computer simulations. Though experiments have been done under terrestrial gravity and in low-gravity conditions on parabolic flights, experimental setups cannot fully model the BNE for three-dimensional, self-gravitating, conglomerate objects such as asteroids. Computer simulations have been done in low-gravity conditions utilizing rectangular and cylindrical box configurations and recently in a spherical configuration of particles. Most works have focused on using one large particle embedded with smaller particles (i.e. the intruder model). This has been due to the simplicity and the lack of detailed knowledge about the interior of asteroids. However, in this work we show that the intruder BNE, though important in a wider granular flow context, is not relevant to asteroids. We have run BNE simulations for one, two, and three intruders in a spherical configuration of particles and we find that unless the intruder starts off near the surface of our simulated aggregates they generally do not rise to the surface. This contrasts with a bimodal population of particles where strong size-sorting occurs. Our work might also indicate that, in the context of asteroids, the mechanism of the BNE that is most relevant is that of percolation and not convection.

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222.03 – A Fragment-Cloud Approach for Modeling Atmospheric Breakup of Asteroids with Varied Internal Structures

As an asteroid descends toward Earth, it deposits energy in the atmosphere through aerodynamic drag and ablation. Asteroid impact risk assessments rely on energy deposition estimates to predict blast overpressures and ground damage that may result from an airburst, such as the one that occurred over Chelyabinsk, Russia in 2013. The rates and altitudes at which energy is deposited along the entry trajectory depend upon how the bolide fragments, which in turn depends upon its internal structure and composition. In this work, an analytic asteroid fragmentation model has been developed to model the atmospheric breakup and resulting energy deposition of asteroids with a range of internal structures. The modeling approach combines successive fragmentation of larger independent pieces with aggregate debris clouds released with each fragmentation event. The model can vary the number and masses of fragments produced, the amount of mass released as debris clouds, and the size-strength scaling used to increase the robustness of smaller fragments. The initial asteroid body can be seeded with a distribution of independent fragment sizes amid a remaining debris mass to represent loose rubble pile conglomerations, or can be defined as a monolith with an outer regolith layer. This approach enables the model to represent a range of breakup behaviors and reproduce detailed energy deposition features such as multiple flares due to successive burst events, high-altitude regolith blow-off, or initial disruption of rubble piles followed by more energetic breakup of the constituent boulders. These capabilities provide a means to investigate sensitivities of ground damage to potential variations in asteroid structure.

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222.04 – The Micro-mechanics of Asteroid Dust

Current understanding is that small asteroids in the Solar System are gravitational aggregates that are held together by gravitational, cohesive and adhesive forces. Though the mechanics of how gravitational forces work is very well understood, the same cannot be said about the other two.

In our earlier research we used a Discrete-Element-Method simulation code to calculate the tensile strength of an assemblage of cohesive particles and found that the main geometrical factor controlling bulk strength was the average size of the particles (Sanchez and Scheeres 2014, MAPS). Specifically, the smaller the average size, the greater the tensile strength as r^-1, as though the magnitude of the van der Waals force applied decrease with the radius of the grains (r), the number of contacts per unit area increases with r^-2. This dependency has been corroborated by some observational evidence of the global strength of granular asteroids; however, our simulations were carried out with spherical particles and therefore in these simulations it is impossible to consider more than one contact per pair of particles. Other parameters such as different chemical composition and wider size distribution of the grains, changes in porosity and number of contacts per particle (coordination number) were not taken into direct account either. The study of each one of these parameters is of interest, and our research has started to explore the effect of these on the net cohesive force found in an asteroid's regolith and

interior.
Our initial study will simulate the effect of a wider size distribution in the granular material, comparing this with theoretical predictions. This parameter can cause a change in porosity and coordination number of the grains. This will have a measurable effect in the tensile strength of the aggregate and will provide a first look into the strength of a more realistic cohesive granular media. The results of this research will be shown at the conference.
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223 – Moon: Surface and Atmosphere Posters

223.01 – ARTEMIS Low Altitude Magnetic Field Measurements
Since 2011, two spacecraft of the five THEMIS mission spacecraft are in orbit around the Moon. These two ARTEMIS probes provide for very interesting observations of plasma physical properties of the lunar environment. In particular, the very low periselene of the ARTEMIS probes allows for the detection of crustal magnetic features of our terrestrial companion. Repeated low passes over the same region are used to confirm the crustal origin of the measured magnetic field variations. Using a model for the decay of the magnetic field intensity and measurements at several altitudes, we estimate the magnetic moment and the depth of the equivalent dipole. Some of these magnetic anomalies are strong enough to produce upstream waves due to the interaction with the solar wind with the anomaly driven mini-magnetospheres.
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223.02 – Hybrid Image Fusion for Sharpness Enhancement of Multi-Spectral Lunar Images
Image fusion enhances the sharpness of a multi-spectral (MS) image by incorporating spatial details from a higher-resolution panchromatic (Pan) image [1,2]. Known applications of image fusion for planetary images are rare, although image fusion is well-known for its applications to Earth-based remote sensing. In a recent work [3], six different image fusion algorithms were implemented and their performances were verified with images from the Lunar Reconnaissance Orbiter (LRO) Camera. The image fusion procedure obtained a high-resolution multi-spectral (HRMS) product from the LRO Narrow Angle Camera (used as Pan) and LRO Wide Angle Camera (used as MS) images. The results showed that the Intensity-Hue-Saturation (IHS) algorithm results in a high-spatial quality product while the Wavelet-based image fusion algorithm best preserves spectral quality among all the algorithms. In this work we show the results of a hybrid IHS-Wavelet image fusion algorithm when applied to LROC MS images. The hybrid method provides the best HRMS product - both in terms of spatial resolution and preservation of spectral details. Results from hybrid image fusion can enable new science and increase the science return from existing LROC images.
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223.03 – Lunar Ice Cube: Searching for Lunar Volatiles with a lunar cubesat orbiter
Lunar Ice Cube, a NASA HEOMD NextSTEP science requirements-driven deep space exploration 6U cubesat, will be deployed, with 12 others, by NASA's EM1 mission. The mission's high priority science application is understanding volatile origin, distribution, and ongoing processes in the inner solar system. JPL's Lunar Flashlight, and Arizona State University's LunaH-Map, also lunar orbiters to be deployed by EM1, will provide complementary observations. Lunar Ice Cube utilizes a versatile GSFC-developed payload: BIRCHES, Broadband InfraRed Compact, High-resolution Exploration Spectrometer, a miniaturized version of OVIRS on OSIRIS-REx. BIRCHES is a compact (1.5U, 2 kg, 20 W including cryocooler) point spectrometer with a compact cryocooled HgCdTe focal plane array for broadband (1 to 4 micron) measurements and Linear Variable Filter enabling 10 nm spectral resolution. The instrument will achieve sufficient SNR to identify water in various forms, mineral bands, and potentially other volatiles seen by LCROSS (e.g., CH_4) as well. GSFC is developing compact instrument electronics easily configurable for H1RG family of focal plane arrays. The Lunar Ice Cube team is led by Morehead State University, who will provide build, integrate and test the spacecraft and provide mission operations. Onboard communication will be provided by the X-band JPL Iris Radio and dual X-band patch antennas. Ground communication will be provided by the DSN X-band network, particularly the Morehead State University 21-meter substation. Flight Dynamics support is provided by GSFC. The Busek micropropulsion system in a low energy trajectory will allow the spacecraft to achieve the science orbit less than a year. The high inclination, equatorial periapsis orbit will allow coverage of overlapping swaths once every lunar cycle at up to six different times of day (from dawn to dusk) as the mission progresses during its nominal six month science mapping period. Led by the JPL Science PI, the Lunar Ice Cube mission science team will determine composition and distribution of volatiles in lunar regolith as a function of time of day, latitude, regolith age and composition, and thus enable understanding of current dynamics of lunar volatiles.
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Contributing team(s): Lunar Ice Cube Team

223.04 – Quantifying Slope Effects and Variations in Crater Density across a Single Geologic Unit
Steep underlying slopes (>~5°) significantly increase the rate of degradation of craters [1-3]. As a result, the density of craters is less on steeper slopes for terrains of the same age [2, 4]. Thus, when age-dating a planetary surface, an area encompassing one geologic unit of constant low slope is chosen. However, many key geologic units, such as ejecta blankets, lack sufficient area of constant slope to derive robust age estimates. Therefore, accurate age-dating of such units requires an accurate understanding of the effects of slope on age estimates. This work seeks to determine if the observed trend of decreasing crater density with increasing slopes [2] holds for craters >1 km and to quantify the effect of slope for craters of this size, focusing on the effect of slopes over the kilometer scale. Our study focuses on the continuous ejecta of Orientale basin, where we measure craters >1 km excluding secondaries that occur as chains or clusters. Age-dating via crater density measurements

relies on uniform cratering across a single geologic unit. In the case of ejecta blankets and other impact related surfaces, this assumption may not hold due to the formation of auto- secondary craters. As such, we use LRO WAC mosaics [5], crater size-frequency distributions, absolute age estimates, a 3 km slope map derived from the WAC GLD100 [6], and density maps for various crater size ranges to look for evidence of non-uniform cratering across the continuous ejecta of Orientale and to determine the effect of slope on crater density. Preliminary results suggest that crater density does decrease with increasing slope for craters >1 km in diameter though at a slower rate than for smaller craters.

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223.05 – OH/H ₂O Detection Capability Evaluation on Chang’e-5 Lunar Mineralogical Spectrometer (LMS)

The Chang’e-5 (CE-5) lunar sample return mission is scheduled to launch in 2017 to bring back lunar regolith and drill samples. The Chang'e-5 Lunar Mineralogical Spectrometer (LMS), as one of the three sets of scientific payload installed on the lander, is used to collect in-situ spectrum and analyze the mineralogical composition of the samplingsite. It can also help to select the sampling site, and to compare the measured laboratory spectrum of returned sample with in-situ data. LMS employs acousto-optic tunable filters (AOTFs) and is composed of a VIS/NIR module (0.48μm-1.45μm) and an IR module (1.4μm -3.2μm). It has spectral resolution ranging from 3 to 25 nm, with a field of view (FOV) of 4.24°×4.24°. Unlike Chang’e-3 VIS/NIR Imaging Spectrometer (VNIS), the spectral coverage of LMS is extended from 2.4μm to 3.2μm, which has capability to identify H_2O/OH absorption features around 2.7μm. An aluminum plate and an Infragold plate are fixed in the dust cover, being used as calibration targets in the VIS/NIR and IR spectral range respectively when the dust cover is open. Before launch, a ground verification test of LMS needs to be conducted in order to: 1) test and verify the detection capability of LMS through evaluation on the quality of image and spectral data collected for the simulated lunar samples; and 2) evaluate the accuracy of data processing methods by the simulation of instrument working on the moon. The ground verification test will be conducted both in the lab and field. The spectra of simulated lunar regolith/mineral samples will be collected simultaneously by the LMS and two calibrated spectrometers: a FTIR spectrometer (Model 102F) and an ASD FieldSpec 4 Hi-Res spectrometer. In this study, the results of the LMS ground verification test will be reported, and OH/H_2O Detection Capability will be evaluated especially.

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223.06 – Chang’E Microwave Radiometer Data Calibration with LRO Diviner Data and Machine Learning

Following usual practice in microwave remote sensing, raw data from multi-channel microwave radiometers (MR) onboard the Chinese Chang’E lunar obiters (CE1 & CE2) were acquired as observed antenna voltages, which were then calibrated and converted to brightness temperatures (TB) by a two-point calibration procedure. While the CE cold calibration antenna is supposed to point to the deep space and taking data for the cold reference point in the two-point calibration scheme, in reality, it picked up undesirable thermal microwave radiation from the lunar surface. Thus the “cold” reference point is not exactly the 2.7K cosmic background assumed and this affects the quality of the calibration.
In this work, the small but puzzling differences between the two sets of Level 2C MR data released for CE1 & 2 are attributed to the difference in orbital altitudes between CE1 & 2. This leads to the different degrees of contamination to the cold antenna on CE1 & 2 by thermal radiations from the lunar surface, which showed up as persistent lower night-time TB values in the Level 2C CE2 dataset. We proposed a machine learning approach applied directly to pre-Level 2C data in the voltages to TB convertion process. Since all the antenna voltage data as well as the high temperature referencing point in the calibration procedure are directly measurable, optimized regression algorithms have been employed to determine the effective low temperature referencing points and obtain a single set of statistical consistent TB by combining raw data from CE1 & 2, due to the fact that seasonal variations are less than resolution of the CE MR data from low to medium latitudes.
Finally, the Lunar Reconnaissance Orbiter (LRO) Diviner IR data are used as constraints on the boundary condition of the top layer regolith temperature to obtain a consistent sub-surface temperature profile, from which the measured CE MR data can be computed through multi-layer radiation transfer model. This step removes most of the uncertainties in the calibration of the CE MR data. Successful applications of this approach in a few localities, e.g. the Apollo 17 landing site, will be presented.

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Contributing team(s): This work is supported by BNU-HKBU United International College Research Grant R201626, Zhuhai Premier Discipline Enhancement Grant code: R1050, and Science and Technology Development Fund in Macao SAR 039/2013/A2

223.07 – RLS Instrument Radiometric Model: Instrument performance theoretical evaluation and experimental checks

Raman Laser Spectrometer (RLS) is one of the Pasteur payload instruments located at the Rover of the ExoMars mission and within the ESA’s Aurora Exploration Programme. RLS will explore the Mars surface composition through the Raman spectroscopy technique. The instrument is divided into several units: a laser for Raman emission stimulation, an internal optical head (iOH) for sample excitation and for Raman emission recovering, a spectrometer with a CCD located at its output (SPU), the optical harness (OH) for the units connection, from the laser to the excitation path of the iOH and from the iOH reception path to the spectrometer, and the corresponding electronics for the CCD operation.
Due to the variability of the samples to be analyzed on Mars, a radiometry prediction for the instrument performance results to be of the critical importance. In such a framework, and taking into account the SNR (signal to noise ratio) required for the achievement of successful results from the scientific point of view (a proper information about the Mars surface composition), a radiometric model has been developed to provide the requirements for the different units, i.e. the laser irradiance, the iOH, OH, and SPU throughputs, and the samples that will be possible to be analyzed in terms of its Raman emission and the relationship of the Raman

signal with respect to fluorescence emission, among others.
The radiometric model fundamentals (calculations and approximations), as well as the first results obtained during the bread board characterization campaign are here reported on.

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223.08 – Modeling the Influence of Small-Scale Surface Roughness on the Lunar Exosphere

The Moon and other virtually airless bodies provide distinctive environments for the transport and sequestration of water and other volatiles delivered to their surfaces by various sources. In this work, we conduct Monte Carlo simulations of water vapor transport on the Moon to investigate the role of small-scale roughness (unresolved by orbital measurements) in the migration and cold-trapping of volatiles. Observations indicate that the roughness of the lunar surface, together with the insulating nature of lunar regolith and the absence of significant exospheric heat flow, can cause large variations in temperature over very small scales. Surface temperature is a critical parameter in determining the residence time of migrating water molecules on the lunar surface, which in turn affects the rate and magnitude of volatile transport to permanently shadowed craters (cold traps) near the lunar poles, as well as exospheric structure and the susceptibility of migrating molecules to photodestruction. Here, we develop a rough surface temperature model suitable for simulations of volatile transport on a global scale. We compare results of Monte Carlo simulations of volatile transport with and without the surface roughness model and find that including small-scale temperature variations and shadowing leads to an increased probability of polar cold-trapping, as well as increased thermal escape, compensated for by decreased photodestruction. Exospheric structure is altered only slightly, primarily at the dawn terminator. We also examine the sensitivity of our results to the temperature of small-scale shadows, and the energetics of water molecule desorption from the lunar regolith (two factors that remain to be definitively constrained by other methods) and find that both these factors affect the rate at which cold trap capture and photodissociation occur, as well as exospheric longevity and density.

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223.09 – The fractal method of the lunar surface parameters analysis

Analysis of complex selenographic systems is a complicated issue. This fully applies to the lunar topography. In this report a new method of the comparative reliable estimation of the lunar maps data is represented. The estimation was made by the comparison of high-altitude lines using the fractal analysis. The influence of the lunar macrofigure variances were determined by the method of fractal dimensions comparison.
By now the highly accurate theories of the lunar movement have been obtained and stars coordinates have been determined on the basis of space measurements with the several mas accuracy but there are factors highly influencingon the accuracy of the results of these observations. They are: exactitude of the occultation moment recording, errors of the stars coordinates, accuracy of lunar ephemeris positions and unreliability of lunar marginal zone maps. Existing charts of the lunar marginal zone have some defects. To resolve this task thecomparison method in which the structure of the high-altitude lines of data appropriated with identical lunar coordinates can use. However, such comparison requires a lot of calculations.
In order to find the variations of irregularities for the limb points above the mean level of lunar surface were computed the position angles of this points P and D by Hayn' coordinates. Thus the data of our studies was obtained by identical types.
Then the first, segments of a lunar marginal zone for every 45" on P were considered. For each segment profile of the surface for a constant D were constructed with a step of 2". Thus 80 profiles were obtained. Secondly the fractal dimensions d for each considered structure was defined. Third the obtained values d were compared with the others maps considered in this work.
The obtained results show some well agreement between the mean fractal dimensions for maps. Thus it can be concluded that the using of fractal method for lunar maps analysis to determine the accuracy of the presented to themdata give good results.
The work was supported by grants RFBR 15-02-01638-a, 16-32-60071-mol-dk-a and 16-02-00496-a.

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223.10 – CPR evolution of kilometer-scale craters on the lunar mare

This study analyzes the 12.6-cm radar signature of kilometer-scale craters using data from the Mini-RF instrument on the Lunar Reconnaissance Orbiter. We examine the circular polarization ratio (CPR), which is sensitive to rockiness and surface roughness at the decimeter scale, to determine if there is a relationship between CPR signature and age for craters on the lunar mare. The craters come from an existing dataset of >13,000 craters ranging 800 m to 5 km in diameter that have previously determined degradation states based on their topography. The locations of craters in the original data set were manually co-registered to Mini-RF level 2 observations from the PDS, and for each crater, radial CPR profiles were extracted. In total, there were 5,142 unique craters with Mini-RF observations; 914 craters had repeat measurements that were used to assess uncertainties in CPR profiles. To characterize the time evolution of CPR, the craters were analyzed by finding the median profiles for groups of craters sorted by age and diameter. The highest CPR values are found in the interiors of the craters, and for craters ≤2 km, the freshest craters have the highest CPR values. In the ejecta, fresh craters exhibit the highest CPR, and this decreases with time until an equilibrium is reached. As expected from theory, larger craters' profiles evolve less quickly, with only minor changes in CPR inside their rim and a slower decrease of CPR in their ejecta. In conjunction with other datasets like topography, optical maturity, and rockiness, these data are important for constraining models of regolith evolution and crater degradation on the Moon.

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223.11 – NASA's Solar System Exploration Research Virtual Institute: Merging Science and Exploration

Established in 2013, through joint funding from the NASA Science Mission Directorate (SMD) and Human Exploration and Operations Mission Directorate (HEOMD), NASA's Solar System Exploration Research Virtual Institute (SSERVI) is focused on science at the intersection of these two enterprises. Addressing questions of value to the human exploration program that also represent important

research relevant to planetary science, SSERVI creates a bridge between HEOMD and SMD. The virtual institute model reduces travel costs, but its primary virtue is the ability to join together colleagues who bring the right expertise, techniques and tools, regardless of their physical location, to address multi-faceted problems, at a deeper level than could be achieved through the typical period of smaller research grants. In addition, collaboration across team lines and international borders fosters the creation of new knowledge, especially at the intersections of disciplines that might not otherwise overlap.
SSERVI teams investigate the Moon, Near-Earth Asteroids, and the moons of Mars, addressing questions fundamental to these target bodies and their near space environments. The institute is currently composed of nine U.S. teams of 30-50 members each, distributed geographically across the United States, ten international partners, and a Central Office located at NASA Ames Research Center in Silicon Valley, CA. U.S. teams are competitively selected through peer-reviewed proposals submitted to NASA every 2-3 years, in response to a Cooperative Agreement Notice (CAN). The current teams were selected under CAN-1, with funding for five years (2014-2019). A smaller, overlapping set of teams are expected to be added in 2017 in response to CAN-2, thereby providing continuity and a firm foundation for any directional changes NASA requires as the CAN-1 teams end their term. This poster describes the research areas and composition of the institute to introduce SSERVI to the broader planetary science community and to researchers who want to participate in future opportunities.
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223.12 – The method for the modern selenographic reference systems analysis

In this work analysis of the reference systems of modern selenographic systems was made. The center of the Moon's mass position relative to its center of figure was determined from the data of "Clementine" and "Kaguya" missions and "ULCN" and "KSC-1162" catalogues. The knowledge of the Moon's center of mass position relative to its center of figure is important for researches of the lunar origin, structure and evolution and in terms of precision solutions circumlunar navigation tasks. At the present this task is the most relevant and demanded for cosmic lunar missions.The expansions by spherical harmonics N=5 degree and order of the lunar function h (selenographic longitude, selenographic latitude) using the package ASNI were executed. Module of the expansion of the local area to surfaces to full sphere was used. The parameters of cosmic missions are given for comparison (SAI; Bills, Ferrari).
As a model describing the behavior of the relief on the lunar sphere is used the expansion of the height in a series of spherical harmonics (Sagitov, 1979) in the form of a regression model (Valeev, 2001). To obtain the expansions in spherical harmonics in order to create a digital model and determine estimations of the center of mass position of the Moon relative to its center of the figure required in the future was usedsoftware package ASSR "Sphere" (an automated system of scientific research).ASSR "Sphere" is intended to describe the distribution of various values of the parameters (topography, gravity, magnetic, and other types of potential fields) on the sphere and its parts which were measured in points with known coordinates. Using this bundled software one can generate models of the specificform,carry out forecasting in the form of cross-sections, contour, tone and three-dimensional representation of the distribution of characteristicsvalues. The formation of models is accompanied by estimation of their quality and diagnostic of adherence of least square method.
Work was supported by grants RFBR 15-02-01638-a, 16-32-60071-mol-dk-a and 16-02-00496-a.
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224 – Pluto System Posters

224.01 – Scattering and extinction: interpreting hazes in stellar occultation data

There has been debate concerning interpretation of stellar occultation data and whether those data contain evidence for hazes within Pluto's atmosphere. Multiple layers of haze have been imaged in at Pluto with the New Horizons spacecraft; color-dependent differences in minimum flux from stellar occultations also suggests haze. We look at a purely geometric approach, to evaluate whether it is valid to sidestep details of atmospheric temperature structure and, in an approximate manner, conduct an analysis of the 2015 stellar occultation data that is consistent with the New Horizons imaging results. Support for this work was provided by NASA SSO grant NNX15AJ82G to Lowell Observatory.
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224.02 – Structure and evolution of Pluto's Atmosphere from ground-based stellar occultations between 2002 and 2015

Ground-Based stellar occultations probe Pluto's atmosphere from about 3 km altitude (~ 10 µbar pressure level) up to 260 km altitude (~0.1 µbar). Our main goal is to derive Pluto's atmosphere evolution using thirteen ground-based occultations observed between 2002 and 2015 (plus 2016, if available). We consistently analyze the light curves using the Dias et al. (*ApJ* **811**, 53, 2015) model, and confirm the general pressure increase by a factor of about 1.5 between 2002 and 2015 and a factor of almost three between 1988 and 2015. Implications for Pluto's seasonal evolution will be briefly discussed in the context of the New Horizons (NH) findings.
Ground-based-derived temperature profiles will be compared with NH's results, where we use new temperature boundary conditions in our inversion procedures, as given by NH near 260 km altitude. Although the profiles reasonably agree, significant discrepancies are observed both in the deeper stratospheric zone (altitude < 30 km), and the mesospheric zone (altitudes between 30 and 260 km). Possible biases will be discussed.
Additionally, we use a central flash event observed in New Zealand on June 29, 2015 (close to the NH flyby) to provide an upper limit of Pluto's atmospheric oblateness near 4 km altitude. We will also explore the possibility that small deviations in the observed flash (compared to the model) are caused by the local topographic features revealed by NH.
Finally, possible correlations between spike activity in the occultation light-curves and local underlying presence of free nitrogen ice terrains will be investigated.
Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR").
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Contributing team(s): Rio de Janeiro occultation team, Granada occultation team, International Occultation and Timing Association

224.03 – Radio Occultation Measurements of Pluto's Atmosphere with New Horizons

The reconnaissance of the Pluto System by New Horizons in July 2015 included a radio occultation at Pluto. The observation was performed with signals transmitted simultaneously by four antennas of the NASA Deep Space Network, two at the Goldstone complex in California and two at the Canberra complex in Australia. Each antenna radiated 20 kW without modulation at a wavelength of 4.17 cm. New Horizons received the four signals with its 2.1-m high-gain antenna, where the signals were split into pairs and processed independently by two identical REX radio science instruments. Each REX relied on a different ultra-stable oscillator as its frequency reference. The signals were digitized and filtered, and the data samples were stored on the spacecraft for later transmission to Earth. Six months elapsed before all data had arrived on the ground, and the results reported here are the first to utilize the complete set of observations. Pluto's tenuous atmosphere is a significant challenge for radio occultation sounding, which led us to develop a specialized method of analysis. We began by calibrating each signal to remove effects not associated with Pluto's atmosphere, including the diffraction pattern from Pluto's surface. We reduced the noise and increased our sensitivity to the atmosphere by averaging the results from the four signals, while using other combinations of the signals to characterize the noise. We then retrieved profiles of number density, pressure, and temperature from the averaged phase profiles at both occultation entry and exit. Finally, we used a combination of analytical methods and Monte Carlo simulations to determine the accuracy of the measurements. The REX profiles provide the first direct measure of the surface pressure and temperature structure in Pluto's lower atmosphere. There are significant differences between the structure at entry (193.5°E, 17.0°S, sunset) and exit (15.7°E, 15.1°N, sunrise), which arise from spatial variations in surface composition coupled with the diurnal cycle of condensation and sublimation of nitrogen. This work is supported by the NASA New Horizons Mission.

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224.04 – Implications of the Central Flash Analysis from the 2015 Pluto Stellar Occultation

Two weeks before the historic New Horizons flyby of Pluto, a stellar occultation was observed from Australia and New Zealand (Bosh *et al*., 2016, Pasachoff *et al*., 2016, Sicardy *et al*., 2016). Prior to these observations, an extensive astrometric campaign (Bosh *et al*., this meeting) was conducted to carefully place the SOFIA aircraft within the central flash region of the occultation shadow. Multiple central flash chords were obtained and initial analysis indicated global asymmetry of Pluto's atmosphere (Person *et al*., 2015).
Further analysis of these chords reveals asymmetries in Pluto's atmosphere stronger than those previously observed by either central flash measurements or occultation shadow fitting (Person *et al*., 2006, Olkin *et al*., 2014). Here we will discuss this revealed atmospheric asymmetry in terms of the bulk atmospheric movements necessary to cause distortions of this order, given the extreme surface sphericity seen by New Horizons (Nimmo *et al*., 2016), and its implications for surface ice transport scenarios (Hansen *et al*., 2015), and Pluto's seasonal evolution (Earle *et al*., 2015).

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224.05 – The Effect of Surface Ice and Topography on the Atmospheric Circulation and Distribution of Nitrogen Ice on Pluto

A newly developed general circulation model (GCM) for Pluto is used to investigate the impact of a heterogeneous distribution of nitrogen surface ice and large scale topography on Pluto's atmospheric circulation. The GCM is based on the GFDL Flexible Modeling System (FSM). Physics include a gray model radiative-conductive scheme, subsurface conduction, and a nitrogen volatile cycle. The radiative-conductive model takes into account the 2.3, 3.3 and 7.8 μm bands of CH_4 and CO, including non-local thermodynamic equilibrium effects. including non-local thermodynamic equilibrium effects. The nitrogen volatile cycle is based on a vapor pressure equilibrium assumption between the atmosphere and surface. Prior to the arrival of the New Horizons spacecraft, the expectation was that the volatile ice distribution on the surface of Pluto would be strongly controlled by the latitudinal temperature gradient. If this were the case, then Pluto would have broad latitudinal bands of both ice covered surface and ice free surface, as dictated by the season. Further, the circulation, and the thus the transport of volatiles, was thought to be driven almost exclusively by sublimation and deposition flows associated with the volatile cycle. In contrast to expectations, images from New Horizon showed an extremely complex, heterogeneous distribution of surface ices draped over substantial and variable topography. To produce such an ice distribution, the atmospheric circulation and volatile transport must be more complex than previously envisioned. Simulations where topography, surface ice distributions, and volatile cycle physics are added individually and in various combinations are used to individually quantify the importance of the general circulation, topography, surface ice distributions, and condensation flows. It is shown that even regional patches of ice or large craters can have global impacts on the atmospheric circulation, the volatile cycle, and hence, the distribution of surface ices. The work demonstrates that explaining Pluto's volatile cycle and the expression of that cycle in the surface ice distributions requires consideration of atmospheric processes beyond simple vapor pressure equilibrium arguments.

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224.06 – Photochemical aerosol formation in planetary atmospheres: A comparison between Pluto and Titan

The New Horizons mission observations have revealed us that Pluto's atmosphere is rich in photochemical hazes that extend to high altitudes above its surface [1], apparently similar to those observed in Titan's atmosphere [2].
We use detailed models combining photochemistry and microphysics in order to simulate the aerosol formation and growth in Pluto's atmosphere, as performed for Titan's atmosphere [3]. Here we discuss the possible mechanisms leading to the formation of haze particles in Pluto's atmosphere, and we evaluate the contribution of different growth processes (e.g. coagulation vs. condensation) to the resulting particle properties.
Moreover we investigate the role of these particles in the radiative balance of Pluto's atmosphere and we compare the resulting particle properties, with those retrieved for Titan's upper atmosphere based on Cassini observations [4]. We discuss the similarities and difference between Pluto's and Titan's aerosols.

[1] Gladstone et al., 2016, Science, 351, 6271
[2] West et al., 2015, Titan's Haze, in Titan, Interior, Surface, Atmosphere and Space environment, Cambridge University Press
[3] Lavvas et al., 2013, PNAS, pnas.1217059110
[4] Lavvas et al., 2015, DPS47, id.205.08

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224.07 – The evolution of nitrogen in the atmospheres of Pluto, Titan and Triton

The origin and evolution of nitrogen in solar system bodies is an important question for understanding processes that took place during the formation of the planets and solar system bodies. The most abundant molecule in the Earth's, Titan's, Pluto's and Triton's atmospheres is molecular nitrogen. The nitrogen isotope ratio, $^{14}N/^{15}N$, is an important tracer of the origin of nitrogen on these solar system bodies. By modeling the evolution of the nitrogen isotope ratio from its primordial value to its current value, we can determine if this nitrogen originated as molecular nitrogen or is derived from ammonia in the protosolar nebula. We evaluate the potential impact of escape and photochemistry on $^{14}N/^{15}N$ in these atmospheres to determine constraints for the origin of nitrogen on these bodies. These results have implications for formation processes in the outer solar system and provide guidance for measurements needed by future a future Ice Giants mission to study Triton and any mission to follow New Horizons and Cassini in exploring Pluto and Titan.

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224.08 – Spectroscopy of Pluto and Charon with HST during the encounter year

Pluto is the largest of the handful of transneptunian bodies massive enough to retain, over the age of the solar system, an abundant inventory of volatiles including N2, CH4, and CO (Schaller et al. 2007). Sublimation and condensation act in concert with wind to efficiently transport heat (as well as the ices themselves) in response to diurnally and seasonally changing patterns of insolation (Spencer et al. 1997, Trafton et al. 1998). Recent indications suggest that observable changes could occur from one Earth year to the next (Grundy et al. 2014) and observations of Triton, with a similar inventory of volatile ices suggest that dramatic changes could occur on relatively short timescale (Hicks et al. 2000). The goal of this study is therefore to bridge the gap between sparse, multi-year spectral monitoring of Pluto and the brief, but extremely detailed snapshot provided by New Horizons spacecraft.
We obtained high S/N spectra of Pluto and Charon separately with the HST's WFC3/IR grism G141. Altogether, we have collected data from ten visits at various sub-HST longitudes centered on the New Horizons encounter hemisphere. During each visit we obtained 8 dithered spectral images and 4 direct images in the F139M filter. The spectral reduction followed the recipe outlined in the WFC3 IR Grism Data Reduction Cookbook. The final spectra were combined to achieve spectral uncertainty at the level of around 0.2\% (that is five times better
than in our previous studies). The combined spectra were then explored for sub-latitude, sub-longitude, and phase angle dependences.

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224.09 – HST- STIS Observations of Pluto and Charon Contemporaneous with the New Horizons Encounter

We present mid-ultraviolet (MUV) observations of Pluto and Charon taken with the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope. These spectra were taken in June 2015, one month prior to the close encounter of the New Horizons spacecraft with the Pluto system. Based on New Horizons' characterization of Pluto's atmosphere, we expect significant but spectrally flat attenuation by haze at MUV wavelengths, and insufficient absorption by atmospheric hydrocarbons to produce measurable spectral features. We use the new STIS spectra to characterize the surfaces of Pluto and Charon by fitting Hapke models to the measured MUV geometric albedos of Pluto and Charon. We find that fitting Pluto's measured albedo slope requires inclusion of water ice and tholins in the model, consistent with New Horizons results; modeling of Charon's flat albedo slope does not yield significant constraints on surface composition.

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224.10 – A Low Temperature Eutectic Methane-Ethane Liquid: A Potential Geologic Fluid in the Outermost Solar System

Many icy bodies and moons in the solar system contain methane and ethane, including Titan, Triton, Pluto, Eris, Makemake, and likely others. The material properties of these species and their interactions with one another are still inadequately characterized. To provide insight into the behaviors of these species we conducted a series of laboratory experiments to map the liquidus line as a function of temperature and composition. The interaction of ethane and methane yields a eutectic mixture and depresses the freezing point to ~72 K, almost 20 K colder than the normal freezing points of either pure species. The eutectic composition is 64% CH_4 and 36% C_2H_6. This phenomenon may enable geological processes involving liquids in the near surface environments of bodies once thought too cold and/or that have surface pressures too low to support liquid phases. The addition of other cosmochemically abundant species may suppress freezing points even further (see Hanley et al., this conference).

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224.11 – A Search for Temporal Changes on Pluto and Charon

A search for short-term temporal changes on Pluto and Charon was conducted using the highest resolution New Horizons encounter images. To accomplish this, different images of the same region were overlaid and blinked; at least two researchers searched each image set for evidence of temporal changes. The images included all of the New Horizons LORRI observations between about 3.6 hours prior to closest approach and closest approach; the longest change detection search interval for both Pluto and Charon was about 3.2 hours. Each image was compared to all lower resolution images of the same region, for a total of more than 100 image sets. The resolution of the images searched varied from about 80 m to 880 m. Variability between the images was observed, but is attributed to the variable image resolutions, photometric angles, and instrument artifacts. No definitive variability that is indicative of a temporal change on either Pluto or Charon was found. In contrast, plumes on Triton were observed to be variable in images of similar resolution over intervals of less than 45 minutes (L. Soderblom et al., Science 250, 410, (1990)). This search for temporal changes will be extended to include lower-resolution, full-disk images such that all illuminated regions of both Pluto and Charon will be investigated. NASA funding for this research is gratefully acknowledged.

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Contributing team(s): The New Horizons Geology, Geophysics and Imaging Science Theme Team

224.12 – In search of a signature of binary Kuiper Belt Objects in the Pluto-Charon crater population

In July 2015, New Horizons flew by Pluto and Charon, allowing mapping of the encounter hemisphere at high enough resolution to produce crater counts from the surfaces of the pair. We investigate the distribution of craters in search of a signature of binary impactors. The Kuiper Belt -- especially the cold classical region -- has a large fraction of binary objects, many of which are close-in, equal-mass binaries. We will present results on how the distribution of craters seen on Pluto and Charon compares to a random distribution of single body impactors on the surfaces of each. Examining the surfaces of Pluto and Charon proves challenging due to resurfacing, and the presence of tectonic and other geographic features. For example, the informally-named Cthulhu region is among the oldest on Pluto, yet it abuts a craterless region millions of years young. On Charon, chastmata divide the surface into regions informally named Vulcan Planum and Oz terra. In our statistics, we pay careful attention to the boundaries of where craters may appear, and the dependence of our results on crater size. This work was supported by NASA's New Horizons project.

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224.13 – The Binary Fission Model for the Formation of the Pluto system

The ratio *F* of the mass of Pluto (P) to Charon (C), viz. $F \approx 8:1$, is the largest ratio of any planet-satellite pair in the solar system. Another measure of the PC binary is its normalized angular momentum density *J* (see McKinnon 1989). Analysis of astrometric data (Brozovic et al 2015) acquired before the New Horizons (NH) arrival at Pluto and new measurements made by NH (Stern et al 2015) show that $J = 0.39$. Yet these *F* & *J* values are ones expected if the PC binary had formed by the rotational fission of a single liquid mass (Darwin 1902; Lyttleton 1953). At first glance, therefore, the fission model seems to be a viable model for the formation of the Pluto system. In fact, Prentice (1993 *Aust J Astron* **5** 111) had used this model to successfully predict the existence of several moons orbiting beyond Charon, before their discovery in 2005-2012. The main problem with the fission model is that the observed mean density of Charon, namely 1.70 g/cm^3, greatly exceeds that of water ice. Charon thus could not have once been a globe of pure water. Here I review the fission model within the framework of the modern Laplacian theory of solar system origin (Prentice 1978 *Moon Planets* **19** 341; 2006 *PASA* **23** 1) and the NH results. I assume that Pluto and Charon were initially a single object (proto-Pluto [p-P]) which had condensed within the same gas ring shed by the proto-solar cloud at orbital distance ~43 AU, where the Kuiper belt was born. The temperature of this gas ring is 26 K and the mean orbit pressure is 1.3×10^{-9} bar. After the gas ring is shed, chemical condensation takes place. The bulk chemical composition of the condensate is anhydrous rock (mass fraction 0.5255), graphite (0.0163), water ice (0.1858), CO_2 ice (0.2211) and methane ice (0.0513). Next I assume that melting of the ices in p-P takes place through the decay of short-lived radioactive nuclides, thus causing internal segregation of the rock & graphite. Settling of heavy grains to the centre lowers the MOI of p-P, so triggering rotational disruption. Pluto's moons would then form from liquid water and liquid CO_2, as well as entrained rock-graphite grains. Charon's mean density implies that the rock-graphite mass fraction of the fissioned mass was $\sim$0.41.

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224.14 – Study of the *sailboat* stable region for binaries systems

Before the visit of the New Horizons mission, Giuliatti Winter et al. (2013) through numerical simulations analysed the Pluto-Charon system looking for possible stable regions. Among their results it was found a peculiar stable region located at $a = (0.5d, 0.7d)$ and $e = (0.2, 0.9)$, being a, d and e the values of semimajor axis, Pluto-Charon's distance and the eccentricity, respectively. In this work we explore in details the variation of the size and shape of this region for different binaries systems, considering several parameters for the massive bodies and initial conditions of the test particles. We first created hypothetical systems with different mass ratio (μ) and then we numerically integrated the orbit of test particles for a time span of 10^4 orbital periods of the binary. Our results show that the existence of the sailboat is limited to $\mu=(0.05, 0.27)$ and small changes in the eccentricity of the secondary body are enough to decrease substantially the extend of the stable region. However, the sailboat is robust to changes in the inclination of the particles and the region exists even for retrograde orbits. We also found a larger extend of the sailboat for intervals of pericentre ω around $0°$ and $180°$, but the size of the interval varies with the mass ratio of system.

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224.15 – Search for Short-term temporal evolution of Pluto's surface

Kuiper Belt Objects (KBOs) outnumber other bodies within our Solar System; however, studies of KBO temporal evolution are limited. At present, Pluto is moving farther away from the Sun and the sub-observer latitude is increasing quickly, therefore we might expect to see ongoing changes in the atmosphere and on its surface. In order to search for these changes and minimize the effects of rotational phase and viewing geometry, we observed Pluto at approximately the same sub-observer latitude and longitude between June 2014 and August 2016 with the TripleSpec spectrograph at the Apache Point Observatory. These "matched pairs" correspond to the June observations in one year and the August observations of the following year and allow us to search for purely temporal changes. We investigated how absorption features of the volatile ices changed over the course of one Earth-year and place constraints on the timescale for observable surface-atmosphere interactions of these ices on Pluto.

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225 – Enceladus Posters

225.01 – Explorer of Enceladus and Titan (E^2T): Investigating the habitability and evolution of ocean worlds in the Saturn system

The NASA-ESA-ASI Cassini-Huygens mission has revealed Titan and Enceladus to be two of the most enigmatic worlds in the Solar System. Titan, with its organically rich and dynamic atmosphere and geology, and Enceladus, with its active plume of water vapor and ice laced with organics, salts, and silica nano-particles, both harbouring subsurface oceans, are prime environments in which to investigate the conditions for the emergence of life and the habitability potential of ocean worlds as well as the origin and evolution of unique complex planetary systems. Explorer of Enceladus and Titan (E^2T) is a space mission concept dedicated to investigating the evolution and habitability of these Saturnian satellites and is proposed as a medium-class mission led by ESA in collaboration with NASA in response to ESA's M5 Cosmic Vision Call. E^2T has a focused state-of-the-art adapted payload that will provide in-situ sampling, high-resolution imaging and radio science measurements from multiple flybys of Enceladus and Titan using a solar-electric powered spacecraft in orbit around Saturn. With significant improvements in mass range and resolution, as compared with Cassini, the Ion and Neutral Gas Mass Spectrometer (INMS) and the Enceladus Icy Jet Analyzer (ENIJA) time of flight mass spectrometers will provide the data needed to decipher the subtle details of the aqueous environment of Enceladus from plume sampling and of the complex pre-biotic chemistry occurring in Titan's atmosphere. The Titan Imaging and Geology, Enceladus Reconnaissance (TIGER) mid-wave infrared camera will map thermal emission from Enceladus' tiger stripes at meter scales and investigate Titan's geology and compositional variability at decameter scales. The Radio Science Experiment (RSE) measurements will provide constraints on the ice shell structure and the properties of the internal oceans of Enceladus and Titan. We will present the concept and discuss the major improvements to our understanding of these two unique worlds around Saturn that the mission could provide.

Author(s): Giuseppe Mitri[14], Frank Postberg[11], Jason M. Soderblom[7], Gabriel Tobie[14], Paolo Tortora[9], Peter Wurz[8], Jason W. Barnes[12], Athena Coustenis[5], Francesca Ferri[16], Alexander Hayes[1], Paul O. Hayne[3], Jon Hillier[13], Sascha Kempf [10], Jean-Pierre Lebreton[6], Ralph Lorenz[4], Roberto Orosei[2], Anastassios Petropoulos [3], Chen-wan Yen [3],Kim R. Reh[3], Jürgen Schmidt[15], Jon Sims [3], Christophe Sotin[3], Ralf Srama [17]
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225.02 – Porous flow of liquid water in Enceladus rock core driven by heterogeneous tidal heating

Surface heat flux estimates in excess of 15 GW (e.g. Howett et al., 2016) raise the question of the origin of Enceladus' heat production. While strong heating by tidal dissipation is probably the only viable source, whether the maximum production occurs in the outer ice shell or, deeper, in the ocean or in the rock core, is however unclear. While the analysis of measurements by the Cassini mission (gravity and topography data, observed libration), seems to favor an extremely thin shell at Enceladus South Pole (a few kms only, cf. Thomas et al., 2016, Cadek et al., 2016), the distribution of heat sources remains a major issue in the light of the evolutionary trend that led to this present-day physical state of the moon.
Here, we build up on a recent evaluation of tidal deformation in a porous rock core saturated with liquid water indicating that, owing to its unconsolidated state, plausible core rheologies could lead to significant heat production there (typically 20 GW, Tobie et al., in prep.). We describe porous flow in a 3D spherical model following the work of Travis and Schubert (2015). Compaction of the rock matrix is neglected. Water characteristics (density and viscosity), and the bulk thermal conductivity of the porous core are temperature-dependent and the effect of non-water compounds can be considered. Tidal heating is introduced as a heterogeneous heat source with a pattern inferred from numerical models of the tidal response. Our analysis focuses particularly on the heat flux pattern at the ocean/core interface where water is advected in/out of the porous medium.

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225.03 – Global Tectonics of Enceladus: Numerical Model

Introduction: Enceladus, a satellite of Saturn, is the smallest celestial body in the Solar System where volcanic and tectonic activities are observed. Every second, the mass of 200 kg is ejected into space from the South Polar Terrain (SPT) – [1]. The loss of matter from the body's interior should lead to global compression of the crust. Typical effects of compression are: thrust faults, folding and subduction. However, such forms are not dominant on Enceladus. We propose here special tectonic process that could explain this paradox. Our hypotheses states that the mass loss from SPT is the main driving mechanism of the following tectonic processes: subsidence of SPT, flow in the mantle and motion of adjacent tectonic plates. The hypotheses is presented in [2], [3] and[4].
We suggest that the loss of the volatiles results in a void, an instability, and motion of solid matter to fill the void. The motion is presented at the Fig.1 and includes:
Subsidence of the 'lithosphere' of SPT.
Flow of the matter in the mantle.
Motion of plates adjacent to SPT towards the active region
Methods and results: The numerical model of processes presented is developed. It is based on the equations of continuous media..

If emerging void is being filled by the subsidence of SPT only, then the velocity of subsidence is 0.05 $mmyr^{-1}$. However, numerical calculations indicate that all three types of motion are usually important. The role of a given motion depends on the viscosity distribution. Generally, for most of the models the subsidence is 0.02 $mmyr^{-1}$, but mantle flow and plates' motion also play a role in filling the void. The preliminary results of the numerical model indicate also that the velocity of adjacent plates could be 0.02 $mmyr^{-1}$ for the Newtonian rheology.
Note that in our model the reduction of the crust area is not a result of compression but it is a result of the plate sinking. Therefore the compressional surface features do not have to be dominant. The SPT does not have to be compressed, so the open "tiger stripes" could exist for long time. e suppose that it means the end of activity in the given region.

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225.04 – Understanding Enceladus

We offer answers to the following questions?
1, How did the global ocean form?
2, Why is thermal activity concentrated at the south pole?
3, What maintains the current small orbital eccentricity?
4, How is the thickness of the ice shell changing?
5, Why are the tiger stripes so hot?

6, What sets the area of the south polar terrain?

Author(s): Jing Luan[2], Peter Goldreich[1]
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225.05 – H_2 production by ice grains impacts in the Cassini Ion and Neutral Mass Spectrometer at Enceladus: Modeling of the total amount by flyby to constrain the quantity of H2 in the plumes

The data from the closed source of the Cassini-Ion and Neutral Mass Spectrometer (INMS) at Enceladus' plumes shows presence of H_2 but the detected quantities are dependant on spacecraft velocity. This is attributed to the presence of ice grains in the plumes: their impacts on the walls of the titanium antechamber of INMS' closed source expose/project fresh titanium that will react with water to form H_2. The large number of small ice grains arriving during a single integration period of INMS creates a background signal in addition of large grains causing punctual spikes.). This poses the question of how much of the detected hydrogen is native and how much is an artifact. Signficant quantities of native H_2 could be considered as a "smoking gun" for the suspected hydrothermal activity in Enceladus' ocean as it is ultravolatile and would need to be the result of an ongoing production.
A surface chemistry model of the INMS has been developed in order to determine how much H_2 is produced from the expected ice grains distribution for each flyby. This model considers adsorption and chemisorption effects to follow the evolution of surface and gas phase species in the antechamber. It estimates production of titanium from results of multiple CTH simulations of impacts of ice grains on a titanium surface.
Low velocity (7.5 km/s) impacts produce mostly solid titanium that causes a slow and persistent production of H_2, inducing a mass 2 signal after the spacecraft has exited the plume. This persistent signal is key to the evaluation of the total quantity of titanium released, and therefore H_2 produced, during the flyby.
However the quasi-instant reaction of the titanium fragments with the surrounding water vapor creates an additional difficulty. An adiabatic expansion model of the cloud is used to estimate how much of the titanium is immediately reacted.
We discuss how the simulation results compare to observations, both in term of background signal and in creating spikes from big grains (> 1 micron), what constrains can be derived on the native quantity of H_2 at Enceladus, and how sensitive the results are to uncertanties (e.g., reaction at impact).

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Contributing team(s): Cassini-INMS

225.06 – The Plasma Environment at Enceladus

The plasma environment near Enceladus is complex. The well documented Enceladus plumes create a dusty, asymmetric exosphere in which electrons can attach to small ice particles - forming anions, and negatively charged nanograins and dust - to the extent that cations can be the lightest charged particles present and, as a result, the dominant current carriers. Several instruments on the Cassini spacecraft are able to measure this environment in both expected and unexpected ways. Cassini Plasma Spectrometer (CAPS) is designed and calibrated to measure the thermal plasma ions and electrons and also measures the energy/charge of charged nanograins when present. Cassini Radio Plasma Wave Sensor (RPWS) measures electron density as derived from the 'upper hybrid frequency' which is a function of the total free electron density and magnetic field strength and provides a vital ground truth measurement for Cassini calibration when the density is sufficiently high for it to be well measured. Cassini Langmuir Probe (LP) measures the electron density and temperature via direct current measurement, and both CAPS and LP can provide estimates for the spacecraft potential which we compare. Cassini Magnetospheric Imaging Instrument (MIMI) directly measures energetic particles that are manifest in the CAPS measurements as penetrating background in this region and, while not particularly efficient ionisers, create sputtering and surface weathering of Enceladus surface, MIMI also measures energetic neutral atoms produced during the charge exchange interactions in and near the plumes.
In this presentation we exploit two almost identical Cassini-Enceladus flybys 'E17' and 'E18' which took place in March/April 2012. We present a detailed comparison of data from these Cassini sensors in order to assess the plasma environment observed by the different instruments, discuss what is consistent and otherwise, and the implications for the plasma environment at Enceladus in the context of work to date as well as implications for future studies.

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225.07 – Spatial Variability in Enceladus' Plume Material: Convergence of Evidence or Coincidence?

Systematic spatial trends in the properties of the plume material emerging from Enceladus' tiger stripes can be observed in multiple observations from the Cassini mission. Subtle near infrared spectral differences within the plume have been reported across tiger stripes based on Visual and Infrared Mapping Spectrometer (VIMS) observations at high spatial resolution [1]. These spectral differences are likely due to variable water-ice grain size distribution along the source fissures (i.e. tiger stripes) and perhaps by the presence/absence of water vapor emission [2]. We now report a correlation of this spatial trend (along tiger stripes) with several other published results including (a) differences in the ice particle sizes across tiger stripes on Enceladus' surface [3, 4], (b) the surface abundance of organic material [3] and finally, (c) the relative proportion of type II grains (associated with organic/siliceous material) in the plume [5] from Damascus to Alexandria as measured by the Cosmic Dust Analyzer (CDA) instrument.

The general trend indicates that at least some of the plume properties (viz. particle size, organic abundance) achieve a peak over Damascus and then become gradually subtle towards Alexandria. The observed differences between tiger stripes eruptions and the nature of correlations (trends from Damascus to Alexandria) hold important clues to the subsurface environment at Enceladus including differences in the geological setting of the individual tiger stripes [6]. The latter is a likely possibility given the large spatial spread of eruptions in Encealdus' South Polar Terrain (SPT).

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225.08 – The neutral and ion tori of Saturn

The magnetosphere of Saturn is dominated by a large neutral close derived mainly from Enceladus.
This cloud is ionized to form the plasma torus. We use a self-consistent model to find the neutral
cloud and plasma densities and composition and show how changing source rates modify these
parameters.

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225.10 – Analysis of Cassini UVIS Image Cube Vectors of Enceladus

Cassini UVIS image cubes of Enceladus from a spacecraft range of <= 300 RE show complexity in the <20 RE region of satellite center. This presentation discusses some of the salient features. The image cube matrix discussed here is a virtual 20 X 20 RE structure centered on the satellite body with pixel size 0.2 X 0.2 RE. The pixels are composed of FUV spectral vectors accumulated from multiple exposures by the Cassini experiments in the years 2005 - 2015. In spite of the multiple year exposure, the matrix structure is significantly non-uniform in brightness and spectral content. The features that can be presented at this time are: 1) The pixels at the center of the body show a strong solar reflection that over the 1500 – 1900 A region indicates a spectrally structureless albedo. 2) The central pixels show no discrete emissions other than a weak optically thick atomic hydrogen resonance line (HLya) at 1216 A. 3) Above the limb the solar reflection spectrum appears at irregular locations. One of these is recognized as the south polar plume. The plume solar reflection albedo shows a multiply scattered spectrum dominantly composed of hydrocarbon absorbers, primarily C2H4. 4) Above the limb, the HLya line shows spatially irregular structure with emission peaks in the north 50X brighter than the signal from body center. No discrete emissions other than HLya are observed in the < 2RE region above the limb. The neutral torus at the Enceladus orbit shows only the OI 1304 A line emission. Limits on the presence of other species, H2 in particular, will be presented.

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300 – Comet Surfaces: Evolution and Variation

300.01 – VIRTIS-M observations of 67P/Churyumov-Gerasimenko at low phase angle

On 9-10 of April 2016, the Rosetta orbiter completed a close flyby around the nucleus of 67P/Churyumov-Gerasimenko (CG), when the comet was at heliocentric distance of 2.76 AU, along the outbound leg of its orbit around the Sun. This allowed the VIRTIS imaging spectrometer to observe the surface of CG at visible wavelengths (0.2-1 µm) in the 0.93°-89.7° phase angle range with a spatial resolution ranging from 7 to 46 m/pix, resulting in a total of 105 hyperspectral images. Previous observations of the comet at low phase angle where acquired by VIRTIS during the approach phase on July 2014 (3.7 AU), with pixel resolution varying from 450 to 3200 m/pix, preventing disk-resolved imaging. The April 2016 observations fill this gap, allowing us to constrain the spectrophotometric properties of the surface at higher spatial resolution in the opposition surge geometry, therefore investigating both the 'shadow hiding' and 'coherent backscattering' opposition effect. Extrapolation to 0° phase angle of the reflectance measured during the flyby at latitude between -10° and 30°indicates a surface normal albedo of 0.06 at 0.55 µm. This result is close to the previous average value derived by Ciarniello et al. (2015) from a full-disk analysis giving 0.062+/-0.002 (3.7 AU, inbound orbit). Subsequent measurements by Filacchione et al. (2016) and Ciarniello et al. (in preparation), derived from pre-perihelion observations at lower heliocentric distances, revealed a progressive enrichment of water ice abundance on the nucleus, in northern hemisphere regions, with a consequent brightening of the surface. The measured normal albedo derived from the 9-10 April 2016 dataset seems to indicate that during the post-perihelion phase the northern hemisphere has returned to albedo values compatible to the ones measured during the inbound part of the orbit, when the comet was at 3.7 AU from the Sun. This could be an indication that the northern hemisphere has been either covered by dust emitted by the southern hemisphere during the very active perihelion phase, or that dehydration of the upper surface layers has taken place.

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Contributing team(s): VIRTIS Team

300.02 – Comet P/2010 V1 as a Natural Disintegration Laboratory

Discovered in outburst in 2010, Jupiter-family comet P/2010 V1 (Ikeya-Murukami) was found to be split in observations at the end of 2015. We used the Hubble Space Telescope to obtain deep images of P/2010 V1 at high angular resolution in the 2016 January to March period. The resulting data, by far the best yet obtained for any split or disrupting comet, show the astrometric, photometric and morphological evolution of about 30 fragments. We will present the first results for the velocity dispersion, photometric distribution and variability and discuss the measurements in terms of models for the breakup.

Author(s): David Jewitt[6], Harold A. Weaver[2], Maximilian J. Mutchler[5], Jessica Agarwal[3], Karen Jean Meech[1], Jing Li[6], Jan Kleyna[1], Masateru Ishiguro[4], Richard J. Wainscoat[1], Man-To Hui[6]
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300.03 – Detection and evolution of H_2O ice spots on 67P/Churyumov-Gerasimenko's nucleus

The OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System), and VIRTIS (Visible InfraRed Thermal Imaging Spectrometer) instruments on board Rosetta spacecraft acquired a huge quantity of resolved images and spectra of the comet 67P/Churyumov-Gerasimenko, producing the most detailed maps at the highest spatial resolution of a cometary nucleus surface. After almost two years of observations, 67P was revealed as an intriguing body with a surface rich in heterogeneous geological structures, different surface properties (albedo, colors, texture, tensile strength, layers, pits, boulders…).

A large quantity of bright spots of different size with high visible albedo and flat visible spectrophotometry have been identified by OSIRIS high resolution images. Comparing the image data with near-infrared spectra and modeling the spectra (using Hapke's radiative transfer model) as a mixture of H_2O ice and the ubiquitios « Dark Material » present on the nucleus' surface, we were able to study at the same time the morphological, thermal and compositional properties of these areas.

With this complementary study we are able to confirm the presence of H_2O ice on many brighter areas distributed on the two lobes of 67P.

The detected bright spots are mostly situated on consolidated dust free material surfaces, distributed on the two lobes of 67P in locations which stay longer in shadow, mostly concentrated in near equatorial latitudes. Some spots are stable for several months and others show temporal changes connected to diurnal and seasonal variations. Stability of the spots is corroborated by the temperature retrieved at the surface. The behavior of ice at these locations is in very good agreement with theoretical expectations. The majority of the detected H_2O ice spots are located in the same approximate position of previously detected cometary outbursts. A general overview of these icy spots on the surface of comet 67P will be presented and discussed.

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Contributing team(s): OSIRIS Team, VIRTIS Team

300.04 – OSIRIS' decimeter observations of comet 67P/Churyumov-Gerasimenko

Since July 2014, the ESA spacecraft Rosetta has been escorting the comet 67P/Churyumov-Gerasimenko, thus allowing for a detailed analysis of both inner coma and nucleus of the comet. The on-board scientific imaging system OSIRIS (Keller et al., 2007), has been key to understand the structure (Massironi et al., 2015), the morphology and the processes occurring on the comet (Vincent et al., 2015 ; Thomas et al., 2015).

On the 14th of February 2015, the spacecraft performed a flyby-manoeuvre close to the frontier between Ash, Apis and Imhotep regions, and came in as close as 6km to the nucleus surface. During this flyby, the Narrow-Angle Camera imaged this region at a resolution of 11cm per pixel, while the phase angle varied between 0° and 37° thus allowing us to investigate the opposition effect.

We will present here the results of our photometric and spectrophotometric analyses of the 14th February 2015 flyby dataset. Using a dedicated digital terrain model, we were able to compute the 3D geometry of each frame with a sub-meter accuracy, which were used to correct for the illumination conditions. We fitted our dataset with the Hapke radiative transfer model that included a porosity correction (Helfenstein et al., 2011).

This unique observations at decimetre scale indicate that the comet surface is heterogeneous both in terms of absolute reflectance (variations up to 40%) and colours. Furthermore, according to our photometric analysis, this flown-by region is as sombre as the comet's nucleus (geometric albedo : 6.8 %), the single-scattering albedo is quite low (0.038) and we found a similar high porosity (86%) of the uppermost layer. The opposition effect is dominated by the shadow hiding phenomenon, while the coherent backscattering contribution is found to be negligible.

The spectral reddening effect observed by Fornasier et al., 2015 globally on the comet surface is also observed locally on the flown-by region, but with a less steep behaviour.

The comparisons of the photometry results at several wavelengths with laboratory experiments on simulants of cometary soil will also be presented.

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Contributing team(s): OSIRIS Team

300.05 – The 67P nucleus: seasonal and diurnal color variations from inbound orbits to the perihelion passage

The Rosetta mission has been orbiting comet 67P/Churyumov-Gerasimenko since August 2014, observing it for about 2 years and providing the unique opportunity to continuously investigate the 67P nucleus composition and its evolution from ~4 AU to perihelion, and beyond.

Here we report on seasonal and diurnal color variations of the surface of 67P's nucleus, observed in the 250-1000 nm wavelength range with the Narrow Angle Camera of the OSIRIS imaging system onboard Rosetta

The analysis of colors and of the spectral slope values, evaluated in the 535-882 nm wavelength range, clearly indicates spectacular changes. The nucleus has become spectrally less red, i.e. the spectral slope has decreased, as it approached perihelion, indicating that increasing activity had progressively shed the surface dust, partially showing the underlying ice-rich layer. In addition to the change of color, the amount of phase reddening (the increase of spectral slope with phase angle) decreased when the comet approached its perihelion, by a factor of two in the 2015 observations compared to the August 2014 ones, indicating a change in the physical properties of the outermost layer of the nucleus. We also identified large ice-rich patches (1500 m^2 per patch) appearing and then vanishing in about 10 days, indicating small scale heterogeneities in the nucleus. While approaching perihelion, the nucleus has shown also considerable diurnal color variations on extended areas and the indisputable occurrence of water frost close to the morning shadows, moving with them and sublimating in few minutes when fully illuminated by the Sun.

With an unprecedented spatial resolution and time coverage the

OSIRIS images indicate that important recondensation processes of volatiles are ongoing on cometary nuclei and that solid frost/ices are widespread present on the surface but with extremely short lifetime.

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Contributing team(s): OSIRIS Team

300.06 – A Summary of Comet Nuclei Diameters and Dust Photometry from the WISE/NEOWISE Prime Mission

While the ROSETTA mission has shown us for the first time up-close manifestations of cometary behavior over the course of a comet's complete orbit, and so given us new insight into how to interpret cometary phenomena seen from Earth, even the most basic of properties, the distribution of effective nuclear diameters, is not well understood. Milestone surveys in the infrared are significantly advancing the number of measured comet diameters (e.g. Fernandez et al. 2013). Now with the NEOWISE prime mission data, we have new diameter constraints for 155 cometary nuclei, 55 of which are of long-period. This makes the NEOWISE dataset the largest diameter sample size in a single survey. The dataset also provides information on large-grained dust production via measurements of εfρ. These data, in concert with parallel studies regarding the ejection times and size distributions of the dust (Kramer et al. 2016), and the gas production (Bauer et al. 2015), yield a remarkable amount of information regarding the correlations amongst these properties and as a function of comet orbital classification. We will summarize the final results of the NEOWISE prime mission (Mainzer et al. 2011) comet nuclei survey, and provide an overview of what the restarted mission (Mainzer et al. 2014) results are yielding in terms of constraints on dust and gas production at these crucial wavelengths.

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Contributing team(s): The NEOWISE Team

301 – Comet Dynamics I - Spins and Strengths

301.01 – The Rotation State of Comet 103P/Hartley 2

On November 4, 2010, the Deep Impact (DI) spacecraft made its closest approach to comet 103P/Hartley 2, passing only 694 km from the nucleus. Observations of the coma produced a lightcurve that shows the nucleus is in a state of non-principal axis rotation that evolves with time, while other observations revealed a nucleus that has concentrated collimated jets driven by CO_2 emission (A'Hearn et al., 2011), large variability in the production of H_2O and CO_2 (Besse et al. 2016), and ice patches on the surface (Sunshine et al. 2011). To properly interpret the significance of these phenomena, it is necessary to understand the rotation of the nucleus, so that its thermal history can be derived and properly modeled, while at the same time, it is likely that the comet's high activity levels play an important role in the nucleus dynamics.
An analysis of the lightcurve by Belton et al (2013) described the comet's rotation state, with two periodicities (primary of 18 h, secondary of 28 or 55 h) that change with time. Although their solution describes the periodicities observed around closest approach, it is insufficient to reproduce the changes in coma morphology with time. We are performing an analysis of the structures in the coma (Farnham 2009), using Monte Carlo routines to model the outflowing dust produced by active sources on the nucleus, to derive a comprehensive solution for the nucleus' rotation.
We are also obtaining new observations of Hartley 2 in June/July 2016 (r~3.2 AU) to measure the nucleus' primary component period before the comet becomes highly active. This will provide an end-state measure of the rotation from the 2010 apparition, as well as a starting value for the current apparition, to allow its continuing evolution to be monitored. We will present an update on the status and preliminary results of these analyses.
This work is funded by NASA Grant NNX12AQ64G.
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Belton M.J.S., et al. (2013) Icarus 222, 595-609.
Besse, S., et al. (2016) This meeting.
Farnham, T.L., (2009) Planetary and Space Science 57, 1192-1217.
Sunshine, J.M., et al., (2011) EPSC-DPS Abs. 6, #1345.
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301.02 – Dynamical evolution of comet pairs

Some Jupiter family comets in near-Earth orbits (thereafter NEJFCs) show a remarkable similarity in their present orbits, like for instance 169P/NEAT and P/2003 T12 (SOHO), or 252P/LINEAR and P/2016 BA14 (PANSTARRS). By means of numerical integrations we studied the dynamical evolution of these objects. In particular, for each pair of presumably related objects, we are interested in assessing the stability of the orbital parameters for several thousand years, and to find a minimum of their relative spatial distance, coincident with a low value of their relative velocity. For those cases for which we find a well defined minimum of their relative orbital separation, we are trying to reproduce the actual orbit of the hypothetical fragment by modeling a fragmentation of the parent body. Some model parameters are the relative ejection velocity (a few m/s), the orbital point at which the fragmentation could have happened (e.g. perihelion), and the elapsed time since fragmentation. In addition, some possible fragmentation mechanisms, like thermal stress, rotational instability, or collisions, could be explored. According to Fernández J.A and Sosa A. 2015 (Planetary and Space Science

118,pp.14-24), some NEJFCs might come from the outer asteroid belt, and then they would have a more consolidated structure and a higher mineral content than that of comets coming from the trans-Neptunian belt or the Oort cloud. Therefore, such objects would have a much longer physical lifetime in the near-Earth region, and could become potential candidates to produce visible meteor showers (as for example 169P/NEAT which has been identified as the parent body of the alpha-Capricornid meteoroid stream, according to Jenniskens, P., Vaubaillon, J., 2010 (Astron. J. 139), and Kasuga, T., Balam, D.D., Wiegert, P.A., 2010 (Astron. J. 139).

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301.03 – Analysis of *Hubble Space Telescope* Observations of an Outburst of Comet 29P/Schwassmann-Wachmann 1

We present results of a continuing analysis on the spin state of the enigmatic Comet 29P/Schwassmann-Wachmann 1 (SW1). Previous works have reported possible constraints on the spin state including a non-principal axis state [1] or a rotation period of tens of days [2]. This diversity of published answers highlights the complexity of determining the spin state of an active comet nucleus. Previous work by our group using 3D Monte Carlo coma modeling of ground-based outburst observations from 2008 [3] has placed constraints on the spin period for a set of assumed spin-pole orientations. Due to the nature of the 2008 outburst morphology no constraints on the spin-pole orientation could be found.

We present here an analysis of *Hubble Space Telescope* WFPC2 observations of SW1 shortly after a 1996 outburst [4] with which we have further constrained the spin state. The 0.046-arcsec/pixel scale (176 km/pixel at SW1) of the PC detector gives an order-of-magnitude improvement in spatial resolution over our ground-based observations. Two sets of observations from UT 1996 Mar. 11.3 and 12.1 show the ejected dust forming an asymmetric outflow contained on the sunward side of the coma. A projected outflow velocity of 0.15 ± 0.02 km/s was measured, similar to our measured value from the 2008 observations. Enhancements of the images were performed [5] to bring out subtle variations in coma brightness (i.e., jets) and to allow us to search for signatures of the nucleus' rotation during the outburst. Three curved features are seen in both sets of observations and were modeled using the 3D Monte Carlo coma model [6]. We find a spin period on the order of several days, in agreement with our earlier 2008 analysis.

[1] Meech, K. J., et al.: 1993, *Astron.* J., **106**, 1222. [2] Miles, R., et al.: 2016, *Icarus*, **272**, 327. [3] Schambeau, C. A., et al.: 2016, *Icarus*, submitted. [4] Feldman, P. D., et al.: 1996,*AAS/DPS Meeting Abstracts,* **28**, 1084. [5] Samarasinha, N. and Larson, S.: 2014, *Icarus*, **239**, 168. [6] Samarasinha, N. H., 2000, *Astron. J. Letters*, **529**, L107-L110. We thank the Space Telescope Science Institute (AR14294), and the Center for Lunar and Asteroid Surface Science (CLASS, NNA14AB05A) for support of this work.

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302 – Extrasolar Planets: Terrestrial Planets Atmospheres

302.01 – Using K2 to Investigate Planetary Systems Orbiting Low-Mass Stars

The NASA K2 mission is using the repurposed Kepler spacecraft to search for transiting planets in multiple fields along the ecliptic plane. Unlike the original Kepler mission, which stared at a single region of the sky for four years, K2 observes each field for a much shorter timespan of roughly 80 days. While planets in the habitable zones of Sun-like stars would be unlikely to transit even once during an 80-day interval, planets in the habitable zones of faint low-mass stars have much shorter orbital periods and may even transit multiple times during a single K2 campaign. Accordingly, M and K dwarfs are frequently nominated as K2 Guest Observer targets and K2 has already observed significantly more low-mass stars than the original Kepler mission. While the K2 data are therefore an enticing resource for studying the properties and frequency of planetary systems orbiting low-mass stars, many K2 target stars are not well-characterized and some candidate low-mass stars are actually giants or reddened Sun-like stars. We are improving the characterization of K2 planetary systems orbiting low-mass stars by using SpeX on the NASA Infrared Telescope Facility and TripleSpec on the 200-inch Hale Telescope at Palomar Observatory to acquire near-infrared spectra of K2 target stars. We then employ empirically-based relations to determine the temperatures, radii, luminosities, and metallicities of K2 planet candidate host stars. Refining the stellar parameters allows us to identify astrophysical false positives and better constrain the radii and insolation flux environments of bona fide transiting planets. I will present our resulting catalog of stellar properties and discuss the prospects for using K2 data to investigate whether planet occurrence rates for mid-M dwarfs are similar to those for early-M and late-K dwarfs.

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Contributing team(s): The K2 CHAI Consortium

302.02 – Microphysics of KCl and ZnS Clouds on GJ 1214 b

Clouds are ubiquitous in the atmospheres of exoplanets. However, as most of these planets have temperatures between 600 and 2000 K, their clouds are likely composed of exotic condensates such as salts, sulfides, silicates, and metals. Treatment of these clouds in current exoplanet atmosphere models do not consider the microphysical processes that govern their formation, evolution, and distribution, such as nucleation and condensation/evaporation, thus creating a gulf between the cloud properties retrieved from observations and the cloud composition predictions from condensation equilibrium models. In this work, we apply a 1D microphysical cloud model to GJ 1214 b and investigate the properties of potassium chloride (KCl) and zinc sulfide (ZnS) clouds as a function of atmospheric metallicity, the intensity of vertical mixing, and the mode of nucleation. Our cloud model has been widely applied to planets in our own Solar System, and as such our work bridges a gap between planetary science and exoplanets. Using model background atmospheres calculated by the SCARLET code, we find that (1) the cloud distribution is not significantly affected by metallicity unless [Fe/H] > 2, (2) higher intensities of vertical mixing leads to more extended cloud decks, more cloud particles at all altitudes, and smaller mean particle radii, (3) the high surface energy of solid ZnS prevents the homogeneous nucleation of pure ZnS cloud particles, such that KCl clouds dominate; solid ZnS can only manifest by nucleating onto pre-existing surfaces (heterogeneous nucleation), such as KCl cloud particles, resulting in mixed clouds, and (4) formation of KCl clouds results in a KCl vapor abundance above the cloud deck ~5 orders of magnitude less than that calculated from equilibrium chemistry. We also examine the transmission spectra that would result from these different cases. Extension of this model to other planets and condensates will shed light on the observed continuum in the "cloudiness" of exoplanets.

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302.03 – An Optical Transmission Spectrum of GJ 1214b Suggesting a Heterogeneous Stellar Photosphere

Measurements of the transmission spectrum of a transiting exoplanet require an understanding of the host star's photosphere. If the transit chord differs from the rest of the photosphere, as is the case when unocculted starspots are present, the difference between the two regions will be imprinted on the transmission spectrum we observe. This issue is particularly important for M-dwarf host stars, which provide the best opportunities to study smaller transiting planets, but also remain active for longer after formation than their higher-mass counterparts.

Here, we present an optical transmission (4,500–9,260 Å) of the sub-Neptune GJ 1214b measured with Magellan/IMACS, which points to features potentially imprinted by its mid-M-dwarf host star. Our optical spectrum is generally offset below values found in the near-infrared for this target, and tends to decrease at shorter wavelengths. We find the ensemble of optical and near-infrared transit depths are best explained by the combination of a flat planetary transmission spectrum—owing to lofted, equilibrium condensate clouds or thick photochemical hazes—and another signal produced by heterogeneities in the stellar photosphere. We present the Composite Photosphere and Atmospheric Transmission (CPAT) model for jointly incorporating stellar and exoplanetary signals. Using the CPAT model, we show that unocculted stellar faculae with temperature contrasts and covering fractions similar to those found for solar limb faculae can explain the observed optical transmission spectrum.

We show how the CPAT model can be used to correct transmission spectra for persistent heterogeneities in stellar photospheres, like limb faculae, and discuss the implications of stellar photospheric heterogeneities for transmission spectroscopy of exciting M-dwarf-hosted exoplanets that will be discovered by the Transiting Exoplanet Survey Satellite.

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302.04 – An atmosphere around the super-Earth 55 Cancri e

One of the most successful instruments for observing exoplanetary atmospheres is the Wide Field Camera 3 (WFC3) onboard the Hubble Space Telescope (HST). In particular, the use of the spatial scanning technique has given us the opportunity for even more efficient observations of the brightest targets, achieving the necessary precision of 10 – 100 ppm. With such data and new advanced reduction and statistical techniques, we were able to detect modulations in the spectrum of the hot super-Earth 55 Cancri e, which suggest the existence of a light-weight atmosphere around this planet. Given the brightness of 55 Cancri, the observers adopted a very long scanning length and a very high scanning speed. We took these effects into account, as they can introduce systematics when coupled with the geometrical distortions of the instrument. Our fully Bayesian spectral retrieval code, T-REx, has identified HCN to be the most likely molecular candidate able to explain the features at 1.42 and 1.54 µm. While additional spectroscopic observations in a broader wavelength range in the infrared will be needed to confirm the HCN detection, we used a chemical model, developed with combustion specialists, to explain its pressence. This model indicates that relatively high mixing ratios of HCN may be caused by a high C/O ratio, suggesting this super-Earth is a carbon-rich environment even more exotic than previously thought.

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Contributing team(s): ExoLights, ExoMol

302.05 – Light Scattering in Exoplanet Transits

Transit spectroscopy is currently the leading technique for studying exoplanet atmospheric composition, and has led to the detection of molecular species, clouds, and/or hazes for numerous worlds outside the Solar System. The field of exoplanet transit spectroscopy will be revolutionized with the anticipated launch of NASA's James Webb Space Telescope (JWST) in 2018. Over the course of the design five year mission for JWST, the observatory is expected to provide in-depth observations of many tens of transiting exoplanets, including some worlds in the poorly understood 2–4 Earth-mass regime. As the quality of transit spectrum observations continues to improve, so should models of exoplanet transits. Thus, certain processes initially thought to be of second-order importance should be revisited and possibly added to modeling tools. For example, atmospheric refraction, which was commonly omitted from early transit spectrum models, has recently been shown to be of critical importance in some terrestrial exoplanet transits. Beyond refraction, another process that has seen little study with regards to exoplanet transits is light multiple scattering. In most cases, scattering opacity in exoplanet transits has been treated as equivalent to absorption opacity. However, this equivalence cannot always hold, such as in the case of a strongly forward scattering, weakly absorbing aerosol. In this presentation, we outline a theory of exoplanet transit spectroscopy that spans the geometric limit (used in most modern models) to a fully multiple scattering approach. We discuss a new technique for improving model efficiency that effectively separates photon paths, which tend to vary slowly in wavelength, from photon absorption, which can vary rapidly in wavelength. Using this newly developed approach, we explore situations where cloud or haze scattering may be important to JWST observations of gas giants, and comment on the conditions necessary for scattering to become a major influence on an exoplanet transit spectrum.

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302.06 – A Large Hubble Space Telescope Survey of Low-Mass Exoplanets

The discovery of short-period planets with masses and radii between Earth and Neptune was one of the biggest surprises in the brief history of exoplanet science. From the Kepler mission, we know that these "super-Earths" or "sub-Neptunes" orbit at least 40% of stars, likely representing the most common outcome of planet formation. Despite this ubiquity, we know little about their typical compositions and formation histories. In this talk, we will shed new light on these worlds by presenting the multiple the main results from our 124-orbit HST transit spectroscopy survey to probe the chemical compositions of low-mass exoplanets. We will report on multiple molecular detections. Our unprecedented HST survey provides the first comprehensive look at this intriguing new class of planets by covering seven planets ranging from 1 Neptune mass and temperatures close to 2000K to a 1 Earth-mass planet near the habitable zone of its host star.

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302.07 – Discovery of temperate Earth-sized planets transiting a nearby ultracool dwarf star

We report the discovery of three short-period Earth-sized planets transiting a nearby ultracool dwarf star using data collected by the Liège TRAPPIST telescope, located in la Silla (Chile). TRAPPIST-1 is an isolated M8.0±0.5-type dwarf star at a distance of 12.0±0.4 parsecs as measured by its trigonometric parallax, with an age constrained to be > 500 Myr, and with a luminosity, mass, and radius of 0.05%, 8% and 11.5% those of the Sun, respectively. The small size of the host star, only slightly larger than Jupiter, translates into Earth-like radii for the three discovered planets, as deduced from their transit depths. The inner two planets receive four and two times the irradiation of Earth, respectively, placing them close to the inner edge of the habitable zone of the star. Several orbits remain possible for the third planet based on our current data. The infrared brightness of the host star combined with its Jupiter-like size offer the possibility of thoroughly characterizing the components of this nearby planetary system.

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302.08 – Water loss from terrestrial planets orbiting ultracool dwarfs: Implications for the planets of TRAPPIST-1

Ultracool dwarfs (UCDs) encompass the population of extremely low mass stars (later than M6-type) and brown dwarfs.
Because UCDs cool monotonically, their habitable zone (HZ) sweeps inward in time.
Assuming they possess water, planets found in the HZ of UCDs have experienced a runaway greenhouse phase too hot for liquid water prior to entering the HZ.
It has been proposed that such planets are desiccated by this hot early phase and enter the HZ as dry, inhospitable worlds.
Here we model the water loss during this pre-HZ hot phase taking into account recent upper limits on the XUV emission of UCDs and using 1D radiation-hydrodynamic simulations.
We address the whole range of UCDs but also focus on the planets b, c and d recently found around the 0.08 M⨀ dwarf TRAPPIST-1.
Despite assumptions maximizing the FUV-photolysis of water and the XUV-driven escape of hydrogen, we find that planets can retain significant amounts of water in the HZ of UCDs, with a sweet spot in the 0.04-0.06 M⨀ range.
We also studied the TRAPPIST-1 system using observed constraints on the XUV-flux.
We found that TRAPPIST-1b and c can lose as much as 15 Earth Ocean and planet d -- which may be inside the HZ depending on its actual period -- may have lost less than 1 Earth Ocean.
Depending on its initial content, they could have enough water to remain habitable.
TRAPPIST-1 planets are key targets for atmospheric characterization and could provide strong constraints on the water erosion around UCDs.

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302.09 – The Effect of Carbon Dioxide (CO_2) Ice Cloud Condensation on the Habitable Zone

The currently accepted outer limit of the habitable zone (OHZ) is defined by the "maximum greenhouse" limit, where Rayleigh scattering from additional CO_2 gas overwhelms greenhouse warming. However, this long-standing definition neglects the radiative effects of CO_2 clouds (Kopparapu, 2013); this omission was justified based on studies using the two-stream approximation, which found CO_2 clouds to be highly likely to produce a net warming. However, recent comparisons of the radiative effect of CO_2 clouds using both a two-stream and multi-stream radiative transfer model (Kitzmann et al, 2013; Kitzmann, 2016) found that the warming effect was reduced when the more sophisticated multi-stream models were used. In many cases CO_2 clouds caused a cooling effect, meaning that their impact on climate could not be neglected when calculating the outer edge of the habitable zone. To better understand the impact of CO_2 ice clouds on the OHZ, we have integrated CO_2 cloud condensation into a versatile 1-D climate model for terrestrial planets (Robinson et al, 2012) that uses the validated multi-stream SMART radiative transfer code (Meadows & Crisp, 1996; Crisp, 1997) with a simple microphysical model. We present preliminary results on the habitable zone with self-consistent CO_2 clouds for a range of atmospheric masses, compositions and host star spectra, and the subsequent effect on surface temperature. In particular, we evaluate the habitable zone for TRAPPIST-1d (Gillon et al, 2016) with a variety of atmospheric compositions and masses. We present reflectance and transit spectra of these cold terrestrial planets. We identify any consequences for the OHZ in general and TRAPPIST-1d in particular. This more comprehensive treatment of the OHZ could impact our understanding of the distribution of habitable planets in the universe, and provide better constraints for statistical target selection techniques, such as the habitability index (Barnes et al, 2015), for missions like JWST, WFIRST-AFTA and the LUVOIR mission concept.

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303 – MAVEN Results and the Martian Ionosphere I

303.01 – Science highlights from MAVEN/IUVS after two years in Mars orbit

The broad capabilities of the Imaging UltraViolet Spectrograph on the MAVEN mission are enabling new science ranging from Mars' lower atmosphere up though the escaping corona. After two years in Mars orbit, the instrument has yielded insights on the Mars dayglow, season cycles, nightglow, aurora, meteor showers, clouds, solar-planetary interactions and atmospheric escape. In this presentation we will highlight several new discoveries. First, IUVS has observed a third type of aurora not previously seen at Mars, indicative of a new kind of solar-planet interaction for non-magnetized planets. Second, spatial mapping of nitric oxide nightglow reveals regions of atmospheric downwelling necessitating substantial changes to global atmospheric circulation models. Finally, a new high-spatial-resolution UV imaging mode allows unprecedented determinations of Mars' low-altitude ozone, as well as detection of clouds from nadir to limb.

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303.02 – Mars Atmospheric History Derived from Upper-Atmospheric Structure of $^{38}Ar/^{36}Ar$ Measured From MAVEN

Measurements of the structure of the Martian upper atmosphere made from MAVEN observations allow us to derive homopause and exobase altitudes in the Mars upper atmosphere and to determine the isotopic fractionation that occurs between them. Fractionation in the ratio of $^{38}Ar/^{36}Ar$ occurs between the homopause and exobase due to diffusive separation. This fractionation, combined with measurements of the bulk atmospheric ratio, is used to determine the total amount of argon lost to space by pick-up-ion sputtering. Our analysis is based on Rayleigh distillation, modified by replenishment of gas to the atmosphere by outgassing, impact, and crustal weathering. Approximately 80 % of the ^{36}Ar that was ever in the atmosphere has been removed through time. This high value requires that a major fraction of Mars atmospheric gas has been lost to space. It points strongly to loss to space as having been the dominant mechanism driving the transition in Martian climate from an early, warm, wet environment to today's cold, dry, thin atmosphere.

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303.03 – Measurements of D and H in the Upper Atmosphere of Mars with the MAVEN IUVS Echelle Channel

The enhanced ratio of D/H in the martian atmosphere has long been interpreted to provide evidence for the historic loss rate of water into space, with the enhancement resulting from the mass ratio of the species. Understanding the dependence of the enrichment of D on the loss rate of water requires that one understand the controlling factors, including all sources of exospheric hydrogen and the present-day transport of D and H into the upper atmosphere. Toward this end the MAVEN mission has included an echelle channel in the IUVS instrument that resolves the D and H Lyman alpha emissions produced by resonant scattering of bright solar emission. In this mode it has now been possible to measure the upper atmospheric D and H abundances over most of a martian year. The results are surprising, with larger than expected changes in the D and H abundances and a changing ratio of D/H with a strong seasonal dependence. This talk will present the D and H data to date (Mars will be near perihelion by the time of the DPS meeting) and discuss the interpretation of the large changes that have been observed.

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303.04 – H Escape Rates Inferred from MAVEN/IUVS Observations of the Mars Hydrogen Corona

H escape oxidizes and dessicates the Mars atmosphere and surface, providing a key control on the present-day chemistry and long-term evolution of the planet. Recently, large variations in the escape rate of H as a function of season have been reported by several studies, making continued observation of the variation a high priority. We present escape rates derived from Mars Atmosphere and Volatile EvolutioN (MAVEN) mission Imaging UltraViolet Spectrograph (IUVS) observations of the extended atmosphere of Mars at H Lyman alpha (121.6 nm), which must be interpreted with a coupled density/radiative transfer model owing to the optically thick nature of the emission and the small fraction of H present in the corona on escaping trajectories. We recover densities, temperatures, and escape rates under the assumption of spherical symmetry for multiple periods across MAVEN's mission so far, beginning in December 2014 (escape rates ~4e8/cm2/s). We describe the observed variation and compare it with previously observed seasonal variation in retrieved H escape rates, providing a necessary input for future photochemical modeling studies and estimates of water loss from Mars over its history.

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303.05 – How many ions have escaped the Martian atmosphere?

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission has been making science measurements of the Martian upper atmosphere and its escape to space since November 2014. A key part of this effort is the measurement of the escape rates of charged particles (ions) at present and over solar system history. The lack of a global dynamo magnetic field at Mars leaves its upper atmosphere more directly exposed to the impinging solar wind than magnetized planets such as Earth. For this reason it is thought that ion escape at Mars may have played a significant role in long term climate change. MAVEN measures escaping planetary ions directly, with high energy, mass, and time resolution.
With nearly two years of observations in hand, we will report the average ion escape rate and the spatial distribution of escaping ions as measured by MAVEN and place them in context with previous measurements of ion loss by other spacecraft (e.g. Phobos 2 and Mars Express). We will then report on the measured variability in ion escape rates with different drivers (e.g. solar EUV, solar wind pressure, etc.). Finally, we will use these results to provide an initial estimate of the total ion escape from Mars over billions of years.

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303.06 – Sputtering at Mars: MAVEN observations of precipitating and escaping oxygen during nominal and extreme conditions

Sputtering is believed to be one of the dominant escape mechanisms during the early epochs of our solar system when the solar activity and EUV intensities were much higher than the present day. Mars lacks a global dynamo magnetic field, which creates a

scenario where the solar wind directly interacts with the upper atmosphere and newly created ions can be picked up and swept away by the background convection electric field. These pick-up ions can directly escape or precipitate back into the atmosphere and induce atmospheric sputtering of neutrals.

The MAVEN spacecraft has observed the Mars upper atmosphere, ionosphere, magnetic topology and interactions with the Sun and solar wind during numerous Interplanetary Coronal Mass Ejection (ICME) impacts spanning from March 2015 to June 2016. ICMEs are associated with enhanced solar wind velocities, densities and magnetic field strength, and often drive heavy ion precipitation at much higher rates than during nominal conditions. Thus, ICMEs provide a unique environment for observing sputtering. We will compare MAVEN observations of heavy ion precipitation during nominal conditions as well as during ICMEs. Additionally, we will present global MHD and test particle simulations of the ICMEs in order to calculate sputtering escape rates for oxygen. Finally, we will use the observed and modeled sputtering escape rates to provide an initial estimate of the total sputtered atmospheric escape from Mars over billions of years.

Author(s): Shannon Curry[7], Janet Luhmann[7], Chuanfei Dong[2], Yingjuan Ma[4], Francois Leblanc[1], Ronan Modolo[1], David Brain[5], Jacob Gruesbeck[6], Takuya Hara[7], Jasper Halekas[3], Yaxue Dong[5], Hayley N Williamson[8], Robert E. Johnson[8], James McFadden[7], Jared R. Espley[6], David Mitchell[7], Jack Connerney[6], Frank Eparvier[5], Robert J. Lillis[7],Bruce Jakosky[5]

Institution(s): *1. CNRS, UPMC Univ. Paris 06 Sorbonne Universités, 2. Department of Astrophysical Sciences, Princeton University, 3. Department of Physics and Astronomy, University of Iowa, 4. Dept. Earth, Planetary, and Space Sciences, UCLA, 5. LASP, University of Colorado, 6. NASA Goddard Space Flight Center, 7. SSL, UC Berkeley, 8. University of Virginia*

303.07 – Solar Energetic Particle Precipitation Effects on the ionosphere of Mars

Solar Energetic Particles (SEPs) are an important, if irregular, source of ionization and energy input to the Martian atmosphere. As is the case for much-studied Polar Cap precipitation events on the earth, when SEPs precipitate into the Mars atmosphere, they cause heating, ionization, excitation and dissociation, leading to altitude-dependent changes in chemistry. We present a study of the effects of SEP ionization in the Martian atmosphere using data from the Mars Atmosphere and Volatile Evolution (MAVEN) mission. Specifically, we will correlate altitude profiles of thermal planetary ions (O+, CO2+ and O2+) and electrons measured by the Neutral Gas and Ion Mass Spectrometer (NGIMS) and Langmuir Probe on the MAVEN spacecraft with fluxes of energetic protons and electrons measured by the Solar Energetic Particle (SEP) detector. First, we will present case studies of this correlation, before and during SEP events to examine short-term effects of SEP ionization. We will also examine SEP ionization under different heliospheric conditions, leading to different SEP shadowing geometries and ionization rates. Second, we will present a statistical study showing the degree to which ionospheric densities are affected by the presence of energetic particles, as a function of altitude, SEP spectrum flux and solar zenith angle. This work will provide a better understanding of this important source of ionization in the Martian upper atmosphere and hence, how more frequent and more intense SEP events in Mars' past may have affected the structure of the Martian upper atmosphere and hence atmospheric escape.

Author(s): Robert Lillis[1], Davin Larson[1], Janet Luhmann[1], Christina Lee[1], Bruce Jakosky[2]

Institution(s): *1. University of California Berkeley, 2. University of Colorado, Boulder*

303.08 – Temperature Variations in the Martian Upper Atmosphere from the MAVEN Neutral Gas and Ion Mass Spectrometer

The MAVEN Neutral Gas and Ion Mass Spectrometer (NGIMS) measures composition and variability of neutral and ionic species in the Martian upper atmosphere, allowing us to calculate neutral temperatures from roughly 130 km to 300 km above the surface. Over the past two years at Mars, NGIMS has collected an extensive and useful data set that covers much of the Martian thermosphere and exosphere. We use new, improved algorithms for the most accurate determination of densities from the NGIMS data. We use the densities of inert species (specifically CO_2, Ar, and N_2) along with a hydrostatic equilibrium model to infer the temperature profile and its uncertainty. Uncertainties include the errors in the density measurements, unknown upper boundary conditions, and horizontal variations in the atmosphere. Our calculations reveal diurnal temperature variations of up to 90 K and maximum latitudinal temperature variations of 130 K. These fluctuations in temperature in the upper atmosphere are surprising because they are significantly larger than those predicted by the latest 3D general circulation models for Mars.

Author(s): Shane W. Stone[2], Roger Yelle[2], Paul Mahaffy[1], Mehdi Benna[1], Meredith K Elrod[1], Stephen W. Bougher[3]

Institution(s): *1. NASA GSFC, 2. University of Arizona, 3. University of Michigan*

Contributing team(s): MAVEN

303.09 – Martian upper atmosphere response to solar EUV flux and soft X-ray flares

Planetary upper atmosphere energetics is mainly governed by absorption of solar extreme ultraviolet (EUV) radiation. Understanding the response of planetary upper atmosphere to the daily, long and short term variation in solar flux is very important to quantify energy budget of upper atmosphere. We report a comprehensive study of Mars dayglow observations made by the IUVS instrument aboard the MAVEN spacecraft, focusing on upper atmospheric response to solar EUV flux. Our analysis shows both short and long term effect of solar EUV flux on Martian thermospheric temperature. We find a significant drop (> 100 K) in thermospheric temperature between Ls = 218° and Ls = 140°, attributed primarily to the decrease in solar activity and increase in heliocentric distance. IUVS has observed response of Martian thermosphere to the 27-day solar flux variation due to solar rotation.

We also report effect of two solar flare events (19 Oct. 2014 and 24 March 2015) on Martian dayglow observations. IUVS observed about ~25% increase in observed brightness of major ultraviolet dayglow emissions below 120 km, where most of the high energy photons (< 10 nm) deposit their energy. The results presented in this talk will help us better understand the role of EUV flux in total heat budget of Martian thermosphere.

Author(s): Sonal Jain[4], Ian Stewart[4], Nicholas M. Schneider[4], Justin Deighan[4], Arnaud Stiepen[3], J. Scott Evans[2], Michael H. Stevens[6], Michael S. Chaffin[4], Matteo Crismani[4], William McClintock[4], Franck Montmessin[1], E M Thiemann[4], Frank Eparvier[4], Phillip C. Chamberlin[5], Bruce Jacosky[4]

Institution(s): *1. CNRS LATMOS, 2. Computational Physics, Inc., 3. Laboratory for Planetary and Atmospheric Physics, University of Liege, 4. Laboratory of Atmospheric and Space Physics, 5. NASA/GSFC, 6. Naval Research Laboratory*

304 – Astrobiology

304.01 – Direct mass spectrometry of prebiotically-relevant molecules in irradiated astrophysical ices

Despite overwhelming evidence of complex chemistry in space from ground and space-based observations, much is still unknown about radiation-induced chemistry icy grains. While significant laboratory efforts have been made to understand these reactions, radiation chemistry in ice has so far been studied mainly either by spectroscopic methods or by analyzing the reaction products during warm-up of the ices.

To directly probe these reactions in situ with mass spectrometry, we use a two-step (two-color) laser ablation and ionization (2S-LAI) mass spectrometry method, recently developed in our lab [1]. This method enables direct mass spectrometric detection of organic species of prebiotic importance in energetically-processed comet or planetary ice analogs in situ, without the need for sample warming or processing. With this method, we have previously successfully identified reactive intermediates and photoproducts in energetically processed ices with 2S-LAI mass spectrometry [2][3] at temperatures as low as 5 K. Low-temperature electron irradiation of cometary ice analogs generated CHNO species of potential prebiotic importance (i.e. formamide, methylamine). Our work suggests that complex chemistry may be ubiquitous throughout the universe, and aligns with the current observation of glycine in a cometary coma [4] and theories involving delivery of prebiotically-important molecules through comet and asteroid impacts to the early Earth.

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[4] K. Altwegg, et al., *Science Advances* **2.5** (2016): e1600285.

Author(s): Bryana Henderson[1], Murthy Gudipati[1]

Institution(s): *1. Jet Propulsion Laboratory*

304.02 – Toward the formation of alkylphosphonic acids in phosphine ices

Phosphorus is one of the elemental building blocks of life on Earth and is important for information storage (RNA/DNA), energy transfer (ATP), cell membranes (phospholipids), and structure (bones & teeth). Due to the poor bioavailability of highly oxidized phosphorus (P(V)) found in ubiquitous phosphate (PO_4^{3-}) minerals, reduced oxidation state (P(III)) compounds have been proposed as a phosphorus source for early life on Earth. Among these, the alkylphosphonic acids, which are the only phosphorus-containing organic compounds discovered in the Murchison meteorite, are a suggested exogenous source of prebiotic phosphorus. Phosphine (PH_3) is a known component of the atmospheres of Jupiter and Saturn, and the confirmation of circumstellar phosphine in the carbon-rich envelop of IRC +10216 along with the recent detection of phosphorus in the comet 67P/Churyumov-Gerasimenko provide an additional foundation for studying extraterrestrial phosphorus chemistry and the origins of the alkylphosphonic acids. In the present study, reactions of phosphine ices with water (H_2O), carbon dioxide (CO_2), and methane (CH_4) were investigated using Fourier transform infrared spectroscopy (FTIR), quadrupole mass spectrometry (QMS), and most notably, reflectron time-of-flight mass spectrometry using tunable photoionization (PI-ReTOF-MS). Experiments were conducted at ultra-high vacuum pressures and cryogenic temperatures to better understand reaction pathways and products of phosphorus-containing compounds under icy conditions found in comets or the interstellar medium. The results of this study can provide support to the hypothesis that the alkylphosphonic acids were formed from interstellar phosphine and incorporated into meteorites such as Murchison.

Author(s): Andrew Turner[1], Ralf-Ingo Kaiser[1]

Institution(s): *1. University of Hawaii*

304.03 – Finding a planet's heartbeat: surprising results from patient Mars

We explore, from a 3D time-dependent perspective, the evolution of oxidizing and reducing planetary niches and how they form a planetary-scale redox network – from a planet's deep interior to its atmosphere. Such redox networks are similar to the circulatory system of animals, but instead of pressure gradients redox gradients drive the flow of electrons and create hotspots for nutrients and metabolic activity.

Using time-dependent geodynamic and atmospheric models, we compute for Mars the time-dependent 3D distribution of 1) hydrogen- and methane-rich reducing subsurface environments, driven by serpentinization and radiolysis of water, and 2) oxygen-rich oases as a product of atmosphere-brine interactions governed by climate and surface chemistry.

This is only a first step towards our greater goal to globally model the evolution of local redox environments through time for rocky planets. However, already now our preliminary results show where on Mars oxidizing and reducing oases might have existed and might still exist today. This opens the window to search for extinct and extant life on Mars from a probabilistic global 3D perspective.

Author(s): Vlada Stamenkovic[1], Lewis Ward[1], Woodward Fischer[1], Michael J. Russell[2]

Institution(s): *1. California Institute of Technology, 2. Jet Propulsion Laboratories*

305 – Asteroid Dynamics NEO I: Too Close for Comfort

305.01 – Asteroid airburst altitude vs. strength

Small NEO asteroids (<Ø140m) may not be a threat on a national or global level but can still cause a significant amount of local damage as demonstrated by the Chelyabinsk event where there was over $33 million worth of damage (1 billion roubles) and 1500 were injured, mostly due to broken glass. The ground damage from a small asteroid depends strongly on the altitude at which they "burst" where most of the energy is deposited in the atmosphere. The ability to accurately predict ground damage is useful in determining appropriate evacuation or shelter plans and emergency management.

Strong asteroids, such as a monolithic boulder, fail and create peak energy deposition close to the altitude at which ram dynamic pressure exceeds the material cohesive strength. Weaker asteroids, such as a rubble pile, structurally fail at higher altitude, but it requires the increased aerodynamic pressure at lower altitude to disrupt and disperse the rubble. Consequently the resulting airbursts have a peak energy deposition at similar altitudes.

In this study hydrocode simulations of the entry and break-up of small asteroids were performed to examine the effect of strength, size, composition, entry angle, and speed on the resulting airburst. This presentation will show movies of the simulations, the results of peak burst height, and the comparison to semi-analytical models.

Author(s): Darrel Robertson[1], Lorien Wheeler[1], Donovan Mathias[1]

Institution(s): *1. NASA Ames Research Center*

305.02 – Sensitivity of Airburst Damage Prediction to Asteroid Characterization Uncertainty

Characterizing the level of risk posed by asteroid impacts is quintessential to developing informed mitigation criteria, response

plans, and long-term survey and characterization strategies for potentially hazardous asteroids. A physics-based impact risk (PBIR) model has been created to assess the consequences of potential asteroid strikes by combining probabilistic sampling of uncertain impact parameters with numerical simulation of the atmospheric flight, breakup, and resulting ground damage for each sampled impact case. The model incudes a Monte Carlo framework that allows the uncertainties in the potential impact parameters to be described in terms of probability distributions, and produces statistical results that support inference regarding the threat level across those ranges. This work considers the PBIR model outputs in terms of potential threat characterization metrics for decision support. Several metrics are assessed, from the single estimated casualty (Ec) parameter to more descriptive distribution functions. Distributions are shown for aggregate risk, risk versus asteroid size, and risk to specific geographic regions. In addition, these results show how the uncertain properties of potential impactors can lead to different conclusions about optimal survey and characterization strategies.
Author(s): Donovan Mathias[1], Lorien Wheeler[1], Jessie L. Dotson[1]
Institution(s): *1. NASA Ames Research Center*

305.03 – Scout: orbit analysis and hazard assessment for NEOCP objects

It typically takes a few days for a newly discovered asteroid to be officially recognized as a real object. During this time, the tentative discovery is published on the Minor Planet Center's Near-Earth Object Confirmation Page (NEOCP) until additional observations confirm that the object is a real asteroid rather than an observational artifact or an artificial object. Also, NEOCP objects could have a limited observability window and yet be scientifically interesting, e.g., radar and lightcurve targets, mini-moons (temporary Earth captures), mission accessible targets, close approachers or even impactors. For instance, the only two asteroids discovered before an impact, 2008 TC3 and 2014 AA, both reached the Earth less than a day after discovery. For these reasons we developed Scout, an automated system that provides an orbital and hazard assessment for NEOCP objects within minutes after the observations are available. Scout's rapid analysis increases the chances of securing the trajectory of interesting NEOCP objects before the ephemeris uncertainty grows too large or the observing geometry becomes unfavorable. The generally short observation arcs, perhaps only a few hours or even less, lead severe degeneracies in the orbit estimation process. To overcome these degeneracies Scout relies on systematic ranging, a technique that derives possible orbits by scanning a grid in the poorly constrained space of topocentric range and range rate, while the plane-of-sky position and motion are directly tied to the recorded observations. This scan allows us to derive a distribution of the possible orbits and in turn identify the NEOCP objects of most interest to prioritize followup efforts. In particular, Scout ranks objects according to the likelihood of an impact, estimates the close approach distance, the Earth-relative minimum orbit intersection distance and v-infinity, and computes scores to identify objects more likely to be an NEO, a km-sized NEO, a Potentially Hazardous Asteroid, and those on a geocentric orbit. Moreover, Scout provides an ephemeris service that makes use of the statistical information to support observers in their followup efforts.
Author(s): Davide Farnocchia[1], Steven R. Chesley[1], Alan B. Chamberlin[1]
Institution(s): *1. JPL, Caltech*

305.04 – Benchmarking Asteroid-Deflection Experiment

An asteroid impacting Earth could have devastating consequences. In preparation to deflect or disrupt one before it reaches Earth, it is imperative to have modeling capabilities that adequately simulate the deflection actions. Code validation is key to ensuring full confidence in simulation results used in an asteroid-mitigation plan. We are benchmarking well-known impact experiments using Spheral, an adaptive smoothed-particle hydrodynamics code, to validate our modeling of asteroid deflection. We describe our simulation results, compare them with experimental data, and discuss what we have learned from our work. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-695540
Author(s): Tane Remington[1], Megan Bruck Syal[1], John Michael Owen[1], Paul L. Miller[1]
Institution(s): *1. Lawrence Livermore National Laboratory*

305.05 – Life and Death Near Zero: The distribution and evolution of NEA orbits of near-zero *MOID*, (*e*, *i*), and *q*

Modeling the distribution of orbits with near-zero orbital parameters requires special attention to the dimensionality of the parameters in question. This is even more true since orbits of near-zero *MOID*, (*e*, *i*), or *q* are especially interesting as sources or sinks of NEAs. An essentially zero value of *MOID* (Minimum Orbital Intersection Distance) with respect to the Earth's orbit is a requirement for an impact trajectory, and initially also for ejecta from lunar impacts into heliocentric orbits. The collision cross section of the Earth goes up greatly with decreasing relative encounter velocity, v_{enc}, thus the impact flux onto the Earth is enhanced in such low-v_{enc} objects, which correspond to near-zero (*e*,*i*) orbits. And lunar ejecta that escapes from the Earth-moon system mostly does so at only barely greater than minimum velocity for escape (Gladman, *et al*., 1995, *Icarus* **118**, 302-321), so the Earth-moon system is both a source and a sink of such low-v_{enc} orbits, and understanding the evolution of these populations requires accurately modeling the orbit distributions. Lastly, orbits of very low heliocentric perihelion distance, *q*, are particularly interesting as a "sink" in the NEA population as asteroids "fall into the sun" (Farinella, *et al*., 1994,*Nature* **371**, 314-317). Understanding this process, and especially the role of disintegration of small asteroids as they evolve into low-*q* orbits (Granvik *et al*., 2016, Nature 530, 303-306), requires accurate modeling of the *q* distribution that would exist in the absence of a "sink" in the distribution. In this paper, we derive analytical expressions for the expected steady-state distributions near zero of *MOID*, (*e,i*), and *q* in the absence of sources or sinks, compare those to numerical simulations of orbit distributions, and lastly evaluate the distributions of discovered NEAs to try to understand the sources and sinks of NEAs "near zero" of these orbital parameters.
Author(s): Alan W Harris[2], Alessandro Morbidelli[3], Mikael Granvik[1]
Institution(s): *1. Department of Physics, University of Helsinki, 2. MoreData!, 3. Obs. de la Cote d'Azur*

305.06 – NEO Follow-up Using the University of Hawaii 88-inch Telescope

The University of Hawaii 2.2m telescope (UH88) has been used for running a successful NEO follow-up program for many years. We currently observe eight nights per month for NEO recovery and orbital refinement, with 20% of the observing time funded by NASA under grants from ROSES12 and ROSES13. We focus on targets fainter than 21 magnitude and are capable of achieving RMS uncertainties approaching 0.1 arcsec. Under the NASA ROSES13 Grant we are refurbishing the telescope with a new STA 1600 10K x

10K monolithic CCD camera, which will increase our field of view by a factor of four to 14′ x 14′ and improve our readout time.

We present the current status of the asteroid recovery program and the criteria we use for target selection.

Author(s): Dora Fohring[1], David J. Tholen[1], Yudish Ramanjooloo[1], Denise Hung[1], Colin Aspin[1]
Institution(s): *1. Institute for Astronomy, University of Hawaii*

306 – Pluto's Atmospheric and Surface Chemistry

306.01 – Haze in Pluto's Atmosphere: Implications for Processes and Evolution

Haze in Pluto's atmosphere was detected by New Horizons imaging to altitudes above 200 km at solar phase angles from ~20° to ~169°, and it was detected by the UV solar occultation up to 300 km altitude. The haze is strongly forward scattering in the visible, and a microphysical model of haze reproduces the visible phase function just above the surface with 0.5 µm spherical particles, but also invokes fractal aggregate particles to fit the visible phase function at 45 km altitude and to account for UV extinction. The visible phase function at the bottom of the atmosphere has a back scatter lobe which is absent from the phase function measured 45 km above the surface, making the latter phase function similar to that for haze in Titan's upper atmosphere. Pluto's haze is found at altitudes where direct condensation is not possible, but the haze may form by similar processes to those responsible for the detached haze layer in the upper atmosphere of Titan. It is suggested that haze particles form fractal aggregates which grow larger and more spherical as they settle downwards through the bottom 15 km of the atmosphere. Haze particles settle onto Pluto's surface, at a rate sufficient to alter surface optical properties on seasonal (hundred-year) time scales. However, if this picture applies to Pluto's atmosphere throughout the Pluto year, then haze particles would rapidly accumulate to an optically thick surface layer within thousands of years. These particles would not be processed into tholins except by cosmic rays, and the striking albedo contrasts on Pluto, with very bright and dark regions, would be difficult to understand. Pluto's regional scale albedo contrasts may be preserved by atmospheric collapse.

Author(s): Andrew F. Cheng[3], Michael Summers[1], Randy Gladstone[6], Darrell F. Strobel[2], Leslie Young[5], Panayotis Lavvas[7], Joshua A. Kammer[5], Casey M. Lisse[3], Alex Harrison Parker[5], Eliot F. Young[5], S. Alan Stern[5], Harold A. Weaver[3], Catherine B. Olkin[5], Kimberly Ennico[4]
Institution(s): *1. George Mason Univ, 2. JHU, 3. Johns Hopkins, APL, 4. NASA Ames, 5. SwRI, 6. SwRI, 7. Univ. Reims*

306.02 – Stargazing from New Horizons: Ultraviolet Stellar Occultations by Pluto's Atmosphere

Not long after the New Horizons encounter with Pluto last July, the Alice ultraviolet imaging spectrograph observed signatures of UV absorption by Pluto's atmosphere during two distinct occultation events. During these events, UV bright stars (the Sun, as well as two B-type stars) passed behind Pluto as seen by the spacecraft, and the attenuated starlight revealed the clear presence of nitrogen, methane, and several other hydrocarbons. Their mixing ratios vary with altitude, including localized peaks in the density of minor hydrocarbons such as C_2H_2 and C_2H_4. At about 300 km above Pluto's surface, these particular species are found to have mixing ratios relative to CH_4 of approximately 10% and 1%, respectively. While this overall composition was expected pre-New Horizons, the vertical profiles of these species were surprising. In this presentation I will discuss the analysis of these occultations, including several profiles of key atmospheric species, and how they might play a role in explaining the presence of high-altitude haze on this cold, small, distant planet.

Author(s): Joshua A. Kammer[5], S. Alan Stern[5], Harold A. Weaver[2], Leslie Young[5], Kimberly Ennico[4], Catherine B. Olkin[5], Randy Gladstone[6], Michael Summers[1], Andrew Steffl[5], Thomas K. Greathouse[6], Maarten Versteeg[6], Kurt D. Retherford[6], Joel Wm. Parker[5], Eric Schindhelm[5], Darrell F. Strobel[3]
Institution(s): *1. George Mason University, 2. JHU Applied Physics Lab, 3. Johns Hopkins University, 4. NASA Ames Research Center, 5. Southwest Research Institute, 6. Southwest Research Institute*
Contributing team(s): New Horizons ATM Theme Team, New Horizons Science Team

306.03 – The photochemistry of Pluto's atmosphere as illuminated by New Horizons

New Horizons has granted us an unprecedented glimpse at the structure and composition of Pluto's atmosphere, which is comprised mostly of N_2 with trace amounts of CH_4, CO, and the photochemical products thereof. Through photochemistry, higher-order hydrocarbons are generated, coagulating into tholins and resulting in global haze layers. The photochemical processes on Pluto are analogous to those occurring in Titan's atmosphere, which have been constrained by comparison to Cassini measurements. The New Horizons dataset offers us a second glimpse at a natural hydrocarbon factory, which will teach us how these processes operate at lower pressures and temperatures. Here we present a state-of-the-art photochemical model for Pluto's atmosphere to explain the abundance profiles of CH_4, C_2H_2, C_2H_4, and C_2H_6, the total column density of HCN, and to predict the abundance profiles of oxygen-bearing species. The CH_4 profile can be best matched by taking a constant-with-altitude K_{zz} of 1×10^3 cm_2 s^{-1} and a fixed CH_4 surface mixing ratio of 4×10^{-3}. Condensation is key to fitting the C_2 hydrocarbon profiles. We find that C_2H_4 must have a much lower saturation vapor pressure than predicted by extrapolations of laboratory measurements to Pluto temperatures. We also find best-fit values for the sticking coefficients of C_2H_2, C_2H_4, C_2H_6, and HCN.

Author(s): Michael L Wong[2], Siteng Fan[2], Peter Gao[2], Mao-Chang Liang[1], Run-Lie Shia[2], Yuk Yung[2], Joshua A. Kammer[4], Michael Summers[3], Randy Gladstone[5], Leslie Young[4]
Institution(s): *1. Academia Sinica, 2. California Institute of Technology, 3. George Mason University, 4. Southwest Research Institute, 5. Southwest Research Institute*
Contributing team(s): The New Horizons Science Team

306.04 – Pluto's Photochemical Haze and Comparison to that of Titan

The *New Horizons* flyby of Pluto confirmed the existence of hazes in its atmosphere. The observations suggest that the haze particles are fractal aggregates, analogous to the photochemical hazes on Titan. Therefore, studying the Pluto hazes can shed light on the similarities and differences between the Pluto and Titan atmospheres. We model the haze distributions of both worlds using the Community Aerosol and Radiation Model for Atmospheres assuming that the distribution is shaped by transport and aggregation of particles originating from photochemistry. The results of our models are compared to solar occultation observations taken by New Horizons for Pluto, and Cassini for Titan. For Pluto, satisfactory agreement with observations is obtained when the aggregate monomer size is 10 nm and the downward mass flux of photochemical products is equal to the column-integrated methane destruction rate. The effective particle radius is ~0.1-0.2 µm near Pluto's surface, consistent with forward scattering measurements. We also consider the effect of condensation of HCN, C_2H_2, C_2H_4, and C_2H_6 on the haze particles, which may play an important effect in shaping their altitude and size distributions. An alternative spherical particle case requires a downward mass flux 2-3 times larger, and resulted in particles 4 times smaller near the surface. For Titan, satisfactory agreement with data is found with comparatively smaller monomers and a downward mass flux of photochemical products much less than Titan's column-integrated methane destruction rate, though degeneracy between these two parameters may affect our results.

Author(s): Yuk Yung[1], Peter Gao[1], Siteng Fan[1], Michael Wong[1], Joshua A. Kammer[3], Michael Summers[2], Randy Gladstone[3], Leslie Young[3]
Institution(s): *1. Caltech, 2. George Mason University, 3. Southwest Research Institute*

306.05 – Distribution, physical state and mixing of materials at the surface of Pluto from New Horizons

In July 2015 the New Horizons spacecraft recorded a large set of data on Pluto, in particular with the LEISA spectro-imager dedicated to the study of the surface composition.
In this talk we report a study of the distribution and physical state of the ices and non-ice materials on Pluto's surface and their mode and degree of mixing. Principal Component analysis as well as specific spectral indicators and correlation plots are used on high resolution LEISA spectro-images covering the whole illuminated face of Pluto. Qualitative distribution maps have been obtained for the 4 main condensed molecules, N2, CH4, CO, H2O as well as for the visible-dark red material. These maps indicate the presence of 3 different types of ices: N2-rich:CH4:CO ices, CH4-rich:(CO:N2?) ices and H2O ice. Their mixing lines and with the dark reddish material are studied. CH4 is mixed at the molecular level with N2 and CO, thus forming a ternary molecular mixture that follows its phase diagram with low solubility limits. The occurrence of a N2-rich – CH4-rich ices mixing line associated with a decrease of the CO/CH4 ratio tell us that a fractionation sublimation sequence transforms N2-rich ice into either a N2-rich – CH4-rich binary mixture at the surface or an upper CH4-rich(:CO:N2) ice crust that may hide the N2-rich ice below. The CH4-rich – H2O mixing line witnesses the subsequent sublimation of CH4 ice left behind by the N2:CO sublimation (N spring-summer), or a direct condensation of CH4 ice on cold H2O ice (S autumn). The very sharp spatial transitions between CH4-containing ices and the dark red material are probably due to thermal incompatibility. Finally there is some spatial mixing of the reddish material covering H2O ice. H2O ice appears to be the substratum on which other ices condense or non-volatile organic material is deposited from the atmosphere. The spatial distribution of these materials is very complex.
The high spatial definition of all these composition maps will allow us to compare them with Pluto's geologic features observed by LORRI panchromatic and MVIC multispectral imagers to better understand the geophysical processes in action at the surface of this astonishingly active cold world.

Author(s): Bernard Schmitt[11], Sylvain Philippe[11], Will Grundy[4], D. C. Reuter[7], Eric Quirico[11], Silvia Protopapa[1], Rémi Côte[11], Leslie Young[8], Richard Binzel[5], Jason C. Cook[8],Dale P. Cruikshank[6], Cristina M. Dalle Ore[6], Alissa M. Earle[5], Kimberly Ennico[6], Carly Howett[8], Donald Jennings[7], Ivan Linscott[10], A.W. Lunsford[7], Catherine B. Olkin[8], Joel Wm. Parker[8], Alex Parker[8], Kelsi N. Singer[8], John R. Spencer[8], John A Stansberry[9], S. Alan Stern[8], Constantine Tsang[8], Anne J. Verbiscer[2], Harold A. Weaver[3]
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Contributing team(s): the New Horizons Science Team

306.06 – Unveiling Pluto's global surface composition through modeling of New Horizons Ralph/LEISA data

We present compositional maps of Pluto derived from data collected with the Linear Etalon Imaging Spectral Array (LEISA), part of the New Horizons Ralph instrument (Reuter et al., 2008). Previous analysis of band depths, equivalent widths, and principal components have permitted qualitative analysis of the physical state of Pluto's surface (Grundy et al. 2016; Schmitt et al. 2016); the maps presented here are fully quantitative, generated by applying a complete pixel-by-pixel Hapke radiative transfer model to the near infrared LEISA spectral cubes. These maps quantify the spatial distribution of both the absolute abundances and textural properties of the volatiles methane and nitrogen ices and non volatiles water ice and tholin. Substantial reservoirs of methane and nitrogen ices cover the substratum which, in the absence of volatiles, reveals the presence of water ice, as expected given Pluto's size and temperature. We identify large scale latitudinal variations of methane and nitrogen ices which can help setting constraints to volatile transport models. To the north, by about 55 deg latitude, the nitrogen abundance smoothly tapers off to an expansive polar plain of predominantly methane ice. This transition well correlates with expectations of vigorous spring sublimation after a long polar winter. Continuous illumination northward of 75 deg over the past twenty years, and northward of 55 deg over the past ten years, seems to have sublimated the most volatile nitrogen into the atmosphere, with the best chance for redeposition occurring at points southward. This loss of surface nitrogen appears to have created the polar bald spot seen in our maps and also predicted by Hansen and Paige (1996). Regions that stands out for composition with respect to the latitudinal pattern described above are also going to be discussed. An example is given by informally named Sputnik Planum, where the physical properties of methane and nitrogen are suggestive of the presence of a cold trap or possible volatile stratification.
This work was supported by NASA's New Horizons project. S. Protopapa thanks the NASA grant #NNX16AC83G.

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Contributing team(s): New Horizons Science Team

306.07 – Pluto's Nonvolatile Chemical Compounds

Despite the migration of Pluto's volatile ices (N_2, CO, and CH_4) around the surface on seasonal timescales, the planet's non-volatile materials are not completely hidden from view. They occur in a variety of provinces formed over a wide range of timescales, including rugged mountains and chasms, the floors of mid-latitude craters, and an equatorial belt of especially dark and reddish material typified by the informally named Cthulhu Regio. NASA's New Horizons probe observed several of these regions at spatial resolutions as fine as 3 km/pixel with its LEISA imaging spectrometer, covering wavelengths from 1.25 to 2.5 microns.

Various compounds that are much lighter than the tholin-like macromolecules responsible for the reddish coloration, but that are not volatile at Pluto surface temperatures such as methanol (CH_3OH) and ethane (C_2H_6) have characteristic absorption bands within LEISA's wavelength range. This presentation will describe their geographic distributions and attempt to constrain their origins. Possibilities include an inheritance from Pluto's primordial composition (the likely source of H_2O ice seen on Pluto's surface) or ongoing production from volatile precursors through photochemistry in Pluto's atmosphere or through radiolysis on Pluto's surface. New laboratory data inform the analysis.
This work was supported by NASA's New Horizons project.
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306.08 – The Color and Surface Composition of Mountains on Pluto

The New Horizons mission revealed that there are mountains along the western edge of the large glacier that dominates Pluto's anti-Charon hemisphere. This talk will focus on the color and surface composition of the four large mountainous regions named Al Idrisi Montes, Bare Montes, Hillary Montes and Norgay Montes (all feature names are informal).
The Al Idrisi Montes are large blocks up to 40 km across and 5 km high that appear to be broken off of the ice crust and transported into Sputnik Planum (Moore et al. 2016). The color of this region as a function of latitude will be presented as well as the color differences between the blocks and the interstitial material between the blocks. Moving south along the edge of Sputnik Planum, the next mountainous region is Bare Montes. Part of the Bare Montes resembles Al Idrisi Montes with its chaotic blocky structure, but there is a significant difference in color between these regions. The Bare Montes are more red than Al Idrisi Montes and this region's color more closely matches the nearby terrain of Cthulhu Regio. Continuing south, to the Hillary and Norgay Montes regions these topographic features become less red with both red and neutral colors on their slopes. The Hillary Montes show both red and neutral colors in the ices surrounding the peaks.
This work will provide a quantitative comparison of the color and composition across these 4 mountainous regions using data from the Ralph instrument. Ralph has 4 color filters: blue (400-550 nm), red (540-700 nm), near IR (780-975) and methane filter (860-910 nm) and collects infrared imaging spectrometric data (from 1.25-2.5 microns).
This work was supported by NASA's New Horizons project.
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306.09 – Charon's, Hydra's, and Nix's near IR spectra as seen by New Horizons

Charon, Pluto's largest satellite, is a predominantly grey-color icy world covered mostly in H_2O ice, with spectral evidence for NH_3 and/or its hydrates, as previously reported (Cook et al. 2007, ApJ. 663, 1406; Verbiscer et al. 2007, LPSC 38, 2318; Merlin et al. 2010, Icarus, 210, 930; Cook et al. 2014, AAS/DPS Abstracts, 46, #401.04; Holler et al. 2016, submitted, arXiv:1606.05695). In their 2010 work, Merlin et al. reported the presence of ammonia species along with H_2O ice both in crystalline and amorphous phase. They introduced a blue component to model the slope present in their near-IR observations, which could not be otherwise reproduced without the adoption of an *ad hoc* component. The presence of ammonia and H_2O in its crystalline form prompted Cook et al. (2007) to suggest cryovolcanism as a favored mechanism of resurfacing although the geological evidence for volcanism reported from New Horizons imaging observations does not appear to be recent (Moore et al. Science, 351, 1284).
We analyze one of New Horizons' observations of Charon taken with the LEISA imaging spectrometer from a distance of ~82,000 km at high spatial resolution (4.9 km/pixel). Images from the New Horizons spacecraft reveal a surface with terrains of seemingly different ages and a moderate degree of localized coloration.
Hydra was observed by New Horizons at a distance 240,000 and 370,000 hardly resolving its disk. Nix on the other hand was observed from a much more favorable distance of 60,000 and 162,000 km revealing a nearly uniform surface coloration and structure.
Although Hydra could hardly be resolved at the flyby distance we have obtained its spectral signature and we compare it with those of Charon and Nix. A feature at ~2.2 µm, corresponding to the NH_3 and/or NH_3 hydrates, is visible subtly on Charon and clearly on Hydra and Nix hinting at the possibility that NH_3 might be less volatile than previously thought and making the need for recent cryovolcanism less crucial.
Preliminary modeling indicates uniformity in amounts and grain sizes of most components, a homogeneity that seems to be the trademark of Charon's surface.
This work was supported by NASA's New Horizons project.
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Contributing team(s): New Horizons Surface Composition Theme Team

307 – Comet Dynamics II - Evolution and Origins

307.01 – Constraints on Comet 332P/Ikeya-Murakami

Encke-type comet 332P/Ikeya-Murakami is experiencing a series of cascading fragmentation events during its 2016 apparition. It is likely the first splitting Encke-type comet ever being observed. A nongravitational solution to the available astrometry including high quality observations from the Canada-France-Hawaii Telescope by

Kleyna et al. (private communication) reveals a statistical detection of the radial and transverse nongravitational parameters, $A1 = (1.54 \pm 0.39) \times 10^{-8}$ AU day^{-2}, and $A2 = (7.19 \pm 1.92) \times 10^{-9}$ AU day^{-2}, respectively, based upon which we calculated the erosion rate of the comet, which is large and hence is likely related to the ongoing fragmentation events. We have constrained the nucleus size from our archival search for serendipitously pre-discovery observations of the comet from major sky surveys. Our study also suggests a potential generic relationship between comet P/2010 B2 (WISE) and 332P. Detailed information will be presented.

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307.02 – Periodicity Signatures of Lightcurves of Active Comets in Non-Principal-Axis Rotational States

There are two comets (1P/Halley, 103P/Hartley 2) that are unambiguously in non-principal-axis (NPA) rotational states in addition to a few more comets that are candidates for NPA rotation. Considering this fact, and the ambiguities associated with how to accurately interpret the periodicity signatures seen in lightcurves of active comets, we have started an investigation to identify and characterize the periodicity signatures present in simulated lightcurves of active comets. We carried out aperture photometry of simulated cometary comae to generate model lightcurves and analyzed them with Fourier techniques to identify their periodicity signatures. These signatures were then compared with the input component periods of the respective NPA rotational states facilitating the identification of how these periodicity signatures are related to different component periods of the NPA rotation. Ultimately, we also expect this study to shed light on why only a small fraction of periodic comets is in NPA rotational states, whereas theory indicates a large fraction of them should be in NPA states (e.g., Jewitt 1999, EMP, 79, 35). We explore the parameter space with respect to different rotational states, different orientations for the total rotational angular momentum vector, and different locations on the nucleus for the source region(s). As for special cases, we also investigate potential NPA rotational states representative of comet 103P/Hartley2, the cometary target of the EPOXI mission. The initial results from our investigation will be presented at the meeting.

The NASA DDAP Program supports this work through grant NNX15AL66G.

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307.03 – Testing solar system formation models using Pan-STARRS1 detections of nearly inactive Manx comets

Newly discovered Manx comets show low levels of sublimation at perihelion indicating significantly lower volatile abundance compared to typical long period comets. The S-class spectrum of Manx comet C/2014 S3 (PANSTARRS) indicates that they may have formed in the inner solar system and were later perturbed to the highly eccentric orbits observed today (Meech et al. 2016). We used the Pan-STARRS1 observation history and its Moving Object Processing System (MOPS) (Denneau et al. 2013) to model Manx detections since Pan-STARRS has been the primary discovery source of Manx comets. A synthetic Manx population was generated according to the Wiegert and Tremaine (1999) model and processed through MOPS to determine the expected Pan-STARRS1 detections and the corresponding detection efficiencies for Manx comets as a function of each orbital parameter and object size. The population of normal long period comets (LPCs) was modeled in the same fashion. Unbiased populations for LPCs and Manx comets were computed by correcting the real comet populations with the detection efficiencies. Finally, the ratio of the bias corrected number of Manx comets to LPCs is compared to the predictions of various solar system formation models.

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Denneau, L. et al. (2013), Publications of the Astronomical Society of the Pacific, 125, 926, 357-395
Wiegert, P. and Tremaine, S. (1999), Icarus, 137, 1, 84-121.

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308 – Comets: Chemical Composition/Origins and Theory - New Constraints

308.01 – The diiversity of rocky materials in comets

Comets have spectacularly diverse surface morphologies and notable differences in volatile contents. Is it possible that these seemingly diverse bodies actually contain similar mixes of rocky materials and that this is a fundamental property of small bodies that accreted in the outer parts of the early solar system? Detailed laboratory analyses of comet Wild 2 samples returned by the Stardust mission show, to first order, that the majority of preserved rocky materials >1µm are similar to those in primitive asteroidal meteorites. Nearly all of these components have solar system isotopic compositions and appear for have formed in hot environments in the inner solar system by the same high temperature processes than made condensates, chondrules and refractory inclusions found in primitive meteorites. It appears that the major difference between the rocky materials in the comet and meteorites is that the comet materials are an amazing potpourri of materials made in numerous nebular environments while meteorite groups are dominated by regional materials whose properties give each group its distinctive isotopic, elemental and mineralogical compositions. Olivine is one of the most abundant minerals in primitive meteorites and in Wild 2. The Mn & Fe abundances in olivine show distinct trends in different meteorite groups. The dispersion of Mn and Fe in 200 comet olivine grains shows that the comet is not dominated by grains from any of the meteorite group reservoirs but requires broad contributions from many nebular environments. This is very strong evidence that the comet rocky materials came from multiple solar system environments and were broadly mixed during long distant transport from high temperature environments to cold comet-forming regions. Results from interplanetary dust of probably cometary origin matches the Wild 2 data. These findings suggest that outer solar system bodies may have received similar mixes of inner solar system rocky particles. The great diversity seen in asteroids is due to regional processes, while the rocky materials incorporated into comets were all transported and mixed over great distances. Mixing averages out bulk body-to-body diversity .

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308.02D – Aging comets and their meteor showers

Comets are thought to be responsible for the terrestrial accretion of water and organic materials. The aging of comets is one of the most critical yet poorly understood problems in planetary astronomy. Here we attack this problem by examining different parts of the cometary aging spectrum of Jupiter-family comets (JFCs), a group of

comets that dominates the cometary influx in the near-Earth space, using both telescopic and meteor observations.
We examine two representative JFCs and the population of dormant comets. At the younger end of the aging spectrum, we examine a moderately active JFC, 15P/Finlay, and review the puzzle of the non-detection of the associated Finlayid meteor shower. We find that, although having been behaved like a dying comet in the past several 10^2 years, 15P/Finlay does possess ability for energetic outbursts without a clear reason. Towards the more aged end of the spectrum, we examine a weakly active JFC, 209P/LINEAR. By bridging telescopic observations at visible and infrared wavelength, meteor observations and dynamical investigations, we find that 209P/LINEAR is indeed likely an aged yet long-lived comet. At the other end of the spectrum, we examine the population of dormant near-Earth comets, by conducting a comprehensive meteor-based survey looking for dormant comets that have recently been active. We find the lower limit of the dormant comet fraction in the near-Earth object (NEO) population to be 2.0 ± 1.7%. This number is at the lower end of the numbers found using dynamical and telescopic techniques, which may imply that a significant fraction of comets in the true JFC population are weakly active and are not yet detected. These results have revealed interesting diversities in dying or dead comets, both in their behaviors as well as their natures. An immediate quest in the understanding of cometary aging would be to examine a large number of dying or dead comets and understand their general characteristics.
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308.03 – A Cometary Update from the First Two Years of the NEOWISE Mission

The NEOWISE augmentation to the Wide-Field Infrared Survey Explorer (WISE) mission has provided the largest survey of comets in the infrared [1]. During the fully cryogenic prime mission, 163 comets were detected in four infrared wavelength bands (3.4, 4.6, 12, and 22 µm) [2], and over 100 comets have been detected (as of June 2016) in the two-band (3.4 and 4.6 µm) restarted mission. Twenty-two comets were discovered during the prime mission, and 8 have been discovered to date with the restarted mission.
The comets detected by NEOWISE represent a substantial fraction of the known population, allowing characterization to be done across a wide range of objects. The non-targeted nature of the survey allows for population-wide characterization to be done with fewer biases than with a targeted survey. The comets detected were split roughly evenly between short-period and long-period comets, and many displayed extended dust structures. Several of the comets have been detected multiple times over the course of the WISE prime and NEOWISE restarted mission, allowing for long-term analysis of cometary behavior.
We present here an update of the NEOWISE cometary database, including comets from the prime mission and first two years of the restarted mission, and a selection of particularly interesting comets from the third year of the restarted mission. This unique data set will be a valuable resource for the analysis of comets in the infrared for years to come.
References: [1] Mainzer, A. et al., 2014, ApJ, 792:1; [2] Bauer et al. 2015, ApJ, 814:2 **Acknowledgments:** This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA. EK and SS gratefully acknowledge support from the NASA Postdoctoral Program.
Author(s): Emily A. Kramer[2], James M. Bauer[2], Yanga R. Fernandez[4], Amy K. Mainzer[2], Tommy Grav[3], Joseph R. Masiero[2], Carolyn Nugent[1], Sarah M. Sonnett[2], Roc M. Cutri[1], Rachel Stevenson[2]
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Contributing team(s): The NEOWISE Team

308.04 – Chemical and Physical Properties of Comets in the Lowell Database: Results from Four Decades of Narrowband Photometry

As remnants from the epoch of early solar system formation, comet nuclei are less processed than any other class of objects currently available for detailed study. Compositional and physical studies can therefore be used to investigate primordial conditions across the region of comet formation and/or subsequent evolutionary effects. With these goals, a long duration program of comet narrowband photometry was begun in 1976 and results for 85 comets were published by A'Hearn et al. (1995; Icarus 118, 223). Observations continued and we performed a new set of analyses of data obtained through mid-2011. Following a hiatus due to lack of funding and other competing priorities, we have now resumed our efforts at completing this project while also incorporating the most recent five years of data. The database now includes 191 comets obtained over 848 nights. A restricted subset of 116 objects were observed multiple times and are considered well-determined; these form the basis of our compositional studies. Using a variety of taxonomic techniques, we identified seven compositional classes for the data up to 2011 and anticipate no changes with the newest additions. Several classes are simply sub-groups of the original carbon-chain depleted class found by A'Hearn et al.; all evidence continues to indicate that carbon-chain depletion reflects the primordial composition at the time and location of cometary accretion and is not associated with evolution. Another new class contains five comets depleted in ammonia but not depleted in carbon-chain molecules; it is unclear if this group is primordial or not. In comparison, clear evidence for evolutionary effects are seen in the active fractions for comet nuclei -- decreasing with age -- and with the dust-to-gas ratio -- decreasing with age and perihelion distance, implying an evolution of the surface of the nucleus associated with the peak temperature attained and how often such temperatures have been reached. Updates of these and other results including data from the last five years will be presented. Support was provided by NASA Planetary Atmospheres grant NNX08AG19G.
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308.05 – Far-ultraviolet Spectroscopy of Recent Comets with the Cosmic Origins Spectrograph on the Hubble Space Telescope

Since its launch in 1990, the Hubble Space Telescope (HST) has served as a platform with unique capabilities for remote observations of comets. Successive generations of imagers and spectrographs have seen large advances in sensitivity and spectral resolution enabling observations of the diverse properties of a representative number of comets during the past 25 years. To date, four comets have been observed in the far-ultraviolet by the Cosmic Origins Spectrograph (COS), the last spectrograph to be installed in HST, in 2009: 103P/Hartley 2, C/2009 P1 (Garradd), C/2012 S1 (ISON), and C/2014 Q2 (Lovejoy). COS has unprecedented sensitivity, albeit no spatial resolution, and the principal objective was to determine the relative CO abundance from measurements of the CO Fourth Positive system in the spectral range of 1400 to 1700 Å. In the two brightest comets, nineteen bands of this system were clearly identified. The water production rate was derived from nearly simultaneous observations of the OH (0,0) band at 3085 Å by the Space Telescope Imaging Spectrograph (STIS). The derived CO/H_2O production rate ratio ranged from ~0.3% for Hartley 2

(Weaver et al., ApJ 734:L5, 2011) to ~20% for Garradd. In addition, strong partially resolved emission features due to multiplets of S I, centered at 1429 Å and 1479 Å, and of C I at 1561 Å and 1657 Å, were observed in all four comets. Weak emission from several lines of the H_2 Lyman band system, excited by solar Lyman-α and Lyman-β pumped fluorescence, were detected in comet Lovejoy.
This work is based on observations made with the NASA/ESA Hubble Space Telescope, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. Support was provided by NASA through grants from the Space Telescope Science Institute.
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308.06 – Watching a Long Period Comet Turn On – C/2015 ER61 (PANSTARRS)

Comet C/2015 ER61 (PANSTARRS) was discovered on 2015 March 14 by the PS1 survey. The object is on a long period comet orbit but is not dynamically new (a = 3224.1 AU, e = 0.99967, I = 6.1882 degrees) and will come to perihelion at 1.042 AU on 2017 May 9. At the time of its discovery, at a heliocentric distance of r=8.44 AU, the object appeared inactive. We considered it as a Manx object candidate (an object on long-period comet orbits which exhibit minimal or no activity even near the Sun; Meech et al. 2016) for follow-up observations to obtain its surface spectral reflectivity. Data were obtained of the nucleus with the Gemini North 8-m telescope through griz filters on 2015 June 12.3 UT at r=7.74 AU. The composite images showed weak activity in the form of a slightly extended PSF (FWHM=1.0 arcsec compared with 0.8 arcsec seeing), and a weak tail-like extension, 2 arcsec long at PA~120 degrees. Additional grizY data from Gemini were obtained on 2016 Feb. 4 at r=5.70 AU when the comet was much more active, allowing for a comparison of the surface and coma spectral reflectivities. The WISE observatory also detected C/2015 ER61 on 2015 Dec. 23 and 2016 May 25 at r=6.09 and r=4.64 AU, respectively. We will report on the nucleus characteristics for C/2015 ER61 based on the NEOWISE and Gemini observations. The NEOWISE observations will also be used to place limits on the amount of CO_2 outgassing from the comet. Serendipitous observations were also collected with the VST on Paranal at 11 and 6.2 AU. We have used this data in addition to photometry obtained from the CFHT 3.6m and UH2.2m telescopes on Maunakea the HCT 2m telescope in India, and pre-discovery data from the PS1 survey to model the onset of activity. A strong indication for this activity to be driven by deeply-buried CO or CO_2 is shown by preliminary modeling. C/2015 ER61 is therefore a rare case of a long-period comet discovered and characterized before the activity started, and whose sublimation onset was observed.
References:
Meech, K. J. et al (2016), Science Advances 2, 4, id. E1600038.
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309 – Extrasolar Planets: Orbital Dynamics

309.01 – The Transient State of the HD 106906 Circumstellar Debris Disk

The HD 106906 system poses a challenge for dynamical modelers. The system harbors an extremely distant planetary-mass companion at a projected distance of ~650 au, and a nearly edge-on, asymmetric debris ring oriented ~20° in position angle from the external planet. We show that the gravitational perturbations from the planet excite a collisional cascade in the disk, and we suggest that the observed asymmetric morphology is a result of a transient phase in the disk's evolution. The observed geometry of the system and the morphology of the disk allow us to constrain the current orbital parameters of the system. We also generalize this work and discuss how our model of an external companion perturbing a debris disk could be used to understand disk morphologies in other systems.
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309.02 – Long-Term Stability of Planets in the Alpha Centauri System

The alpha Centauri star system contains the Solar Systems closest stellar neighbors. If an earthlike planet is present in the system, it could in principle be detected using a small space-based telescope (Belikov et al. 2105, Proc. SPIE 9605, 960518). The alpha Centauri system is billions of years old, so planets are only expected to be found in regions where their orbits are long-lived. We evaluate the extent of the regions within the alpha Centauri AB star system where small planets are able to orbit for billion-year timescales, and we map the positions in the sky plane where planets on stable orbits about either stellar component may appear. We confirm the qualitative results of Wiegert & Holman (Astron. J. 113, 1445, 1997) regarding the approximate size of the regions of stable orbits of a single planet, which are larger for retrograde orbits relative to the binary than for prograde orbits. Additionally, we find that mean motion resonances with the binary orbit leave an imprint on the limits of orbital stability, and the effects of the Lidov-Kozai mechanism are also readily apparent. Because the binary companion induces a forced eccentricity upon the orbits of planets in orbit around either star, appropriately-phased circumstellar orbits with small initial eccentricities are stable to somewhat larger initial semimajor axes than are initially circular orbits and the initial mean anomaly of planets is a factor in determining stability. Our results can guide observers designing instrumentation and search strategies to attempt to discover planets orbiting the nearest sunlike stars.
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309.03 – Investigating Normalized Architectures of Multi-Transiting Exoplanetary Systems

The Kepler mission was launched in 2009 to search for Earth-size planets in exoplanetary systems. Kepler has identified ~230 planetary systems with three or more transiting planets. The architectures of these multi-transiting systems provide clues to better understand the structures and dynamics of planetary systems. We investigate the correlation between planetary radii and orbital periods of the ~800 planets in systems with three or more transiting planets. We normalize the periods and radii of each system to get a better understanding of their ordering. All systems can then be plotted on a common normalized scale and we use these plots to identify key features of the population. Preliminary results show a weak but significant preference towards ordered systems (e.g., the smallest planet is in the smallest orbit, the next smallest planet is in the next smallest orbit, etc.). To check whether this is due to observational bias, we weight the detection probability of each multiplanet system considering both the geometric probability of multi-transiting system (from CORBITS, Brakensiek & Ragozzine 2016) and the detection probability of the planets in the system. We also look for trends with respect to other properties, including stellar properties, to assess recent hypotheses that suggest two distinct types of planetary systems.

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309.04 – Demographics of Resonances in Exoplanetary Systems

NASA's Kepler Space Telescope has identified ~700 systems of multiple transiting exoplanets containing ~1700 planets. Most of these multi-transiting systems have 3-5 planets small planets with periods of roughly 5-50 days and are known as Systems with Tightly-spaced Inner Planets (STIPs). These information-rich exoplanetary systems have precisely measured period ratios which allows for the identification and characterization of orbital mean motion resonances. Improved understanding of the resonant populations will reveal much about the formation and evolution of planetary systems. Lissauer, Ragozzine, et al. 2011 found that most Kepler systems were not in resonance, but that there was a small excess of planets wide of resonance. We present new analyses that rigorously identify the frequency of planets in multiple resonances (including three-body resonances) and thus identify many specific new results on the demographics of resonances. We also show that the apparent over-abundance of resonances can be attributed to a difference in inclinations (potentially from dissipation) with implications for the true underlying frequency of resonant systems. We compare the period ratio distribution of Kepler (corrected for inclination biases) to Radial Velocity (RV) surveys and conclude that RV systems are often missing small intermediate planets. This has serious implications for the completeness of RV identification of planets in STIPs.

Author(s): Darin Ragozzine[1], James L Conaway[1], Mariah G MacDonald[2], Victor Sallee[1]
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309.05D – Detection and Characterization of Extrasolar Planets through Mean-Motion Resonances

Exoplanets are often detected indirectly through their influence on the light arriving from their host stars. We propose another indirect method to detect and characterize planets via their resonant interaction with debris disks. Using simulations, we show that the properties of gaps produced by mean-motion resonances with a single planet orbiting interior or exterior to the disk can help constrain the planet's mass and semimajor axis even if the planet itself remains as-yet undetected. Results published in the *Astrophysical Journal*(ApJ, 818, 159) will be discussed as well as a follow-up study that attempts to constrain the perturbing planet's orbital eccentricity based on its effect on the disk. Expressions that allow observers to determine the planet's mass and orbital parameters from the width, shape and location of the gaps will be presented.

Author(s): Maryam Tabeshian[1], Paul Wiegert[1]
Institution(s): *1. University of Western Ontario*

309.06 – Stability of evenly spaced, tightly packed systems of Earth-massed planets around M-dwarfs

M-dwarf stars are prime targets in the search for habitable exoplanets because the stars are smaller and the habitable zone is quite close to the star. Surveys have revealed a considerable number of tightly packed planetary systems around small stars, and this raises the question of how closely planets can be packed together and stay stable for billions of years. Using numerical simulations, we have investigated the stability of hypothetical systems comprised of several Earth-mass planets around an M-dwarf star, where the planets' orbits are all evenly spaced in mutual Hill Radii. We reproduce the obvious: that, in general, the more tightly packed a system is the faster it will go unstable. However, we see structure superimposed on this general trend that can cause a system's lifetime to differ by several orders of magnitude over a small difference in planet spacing. We will discuss implications for the maximum number Earth-mass planets that can fit in an M-dwarfs' habitable zone.

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309.07 – Machine Learning Algorithms For Predicting the Instability Timescales of Compact Planetary Systems

The Kepler mission has uncovered hundreds of compact multi-planet systems. The dynamical pathways to instability in these compact systems and their associated timescales are not well understood theoretically. However, long-term stability is often used as a constraint to narrow down the space of orbital solutions from the transit data. This requires a large suite of N-body integrations that can each take several weeks to complete. This computational bottleneck is therefore an important limitation in our ability to characterize compact multi-planet systems.

From suites of numerical simulations, previous studies have fit simple scaling relations between the instability timescale and various system parameters. However, the numerically simulated systems can deviate strongly from these empirical fits.

We present a new approach to the problem using machine learning algorithms that have enjoyed success across a broad range of high-dimensional industry applications. In particular, we have generated large training sets of direct N-body integrations of synthetic compact planetary systems to train several regression models (support vector machine, gradient boost) that predict the instability timescale. We find that ensembling these models predicts the instability timescale of planetary systems better than previous approaches using the simple scaling relations mentioned above.

Finally, we will discuss how these models provide a powerful tool for not only understanding the current Kepler multi-planet sample, but also for characterizing and shaping the radial-velocity follow-up strategies of multi-planet systems from the upcoming Transiting Exoplanet Survey Satellite (TESS) mission, given its shorter observation baselines.

Author(s): Daniel Tamayo[2], Mohamad Ali-Dib[2], Ryan Cloutier[3], Chelsea Huang[2], Christa L. Van Laerhoven[1], Rejean Leblanc[3], Kristen Menou[2], Norman Murray[1], Alysa Obertas[3], Adiv Paradise[3], Cristobal Petrovich[1], Aleksandar Rachkov[3], Hanno Rein[4], Ari Silburt[3], Nick Tacik[1], Diana Valencia[2]
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309.08 – Probing Spin-Orbit Misalignment Processes Around Early-Type Stars

Planets in early-type systems seem to frequently misalign from their host star's spin axis. These spin-orbit misaligned systems challenge conventional planet-formation theories because planets probably do not form with initially misaligned orbits -- their angular momenta must be conserved with the stellar nursery in which they formed. In such a case, planets must migrate to their misaligned positions. However, very few transiting exoplanets have had their spin-orbit alignment angles measured. Our model constrains spin-orbit alignment angles via photometry and asteroseismology while accounting for the brightness effects of stellar variability and rapid rotation that commonly occur in early-type stars, making the analysis of hundreds of *Kepler* transit light curves possible for the first time. We will employ these techniques to probe spin-orbit misalignment theories by empirically testing the spin-orbit state of exoplanets orbiting early-type stars.

Author(s): Johnathon Ahlers[1], Jason W. Barnes[1]
Institution(s): *1. University of Idaho*

309.09 – Using Dynamical Models to Predict the Terrestrial-Mass Free-Floating Planet Population

In the classical picture of planet formation, planets form within circumstellar disks as a product of star formation. The material in the disk either forms into a planet, remains bound to the star, falls into the star, or is ejected from the system. We explore the properties of this ejected material using N-body simulations of the late stages of terrestrial planet formation. We find that in planetary systems like ours (with Jupiter and Saturn) about half the ejected material is in bodies less massive than the Moon and half is in bodies more massive than Mars. No planets more massive than half an Earth-mass, however, were ejected, primarily because most of the ejections occur before the timescales needed to grow an Earth-mass body. Without giant planets present in the system, very little material is ever ejected. We predict that future space-borne microlensing searches for free-floating terrestrial-mass planets, such as WFIRST, will discover large numbers of Mars-mass planets but will not make significant detections of Earth-mass planets.

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310 – MAVEN Results and the Martian Ionosphere II

310.01 – A Persistent Meteoric Ion Layer in the Martian Atmosphere

We report on a persistent metal ion layer at Mars produced by meteoric ablation in the upper atmosphere, observed by the Imaging Ultraviolet Spectrograph (IUVS) on MAVEN. The response of the Martian atmosphere to meteoroid influx constrains cometary activity, dust dynamics, ionospheric production at Mars and meteoric smoke may represent a site of nucleation for high altitude clouds. Using observations that span more than an Earth year, we find this layer is global and steady state, contrary to previous observations, but in accordance with predictions. IUVS observations cover a range of observation conditions, which allows us to determine the variability of the Mg^+ layer seasonally and geographically. Mars has passed through several predicted meteor showers, though the fluences of these events have hitherto been unconstrained. Analysis of these events will determine whether Mars' atmosphere responds to such events dramatically, as was the case with comet Siding Spring, or more similarly to Earth. Mg is also detected, but the ratio of Mg to Mg^+ is less than predicted, indicative of undetermined chemical processes in the Martian atmosphere.

Author(s): Matteo Crismani[2], Nicholas M. Schneider[2], Sonal Kumar Jain[3], John Plane[5], Juan Deigo Carrillo Sanchez[5], Justin Deighan[3], Michael H. Stevens[4], Scott Evans[1],Michael S. Chaffin[3], Bruce Jacosky[2]
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Contributing team(s): IUVS Team

310.02 – Observations of Metal Ions in the Meteoroid Layer of the Ionosphere of Mars

We report the results of the observations of metal ions in the ionosphere of Mars by the Neutral Gas and Ion Mass Spectrometer (NGIMS). These observations were conducted during the five "deep dip" campaigns of the Mars Atmosphere and Volatile Evolution mission (MAVEN), during which the periapsis altitude of the spacecraft altitude is lowered from its nominal 150 km to ~125 km. The observations revealed the presence of Na^+, Mg^+, and Fe^+ in the ionosphere with peak abundance ranging from 1 to 10 ions/cm^3 at the periapsis altitude. While, the relative abundance of these metals ions varies from a deep dip campaigns to another, their altitude profile exhibit correlated structures with the neutral atmosphere. These structure may be indicative of the transport processes that carry the metals upward from the main ablation layer to the spacecraft's altitude.

Author(s): Mehdi Benna[1], Joseph M Grebowsky[1], Paul Mahaffy[1]
Institution(s): *1. NASA Goddard Space Flight Center*

310.03 – Atomic Oxygen Density Retrievals using FUV Observations by the Imaging Ultraviolet Spectrograph on MAVEN

We present the first direct retrievals of neutral atomic oxygen in Mars's upper atmosphere using daytime FUV periapse limb scan observations from 130 – 200 km tangent altitude. Atmospheric composition is inferred using the Atmospheric Ultraviolet Radiance Integrated Code [Strickland et al., 1999] adapted to the Martian atmosphere [Evans et al., 2015]. For our retrievals we use O I 135.6 nm emission observed by IUVS on MAVEN under daytime conditions (solar zenith angle < 60 degrees) over both northern and southern hemispheres (latitudes between -65 and +35 degrees) from October 2014 to August 2016. We investigate the sensitivity of atomic oxygen density retrievals to variability in solar irradiance, solar longitude, and local time. We compare our retrievals to predictions from the Mars Global Ionosphere-Thermosphere Model [MGITM, Bougher *et al.*, 2015] and the Mars Climate Database [MCD, Forget *et al.*, 1999] and quantify the differences throughout the altitude region of interest. The retrieved densities are used to characterize global transport of atomic oxygen in the Martian thermosphere.

Author(s): J. Scott Evans[1], Michael H. Stevens[3], Nicholas M. Schneider[2], Ian Stewart[2], Justin Deighan[2], Sonal Kumar Jain[2], Francis Eparvier[2], E M Thiemann[2], Stephen W. Bougher[4], Bruce Jakosky[2]
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310.04 – The cause of small scale disturbances in the lower ionosphere of Mars

The radio-science experiment MaRS (Mars Express Radio Science) on the Mars Express spacecraft sounds the neutral atmosphere and ionosphere of Mars since 2004. Approximately 800 vertical profiles of the ionospheric electron density have been acquired until today. A subset of these MaRS dayside observations contains small scale disturbances in the lower part of the ionosphere. Those electron density profiles show unusual small scale features in the M1 altitude range which appear either merged with or completely detached from the M1 layer. Possible explanations for this additional ionospheric electron density may be ionospheric NO^+, enhanced solar X-ray fluxes, solar energetic particle events (SEPs) or meteoroid influx. A 1D photo-chemical model of the Mars dayside ionosphere (IonA-2) is used to investigate the behavior of planetary NO^+ in the lower dayside ionosphere. The influence of variable solar X-ray on the ionospheric electron density is estimated with IonA-2 and the influence of SEPs is discussed. A possible correlation between the meteoroid influx in the Mars atmosphere and the small scale disturbances is investigated based on a model of the ablation/chemical reactions of meteoroids with the atmosphere/ionosphere (MSDM) and on MAVEN IUVS magnesium ion observations.

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310.05 – Ionospheric Currents and Thermospheric Winds at Mars Inferred from MAVEN Observations

MAVEN provides in-situ measurements of the magnetic field throughout the ionosphere of Mars. From these local measurements, we calculate ionospheric currents from the curl of the magnetic field. Since we only have one spacecraft, we have to make assumptions about the uniformity of the magnetic field and the direction of magnetic field gradients. We restrict our analysis to a subset of the data where the ionospheric magnetic fields are horizontal (as determined by the magnetic dip angle) such that the calculated ionospheric currents are likewise horizontal. By considering neutral thermospheric winds as the driving force for these currents, we estimate the thermospheric wind profile necessary to generate the ionospheric currents. This is the first estimate of thermospheric winds from magnetic field data at Mars. We then compare these estimates to measurements of neutral and ion winds from MAVEN as well as to winds given by global thermospheric models.

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Institution(s): *1. NASA Goddard Space Flight Center, 2. University of California, Berkeley, 3. University of Michigan*

310.06 – Solar wind dependent models for the shapes of the Martian plasma boundaries based on Mars Express measurements

The long operational life (2003-) of Mars Express (MEX) has allowed the spacecraft to make plasma measurements in the Martian environment over a wide range of upstream conditions. We have analyzed ~5000 MEX orbits, covering three orders of magnitude in solar wind dynamic pressure, with data from the on-board Analyzer of Space Plasmas and Energetic Particles (ASPERA-3) package, mapping the locations where MEX crosses the main plasma boundaries; induced magnetosphere boundary (IMB), ionosphere boundary (IB) and bow shock (BS). A coincidence scheme was employed, where data from the Ion Mass Analyzer (IMA) and the Electron Spectrometer (ELS) had to agree for a positive boundary identification, which resulted in crossings from 882 orbit segments that were used to create dynamic 2-parameter (solar wind density, n_{sw}, and velocity v_{sw} dependent global dynamic models for the IMB, IB and BS. The modeled response is found to be individual to each boundary; the BS is stationary for all but extremely thin and slow solar wind, the IMB scales solely dependent on dynamic pressure and the IB changes morphology with different trends for n_{sw} and v_{sw}. We find no significant trend in IMB location with changing EUV intensities when the upstream solar wind is constrained to nominal conditions. Finally, the IMB model is used to extrapolate the solar wind stand-off distance in the ancient (0.7 Ga old) solar wind.

Author(s): Robin Ramstad[1], Stas Barabash[1], Yoshifumi Futaana[1], Mats Holmstrom[1]

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310.07 – The composition of the nightside ionosphere of Mars: Comparisons with the dayside and implications for day-to-night ion transport

We present observations of the ionosphere of Mars obtained by the Neutral Gas and Ion Mass Spectrometer (NGIMS) on the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft. We show how the ion composition changes as the ionosphere decays across the day-night terminator and find that, between 150-200 km, O^+ and CO_2^+ densities decay rapidly across the terminator while densities of O_2^+, NO^+, and HCO^+ are long lived. We compare these results to predictions from a photochemical model of the ionosphere of Mars and discuss their implications for the efficiency of day-to-night transport as a source of the nightside ionosphere.

Author(s): Zachary Girazian[2], Paul Mahaffy[2], Mehdi Benna[2], Meredith K Elrod[2], Majd A Mayyasi[1]

Institution(s): *1. Boston University, 2. NASA Goddard Space Flight Center*

310.08 – Mars plasma system response to ICME transients at different phases of the solar cycle

We assess the reaction of the full Martian plasma system after the impact of different Interplanetary Coronal Mass Ejections (ICME) at Mars at different levels of solar activity and phases of the solar cycle 23/24. The Mars' plasma system behaviour is characterised from the surface of the planet to the bow shock position, which is the most external boundary where the solar wind directly interacts with the Martian system. Events at the extreme phases of the solar cycle will be given special attention, i.e. low and high solar activity periods, since variations in the maximum of the thermal pressure of the ionosphere are a key factor in order to create a significant/weak plasma obstacle to compete with the solar wind. The strength of this obstacle is ultimately controlled by the long-term EUV flux modulations. Likewise, the effect of such ICMEs on the plasma boundaries and induced magnetic fields within the ionosphere will be analysed in detail. The study uses data from TIMED, GOES and STEREOs observatories at 1 AU to monitor the solar irradiance and the propagation of such space weather transits. At Mars, long-term data come from Mars Express and Mars Odyssey missions since both spacecraft have been working from more than 12 years. The MAVEN and MSL missions provide supplementary data. Solar wind propagation modelling is used through the WSA-ENLIL+Cone model, as well as several numerical simulations of the ionosphere of Mars for such scenarios are made through the numerical/fluid TRANSMARS model.

Author(s): Beatriz Sanchez-Cano[8], Mark Lester[8], Benjamin E.S. Hall[8], Olivier Witasse[3], M. Leila Mays[2], Pierre-Louis Blelly[4], David G Andrews[7], Marco Cartacci[1], Hermann Opgenoorth[7], Stephen E Milan[8], Richard M Ambrosi[8], Dusan Odstrcil[6], Jeffrey J Plaut[5], Suzanne Imber[8]

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Research Institute, 7. Swedish Institute of Space Physics, IRF, 8. University of Leicester

310.09 – IUVS/MAVEN Stellar Occultations

We present the latest results from stellar occultations observed with the Imaging Ultraviolet Spectrograph (IUVS) instrument on board of Mars Atmosphere and Volatile EvolutioN (MAVEN) mission. So far 9 campaigns have been executed on average every two months since MAVEN began orbiting Mars. Approximately 50 occultations are recorded in each campaign. The IUVS instrument observes in two spectral regions, the far- and mid-UV. The FUV channel covers wavelengths from 110 to 190 nm and the MUV channel from 170 to 350 nm. By combining those two channels we cover the whole altitude range starting from around 30 km to 150 km. We present the geometric dependent CO_2, O_2, and O_3 number densities from these occultations. The derived O_2 mixing ratio varies between 1.5×10^{-3} and 5×10^{-3}. In some of the MUV occultations we also can see aerosol extinction. In addition we present temperatures derived from the CO_2 densities assuming hydrostatic equilibrium. We retrieved mean temperatures of around 180 K at lower altitudes, which decreasing with altitudes down to a mean of around 130 K at higher altitudes. We see a constantly cold layer with temperatures of 105 – 120 K at a pressure level at roughly 7×10^{-6} Pa, equivalent to an altitude of around 140 km. We also discuss possible wave structures with amplitudes between 5 and 15 K and wavelengths between 10 and 15 km in the obtained temperature profiles. The temperature profiles, retrieved with the IUVS instrument, are mostly in agreement with predicted values from the Mars Climate Database model, except where we see the cold layer around 140 km.

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311 – Asteroid Dynamics NEO II: Weird and Wonderful

311.01 – Further evidence for the super-catastrophic destruction of asteroids at small yet nontrivial perihelion distances

For the past two decades or so the consensus in the near-Earth-object (NEO) community was that the majority of the NEOs are destroyed when they plunge into the Sun (Farinella et al. 1994, Nature 371, 314). There is now growing evidence suggesting that NEOs are completely destroyed at nontrivial distances from the Sun as proposed by Granvik et al. (2016, Nature 530, 303). The majority of meteor streams at small perihelion distances lack obvious parent bodies (Brown et al. 2010, Icarus 207, 66), potentially suggesting that the remaining fragments are too small to be telescopically detected from the Earth. Furthermore, orbital estimates for meter-scale Earth-impactors based on airburst observations show that the space interior to the orbit of Mercury is essentially void of objects in that size range and this cannot be explained by observational selection effects (Brown et al. 2016, Icarus 266, 96). This suggest that the remaining fragments must be substantially less than one meter in diameter. The mechanism(s) that could cause such a complete destruction of the parent asteroid is currently not well understood. The analysis by Granvik et al. (2016) found that smaller NEOs are destroyed at larger distances and that the albedo estimates by NEOWISE imply that NEOs with low albedos are destroyed at larger distances compared to their high-albedo counterparts. The discovery of the first asteroid in the process of being destroyed (Knight et al. 2016, ApJL 823(1), L6) and an ongoing observation campaign targeting NEOs at small perihelion distances will hopefully lead to further insight regarding the destruction mechanism. I will synthesize what is currently known about the destruction of asteroids at small perihelion distances, and explain how these super-catastrophic disruptions may be used to statistically constrain the interior structure of asteroids.

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Institution(s): *1. University of Helsinki*

311.02 – Is there a signature of super-catastrophic asteroid disruption in the near-Sun meteoroid environment?

The super-catastrophic disruption of asteroids that pass near the Sun (Granvik et al 2016 Nature 530 303) has been proposed to explain the observed deficit of asteroids with perihelia very near our star. However, the mechanism of their disruption remains an open question. Here we use meteor observations from the Canadian Meteor Orbit Radar (CMOR) collected over the last several years to examine whether or not the population of meteoroids (that is, particles with sizes between a few hundred microns and a few millimeters in radius) with their perihelia near the Sun shows evidence for the asteroid disruption process. An excess of material might support the conjecture that these bodies break up into small particles, while an absence could indicate that the meteoroids themselves are unable to survive near the Sun. The ability of the meteor radar to observe during the day allows particles coming from near the Sun to be easily observed, though admittedly only if their aphelia reach Earth: this restricts the observed sample at low perihelia to those whose orbits have $a > 0.5$ AU. Preliminary results show that there is a deficit rather than an excess of meteoroids with perihelia near the Sun, but the picture is complicated by the effect of Poynting-Robertson drag (which causes particles at these sizes to spiral inwards), the presence of cometary meteoroid streams (which contaminate the sample), and the geometrical requirements that the meteoroids reach the Earth (which create complicated observational biases).

Author(s): Paul Wiegert[1], Peter G. Brown[1], Petr Pokorny[1], Quan-Zhi Ye[1], Karina Lenartowicz[1], Zbyszek Krzeminski[1]
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311.03 – Constraining the Interior Earth Objects population

Interior Earth Objects (IEOs) are among the least known populations in the Solar Sytem. Ground-based surveys are extremely inefficient in surveying them as most of the time IEOs are located inside the orbit of the Earth. We present observational constraints to the IEO population from STEREO (Solar TErrestrial RElations Observatory). This is the first result of searching through the archival STEREO data. Although after analyzing a year's worth of data we found no new IEOs, we observed hundreds of known asteroids. Our survey efficiency is computed with known and implanted synthetic objects, yielding a limiting magnitude of V~14.5. We constrain different IEO population models, yielding an upper limit for the total number of IEOs in line with previous estimates.

Author(s): Cesar Fuentes[3], David E. Trilling[2], Matthew M. Knight[1], Michael Mommert[2], Federico Hechenleitner[3]
Institution(s): *1. Lowell, 2. NAU, 3. Universidad de Chile*

311.04 – The Orbit and Future Motion of Earth Quasi-Satellite 2016 HO3

The newly discovered small asteroid 2016 HO3 is not only co-orbital with the Earth, it is currently trapped as a quasi-satellite, and it will remain a constant companion of our planet for centuries to come. Although it orbits the Sun, not the Earth, in a frame rotating with the Earth the asteroid appears to make yearly loops around our planet, and also bobs up and down through the ecliptic due to its 8-degree orbital inclination. What makes this asteroid a quasi-satellite is the fact that the Earth's gravity influences its motion so that it never wanders farther away than about 100 lunar distances. In the rotating frame, the asteroid's yearly cycles librate back and forth along the Earth's orbit, with a period of about 45 years. One other asteroid, 2003 YN107, followed a similar librational pattern from 1997 to 2006, but has since departed our vicinity. 2016 HO3, on the other hand, will continue to librate about our planet for centuries to come, making it the best and most stable example of a quasi-satellite to date.

Author(s): Paul Chodas[1]
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311.05 – A Potpourri of Near-Earth Asteroid Observations

Ongoing astrometric follow-up of near-Earth asteroids has yielded a variety of interesting results. In the limited space of a DPS abstract, three recently observed objects are worth mentioning.

2008 HU4 is among the most accessible asteroids for a human space flight mission. We successfully recovered this object at a second opposition on 2016 April 26 despite the large ephemeris uncertainty. The small size of this asteroid makes it relatively easy to detect the departure from purely gravitational motion caused by solar radiation pressure, which can be used to estimate the density of the object. At the time of this writing, the object remains bright enough for additional observations, so we expect to improve on our five-sigma detection of a relatively low density (roughly similar to water, indicating a high porosity) between now and the DPS meeting.

2016 HO3 is a newly-discovered co-orbital with the Earth. Our 2016 May 10-11 observations extended the observational arc by enough to permit backward extrapolation that led to prediscovery observations by Pan-STARRS in 2015, and then annually back to 2011, and ultimately to Sloan DSS observations in 2004. The 12-year arc is sufficient to examine the dynamical behavior of the object, which shows how it will remain in the vicinity of the Earth for decades, if not centuries. Our observations also revealed a rapid rotation (less than a half hour) with large brightness variation (in excess of 1 magnitude), which helps to explain why this object eluded discovery until this year.

2011 YV62 is among the top 20 largest near-Earth asteroids with Earth impact solutions (in 2078 and 2080). At the time of this writing, the object is flagged as being "lost", but a re-examination of observations made in 2013 and 2015 finally yielded a successful recovery at a magnitude fainter than 24. We expect the new observations to eliminate the impact possibilities. The story behind this difficult recovery is fascinating.

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311.06 – Impact detections of temporarily captured natural satellites

Temporarily Captured Orbiters (TCOs) are Near-Earth Objects (NEOs) which make a few orbits of Earth before returning to heliocentric orbits. Only one TCO has been observed to date, 2006 RH120, captured by Earth for one year before escaping. Detailed modeling predicts capture should occur from the NEO population predominantly through the Sun-Earth L1 and L2 points, with 1% of TCOs impacting Earth and approximately 0.1% of meteoroids being TCOs. Although thousands of meteoroid orbits have been measured, none until now have conclusively exhibited TCO behaviour, largely due to difficulties in measuring initial meteoroid speed with sufficient precision. We report on a precise meteor observation of January 13, 2014 by a new generation of all-sky fireball digital camera systems operated in the Czech Republic as part of the European Fireball Network, providing the lowest natural object entry speed observed in decades long monitoring by networks world-wide. Modeling atmospheric deceleration and fragmentation yields an initial mass of ~5 kg and diameter of 15 cm, with a maximum Earth-relative velocity just over 11.0 km/s. Spectral observations prove its natural origin. Back-integration across observational uncertainties yields a 92 - 98% probability of TCO behaviour, with close lunar dynamical interaction. The capture duration varies across observational uncertainties from 48 days to 5+ years. We also report on two low-speed impacts recorded by US Government sensors, and we examine Prairie Network event PN39078 from 1965 having an extremely low entry speed of 10.9 km/s. In these cases uncertainties in measurement and origin make TCO designation uncertain.

Author(s): David Clark[3], Pavel Spurný[1], Paul Wiegert[3], Peter G. Brown[3], Jiri Borovicha[1], Ed Tagliaferri[2], Lukas Shrbeny[1]
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311.07 – Detection of Yarkovsky effect and solar radiation pressure on Near-Earth Asteroids

The orbit of small-sized asteroids can be affected by non-gravitational perturbations. When this happens, non-gravitational forces need to be taken into account since they are as important as collisions and gravitational perturbations for the overall understanding of the asteroid orbital evolution.

The Yarkovsky effect and the Solar Radiation Pressure (SRP) are non-gravitational perturbations that can be modelled knowing the physical properties of asteroids, and whose consequences of the motions can be measured from accurate astrometry.

The knowledge of the physical properties of asteroids is usually not sufficient to produce the thermophysical models needed for the computation of the Yarkovsky acceleration. Nevertheless, it can often be measured as a semimajor axis drift if the astrometric dataset contains extremely accurate observations (e.g. radar data), or if the observations span a sufficiently long time interval. Farnocchia et al. 2013 list 21 NEAs with a measurable semimajor-axis drift. Since 2013, the number of asteroids for which it is possible to detect the Yarkovsky effect has grown. This is due to the increased quality and time span of the observations, and to new radar measurements that have since become available. We are able to detect the Yarkovsky effect for more than 40 NEAs, employing a high precision dynamical model, including the Newtonian attraction of 16 massive asteroids and the planetary relativistic terms, and a suitable astrometric data treatment. We present a list of objects with a significant detection of Yarkovksy effect and a value compatible with the Yarkovsky mechanism.

The computed non-gravitational perturbations will be added to the web portal of the ESA SSA-NEO Coordination Centre, highlighting the fact that the orbit has been computed taking the Yarkovsky effect or the SRP into account. The inclusion of non-gravitational perturbations can also affect the results of the impact monitoring, as in the case of (410777) 2009 FD, (29075) 1950 DA, (99942) Apophis and (101555) Bennu.

Author(s): Laura Faggioli[4], Alessio Del Vigna[1], Andrea Milani[1], Federica Spoto[3], Giovanni B. Valsecchi[2]
Institution(s): *1. Department of Mathematics, University of Pisa , 2. IAPS-INAF, 3. Laboratoire Lagrange, Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, 4. SpaceDyS s.r.l.*

311.08 – The Evolutionary Outcomes of Expansive Binary Asteroid Systems

Singly synchronous binary asteroid systems have several evolutionary end-states, which depend heavily on the BYORP effect. In the case of expansive BYORP, the binary system could evolve to become a wide asynchronous binary system (Jacobson, et al 2014), or the system could expand far enough to become disrupted to form a heliocentric pair (Vokrouhlicky et al 2008). Cuk et al (2011) found that upon expanding the secondary will quickly become asynchronous, and will end up re-establishing synchronous rotation with the opposite attitude, causing the binary orbit to subsequently contract. The distinction between these outcomes depends on whether the secondary asteroid stays synchronized, which keeps the BYORP effect active and the orbit expanding. As the orbit expands, the secondary libratation will expand, and the libration will also causes large variations in the binary orbit due to the elongation of the secondary. If the eccentricity and libration are bound to small enough values the system can expand significantly.
This work discusses the stability of the libration and orbital motion as a binary expands from a wide variety of simulation runs with various parameters. We investigate how the strength of tides and BYORP change the stability of the librational motion; an important factor is the speed of BYORP expansion as slower expansion allows tides to have a more stabilizing effect. We also investigate the effect of heliocentric orbit semimajor axis and eccentricity. We find that resonances between the coupled orbit-libration frequencies and the heliocentric orbit cause instability in the binary orbit eccentricity which produces a strong preference for wide binary production, especially amongst retrograde binary systems. This instability also becomes stronger with large heliocentric eccentricities. Prograde binaries are more stable and can possible grow to become asteroid pairs. We find that even in the presence of tides, reestablishment of synchronous spin into a contractive state as was found by Cuk is a less likely outcome that the production of wide binaries or asteroid pairs due to the fact that when a contractive synchronous state is established, these unstable resonances don't allow it to exist for long.

Author(s): Jay W. McMahon[1]
Institution(s): *1. University of Colorado - Boulder*

311.09 – The size distribution of Near-Earth Asteroids from the DECam NEO Survey

We analyzed data from the first year of a survey for Near Earth Objects (NEOs) that we are carrying out with the Dark Energy Camera (DECam) on the 4 meter Blanco telescope at the Cerro Tololo Inter-American Observatory. We implanted synthetic NEOs into the data stream to derive our nightly detection efficiency as a function of magnitude and rate of motion. Using these measured efficiencies and the Solar System absolute magnitudes derived by the Minor Planet Center for the 1377 measurements of 235 unique NEOs detected, we directly derive, for the first time from a single observational data set, the NEO size distribution from 1 km down to 10 meters. We find that there are $10^{6.6}$ NEOs larger than 10 meters. This result implies a factor of ten fewer small NEOs than some previous results (e.g., Harris & D'Abramo 2015, Boslough et al. 2015) but a factor of ten more than Tricarico (2016). This result also implies that the impact risk for small- and medium-sized NEOs is less than previously thought.

Author(s): Lori Allen[2], Francisco Valdes[2], David Trilling[1], David James[2], David Herrera[2], Cesar Fuentes[4], Tim Axelrod[3], Jayadev Rajagopal[2]
Institution(s): *1. NAU, 2. NOAO, 3. University of Arizona, 4. University of Chile*
Contributing team(s): IAU Minor Planet Center, Cerro Tololo Inter-American Observatory

312 – History: Pluto Mission and Atmospheric Studies; Jupiter's Moons; Planetary Atmospheres

312.01 – The Difficult Birth of NASA's Pluto Mission

The complex and contested origins of the New Horizons mission to Pluto, launched by NASA in 2006, provides a window on how space science policy has been formulated in the United States before and after the turn of the twenty-first century, and how the shifting network of institutions that support and shape space science have changed since 1989. Those decades that have so far been little studied except by policy scholars seeking lessons from the NASA Administrator Daniel Goldin's attempt to force a small-spacecraft technological revolution on space science in the 1990s. The New Horizons case study reveals a shift in the balance of power around 2000 among the important players in the field, increasing the influence of non-NASA actors—notably Congress, science groups and planetary-exploration lobbies. In addition, the origins of New Horizons reveals how contingent the emergence of a particular space science mission can be.

Author(s): Michael J Neufeld[1]
Institution(s): *1. Smithsonian Institution*

312.02 – New Horizons at Pluto: Asking the right questions

In the 1980's and 1990's, breakthroughs about Pluto and the outer solar system laid the groundwork for the Outer Planets Science Working Group (1992), the Pluto Kuiper Express mission Science Definition Team (1996), and the Announcement of Opportunity for the Pluto Kuiper-Belt mission in 2001. These included specific science goals that molded the mission design, instrument selection, and observing sequence. These goals held up amazingly well over the decades. This historical review of New Horizons will explain how ground-based and theoretical work prepared us for a successful investigation of Pluto, and speculate on some of the new questions raised by the New Horizons flyby of the Pluto system.
This work was supported by NASA's New Horizons project.

Author(s): Leslie Young[5], S. Alan Stern[5], Catherine B. Olkin[5], John R. Spencer[5], Andrew F. Cheng[2], Harold A. Weaver[2], Kimberly Ennico[4], Jeffrey M. Moore[4], William M. Grundy[3], Fran Bagenal[6], Randy Gladstone[5], Jonathan I. Lunine[1]
Institution(s): *1. Cornell University, 2. Johns Hopkins, APL, 3. Lowell Observatory, 4. NASA Ames Research Center, 5. Southwest Research Inst., 6. University of Colorado*
Contributing team(s): New Horizons Science Team

312.03 – Stellar Occultations from Airborne Platforms: 1988 to 2016

Observing a stellar occultation by a solar system body with an airborne telescope requires precise positioning of the observer within the shadow cast onto the Earth. For small bodies like Pluto and Kuiper Belt objects, smaller than the Earth, the challenge is particularly intense, with the accuracy of the astrometric and flight planning determining whether the observation succeeds or fails. From our first airborne occultation by Pluto in 1988 aboard the Kuiper Airborne Observatory (KAO), to our most recent event by Pluto in 2015 aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA), we have refined our astrometric and flight planning systems to the point where we can now place an airborne observer into the small central flash zone. We will discuss the history of airborne observation of occultations while detailing the improvements in the astrometric processes. Support for this work was provided by NASA SSO grant NNX15AJ82G to Lowell Observatory.

Author(s): Amanda S. Bosh[2], Edward W. Dunham[1], Carlos Zuluaga[2], Stephen Levine[1], Michael J. Person[2], Jeffrey E. Van Cleve[3]
Institution(s): *1. Lowell Observatory, 2. MIT, 3. SETI Institute*

312.04 – Probing Pluto's Atmosphere Using Ground-Based Stellar Occultations

Over the last three decades, some twenty stellar occultations by Pluto have been monitored from Earth. They occur when the dwarf planet blocks the light from a star for a few minutes as it moves on the sky. Such events led to the hint of a Pluto's atmosphere in 1985, that was fully confirmed during another occultation in 1988, but it was only in 2002 that a new occultation could be recorded. From then on, the dwarf planet started to move in front of the galactic center, which amplified by a large factor the number of events observable per year.
Pluto occultations are essentially refractive events during which the stellar rays are bent by the tenuous atmosphere, causing a gradual dimming of the star. This provides the density, pressure and temperature profiles of the atmosphere from a few kilometers above the surface up to about 250 km altitude, corresponding respectively to pressure levels of about 10 and 0.1 µbar. Moreover, the extremely fine spatial resolution (a few km) obtained through this technique allows the detection of atmospheric gravity waves, and permits in principle the detection of hazes, if present.
Several aspects make Pluto stellar occultations quite special: first, they are the only way to probe Pluto's atmosphere in detail, as the dwarf planet is far too small on the sky and the atmosphere is far too tenuous to be directly imaged from Earth. Second, they are an excellent example of participative science, as many amateurs have been able to record those events worldwide with valuable scientific returns, in collaboration with professional astronomers. Third, they reveal Pluto's climatic changes on decade-scales and constrain the various seasonal models currently explored.
Finally, those observations are fully complementary to space exploration, in particular with the *New Horizons* (NH) mission. I will show how ground-based occultations helped to better calibrate some NH profiles, and conversely, how NH results provide some key boundary conditions necessary to analyze ground-based data.
Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR").

Author(s): Bruno Sicardy[1]
Institution(s): *1. Observatoire de Paris/Univ. Pierre et Marie Curie*
Contributing team(s): Rio de Janeiro Occultation Team, Granada Team, International Occultation and Timing Association, Royal Astronomical Society New Zealand Occultation Section, Lucky Star associated teams

312.05 – Planetary Temperatures : Early Estimates, Lowell, and the Albedo of the Earth

While it was recognized by Huygens, as soon as the architecture of the solar system was understood, that outer planets would be much cooler than Earth, quantitative estimation of planetary temperatures only became possible with understanding of radiant heat, and specifically the Stefan law relating heat flux to the fourth power of absolute temperature. This relation appears to have been first applied to planetary temperatures by the Danish physicist Christiansen in 1885, and he derived results for Mars and Saturn of -40 and -180C, rather reasonable values. However, the separate values of the solar constant, absolute planetary albedos (including that of the Earth) and the short- and long-wave transparency of planetary atmospheres were not known, although mountaintop measurements by Langley made some first steps to quantifying these effects. Lowell recognized that the Martian atmosphere was thinner than ours, but had more carbon dioxide, and so considered these factors to cancel out. However, he suggested that the Earth had a reflectivity of some 75%, such that darker Mars would absorb a larger fraction of incident sunlight than the Earth, compensating for Mars' greater distance from the sun and thus allowing clement temperatures. It is difficult not to see this as pushing the numbers to obtain a desired result, and indeed a robust refutation of his calculations swiftly followed by Poynting and Alfred Russel Wallace. I present a brief review of these early days of planetary climate modeling.

Author(s): Ralph Lorenz[1]
Institution(s): *1. JHU/APL*

312.06 – Simon Marius vs. Galileo: Who First Saw Moons of Jupiter?

In his almanac for 1612 and book *Mundus Iovalis* of 1614, Simon Marius in Germany reported his discovery of moons around Jupiter, which he started writing down in late 1609 in the Julian calendar, which translated to 8 January 1610 in the Gregorian calendar in use by Galileo in Italy. Is Marius to be believed? Galileo certainly did not. But a Dutch jury of experts about three hundred years later reported that they validated the claim that Marius independently discovered the moons of Jupiter one day after Galileo first both saw and wrote down his discovery! There is no doubt that the names Io, Europa, Ganymede, and Callisto came from Marius (to whom they were suggested by Kepler). See JMP's *Journal for the History of Astronomy* article, **46**(2), 218-234 (2015).
Marius wrote that he had been observing the moons around Jupiter since November 1609 (Julian), using a neighboring nobleman's telescope, which would mean that he actually saw the Jupiter satellites first (though publish or perish). Whether this feat was technically possible comes down to discussions of the capabilities of telescopes in the early 17th century.
The quadricentennial of Marius's book was celebrated in Nuremberg with a symposium that is now in press in German with an English translation expected. One of us (AVH) has recently prepared a complete English translation of Marius's book, superseding the partial translation made 100 years ago. There is no evidence that, whether he saw what we now call the Galilean satellites first or not, Marius appreciated their cosmological significance the way that Galileo soon did. And Marius was certainly the first to publish tables of the moons of Jupiter.
We thank the Chapin Library of Williams College and the Huntington Library for assistance with first editions of Marius's 1614 book, and we thank Pierre Leich of the Simon Marius Gesellschaft for his consultations.

Author(s): Jay M. Pasachoff[2], Albert Van Helden[1]
Institution(s): *1. Rice U., 2. Williams College*

314 – Gerard P. Kuiper Prize Lecture: Stan Peale's Legacy, Jean-Luc Margot for Stan Peale (University of California)

314.01 – Kuiper Prize Lecture: Stan Peale's Legacy

Stan Peale's career in planetary science spanned over five decades and yielded an impressive record of high-impact results. His contributions include the prediction of widespread volcanism on Jupiter's moon Io, the derivation of a general theoretical framework that governs the rotational states of bodies subject to tides, the study of the origin and evolution of natural satellites, advances in our understanding of exoplanet dynamics, and the promotion of microlensing searches for exoplanets. Stan also developed an ingenious procedure to determine the size and state of Mercury's core. Because of this work, we know more about the core of Mercury than that of any planet other than Earth. Stan left us an enduring legacy that exemplifies the power of physics to probe the interiors of planets.

Author(s): Jean-Luc Margot[1]
Institution(s): *1. University of California, Los Angeles*

315 – Professional Culture and Climate: Addressing Unconscious Bias, Patricia Knezek

315.01 – Professional Culture and Climate: Addressing Unconscious Bias

Unconscious bias reflects expectations or stereotypes that influence our judgments of others (regardless of our own group). Everyone has unconscious biases. The end result of unconscious bias can be an accumulation of advantage or disadvantage that impacts the long term career success of individuals, depending on which biases they are subject to. In order to foster a professional culture and climate, being aware of these unconscious biases and mitigating against them is a first step. This is particularly important when judgements are needed, such as in cases for recruitment, choice of speakers for conferences, and even reviewing papers submitted for publication. This presentation will cover how unconscious bias manifests itself, what evidence exists to demonstrate it exists, and ways it can be addressed.

Author(s): Patricia Knezek[1]
Institution(s): *1. NOAO/WIYN Observatory*

316 – Plenary Talk: Early Results from the Juno Mission at Jupiter, Scott Bolton (Southwest Research Institute)

316.01 – Early Results from the Juno Mission at Jupiter

The Juno mission is the second mission in NASA's New Frontiers program. Launched in August 2011, Juno arrived at Jupiter July 4, 2016. Juno science goals include the study of Jupiter's origin, interior structure, deep atmosphere, aurora and magnetosphere. Juno's orbit around Jupiter is a polar elliptical orbit with perijove approximately 5000 km above the visible cloud tops. The payload consists of a set of microwave antennas for deep sounding, magnetometers, gravity radio science, low and high energy charged particle detectors, electric and magnetic field radio and plasma wave experiment, ultraviolet imaging spectrograph, infrared imager and a visible camera. Early results from the mission will be presented as well as an overview of planned observations.

Author(s): Scott Bolton[1]
Institution(s): *1. SwRI*
Contributing team(s): Juno Science Team

317 – Plenary Talk: Dawn at Ceres, Michael Toplis (IRAP-CNRS-UPS)

317.01 – Dawn at Ceres

Dawn arrived at Ceres in 2015, after a 7.5-year journey. It had orbited and mapped the basaltic asteroid Vesta before arriving at its final target, the innermost dwarf planet [1]. Dawn found a very dark, cratered surface punctuated by small extremely bright spots, including the large bright area in the Occator crater. Ceres' surface has many craters but it is missing the largest expected craters and it is gravitationally relaxed at lowest orders, implying a mechanically strong thick crust with a weaker deep interior [2-4]. Ceres' surface composition is dominated by dark carbon-rich minerals, phyllosilicates, ammoniated clays, and carbonates [5]. The distribution of the observed species across the surface indicates that Ceres underwent widespread aqueous alteration [6]. Water ice has also been observed in fresh craters [7] and elemental composition is consistent with an increasing H content toward high latitudes [8], indicating an increasing content of water ice in the immediate subsurface towards the poles. The composition of the bright area in Occator is mostly consistent with a large amount of carbonate, implying recent hydrothermal activity [9]. Several lines of morphological evidence, like flat crater floors, flows of material across the surface and isolated mountains, point to the importance of volatile-driven activity on Ceres that may involve brine-driven cryovolcanism.

References

[1] Russell, et al., ISBN: 978-1-4614-4902-7, 2011.[2] Russell, et al., Science, 2016.[3] Marchi et al., Nat Comm., 2016 [4] Park et al. Nature, 2016. [5] De Sanctis et al., Nature, 2015, [6] Ammannito et al., Science, 2016.[7] Combe et al., Science 2016. [8] Prettyman et al., this meeting [9] De Sanctis et al., Nature, 2016

Author(s): Michael J Toplis[2], Maria Cristina De Sanctis[1]
Institution(s): *1. IAPS-INAF, 2. IRAP-CNRS-UPS*
Contributing team(s): Dawn Science Team

318 – Formation and Evolution of Planets and Satellites Posters

318.01 – The Inner Rim in Protoplanetary Disks

Many stars host planets orbiting within one astronomical unit (AU). These close planets origins are a mystery that motivates investigating protoplanetary disks central regions.

A key factor governing the conditions near the star is the silicate sublimation front, which largely determines where the starlight is absorbed, and which is often called the inner rim. We present the first radiation hydrodynamical modeling of the sublimation front in the disks around the young intermediate-mass stars called Herbig Ae stars. The models are axisymmetric, and include starlight heating, silicate grains sublimating and condensing to equilibrium at the local, timedependent temperature and density, and accretion stresses parametrizing the results of MHD magneto-rotational turbulence models.

The results show for the first time the dynamical stability of the rim. Passing the model disks into Monte Carlo radiative transfer calculations allows us to directly compare with observational constraints. The inner rim has a substantial radial extent, corresponding to several disk scale heights. A pressure maximum develops at the position of thermal ionization at temperatures about 1000 K. The pressure maximum is capable of halting solid pebbles radial drift and concentrating them in a zone where temperatures are sufficiently high for annealing to form crystalline silicates.

Author(s): Mario Flock[1], Neal J. Turner[1]
Institution(s): *1. Caltech/JPL*

318.02 – Evolution of the Magnetic Field during Chondrule Formation in Planetary Bow Shocks

Recent laboratory efforts (Fu et al., 2014, 2015) have constrained the remanent magnetizations of chondrules and the magnetic field strengths they were exposed to as they cooled below their Curie points. An outstanding question is whether these fields represent the background magnetic field of the solar nebula or were unique to the chondrule-forming environment. We investigate the amplification of the magnetic field above background values in a planetary bow shock, which is one proposed mechanism for chondrule formation. We use a hydrodynamic code to model the temperature and pressure around a 3000 km-radius planetary embryo as it moves supersonically through the nebula gas. We calculate the ionization of hot, shocked gas considering thermionic emission of electrons and ions from grains and thermal ionization of potassium. We calculate the magnetic diffusion rate, including Ohmic dissipation and ambipolar diffusion (assuming a magnetic field strength comparable to 0.5 G). We compute the steady-state magnetic field around in the bow shock and find that behind the planet the field is amplified, but everywhere else it quickly diffuses out of the shocked region and recovers the background value. We consider the trajectories taken by chondrules behind the shock and present likely values of the magnetic field amplification experienced by chondrules as they cool after melting in the shock.

Author(s): Chuhong Mai[1], Steven Desch[1], Aaron C. Boley[2]
Institution(s): *1. Arizona State University, 2. University of British Columbia*

318.03 – Building the giant planet cores by convergent migration of pebble-accreting embryos

An explanation of the accretion buildup of giant planet cores on rather short (~Myr) time scales remains a long-standing challenge for scenarios of planetary system formation. One of the recently proposed processes that can take part during this evolutionary stage is the convergent Type I migration of Earth-sized embryos towards the zero-torque radius, occurring at an opacity transition within the dusty-gaseous protoplanetary disk (e.g. Pierens et al. 2013). Inconveniently, simulations show that such groups of embryos do not merge easily because they often get locked in mutual mean-motion resonances and consequently form an inward-migrating convoy.
We revise this possibility of merging embryos while taking into account their ongoing growth by pebble accretion. Our aim is to check whether the rapid changes of masses combined with the migration of embryos through the feeding zone can break the resonant chain and allow for the giant planet core formation.
The environment of the protoplanetary disk is modeled with the 2D FARGO code (Masset 2000), which we modified in order to perform non-isothermal hydrodynamic simulations, assuming flux-limited radiative diffusion (Levermore & Pomraning 1981). The embedded massive bodies are evolved simultaneously in 3D using the hybrid Wisdom-Holman/Gauss-Radau integrator from the Rebound package (Rein & Spiegel 2015). A semi-analytic method is used to evolve the masses of embryos by pebble accretion (e.g. Levison et al. 2015).

Author(s): Ondrej Chrenko[1], Miroslav Broz[1]
Institution(s): *1. Institute of Astronomy, Charles University in Prague*

318.04 – New Models of Water Delivery To Earth: The Effects of Ice Longevity and Collisional Water Transport

It is widely accepted that the vast majority of Earth's water was delivered to its accretion zone by water-carrying planetesimals and planetary embryos from the outer regions of the asteroid belt while Earth was still forming. Modern simulations of the formation of terrestrial planets show this process with high resolution. However, their treatment of the actual delivery of water is still rudimentary assuming that a water-carrying object will maintain all its water content during its journey from its original orbit to the accretion zone of Earth. Models of the ice longevity have, however, shown that the water-ice may not stay intact, and asteroids and planetary embryos may lose some of their original water in form of ice sublimation during the dynamical evolution of these bodies. Also, collisions among these bodies while on their journey to Earth's accretion zone will result in the loss of large amounts of their water. These effects could be especially important during the formation of terrestrial planets as this process takes tens to hundreds of millions of years. We have developed a more accurate model in which the sublimation of ice during the process of the scattering of icy asteroids and planetary embryos into the accretion zone of Earth is taken into account. Our model includes two different modes of handling ice sublimation, one for sub-surface water and one for deeper ice. We also estimate water loss and retention during collisions which depends on the physical and dynamical parameters of the impacts. The results of our simulations put stringent constraints on the initial water distribution in the protoplanetary disk, the location of snowline, and the contribution of water from the primordial nebula to the final water budget of Earth. In this poster, we will present the results of our new simulations and discuss their implications for models of solar system formation and dynamics.

Author(s): Thomas I. Maindl[2], Nader Haghighipour[1]
Institution(s): *1. Univ. of Hawaii, 2. University of Vienna*

318.05 – Mixing in the Earth's Mantle after the Moon-forming Impact

The giant-impact hypothesis has provided a satisfactory explanation for the most salient characteristics of the Earth-Moon system. Recently, however, the discovery that many isotope patterns of the Earth and Moon are nearly identical have cast serious doubt on the most-accepted scenario of the Moon-forming impact and have forced the consideration of significantly different kinds of impacts. The original scenario pictured the grazing impact of a Mars-mass body on the proto-Earth. However, in this scenario the Moon is formed largely from impactor material which is extremely unlikely to share the isotopic patterning of the proto-Earth. Hence, two other ideas have been put forth: in one, the proto-Earth is extremely rapidly rotating, and the impactor is small: the Moon-forming disk is largely Earth material "spun-out" by the impact. In the other picture, the proto-Earth and impactor are roughly the same mass and both Earth and Moon are amalgams of the combined proto-Earth and the impactor.
As found by Nakajima and Stevenson (2015) in their calculations of all three scenarios, each idea has significantly different consequences for the degree of mixing of the mantle. I will focus in detail on the stability and mixing of a stratified and shearing mantle. The approach will be from a fluid-dynamic standpoint, for which the starting point is the well-known Kelvin-Helmholtz instability, and from shear instabilities in general. The situations will be systematically investigated for relevant profiles of shear and entropy, with the aim of producing a more rigorous assessment of mixing in a post-Moon-forming terrestrial mantle. I will present results from CTH hydrocode simulations of calculations of the mantle under various conditions and velocity profiles to help determine which if any of the competing hypotheses for lunar formation are consistent with inferences of the state of the Earth's mantle in this early period.

Author(s): Donald Korycansky[1]
Institution(s): *1. University of California Santa Cruz*

318.06 – Constraints on the pre-impact orbits of Theia, the Borealis impactor and the progenitor of Mercury

Many aspects of the current dynamical and compositional configuration of the inner Solar System, such as Mercury's large core mass fraction, the angular momentum of the Earth-Moon system, and the reorientation of Mars, have been achieved through the effects of giant impacts. It is possible to relate the impact conditions, especially the velocity, to the pre-impact orbits. This in turn provides insight into the source regions for the terrestrial planets for comparison with N-body accretion models. For example, in the case of the canonical model for the formation of the Moon, previous studies have investigated regions in which the Mars-size impactor, Theia, could be quasi-stable for millions of years. We can however obtain constraints on the orbit of an impactor immediately prior to collision simply by knowing the impact velocity. We consider the canonical Moon formation model, as well as the models of Cuk & Stewart (2012), Canup (2012) and Reufer et al. (2012), to derive

from each model its constraints on the pre-impact orbit of Theia. We also consider Mars, and provide constraints on the pre-impact orbit of the impactor suggested to have formed the Borealis basin, and Mercury, namely the Benz et al. (2007) scenario for the formation of Mercury. We discuss the implication of these pre-impact orbits for the origin of the bodies and their compositions.
Author(s): Alan P Jackson[1], Travis SJ Gabriel[1], Erik Asphaug[1]
Institution(s): *1. Arizona State University*

318.07 – Fate of debris from the Borealis basin impact on Mars and from the formation of the Earth-Moon system

Giant planet-forming collisions can inject significant amounts of debris into the inner solar system. Dynamically the fate of this debris is primarily to re-impact the target body and the other terrestrial planets, defining a post-giant-impact epoch. Giant impact debris leave signatures on the surfaces of terrestrial bodies, influencing and perhaps dominating their early cratering record, and for the largest giant impacts, to intensive surface evolution and even changes in bulk crustal material composition. We use high-resolution N-body simulations to study the fate of debris released by specific giant impacts suggested to have formed the Borealis basin on Mars, and compare it to the fate of debris released by giant impact scenarios for Earth's Moon. We consider how the velocity dependence of Earth-Moon accretion leads to differing velocity distributions of debris-impactors for Earth and Moon, and thus different crater distributions, and study how different assumptions on the size distribution of debris effects these results. We also investigate the influence of collisional grinding within the debris distribution, and the possibility of trapped populations.
Author(s): Erik Asphaug[1], Alan P Jackson[1], Travis SJ Gabriel[1], David A. Minton[2], Andrew Hesselbrock[2]
Institution(s): *1. ASU, 2. Purdue University*

318.08 – The Moon and Phobos: specific responses of two satellites moving off and nearer their respective planets

Two enigmatic structural and petrologic features of two satellites are widely discussed: origin and global spreading of high-Ti lunar basalts and intercrossing ripples of Phobos. The rippling covers the whole surface of this small satellite constantly moving towards Mars, thus narrowing its orbit and increasing its orbital frequency and speed of rotation. The increasing speed of rotation means increasing angular momentum of Phobos and this must be compensated by diminishing radius. Very "fresh" overall rippling cutting majority of structural forms of Phobos is a trace of this global contracting process.
Another trend is in the moving off Moon. Loosing its angular momentum due to slowing rotation a necessary compensation is fulfilled by sending dense basaltic lava into the crust. Varying density basalt flows (high, low, very low-Ti) reflect various stages of the slowing rotation process. Various contents of dense mineral component – ilmenite in basalts means various densities of the rock. Iron in basalts can be in less dense dark minerals and denser ilmenite thus influencing overall basalt densities corresponding to requirements of "healing" diminishing angular momentum.
Spectral mapping of basalt types [3] indicate that for large parts of Oceanus Procellarum younger basalts are more titanium rich than the older basalts, thus somewhat reversing the trend found in the returned samples [2]. In some smaller basins spectral mapping also shows titanium richer basalts being older than titanium pure ones [1]. Thus, one may conclude that decreasing rotation rate of the Moon was not smooth but rather uneven.
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Author(s): Gennady Gregory Kochemasov[1]
Institution(s): *1. IGEM Russian Academy of Sciences*

318.09 – Tilting Uranus without a Collision

The most accepted hypothesis for the origin of Uranus' 98° obliquity is a giant collision during the late stages of planetary accretion. This model requires a single Earth mass object striking Uranus at high latitudes; such events occur with a probability of about 10%. Alternatively, Uranus' obliquity may have arisen from a sequence of smaller impactors which lead to a uniform distribution of obliquities. Here we explore a third model for tilting Uranus using secular spin-orbit resonance theory. We investigate early Solar System configurations in which a secular resonance between Uranus' axial precession frequency and another planet's orbital node precession frequency might occur.
Thommes et al. (1999) hypothesized that Uranus and Neptune initially formed between Jupiter and Saturn, and were then kicked outward. In our scenario, Neptune leaves first while Uranus remains behind. As an exterior Neptune slowly migrates outward, it picks up both Uranus and Saturn in spin-orbit resonances (Ward and Hamilton 2004; Hamilton and Ward 2004). Only a distant Neptune has a nodal frequency slow enough to resonate with Uranus' axial precession.
This scenario, with diverging orbits, results in resonance capture. As Neptune migrates outward its nodal precession slows. While in resonance, Uranus and Saturn each tilt a bit further, slowing their axial precession rates to continually match Neptune's nodal precession rate. Tilting Uranus to high obliquities takes a few 100 Myrs. This timescale may be too long to hold Uranus captive between Jupiter and Saturn, and we are investigating how to reduce it. We also find that resonance capture is rare if Uranus' initial obliquity is greater than about 10°, as the probability of capture decreases as the planet's initial obliquity increases. We will refine this estimate by quantifying capture statistics, and running accretion simulations to test the likelihood of a low early obliquity. Our preliminary findings show that most assumptions about planetary accretion lead to nearly isotropic obliquity distributions for early Uranus. Thus, the odds of Uranus having an initial low obliquity is also about 10%.
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318.10 – Collision experiments between centimeter-sized protoplanetesimals in microgravity

In the early stages of planet formation in a protoplanetary disk the first coalescing bodies are weakly bound. Conditions in the disk, such as the presence of gas (drag), make further growth through centimeter and meter sized bodies difficult. For centimeter-sized aggregates self-gravity is almost non-existent and electrostatic surface forces such as van der Waals-type forces play a critical role in holding loosely bound rubble-piles together during their early formation. In order to understand how aggregates of this size grow we study the mechanical strengths, material, and collisional properties of cm-sized aggregates. The collisional outcomes between two aggregates can be determined by a set of definable collision parameters and experimental constraints on these parameters will aid in astrophysical models of planet formation. We have carried out a series of microgravity laboratory experiments in which we collide a pair of weakly bound aggregates together. In our free-fall chamber we collide two 3-cm aggregates together at collision velocities ranging from 50 to 220 cm/s and with pressure ~1 mbar. The aggregates are made of mm-sized silica bead particles and require internal cohesion to avoid fragmentation above modest collision speeds, which is supplied by adding H_2O (later dehydrated) and between 0 - 0.1 g of a well-mixed liquid adhesive to simulate surface forces and bonds between particles. We measure the compressive strengths of the aggregates (0.5 - 10 kPa), find their coefficients of restitution (CoR), and determine their bouncing and fragmentation thresholds, over a range of velocities and internal strengths. We observed collisional outcomes such as bouncing, erosion (mass-loss), and fragmentation of the aggregates. We find the CoR of the aggregates to have a mean of 0.11 ± 0.1 with no dependence on velocity or strength. Impact velocities above ~2 m/s resulted in fragmentation of our aggregates, higher than the ~1 m/s threshold for porous dust aggregates of roughly the same size implying non-porous aggregates are also capable of easily dissipating energy in collisions.

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318.11 – Mass Transfer via Low Velocity Impacts into Regolith

The study of low velocity collisions (<1 m/s) is essential to understand the growth and formation of aggregates in a number of environments in planetary systems. The Collisions Into Dust Experiment (COLLIDE) and Physics of Regolith Impacts in Microgravity Experiment (PRIME) experiments produced observations of mass transfer from regolith onto an impactor at these velocities in microgravity. We have subsequently carried out ground-based experiments in which a cm-scale sphere impacts and rebounds from a bed of granular material in 1-g laboratory conditions at low impact speeds with the aid of a spring. This allows impacts at v<1 m/s and ensures rebound of the impactor, with the spring providing enough force to overcome gravity. Preliminary results from an impact of a brass impactor into sand (200-500 µm) produced a monolayer of granular material onto the impactor, but the grains are not cohesive enough to allow a significant mass transfer under these conditions. Further experiments with a range of regolith properties, impactor composition and surface properties, impact velocities, and atmospheric conditions will be performed in the laboratory to study the effects of each of these properties on the contact transfer of regolith onto the impactor. Further microgravity experiments with PRIME and in a small drop tower are planned to then study bulk mass transfer with conditions informed by the ground-based experiments. Impacts with the COLLIDE and PRIME microgravity experiments showed mass transfer at speeds < 40 cm/s into JSC-1 lunar regolith simulant and quartz sand targets. We will present the free-fall and laboratory results and implications for the collisional evolution of dust, pebbles and boulders in the protoplanetary disk as well as particles in planetary ring systems.

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318.12 – Effect of oblique impact on impact strength of planetesimals

Collisional processes among planetesimals have played an important role for the formation and the evolution of the bodies in the solar system. Some researchers conducted impact experiments to examine the effects of target material, impact velocity, etc., on the impact strength. Planetesimals could collide with each other at various impact angles. Therefore, the effect of impact angle on the impact strength should be examined, but there are only a few studies about oblique impact experiments. In this study, we conducted oblique impact experiments of porous gypsum and glass spheres simulating planetesimals and examined the effect of the impact angle on the impact strength.

We used a porous gypsum sphere and a glass sphere as a target. We carried out impact experiments by using two-stage H_2 gas gun at Kobe University. A polycarbonate spherical projectile was accelerated at 2 to 7 km/s. The impact angle, ϑ, changed from 10° to 90° (90° at a head-on impact). The impact phenomena were observed by a high-speed camera to measure the fragment velocities.

The impact strength Q^* is defined as an energy density Q, which is the kinetic energy of impactor normalized by the target mass, when the largest fragment mass is half of the original target mass. In both cases of porous gypsum and glass targets, the Q^* became larger as the ϑ decreased. We reanalyzed our results by using the effective energy density,Q_c^*, defined as $Q\sin^2\vartheta$ and we found that the results of oblique impacts matched with those of a head-on impact. Furthermore, the relationship between the Q_c and the normalized largest fragment mass, m_l/M_t, could be fitted by $m_l/M_t=A\times Q_c^{-p}$ and the parameters, A and p, were 82.2 and 0.72 for a porous gypsum target and 1.1×10^6 and 2.12 for a glass target, respectively. We defined the impact strength Q_c^* by using the Q_c, and the Q_c^* was about 1000 J/kg for both targets. The power p for a glass target was about 3 times larger than that for a porous gypsum target. This means that the collisional efficiency on a porous gypsum target is much lower than that on a glass target, and we can say that the power p strongly depends on the porosity.

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318.13 – Kinetics of Methane Clathrate Formation in the Presolar Nebula

Clathrate hydrates are a distinct form of water ice wherein the crystal lattice of the host water molecules forms symmetric, polyhedral cages that trap volatile guest species under appropriate pressures and temperatures. These materials are an abundant source of hydrocarbons on Earth, and have been expected to be present on a number of icy celestial bodies, including Mars, Europa, Titan, and Enceladus. Clathrates are also thought to be one of the most likely traps for volatiles during the condensation of the protostellar nebulae. Prior to the *Voyager* mission, the prevailing expectation was that the elemental composition of the giant planets would reflect the composition of the solar nebula and therefore be similar to solar abundances. However, spacecraft observations by *Voyager, Galileo,* and *Cassini-Huygens*, as well as ground-based observations, have revealed unexpected elemental enrichment, relative to solar abundances, of C, N, S, As, P, and noble gases in the giant planets and in comets. One of the contending explanations is the retention of these volatiles as clathrate hydrates, which may have enabled their capture early in the history of the Solar System. While the formation and stability of clathrates have been addressed theoretically and, to some extent, experimentally at relatively high pressures (10^{-7}–10^{-3} bar), there is a scarcity of experimental undertaking on the kinetics of clathrate formation and their stability at the low pressures relevant to the early outer solar nebula (~10^{-11} bar). This study seeks to elucidate the clathrate formation kinetics under nebula-relevant conditions via a series of optical Raman experiments on ice/gas mixtures over a range of pressures and temperatures. Our work on the methane gas/ice system shows that clathrate formation occurs on a rather fast timescale (typically within minutes at 223-253 K and 30-50 bar CH_4). In addition, the rate of enclathration increases with pressures and temperatures, and the activation energy for clathrate growth is found to be comparable to those for gas diffusion through ice. These results suggest that the energy barrier for clathrate formation is quite low, implying the likelihood of existence of these materials under nebular conditions.

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319 – Dust and Solar Wind Posters

319.01 – Comparative Science and Space Weather Around the Heliosphere

Space weather refers to the variable state of the coupled space environment related to changing conditions on the Sun and in the terrestrial atmosphere. The presentation will focus on the critical missing knowledge or observables needed to significantly advance our modelling and forecasting capabilities throughout the solar system putting these in perspective to the recommendations in the recent COSPAR/ILWS roadmap. The COSPAR/ILWS RoadMap focuses on high-priority challenges in key areas of research leading to a better understanding of the space environment and a demonstrable improvement in the provision of timely, reliable information pertinent to effects on civilian space- and ground-based systems, for all stakeholders around the world.
The RoadMap prioritizes those advances that can be made on short, intermediate and decadal time scales, identifying gaps and opportunities from a predominantly, but not exclusively, geocentric perspective. While discussion of space weather effects has so far largely been concerned to the near-Earth environment, there are significant present and future applications to the locations beyond, and to other planets. Most obviously, perhaps, are the radiation hazards experienced by astronauts on the way to, and on the surface of, the Moon and Mars. Indeed, the environment experienced by planetary spacecraft in transit and at their destinations is of course critical to their design and successful operation. The case of forthcoming missions to Jupiter and Europa is an extreme example. Moreover, such craft can provide information which in turn increases our understanding of geospace.
One initiative is that under Horizon 2020, Europlanet RI will set up a Europlanet Planetary Space Weather Service (PSWS). PSWS will make five entirely new `toolkits' accessible to the research community and to industrial partners planning for space missions: - a General planetary space weather toolkit; Mars (in support of the ESA ExoMars missions to be launched in 2016 and 2018); comets (building on the success of the ESA Rosetta mission); outer planets (in preparation for the ESA JUICE mission to be launched in 2022), as well as a novel “event-diary" toolkit aiming at predicting and detecting planetary events like meteor impacts

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320 – Meteorites Posters

320.01 – A new approach to compute accurate velocity of meteors

The CABERNET project was designed to push the limits of meteoroid orbit measurements by improving the determination of the meteors' velocities. Indeed, despite of the development of the cameras networks dedicated to the observation of meteors, there is still an important discrepancy between the measured orbits of meteoroids computed and the theoretical results. The gap between the observed and theoretic semi-major axis of the orbits is especially significant; an accurate determination of the orbits of meteoroids therefore largely depends on the computation of the pre-atmospheric velocities. It is then imperative to dig out how to increase the precision of the measurements of the velocity.
In this work, we perform an analysis of different methods currently used to compute the velocities and trajectories of the meteors. They are based on the intersecting planes method developed by Ceplecha (1987), the least squares method of Borovicka (1990), and the multi-parameter fitting (MPF) method published by Gural (2012).
In order to objectively compare the performances of these techniques, we have simulated realistic meteors ('fakeors') reproducing the different error measurements of many cameras networks. Some fakeors are built following the propagation models studied by Gural (2012), and others created by numerical integrations using the Borovicka et al. 2007 model. Different optimization techniques have also been investigated in order to pick the most suitable one to solve the MPF, and the influence of the geometry of the trajectory on the result is also presented.
We will present here the results of an improved implementation of the multi-parameter fitting that allow an accurate orbit computation of meteors with CABERNET. The comparison of different velocities computation seems to show that if the MPF is by far the best method to solve the trajectory and the velocity of a meteor, the ill-conditioning of the costs functions used can lead to large estimate errors for noisy data.

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320.03 – FE-SEM/EDS and µ-IR combined analysis of HED meteorites in relation to infrared spectra of Vesta-like asteroids

Knowing the chemico-mineralogical composition of an extraterrestrial body is key to understanding its geological evolution. For this reason, remote-sensing instruments that can gather compositional data by using infrared spectroscopy are often part of the spacecraft missions. In order to acquire a fuller grasp of these data it is fundamental to compare them to analogue samples analysed by means of spectroscopy techniques.
This study is focused on the Howardite-Eucrite-Diogenite meteorites (HEDs) [1] originated from the differentiated asteroid 4 Vesta [2]; this hypothesis was lately reinforced by the data provided by the Dawn mission [3].
These meteorites consist of pyroxene basalts either brecciated or not (eucrites), brecciated orthopyroxenites (diogenites) and polymictic breccias of diogenites and eucrites originated by impacts on their parent body's surface (howardites).
Here we report a FE-SEM/EDS and µ-IR spectroscopy combined study of three HED meteorite samples: 1) NWA 7159, a monomictic brecciated eucrite consisting of exolved orthopyroxene ($Fs_{56.6-57.1}$ $Wo_{2.0-1.9}$) and anorthite with accessory silica polymorph and ilmenite; 2) NWA 7490 a diogenite with a cumulate texture dominated by orthopyroxene ($Fs_{24.1-26}$ $Wo_{3.4-4.6}$), with Ca-plagioclase, minor olivine and chromite and troilite as accessory minerals; 3) NWA 2698, an howardite with eucritic pyroxene (Fs_{45-40} Wo_{7-20}).
The FE-SEM backscattered images coupled with the EDS maps gives information on the morphology (e.g. grain size and texture) and chemistry of the three samples. The µ-IR spectrometer provides reflectance spectra of the selected features of interest and spectral maps of larger areas. With the combined analyses we obtained a comprehensive mineralogical framework for the three HED samples. It was proven that the mineralogical heterogeneity of the HED meteorites is consistent with the spectroscopic diversity seen on Vesta [4], thus this study helps in better constraining and characterising the reflectance spectra performed on Vesta-like bodies.

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320.04 – Physical Property Comparison of Ordinary Chondrite Classes

Measurements of the physical properties of meteorites are essential in helping to determine the physical characteristics of the parent asteroids. Studying of physical properties can provide fundamental information to understand meteoroid behavior in the atmosphere and determine methods to deflect potentially hazardous asteroids. Initial focus of our study is on ordinary chondrites, since they are over 70% of the meteorites.
To date we have measured the density (bulk and grain), porosity, thermal emissivity, and acoustic velocity of 7 ordinary chondrites (Tamdakht, Chelyabinsk, and multiple Antarctic meteorites). Each meteorite is first scanned using a 3D laser scanner to determine bulk density. For the other tests 1.5cm cubes are studied. Grain density is determined using gas pycnometer using nitrogen gas. Acoustic velocity, longitudinal and shear wave, are measured using an Olympus 45-MG in single element mode. Thermal emissivity is measured from 20°C up to atmospheric entry temperatures, and is based on average measurements over the wavelength range of 8 to 14µm.
Tamdakht's bulk density is that of an average H Chondrite (3-4 g/cm^3), while it has a low longitudinal velocity of 3540 m/s compared to the normal rage for H chondrites at 3529-6660 m/s. The velocity is consistent across all three axes in the sample. One possibility is an internal fracture, where part of has been seen on the surface of one of the test cubes. Chelyabinsk and the studied Antarctic meteorites have lower bulk and higher grain densities yielding above average porosities. Tamdakht is on the high end of the emissivity range for H chondrites and Chelyabinsk is on the high end for LL chondrites. Emissivity ranges from 0.985-0.995 at 20°C for the ordinary chondrites studied. Heated samples emissivity decreases slightly, 0.045, from initial 20°C measurement. Between 40-200°C, the emissivity stays fairly constant after decrease from room temperature. BTN 00304 has the highest average over the temperature range, while ALHA77294 has the lowest average.
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320.05 – Spectral modeling for the Chelyabinsk meteorite at UV-Vis-NIR wavelengths

<!--StartFragment-->Asteroids provide us information on the evolution of the Solar System. Meteorites and asteroids can be linked by matching their respective reflectance spectra. However, this is difficult because the spectral features depend strongly on the surface properties. To better interpret the spectra, we need to gain more knowledge of the light-scattering physics involved.
We develop a new light-scattering code based on SIRIS-code (Muinonen et al., JQSRT 110, 2009), which simulates light scattering by Gaussian-random-sphere particles that are large compared to the wavelength of the incident light. SIRIS is able to simulate ray optics, diffraction, and geometric ray optics, which utilizes ray optics that accounts for diffuse scattering. The diffuse scatterers can be uniformly distributed inside or cover the surface of the particle. The new code uses inhomogeneous waves to simulate light scattering by absorbing particles.
The University of Helsinki integrating-sphere spectrometer has been utilized to measure the reflectance spectra of three lithologies of the Chelyabinsk meteorite (light-colored, dark-colored, and impact-melt) at UV-Vis-NIR wavelengths (0.25-3.2 microns). Microtomography images of the light-colored and the dark-colored lithologies have also been taken. The light-colored lithology has the highest reflectance and shows broad absorption bands of olivine and pyroxene near 1.0 and 2.0 microns. The dark-colored lithology has a flat spectrum with diminished intensity. The impact-melt lithology is somewhere between the light-colored and dark-colored lithologies in terms of its spectrum (Kohout et al., Icarus 228, 2013). The differences in the spectra are caused by different patterns of iron and iron sulfides in the samples that can be seen in the microtomography and scanning electron microscope images. We utilize the new light-scattering code to model the effects of iron and iron sulfides in the spectra of the three lithologies of the Chelyabinsk meteorite by entering the physical properties, such as refractive indexes, of the three lithologies as input parameters for the simulations.
Acknowledgments. ERC grant 320773 and Academy of Finland grant 1257966.<!--EndFragment-->
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321 – Ceres and Vesta Posters

321.01 – Crater Ejecta Deposition on Ceres

Since March 6 2015 the Dawn spacecraft (Russell et al., 2012) is orbiting the dwarf planet Ceres inside the asteroid main belt. Color ratio data of the Framing Camera instrument show distinct bluish characteristics of recently exposed materials such as impact ejecta of young craters. Besides the common radial pattern of proximal ejecta, the distribution of remote ejecta is heavily affected by the relatively fast rotation of Ceres. We compare results from n-body simulations of impact ejecta with specific patterns in the color ratio data of the Dawn Framing Camera. Results of this work can also be used in order to predict prominent regions and patterns of secondary cratering.
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321.02 – The surface and interior evolution of Ceres revealed by fractures and secondary crater chains

Dawn became the first spacecraft to visit and orbit Ceres, a dwarf planet and the largest body in the asteroid belt (radius ~470 km) (Russell et al., 2016). Before Dawn's arrival, telescopic observations and thermal evolution modeling indicated Ceres was differentiated, with an average density of 2,100 kg/m^3 (e.g. McCord & Sotin, 2005; Castillo-Rogez & McCord, 2010). Moreover, pervasive viscous relaxation in a water-ice-rich outer layer was predicted to erase most features on Ceres' surface (Bland, 2013). However, a full understanding of Ceres' surface and interior evolution remained elusive. On the basis of global geologic mapping, we identify prevalent ≥1 km wide linear features that formed: 1) as the surface expression of subsurface fractures, and 2) as material ejected during impact-crater formation impacted and scoured the surface, forming secondary crater chains. The formation and preservation of these linear features indicates Ceres' outer layer is relatively strong, and is not dominated by viscous relaxation as predicted. The fractures also give us insights into Ceres' interior: their spacing indicates the fractured layer is ~30 km thick, and we interpret the fractures formed because of uplift and extension induced by an upwelling region, which is consistent with geodynamic modeling (King et al., 2016). In addition, we find that some secondary crater chains do not form radial patterns around their source impact craters, and are located in a different hemisphere from their source impact craters, because of Ceres' fast rotation (period of ~9 hours) and relatively small radius. Our results show Ceres has a surface and outer layer with characteristics that are different than predicted, and underwent complex surface and interior evolution. Our fuller understanding of Ceres, based on Dawn data, gives us important insights into the evolution of bodies in the asteroid belt, and provides unique constraints that can be used to evaluate predictions of the surface and interior evolution of bodies that have not been studied by an orbital mission, such as other dwarf planets and moons in the outer solar system.

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321.03 – Photometric correction of VIR high space resolution data of Ceres

NASA's Dawn spacecraft [1] has been orbiting Ceres since early 2015. The mission is divided into five stages, characterized by different spacecraft altitudes corresponding to different space resolutions, i.e. Approach (CSA), Rotational Characterization (CSR), Survey (CSS), High Altitude Mapping Orbit (HAMO), and Low Altitude Mapping Orbit (LAMO).
Ceres is a dark body (i.e. average albedo at 1.2 um is 0.08 [2]), hence photometric correction is much more important than for brighter asteroids (e.g. S-type and achondritric). Indeed, the negligible role of multiple scattering increases the reflectance dependence on phase angle.
A photometric correction of VIR data at low spatial resolution (i.e. CSA, CSR, CSS) has already been applied with different methodologies (e.g. [2], [3]), These techniques highlight a reflectance and band depths dependency on the phase angle which is homogeneous on the entire surface in agreement with C-type taxonomy.
However, with increasing spatial resolution (i.e. HAMO and LAMO data), the retrieval of a unique set of parameters for the photometric correction is no longer sufficient to obtain reliable albedo/band depth maps. In this work, a new photometric correction is obtained and applied to all the high resolution VIR data of Ceres, taking into account the reflectance variations observed at small scales. The developed algorithm will be implemented on the MATISSE tool [4] in order to be visualized on the Ceres shape model. Finally, an interpretation of the obtained phase functions is given in terms of optical and physical properties of the Ceres regolith.

Acknowledgements
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321.04 – The GIS data model of the Visible and Infrared mapping spectrometer (VIR) onboard NASA/Dawn

The spectrometer onboard Dawn mission to Vesta and Ceres (Russell et al., Earth Moon Planet (2007) 101:65–91) is a hyperspectral spectrometer with imaging capability which returns data useful for the determination of the mineral composition of surface materials in their geologic context. The VIR Spectrometer—covering the range from the near UV (0.25 µm) to the near IR (5.0 µm) and having moderate to high spectral resolution and imaging capabilities—is the appropriate instrument for the determination of Vesta's and Ceres' global and local properties (De Sanctis et al., SSR 2011). VIR combines two data channels in one compact instrument. The visible channel covers 0.25–1.05 µm and the infrared channel covers 1–5.0 µm. VIR is inherited from the VIRTIS mapping spectrometer (Coradini et al. in Planet. Space Sci. 46:1291–1304, 1998; Reininger et al. in Proc. SPIE 2819:66–77, 1996) on board the ESA Rosetta mission.
Since the beginning of the scientific campaign, VIR calibrated data have been converted into a Geographic Information System (GIS) compatible format. Here we present the GIS data model we developed for VIR, which presents some unique peculiarities due to the specific NASA/Dawn mission design. The model has been developed starting from an object oriented modeling. This object oriented design gives the flexibility which is necessary to face, time to time, the unexpected aspects of remote sensing over planetary surfaces unobserved before with this kind of instruments.

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Contributing team(s): VIR Team

321.05 – Ceres interaction with the solar wind

The solar wind interaction with Ceres is studied for a high water vapor release from its surface using a hybrid model including photoionization. We use a water vapor production rate thought to be due to subsurface sublimation, corresponding to a detection on 6 March 2013 by the Herschel Space Observatory. We present the general morphology of the plasma interactions, both close to Ceres and on a larger scale. Mass-loading of water ions causes a magnetic pile-up region in-front of Ceres, where the solar wind deflects and slows down. The large body makes an obstacle to the solar wind and creates an asymmetric wake downstream. On a global scale, Ceres has a comet-like interaction with the solar wind with observable perturbations far downstream of the body.

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321.06 – Optical Polarimetric Mapping of Ceres

The dwarf planet Ceres, with one quarter of its mass possibly as water, is of particular importance to understanding the origin and the evolution history of water in the inner solar system. It is also a real-life laboratory to study astrobiology. NASA's Dawn is returning detailed geological maps of Ceres until the end of this year. As a complement to the Dawn mission, using SPHERE/ZIMPOL at one of

Very Large Telescopes in Chile, we obtained the optical polarimetric maps in the I and V band of the whole surface of Ceres in July and August, 2015. Polarimetric maps of Ceres are sensitive to the physical conditions (such as packing density and particle size distribution) and composition of its surface regolith. The comparative studies between our polarimetric maps and Dawn maps help us to understand the geological evolution and the space weathering processes on Ceres' surface. At the time of the ZIMPOL observations, with the best spatial resolution of about 0.02 arcsecond (equivalent to 30 km), we effectively obtained about 700 independent measurements of the surface in one polarimetric set. I will present the SPHERE observations and discuss our major findings.
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321.07 – Thermal mapping of Ceres at 1.2 mm with ALMA

Ceres' thermal emission distribution, which can be characterized through observations at IR and longer wavelengths, is indicative of radiative and physical properties of its surface such as thermal inertia and roughness. High-resolution maps from the Dawn mission now provide an exquisite geographic and geological context for the interpretation of temperature features, which are at large not accessible to the spacecraft's instruments. In particular, the presence of hydrated minerals and distinctive geological features suggest the existence of ice water reservoirs near the surface, which may be characterized through the analysis of thermal inertia distributions.
We report on observations obtained in Fall 2015 at the Atacama Large Millimeter Array (ALMA), sampling most of the rotation of Ceres and hence allowing one to disentangle local-hour effects from geographical thermal features. The observations were performed during the 2015 Long Baseline Campaign, offering baselines as long as 10 km and yielding a spatial resolution down to 30 mas (~45 km at the equator). At the observed wavelength of 1.2 mm, the thermal emission probes both the emission from the surface and from deeper layers, down to the level of the diurnal skin depth, hence accessing regions where water ice could be stable.
We will describe the diurnal and latitudinal temperature variations derived from our observations as well as preliminary results from thermal modeling in terms of subsurface thermal inertia and ice table latitudinal extent. This work is supported by the NASA Solar System Observations Program grant NNX15AE02G.
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321.08 – Results of a Hubble Space Telescope Search for Natural Satellites of Dwarf Planet 1 Ceres

In order to prepare for the arrival of the Dawn spacecraft at Ceres, a search for satellites was undertaken by the Hubble Space Telescope (HST) to enhance the mission science return and to ensure spacecraft safety. Previous satellite searches from ground-based telescopes have detected no satellites within Ceres' Hill sphere down to a size of 3 km (Gehrels et al. 1987) and early HST investigations searched to a limit of 1-2 km (Bieryla et al. 2011). The Wide Field Camera 3 (WFC3) on board the HST was used to image Ceres between 14 April - 28 April 2014. These images cover approximately the inner third of Ceres' Hill sphere, where the Hill sphere is the region surrounding Ceres where stable satellite orbits are possible. We performed a deep search for possible companions orbiting Ceres. No natural companions were located down to a diameter of 48 meters, over most of the Hill sphere to a distance of 205,000 km (434 Ceres radii) from the surface of Ceres. It was impossible to search all the way to the surface of Ceres because of scattered light, but at a distance of 2865 km (five Ceres radii), the search limit was determined to be 925 meters. The absence of a satellite around Ceres could, in the future, support more refined theories about satellite formation or capture mechanisms in the solar system.
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322 – Extrasolar Planets and Systems: Orbital Dynamics Posters

322.01 – Analyzing Kepler lightcurves of exoplanets

The Kepler space telescope successfully found thousands of exoplanets. The next step is characterizing what those planets are like. Additional processing of the light curves and meticulous removal of spacecraft artifacts from the data such as pointing adjustments, safing events and thermal variations, may yield more information on the features of exoplanet systems. Bond albedo can be measured from the exoplanet's day-side flux contribution prior to secondary eclipse and asymmetries in the day-side contribution may indicate thermal asymmetries driven by motion in the planet's atmosphere. Transit timing variations indicate non-circular or precessing orbits, potentially due to a non-transiting third body, which influence the planetary environment and atmosphere. We investigated transit timing variations and day-side flux contributions of an exoplanet.
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322.02 – Coupled thermo-orbital evolution of tidally-evolved Earth-like planets

Progress in detection techniques of exoplanets inspired increasing number of studies focused on their internal dynamics and evolution. The detection methods tend to favor the discovery of short-period exoplanets, that are predicted to get rapidly tidally locked. During the locking process planets despin and a significant amount of tidal heating may contribute to the thermal budget of the planet. Moreover, tidally locked exoplanets exhibit large surface temperature contrasts between sub-stellar and anti-stellar sides due to uneven insolation which influence the convection pattern and cooling of the planet. Here, we will present the evolution of tidally locked Earth-like exoplanets using numerical tool Antigone (Behounkova et al., 2010, 2011) coupling long-term internal evolution, tidal dissipation (taking into account Maxwell or Andrade rheology) and uneven insolation pattern. For constant orbital parameters, we will focus on numerical simulation of the heat transfer in exoEarths for various rheological properties of planet and various values of spin-orbit resonance, semi-major axis, eccentricity and luminosity of star. In the case of effective heat transfer, our results suggest that the melting is mainly observed within the upper part of the mantle for tidal heating lower than 100TW . For tidal heating higher than 100TW, the melt is produced also within the deep part of the mantle and degree-2 convection is enhanced due to tidal heating pattern. For large tidal heating (larger than 1000TW), global melting is observed and temperature field is homogenized due to global melting, the heat transfer is mainly due to melt extraction and advection is suppressed. We will further present first results of coupled orbital-internal evolution of planets without

companion using numerical model of orbital evolution with realistic (Maxwell or Andrade) rheology (Walterova et al., in prep). We will concentrate on the capture into the spin-orbit resonance. Special attention will be paid to transition between resonances which are preceded by era of pronounced tidal heating.
M.B. and M.W. acknowledge support by the Grant Agency of the Czech Republic (project No. 14-04145S).
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322.03 – Visual Analysis and Comparison of Kepler Transit Timing Variations with Mutli-Transiting System Applications

By noticing the dimming and brightening of the star as an exoplanet transit occurs, NASA's Kepler Space Telescope records the times when the exoplanet passes in front of its star. If other planets are gravitationally influencing the transiting planet, the planet might transit late or early; these deviations from a perfectly periodic set of transits are called transit timing variations (TTVs). Therefore, Kepler TTVs have been very useful in determining exoplanet masses which can be hard to measure in other ways.
We visually analyzed the TTV data of all ~6000 Kepler objects of interest (KOIs) to determine whether interesting TTV signals would be missed by purely statistical analyses. Using data from Rowe et al. 2014 and Holczer et al. 2016, we examined TTV plots, periodograms, and folded quadratic+sinusoid fits. To find the most likely KOIs containing visible TTVs and to organize the over 6000 KOIs analyzed, a rating system was developed based on numerous visual factors. By sorting KOIs as such, we were able to compare our findings of the strongest candidates with the same KOIs statistically analyzed by Holczer et al. 2016. It was found that the majority of our findings matched those of Holczer et al. 2016, with only small discrepancies that were understandable based on our different methodologies. Still, our visual inspection of the full list of KOIs contributed multiple planets that were not identified statistically.
We combined all of these results with planet properties from the NASA Exoplanet Archive, confirmed and cumulative, to investigate the demographics of planetary systems with and without TTVs. We investigated multi-transiting systems with TTVs not attributable to any of the known planets in the system to better understand exoplanetary system architectures in cases where not all of the planets are transiting.
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322.05 – Tidal Decay and Roche-Lobe Overflow of Gaseous Exoplanets

Many gaseous exoplanets in short-period orbits are on the verge or are in the process of Roche-lobe overflow (RLO). Moreover, orbital stability analysis shows tides can drive many hot Jupiters to spiral inevitably toward their host stars, and the distributions of orbital periods and semi-major axes point to non-negligible orbital decay during the main sequence lifetimes of the host stars. Thus, the coupled processes of orbital evolution and RLO likely shape the observed distribution of close-in exoplanets. However, the exact outcome for an overflowing planet depends on its internal response to mass loss, and the accompanying orbital evolution can act to enhance or inhibit RLO. Applying the Modules for Experiments in Stellar Astrophysics (MESA) suite to model RLO, we find that, although the detailed evolution may depend on several properties of the planetary system, it is largely determined by the core mass of the overflowing gas giant. In particular, we find that the orbital expansion that accompanies RLO often stops and reverses at a specific maximum period that depends on the core mass. We suggest that RLO may often strand the remnant of a gas giant near or interior to this orbital period, providing an observational prediction that can corroborate the RLO hypothesis. We conduct a preliminary comparison of this prediction to the observed population of small, short-period planets and find some planets in orbits that may be consistent with this picture.
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322.06 – The Eccentric Response of *Kepler*'s Circumbinary Planets to Common-Envelope Evolution

Inspired by the recent *Kepler* discoveries of circumbinary planets orbiting close binary stars, we explore the fate of the former as the latter evolve off the main sequence. By combining binary stellar evolutionary models and dynamical simulations using numerical integration, we study the orbital evolution of these planets as a result of the common-envelope stages of their host binaries. Half of the *Kepler* systems experiences at least one common-envelope stage using their default physical parameters. During the common-envelope stage, the binary stars either shrink to very short orbits or coalesce; one system may trigger a double-degenerate supernova explosion. As the common-envelope stage is a complex and still-uncertain process, we test multiple efficiency parameters for each system. Much of the uncertainty in circumbinary systems is believed to be a result of tidal effects, and so we also vary the tides within our simulations. We find that, for common-envelope mass-loss rates of 1 solar mass per year, their planets predominantly remain gravitationally bound to the system at the end of this stage, migrate to larger orbits, and gain significant eccentricity. This orbital expansion can be up to an order of magnitude, and occurs over the course of a single planetary orbit. Some systems retain their planets even in the runaway regime of instantaneous mass loss. For slower mass loss rates of 0.1 solar masses per year, our results indicate an adiabatic orbital expansion for all except Kepler-1647, where this mass loss corresponds to the transition regime. Interestingly, the planets can experience both adiabatic and non-adiabatic orbital expansion if the host binaries experience multiple common-envelope stages (i.e. Kepler-1647); multiplanet circumbinary systems like Kepler-47 can experience both modes simultaneously during the same common-envelope stage. Our results show that, unlike Mercury, a circumbinary planet with the same semi-major axis can survive the common-envelope evolution of a close binary star with a total mass of 1 solar mass.
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Contributing team(s): Veselin B. Kostov, Daniel Tamayo, Ray Jayawardhana, Stephen A. Rinehart

322.07 – Eccentric planetary motion due to gravitational perturbations and the influence on the habitability

Gravitational perturbations play an important role in multi body systems. Phenomena like mean motion or secular resonances can be sources of instability and influence the architecture of a planetary system significantly. The determination of the location of these resonances is therefore of particular interest. In this study, we use a semi-analytical approach for S-type motion in binary stars which defines the position of a linear secular resonance without huge integration effort. We show the application to several tight binary stars where a giant planet has been detected and study a possible influence on the habitable zone. Moreover, we discuss the consequences for an Earth-like planet in the habitable zone that is affected by such a resonance.

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323 – Astrobiology Posters

323.01 – Catalytic Diversity in Alkaline Hydrothermal Vent Systems on Ocean Worlds

Hydrothermal systems formed by serpentinization can create moderate-temperature, alkaline systems and it is possible that this type of vent could exist on icy worlds such as Europa which have water-rock interfaces. It has been proposed that some prebiotic chemistry responsible for the emergence of life on Earth and possibly other wet and icy worlds could occur as a result ofredox potential and pH gradients in submarine alkaline hydrothermal vents (Russell et al., 2014). Hydrothermal chimneys formed in laboratory simulations of alkaline vents under early Earth conditions have precipitate membranes that contain minerals such as iron sulfides, which are hypothesized to catalyze reduction of CO_2 (Yamaguchi et al. 2014, Roldan et al. 2014) leading to further organic synthesis. This CO_2 reduction process may be affected by other trace components in the chimney, e.g. nickel or organic molecules. We have conducted experiments to investigate catalytic properties of iron and iron-nickel sulfides containing organic dopants in slightly acidic ocean simulants relevant to early Earth or possibly ocean worlds. We find that the electrochemical properties of the chimney as well as the morphology/chemistry of the precipitate are affected by the concentration and type of organics present. These results imply that synthesis of organics in water-rock systems on ocean worlds may lead to hydrothermal precipitates which can incorporate these organic into the mineral matrix and may affect the role of gradients in alkaline vent systems.Therefore, further understanding on the electroactive roles of various organic species within hydrothermal chimneys will have important implications for habitability as well as prebiotic chemistry. This work is funded by NASA Astrobiology Institute JPL Icy Worlds Team and a NAI Director's Discretionary Fund award.

Yamaguchi A. et al. (2014) Electrochimica Acta, 141, 311–318.
Russell, M. J. et al. (2014), Astrobiology, 14, 308-43.
Roldan, A. (2014) Chem. Comm. 51, 35: 7501-7504.

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323.02 – Amino Acid Synthesis in Seafloor Environments on Icy Worlds

In 2005, the Cassini mission detected plumes erupting from Enceladus' surface, containing carbon dioxide, methane, silica, and possibly ammonia. Subsequent laboratory experiments indicated that the silica particles in the plumes were generated under alkaline conditions and at moderate temperatures of ~90°C (Hsu et al., 2015); one scenario for such conditions would be the existence of alkaline (serpentinization-driven) hydrothermal activity within Enceladus. Alkaline vents are significant since they have been proposed as a likely environment for the emergence of metabolism on the early Earth (Russell et al. 2014) and thus could also provide a mechanism for origin of life on ocean worlds with a water-rock interface. Alkaline vents in an acidic, iron-containing ocean could produce mineral precipitates that could act as primitive enzymes or catalysts mediating organic reactions; for example, metal sulfides can catalyze the reductive amination of pyruvate to alanine (Novikov and Copley 2013). We have conducted experiments testing the synthesis of amino acids catalyzed by other iron minerals that might be expected to precipitate on the seafloor of early Earth or Enceladus. Preliminary results indicate that amino acids as well as other organic products can be synthesized in 1-3 days under alkaline hydrothermal conditions. We also find that the yield and type of organic products is highly dependent on pH and temperature, implying that understanding the specifics of the geochemical hydrothermal gradients on Enceladus (or other ocean worlds) will be significant in determining their potential for synthesizing building blocks for life.

Hsu, H.-W. et al. (2015), Nature 519, 207-210.
Russell, M. J. et al. (2014), Astrobiology, 14, 308-43.
Novikov Y. and Copley S. D. (2013) PNAS 110, 33, 13283-13288.

Author(s): Erika Flores[2], Laura Barge[2], David VanderVelde[1], Kayo Kallas[2], Marc M. Baum[3], Michael J. Russell[2], Isik Kanik[2]
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323.03 – Set-Theoretic Analysis of Ethical Systems for Off-Planet Future Engagement with Living Organisms

Living organisms are a conundrum. Their origin and provenance are open questions. An operational definition for their detection has been settled upon for practical reasons, i.e. in order to plan mission goals. The spirit of such undertakings is typically noble, and yet the question arises clearly related to how humanity will engage with other living organisms. Prudence demands a pre-contact appraisal of ethical requirements towards other living organisms. To answer this question, an anology with the number line in mathematics (integers versus the set of real numbers) will be presented to explore the structure of finite versus open-ended hierarchies. In this, the architecture of set theory will be used as a basis to describe the validity of systems hierarchies in general. Note that how numbers populate sets follow distinct rules when the elements of the sets or the sets themselves are unbounded. Principles of axiomatic versus observed conclusions will be emphasized. Results from mathematics will be used to inform analysis and dilemmas in ethical systems.

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324 – Asteroid Main Belt Posters

324.01 – Asteroid mass estimation using Markov-Chain Monte Carlo techniques

Estimates for asteroid masses are based on their gravitational perturbations on the orbits of other objects such as Mars, spacecraft, or other asteroids and/or their satellites. In the case of asteroid-asteroid perturbations, this leads to a 13-dimensional inverse problem where the aim is to derive the mass of the perturbing asteroid and six orbital elements for both the perturbing asteroid and the test asteroid using astrometric observations. We have developed and implemented three different mass estimation algorithms utilizing asteroid-asteroid perturbations into the OpenOrb asteroid-orbit-computation software: the very rough 'marching' approximation, in which the asteroid orbits are fixed at a given epoch, reducing the problem to a one-dimensional estimation of the mass, an implementation of the Nelder-Mead simplex method, and most significantly, a Markov-Chain Monte Carlo (MCMC) approach. We will introduce each of these algorithms with particular focus on the MCMC algorithm, and present example results for both synthetic and real data. Our results agree with the published mass estimates, but suggest that the published uncertainties may be misleading as a consequence of using linearized mass-estimation methods. Finally, we discuss remaining challenges with the algorithms as well as future plans, particularly in connection with ESA's Gaia mission.

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324.02 – 5m Main Belt Asteroid Population Estimation Using Vesta Imagery

The Main Belt is the largest source of Near-Earth asteroids, but objects <~3 km in diametercannot be reliably detected through conventional means and their number and distribution must be extrapolated. However, craters as small as 50 meters can be seen in the Dawn Framing Camera images from the 2012 mission to Vesta. Since craters of this size are formed by ~5 meter asteroids, counting craters on Vesta allows us to measure the size distribution of asteroids down to sizes that have previously been inaccessible by several orders of magnitude. In the imagery 50m craters were ~2 pixels wide and presented a challenge to reliably count. To validate and calibrate the efficiency and accuracy of counting craters only pixels wide, an experiment was carried out by counting large craters at artificially degraded resolutions. This produced an efficiency curve that was combined with the census of craters >2 pixels in diameter that were counted in a 33km 2 region to give a crater density. By knowing the crater density and making some reasonable assumptions about the orbital distribution of asteroids and the age of Vesta's surface, an estimate of the population of small asteroids in the inner main belt was made. It was found that the inner region of the main asteroid belt contains approximately 20 billion asteroids larger than 5 m. These results agree well with the measured inner Main Belt Size distribution derived by the Wide-field Infrared Survey Explorer, WISE (Masiero et al. 2011).

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324.03 – On the v_W leptokurtic asteroid families

v_W leptokurtic asteroid families are families for which the distribution of the normal component of the terminal ejection velocity field v_W is characterized by a positive value of the γ_2 Pearson kurtosis, i.e., they have a distribution with a more concentrated peak and larger tails than the Gaussian one. Currently, eight families are known to have $\gamma_2(v_W) > 0.25$. This may be caused by the fact that i) the family did not alter significantly its originally leptokurtic inclination distribution since its formation, as it seems to be the case for the Koronis family or ii) some of the family members interacted with a strong node secular resonances, as it is the case for the Astrid (interaction with the s-s_C resonance with Ceres) and Gallia (interaction with the s-s_V resonance with Vesta) families.
In this work, we investigate the families that were affected by strong secular resonances with massive asteroids. By obtaining the time evolution of $\gamma_2(v_W)$ for simulated families under the gravitational influence of planets and the three most massive bodies in the main belt we were able to i) assess the dynamical importance (or lack of) node secular resonances with Ceres, Vesta, and Pallas for the considered families, ii) obtain independent constraints on the family ages, and iii) for the case of the Astrid family set limitations on values of key parameters of the Yarkovsky force such as the surface thermal conductivity and the mean density of members. Overall, the use of the $\gamma_2(v_W)$ parameter could provide useful hints on the original ejection velocity field and dynamical evolution of leptokurtic v_W asteroid families.

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324.04 – The Light-Curve and Rotation Rate of 'Active Asteroid' 313P/Gibbs

The 'Active Asteroids' are a strange, yet newly discovered class of small bodies in the Solar System that have the orbital and dynamical properties of asteroids, but also the physical properties of comets (ejection of dust and volatile materials). Of the known ~25 Active Asteroids discovered thus far (Jewitt, Hseih, Argwal, 2015), only 4 have been known to be active on subsequent multiple occasions 238P/Read, 133P/Elst-Pizarro, 324P/La Sagra, (Jewitt et al. 2016) and 313P/Gibbs. In this work, we have determined the rotation rate and light-curve for Active Asteroid 313P/Gibbs using the Keck 10-m telescope to better understand the mechanisms and drivers of subsequent activity in this Solar System Small Body so that we may form a more complete picture of this population, better characterize them, and add to our inventory of Solar System small bodies to form a more complete model of the formation of the Solar System as well as what this may imply for future detection of activity in the Active Asteroid population.

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324.05 – The dynamical evolution of the asteroid belt in the pebble accretion scenario

The high excitation of the asteroid belt could be the trace of a past cohexistence of asteroids and planetary embryos. After the formation of Jupiter and Saturn, the asteroid belt lost about 99% of its mass, depleted by gravitational interactions with these giant planets and it was left with only Ceres as a relic of the planetary embryo population. Our aim is to construct a main belt (based on new estimates for the birth distribution of asteroids and planetary embryos that grow by pebble accretion) and test its evolution with different parameters and configurations of the giant planets. We test new pebble accretion growth tracks for the giant planets and compare the evolution of the asteroid belt to the classical in-situ growth.

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325 – Asteroid Physical Characteristics: Surfaces Posters

325.01 – On the effect of surface roughness and frequency on the planetary radar echo

Planetary radar is a strong tool for revealing surface properties of near-Earth asteroids, such as the geometric composition, or surface roughness, with implications on the chemical composition. For some asteroids and comets visited with spacecrafts, local variations of the size distribution of surface particles have been observed (Michikami et al., *Earth Planets Space* 60, 2008). The variations can be observed using radar through variations of circular-polarization ratio (Virkki et al. In *Asteroids, Comets, Meteors 2014*, 2014).
We model radar scattering by planetary surfaces using an algorithm of geometric optics with Fresnelian reflections and refractions as well as diffuse scattering (Muinonen et al.,*JQSRT* 110, 2009). Previously, we have shown the effect of various surface properties, such as the material, geometry, and size of the scatterers, e.g., wavelength-scale boulders on the asteroid surface, on the observed radar albedo and circular-polarization ratio when a power-law (r^{-3}) size distribution of irregular particles is used (Virkki and Muinonen,*Icarus* 269, 2016). In this study, we show how different

size distributions affect the radar albedo and circular-polarization ratio. Also, we discuss the effect that the choice of the observation frequency (2380 or 8560 MHz) may have on the echo. As materials, we compare different types of rock and ice.

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325.02 – Bistatic radar observations of 2011 UW158

We report results of intercontinental bistatic radar observations of near-Earth Asteroid 2011 UW158 during its close approach to the Earth in July 2015. High power continuous wave signal at a fixed 8.4 GHz frequency was transmitted to the asteroid from the 70 m antenna of the Goldstone Observatory (DSS-14) and then the echo reflected back from the target was received by the 32 m radio telescopes of Quasar VLBI network in Zelenchukskaya and Badary observatories. Analysis of the echo power spectra allowed us to estimate the size and spin period, which agrees with the photometric observations as well as obtain some information about asteroid's shape and near-surface roughness. We also reported 18 Doppler estimates and computed the heliocentric orbit of 2011 UW158.

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325.03 – Biases affecting radar detection of binary near-Earth Asteroids

Radar observations at Arecibo and Goldstone provide a powerful tool for the discovery, characterization, and orbit estimation of binary near-Earth asteroids (NEAs). To date, 73% of binary and triple NEA systems have been discovered by radar and 87% have been detected by radar. Here we describe biases not discussed in detail in the peer-reviewed literature that can adversely affect radar detection of NEA satellites. In a Doppler-only echo power spectrum, most NEA binaries have a rapidly-spinning primary that appears as a broad echo, and a slowly orbiting, tidally-locked companion that appears as a narrow spike superimposed on the primary echo. The most important factor for detection of a companion is the signal-to-noise ratio (SNR), which is proportional to $(r^{-4})(D^{3/2})(P^{1/2})$, where r is the distance, D is the diameter, and P is the rotation period. Low SNRs occur primarily due to the distance, a small diameter, and rapid rotation and necessitate coarse frequency resolution that limits detection of narrow spikes. Spikes in echo power spectra also occur due to glints, self noise, and radar albedo features, so confirmation of a binary requires delay-Doppler images that show two separate echoes whose positions change with time. Most companions appear tidally locked, but ~25% rotate more rapidly than their orbital periods. For example, in October 2001 the companion of 1998 ST27 was not obvious in echo power spectra or in single delay-Doppler images but was seen only when all the images from each day were summed, revealing a trail of faint pixels. The satellite SNRs were weak because its rotation is much more rapid than its orbital period. Other important factors include differences between the bandwidth of the companion and the Doppler resolution; weak SNRs due to a small diameter; self noise due to a small number of Fourier transforms; rapid orbital motion that decreases the SNR of the satellite into the noise; failure to inspect the data at sufficiently high Doppler resolution; excessively tight vignetting of the data in time delay; overlap and eclipses by the components at the time of the observations; and binaries with comparable diameters that appear to overlap in range but are actually separated.

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Institution(s): *1. JPL*

325.04 – Population trends of binary near-Earth asteroids based on radar and lightcurves observations

The Arecibo and Goldstone planetary radars are invaluable instruments for the discovery and characterization of binary and triple asteroids in the near-Earth asteroid (NEA) population. To date, 41 out of 56 known binaries and triples (~73% of the objects) have been discovered by radar and 49 of these multiple systems have been detected by radar. Their absolute magnitudes range from 12.4 for (1866) Sisyphus to 22.6 for 2015 TD144 and have a mean and rms dispersion of 18.1+-2.0. There is a pronounced decrease in the abundance of binaries for absolute magnitudes H>20. One of the smallest binaries, 1994 CJ1, with an absolute magnitude H=21.4, is also the most accessible binary for a spacecraft rendezvous. Among 365 NEAs with H<22 (corresponding to diameters larger than ~ 140 m) detected by radar since 1999, ~13% have at least one companion. Two triple systems are known, (15391) 2001 SN263 and (136617) 1994 CC, but this is probably an underestimate due to low signal to noise ratios (SNRs) for many of the binary radar detections. Taxonomic classes have been reported for 41 out of 56 currently known multiple systems and some trends are starting to emerge: at least 50% of multiple asteroid systems are S, Sq, Q, or Sk, and at least 20% are optically dark (C, B, P, or U). Thirteen V-class NEAs have been observed by radar and six of them are binaries. Curiously, a comparable number of E-class objects have been detected by radar, but none is known to be a binary.

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325.05 – Understanding the Importance of Shape in Thermal Modeling: The Case of 1627 Ivar

We seek to investigate the compositional surface variation of near Earth asteroids (NEAs). To do this, we employ detailed shape models and near-IR observations, taken over a range of viewing geometries, in order to create thermophysical models. The thermal spectra are therefore linked to regions on the asteroid, and we can seek out a set of thermal parameters that are capable of reproducing the thermal spectra over the entirety of the asteroid's surface. This method also enables us to characterize portions of the asteroid that may have different thermal properties than other regions, in which case there is no single set of thermal parameters that satisfy all of the thermal observations, indicating a heterogeneous surface.
We present our findings on 1627 Ivar, an Amor class NEA with a taxonomic type of Sqw [1], and a rotation period of 4.7951689 hr ± 0.0000026 [2]. During Ivar's apparition in 2013, we obtained CCD lightcurves, radar data, and near-IR spectra. Using the software SHAPE, we have used lightcurve and radar data to generate an improved shape model of Ivar [2][3].
For the thermophysical modeling, we have used SHERMAN [3,4] to determine which reflective, thermal, and surface properties for Ivar best reproduce our spectra, taken using the SpeX instrument at the NASA IRTF [5]. Input parameters for SHERMAN include the asteroid's IR emissivity, optical scattering law and thermal inertia in order to

complete thermal computations based on the shape model. We also compare these results to those created by using the Kaasalainen lightcurve model [6]. Since models created from lightcurve inversion techniques far outnumber those created using radar data, it is important to understand how these two models differ when studying thermal models.

References: [1] DeMeo et al. 2009, Icarus 202, 160-180 [2] Crowell et al. 2016, Icarus, in press [3] Crowell et al. 2014, AAS/DPS 46 [4] Howell et al. 2015, AAS/DPS 47 [5] Rayner et al. 2003, PASP 115, 362 [6] Kaasalainen et al. 2004, Icarus 167, 178-196. We thank NSF (AST-1109855), USRA (06810-05) and the CLASS SSERVI for their support.

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325.06 – Spatial Mapping of NEO 2008 EV5 Using Small Satellite Formation Flying and Steresoscopic Technology

NASA is currently developing the first-ever robotic Asteroid Redirect Robotic Mission (ARRM) to the near-Earth asteroid 2008 EV5 with the objective to capture a multi-ton boulder from the asteroids surface and use its mass to redirect its parent into a CIS lunar orbit where astronauts will study its physical and chemical composition. A critical step towards achieving this mission is to effectively map the target asteroid, identify the candidate boulder for retrieval and characterize its critical parameters. Currently, ARRM utilizes a laser altimeter to characterize the height of the boulders and mapping for final autonomous control of the capture. The proposed Lava-Kusha mission provides the increased of stereoscopic imaging and mapping, not only the Earthward side of the asteroid which has been observed for possible landing sites, but mapping the whole asteroid. LKM will enhance the fidelity of the data collected by the laser altimeter and gather improved topographic data for future Orion missions to 2008 EV5 once in cis lunar space.

LKM consists of two low cost small satellites (6U) as a part of the ARRM. They will launch with ARRM as an integrated part of the system. Once at the target, this formation of pathfinder satellites will image the mission critical boulder to ensure the system design can support its removal. LKM will conduct a series of flybys prior to ARRM's rendezvous. LKMs stereoscopic cameras will provide detailed surveys of the boulder's terrain and environment to ensure ARRM can operate safely, reach the location and interface with the boulder. The LKM attitude control and cold gas propulsion system will enable formation maintenance maneuvers for global mapping of asteroid 2008 EV5 at an altitude of 100 km to a high-spatial resolution imaging altitude of 5 km.

LKM will demonstrate formation flying in deep space and the reliability of stereoscopic cameras to precisely identify a specific target and provide physical characterization of an asteroid. An assessment of the off-the-shelf technology used at JPL will be provided also with technology readiness descriptions, mission architecture, cost analysis and future work required to make the proposed LKM mission a partner to ARRM.

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325.08 – ASPECT spectral imaging satellite proposal to AIDA/AIM CubeSat payload

The Asteroid Spectral Imaging Mission (ASPECT) is a part of the Asteroid Impact Mission (AIM) project, and aims to study the composition of the Didymos binary asteroid and the efects of space weathering and shock metamorphism in order to gain understanding of the formation and evolution of the Solar System. The joint ESA/NASA Asteroid Impact Detection Assessment (AIDA) mission to binary asteroid Didymos consists of the Asteroid Impact Mission (AIM) by ESA and the Double Asteroid Redirection Test (DART) by NASA. DART is targeted to impact the Didymos secondary component (Didymoon) while AIM monitors the impact efects. This will demonstrate the use of a kinetic impactor to detect potentially hazardous asteroids. Both spacecraft will be launched in 2020 and will arrive to Didymos in 2022. The AIM mission will also include two or three CubeSats, which will be released in the Didymos system. This arrangement opens up a possibility for secondary scientifc experiments. ASPECT is one of the proposed CubeSat payloads. ASPECT is a 3U CubeSat equipped with a VIS-NIR spectral imager and it will be used to measure the spectral characteristics of the impact site before and after the DART impact, as the impactor should bring fresh material to the surface. This gives a unique opportunity to study space weathering and shock efects on asteroids.

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325.09 – Mineralogical Mapping of Asteroid Itokawa using Calibrated Hayabusa AMICA images and NIRS Spectrometer Data

The goal of our work is to restore data from the Hayabusa spacecraft that is available in the Planetary Data System (PDS) Small Bodies Node. More specifically, our objectives are to radiometrically calibrate and photometrically correct AMICA (Asteroid Multi-Band Imaging Camera) images of Itokawa. The existing images archived in the PDS are not in reflectance and not corrected from the effect of viewing geometry. AMICA images are processed with the Integrated Software for Imagers and Spectrometers (ISIS) system from USGS, widely used for planetary image analysis. The processing consists in the ingestion of the images in ISIS (*amica2isis*), updates to AMICA start time (*sumspice*), radiometric calibration (*amicacal*) including smear correction, applying SPICE ephemeris, adjusting control using Gaskell SUMFILEs (*sumspice*), projecting individual images (*cam2map*) and creating global or local mosaics. The application *amicacal* has also an option to remove pixels corresponding to the polarizing filters on the left side of the image frame. The *amicacal*application will include a correction for the Point Spread Function. The last version of the PSF published by Ishiguro et al. in 2014 includes correction for the effect of scattered light. This effect is important to correct because it can add 10% level in error and is affecting mostly the longer wavelength filters such as zs and p. The Hayabusa team decided to use the color data for six of the filters for scientific analysis after correcting for the scattered light. We will present calibrated data in I/F for all seven AMICA color filters. All newly implemented ISIS applications and map projections from this work have been or will be distributed to the community via ISIS public releases. We also processed the NIRS spectrometer data, and we will perform photometric modeling, then apply photometric corrections, and finally extract mineralogical parameters. The end results will be the creation of pyroxene chemistry and olivine/pyroxene ratio maps of Itokawa using NIRS and AMICA map products. All the products from this work will be archived on the PDS website. This work was supported by NASA Planetary Missions Data Analysis Program grant NNX13AP27G.

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325.10 – Thermal Inertia Determination of C-type Asteroid Ryugu from in-situ Surface Brightness Temperature Measurements

The Japanese Hayabusa-2 mission is a sample-return mission currently on its way to the C-type asteroid Ryugu. Hayabusa-2 carries the small lander MASCOT (Mobile Asteroid Surface Scout), whose scientific payload includes the infrared radiometer MARA. The primary science goal of MARA is to determine Ryugu's surface brightness temperatures at the landing site for a full asteroid rotation, which will be measured using a long-pass filter, an 8 to 12 µm bandpass, as well as four narrow bandpasses centered at wavelengths between 5 and 15 µm. From these measurements, surface thermal inertia will be derived, but because MARA performs single pixel measurements, heterogeneity in the field of view cannot be resolved. Yet, the surface will likely exhibit different surface textures, and thermal inertia in the field of view could vary from 600 (small rocks) to 50 $Jm^{-2}s^{-0.5}K^{-1}$(fine regolith grains). Sub-pixel heterogeneity is a common problem when interpreting radiometer data, since the associated ambiguities cannot be resolved without additional information on surface texture. For MARA, this information will be provided by the MASCOT camera, and in the present paper we have investigated to what extent different thermal inertias can be retrieved from MARA data. To test the applied approach, we generated synthetic MARA data using a thermal model of Ryugu, assuming different thermal inertias for sections of the field of view. We find that sub-pixel heterogeneity systematically deforms the diurnal temperature curve so that it is not possible to fit the data using a single thermal inertia value. However, including the area fractions of the different surface sections enables us to reconstruct the different thermal inertias to within 10% assuming appropriate measurement noise. The presented approach will increase robustness of the Ryugu thermal inertia determination and results will serve as a ground truth for the global measurements performed by the thermal infrared mapper (TIR) on the Hayabusa-2 main spacecraft.

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325.11 – *NEAR* MSI Images of Asteroid Eros: New Data Products and Analysis

The *Near-Earth Asteroid Rendezvous* (*NEAR*) spacecraft orbited asteroid Eros for approximately one year in 2000–2001, returning thousands of images obtained with the MultiSpectral Imager (MSI) camera system. R. Gaskell used ~20,000 of these images to construct a high-resolution shape model of Eros that was archived in the NASA Planetary Data System (PDS) in 2008. We have produced backplanes for this set of images, and are in the process of preparing them for delivery to the PDS. The 16 backplanes contain information of interest for each pixel in an image: 1. Image pixel value. 2. *x* value of point, body centered coords. 3. *y* value of point. 4. *z* value of point. 5. Latitude. 6. Longitude. 7. Distance from center of asteroid. 8. Solar incidence angle. 9. Emergence angle. 10. Phase angle. 11. Horizontal pixel scale (km/pixel). 12. Vertical pixel scale. 13. Slope. 14. Elevation. 15. Gravitational acceleration. 16. Gravitational potential. This set of backplanes will be provided to the PDS Small Bodies Node, with PDS-4 labels.
The Gaskell shape model, produced with stereophotoclinometry, has more than 3.1 million plates. Hence this model has more than an order of magnitude better spatial resolution compared with the older shape model (200,700 plates). The high-resolution shape model permits substantial improvements in photometric normalization of images to be made, because the incidence, emergence, and phase angles can be determined at smaller scales. We plan to perform new photometric normalization of color image sets in order to search for mineralogical variations at higher resolution than was previously possible. In addition, we will carry out phase-ratio analysis to extract information on surface texture and scattering behavior for features of special interest.

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325.12 – Visible Wavelength Reflectance Spectra of Near-Earth Objects from Apache Point Observatory: Science Highlights

In January 2015 we began a program of near-Earth object (NEO) astrometric follow-up and physical characterization using a 17% share of time on the Astrophysical Research Consortium (ARC) 3.5-meter telescope at Apache Point Observatory (APO). Our roughly 500 hours of annual observing time are split into 2 hour runs usually in the middle of every other night (see poster by K. Nault *et al.*), and frequent half-night runs devoted to physical characterization (this poster). NEO surface compositions are investigated with 0.36-1.0 µm reflectance spectroscopy using the Dual Imaging Spectrograph instrument. As of June 22, 2016 we have obtained reflectance spectra of 129 unique NEOs, ranging in diameter from approximately 5 m to 6 km.
Highlights of this work presented here include 106 spectra of (357439) 2004 BL86 spanning 3 hours 4.5 minutes, more than a full rotation, and spectra of 18 objects with diameters comparable to historical Earth impactors (*e.g.*, Tunguska, Chelyabinsk and smaller bolides).
This work is based on observations obtained with the APO 3.5-meter telescope, which is owned and operated by ARC. We gratefully acknowledge support from NASA NEOO award NNX14AL17G, and thank the University of Chicago Department of Astronomy and Astrophysics for observing time in 2014.

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325.13 – The Four-Color Broadband Photometry for Physical Characterization of Fast Rotator NEOs

Fast rotator NEOs, having size in the range of several meters in diameter (H > 22), turn to be very faint. In order to study their physical characterization using photometry, it is required to use a system of filters that covers for each of them a large bandwidth of at least 0.8 micrometers. Traditional and inexpensive Johnson-Cousins broadband filters (B, V, R, I) work efficiently well.
11 NEOs were observed at the Vatican Advanced Technology Telescope (VATT) from 2014 to 2016. Their absolute magnitudes range from 21.9 to 28.2. We found that their spin rates vary from 0.172+/- 0.003 to 2.300 +/- 0.003 hours. 6 of them (2014 AY28, 2015 TB25, 2015 VM64, 2015 VT64, 2015 XZ1, and 2016 GW221) are clearly of C-type and dominate our sample, while one (2014 KS40) belongs to X-type. One NEO (2016 EW1) falls between C-type and S-type asteroids on the plot (B-V) versus (V-R) while on the plot (V-I) versus (V-R), it is among C-type asteroids. We rule it to be C-type asteroid. NEO 2014 WF201 stays between C-type and S-type on both plots.
NEO 2014 EC appears to us of very special interest as its V-R color index is close to zero. Its relative reflectance normalized to R-filter shows that it belongs to B-type asteroid. Would it be an indication of fresh interior material excavated by a recent impact?

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325.14 – Characterization of the high-albedo NEA 3691 Bede

Characterization of NEAs provides important inputs to models for atmospheric entry, risk assessment and mitigation. Diameter is a key parameter because diameter translates to kinetic energy in atmospheric entry. Diameters can be derived from the absolute magnitude, H(PA=0deg), and from thermal modeling of observed IR fluxes. For both methods, the albedo (pv) is important – high pv surfaces have cooler temperatures, larger diameters for a given Hmag, and shallower phase curves (larger slope parameter G). Thermal model parameters are coupled, however, so that a higher thermal inertia also results in a cooler surface temperature. Multiple parameters contribute to constraining the diameter.
Observations made at multiple observing geometries can contribute to understanding the relationships between and potentially breaking some of the degeneracies between parameters. We present data and analyses on NEA 3691 Bede with the aim of best constraining the diameter and pv from a combination of thermal modeling and light curve analyses. We employ our UKIRT+Michelle mid-IR photometric observations of 3691 Bede's thermal emission at 2 phase angles (27&43 deg 2015-03-19 & 04-13), in addition to WISE data (33deg 2010-05-27, Mainzer+2011).
Observing geometries differ by solar phase angles and by moderate changes in heliocentric distance (e.g., further distances produce somewhat cooler surface temperatures). With the NEATM model and for a constant IR beaming parameter (eta=constant), there is a family of solutions for (diameter, pv, G, eta) where G is the slope parameter from the H-G Relation. NEATM models employing Pravec+2012's choice of G=0.43, produce D=1.8 km and pv≈0.4, given that G=0.43 is assumed from studies of main belt asteroids (Warner+2009). We present an analysis of the light curve of 3691 Bede to constrain G from observations. We also investigate fitting thermophysical models (TPM, Rozitis+11) to constrain the coupled parameters of thermal inertia (Gamma) and surface roughness, which in turn affect diameter and pv. Surface composition can be related to pv. This study focuses on understanding and characterizing the dependency of parameters with the aim of constraining diameter, pv and thermal inertia for 3691 Bede.
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325.15 – Searching for Brazil Nuts on Q-type near-Earth Asteroids
Q-type asteroids, the best spectral analogs of ordinary chondrite meteorites have only been definitively detected in near-Earth space. S-type asteroids, the space weathered counterparts of Q-types, however, are common, indicating that surfaces exposed to the space environment are rapidly weathered. Nevertheless, the existence of Q-type asteroids is evidence that one or more processes act to freshen asteroid surfaces, overturning the regolith to expose the un-weathered material that lies beneath. Nearly all Q-type near-Earth asteroids have been shown to currently or recently exist in orbits that bring them within close proximity to at least one terrestrial planet (i.e. a few planetary radii away). This observation has been used to infer that tidal interactions during close planetary encounters cause regolith mobilization on these bodies. This mechanism may lead to particle size segregation on the surface and interior of these bodies, particularly the sorting of large boulders to the surface. Because a large number of boulders raises the average surface thermal inertia, we hypothesize that the thermal inertia of Q-type asteroids are systematically larger than the average near-Earth asteroid population.
To test this hypothesis, we determine the thermal inertia of approximately one dozen Q-type near-Earth asteroids from measurements of their thermal emission. The targets for this study are selected based on known rotation periods and observations that are made at pre- and post-opposition, with a large difference in solar phase angle. This observing geometry is crucial in constraining thermal inertia, which influences the surficial diurnal temperature variation and thus the thermal emission as a function of phase angle. We have been acquiring observations at 3.6 and 4.5 µm with the InfraRed Array Camera (IRAC) on the Spitzer Space Telescope. At these wavelengths, the measured flux is generally dominated by thermal flux, but may contain a component of reflected flux. A model that removes the reflected light component is therefore used to isolate the thermal flux. We will present the thermal flux measurements along with our thermal inertia estimates in the context of the “tidal freshening” hypothesis
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325.16 – Simulating regolith ejecta due to gas impingement
Space missions operating at or near the surface of a planet or small body must consider possible gas-regolith interactions, as they can cause hazardous effects or, conversely, be employed to accomplish mission goals. They are also directly related to a body’s surface properties; thus understanding these interactions could provide an additional tool to analyze mission data. The Python Regolith Interaction Calculator (PyRIC), built upon a computational technique developed in the Apollo era, was used to assess interactions between rocket exhaust and an asteroid’s surface. It focused specifically on threshold conditions for causing regolith ejecta. To improve this model, and learn more about the underlying physics, we have begun ground-based experiments studying the interaction between gas impingement and regolith simulant. Compressed air, initially standing in for rocket exhaust, is directed through a rocket nozzle at a bed of simulant. We assess the qualitative behavior of various simulants when subjected to a known maximum surface pressure, both in atmosphere and in a chamber initially at vacuum. These behaviors are compared to prior computational results, and possible flow patterns are inferred. Our future work will continue these experiments in microgravity through the use of a drop tower. These will use several simulant types and various pressure levels to observe the effects gas flow can have on target surfaces. Combining this with a characterization of the surface pressure distribution, tighter bounds can be set on the cohesive threshold necessary to maintain regolith integrity. This will aid the characterization of actual regolith distributions, as well as informing the surface operation phase of mission design.
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325.17 – M4AST - A Tool for Asteroid Modelling
M4AST (Modelling for asteroids) is an online tool devoted to the analysis and interpretation of reflection spectra of asteroids in the visible and near-infrared spectral intervals. It consists into a spectral database of individual objects and a set of routines for analysis which address scientific aspects such as: taxonomy, curve matching with laboratory spectra, space weathering models, and mineralogical diagnosis. Spectral data were obtained using groundbased facilities; part of these data are precompiled from the literature[1].
The database is composed by permanent and temporary files. Each

permanent file contains a header and two or three columns (wavelength, spectral reflectance, and the error on spectral reflectance). Temporary files can be uploaded anonymously, and are purged for the property of submitted data. The computing routines are organized in order to accomplish several scientific objectives: visualize spectra, compute the asteroid taxonomic class, compare an asteroid spectrum with similar spectra of meteorites, and computing mineralogical parameters. One facility of using the Virtual Observatory protocols was also developed.
A new version of the service was released in June 2016. This new release of M4AST contains a database and facilities to model more than 6,000 spectra of asteroids. A new web-interface was designed. This development allows new functionalities into a user-friendly environment. A bridge system of access and exploiting the database SMASS-MIT (http://smass.mit.edu) allows the treatment and analysis of these data in the framework of M4AST environment.
Reference:
[1] M. Popescu, M. Birlan, and D.A. Nedelcu, "Modeling of asteroids: M4AST," *Astronomy & Astrophysics 544*, EDP Sciences, pp. A130, 2012.
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325.18 – The composition of the Eureka family of Martian Trojan asteroids

The so-called Martian Trojan asteroids orbit the Sun just inside the terrestrial planet region. They are thought to date from the earliest period of the solar system's history (Scholl et al, Icarus, 2005). Recently, Christou (Icarus, 2013) identified an orbital concentration of Trojans, named the "Eureka" cluster after its largest member, 5261 Eureka. This asteroid belongs to the rare olivine-rich A taxonomic class (Rivkin et al, Icarus, 2007; Lim et al, DPS/EPSC 2011). Unlike asteroids belonging to other taxonomies (e.g. C or S), no orbital concentrations or families of A-types are currently known to exist. These asteroids may represent samples of the building blocks that came together to form Mars and the other terrestrial planets but have since been destroyed by collisions (Sanchez et al, Icarus, 2014, and references therein).
We have used the X-SHOOTER echelle spectrograph on the ESO VLT KUEYEN to obtain vis-NIR reflectance spectra of asteroids in the cluster and test their genetic relationship to Eureka. During the presentation we will show the spectra, compare them with available spectra for Eureka itself and discuss the implications for the origin of this cluster and for other olivine-dominated asteroids in the Main Belt.
Based on observations made with ESO Telescopes at the La Silla-Paranal Observatory under programme ID 296.C-5030 (PI: A. Christou). Astronomical Research at Armagh Observatory is funded by the Northern Ireland Department of Culture, Arts and Leisure (DCAL).
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325.19 – M-type asteroids in the mid-infrared: thermal inertias and emissivity spectra

The M-type asteroid taxon has been inferred to contain metallic asteroids. This inference comes mainly from spectral analogy to iron meteorites and from the observation of high radar albedos among M-types. There is, nevertheless, evidence for significant compositional diversity within the M-type population. Spectral signatures of both high-temperature silicates (λ~0.9 μm) and hydrated minerals (λ~3 μm) are common in this group. The nature of the M-types is, therefore, still not well understood. In order to further test the hypothesis that many M-types are metallic, we have undertaken an observational study at mid-infrared wavelengths (5.2 – 38 μm). Our aim is to characterize the silicate composition and the thermal properties of a sample of M-type asteroids. If metallic, we expect relatively high thermal inertia and an absence of silicate emissivity features. The spectra we analyze were measured with the InfraRed Spectrograph (IRS) on the Spitzer Space Telescope. We present emissivity spectra and the initial results of thermophysical modeling, including derived thermal inertias. We chose our sample because these asteroids have also been observed at complementary wavelengths, such as visible, near-infrared and radar, which places further constraints on the interpretation of our results.
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325.20 – Compositional characterization of asteroid (16) Psyche

We present near-infrared spectra (0.7-2.5 microns) of asteroid (16) Psyche obtained with the NASA Infrared Telescope Facility. Rotationally-resolved spectra were obtained during three nights between December 2015 and February 2016. These data have been combined with three-dimensional shape models of Psyche generated with the SHAPE software package (Magri et al. 2007). From each spectrum, the band center, band depth and spectral slope were measured. We found that the band center varies from 0.92 to 0.94 microns with rotation phase, with an average value of 0.932±0.006 microns. The band depth was found to vary from 1.0 to 1.5±0.1%. Spectral slope values range from 0.25 to 0.35±0.01 microns^{-1}, with rotation phase. We observed a possible anti-correlation between band depth and radar albedo. Using the band depth along with a new laboratory spectral calibration we estimated that Psyche has an average orthopyroxene abundance of 6±1%. The mass-deficit region of Psyche (longitudes ~ 0°-40°), characterized by having the highest radar albedo of the asteroid, also shows the highest value for the spectral slope and the minimum band depth, while the antipode of this region (longitudes ~ 180°-230°), where the radar albedo reaches its lowest value, shows a maximum in band depth and less steep spectral slopes. These results could suggest that the metal-poor antipode region has thicker regolith rich in pyroxene compared to the mass-deficit region.
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325.21 – Basalt here, basalt there: Constraining the basaltic nature of eight Vp-type asteroids in the inner and outer main asteroid belt

The distribution and abundance of basaltic material in the main asteroid belt has multiple implications that impact our understanding of the physical and thermal conditions that existed in the inner solar system during the formation epoch about 4.6 Gyr ago. Subjects impacted by a more accurate basaltic asteroid inventory include the efficacy of current inner solar system heating model predictions (Al-26 and T Tauri induction heating), the existence of differentiated parent bodies other than (4) Vesta, the dispersion efficiency of Vestoids by YORP forces, and the predictive ability of the V-taxonomy in predicting a basaltic surface composition. This work reports on a continuation of an effort to better constrain the basaltic asteroid population in the main asteroid belt with the goal of observing about 650 V_p-type asteroids. This work focuses on two populations: a) those V_p-classified asteroids (Carvano et al., 2010) in the spatial vicinity of (4) Vesta (candidate Vestoids) in the inner main belt, and b) V_p-classified asteroids in the outer main belt beyond 2.5 AU. Thus far, 23 V_p-type asteroids and candidate Vestoids have been observed and analyzed, which are all strongly suggestive of a basaltic surface composition (Hardersen et al., 2014, 2015, 2016 (in preparation)). However, unpublished work is beginning to show that the V_p taxonomic class is less accurate in its ability to identify basaltic surface compositions in outer-belt V_p-type asteroids. We report here on an additional set of V_p-type asteroids that were observed at the NASA Infrared Telescope Facility (IRTF) in December 2015 and January 2016. All observations were obtained with the SpeX spectrograph in prism mode with spectral range from 0.7 to 2.5 microns. They include (4900) Maymelou, (7302) 1993 CQ, (9064) Johndavies, (9531) Jean-Luc, (11341) Babbage, (17480) 1991 PE10, (20171) 1996 WC2, and (25849) 2000 ET107. We present average near-infrared (NIR) reflectance spectra of each asteroid, determine the spectral band parameters necessary for band analysis (band centers, band areas, Band Area Ratios), and provide initial analysis of the basaltic affinities for these asteroids.

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325.22 – Non-detection of gaseous H2O on Asteroids (24) Themis and (65) Cybele using the Herschel HIFI instrument

The detection of water ice on Asteroids (24) Themis and (65) Cybele and comet-like activity on some asteroids have recently provided evidence for water ice in the outer asteroid belt. This supports the suggestion that water in the Earth's oceans may have been delivered from the outer asteroid belt.

On both (24) Themis and (65) Cybele, rotationally resolved near-IR spectra indicated the presence of widespread ice on their surfaces. While the detection of ice served to indicate the wider prevalence of water among minor Solar System bodies, the detection of outgassing through sublimation of this water is considered to be a crucial step in confirming the interpretation of the 2-4 micron spectra. Indeed, an alternative interpretation of the absorption at 3.1 microns has been suggested thus the detection of gaseous H_2O around either, or both, of these asteroids would be a definitive test of the source of this band.

Observations performed on these two asteroids using ground-based ultraviolet and radio telescopes in the search for sublimation of this ice through OH emission were published in late 2010. However the OH observations could not confirm an exosphere but rather served to provide an upper limit of 10^{28} molec./sec on this emission.

We used the Herschel HIFI Instrument (Wide Band Spectrometer (WBS) and High resolution Spectrometer (HRS)) to observe (65) Cybele on the 21st December 2012 and(24) Themis on the 30th January 2013,. In both cases, the line emission from the fundamental ortho-H2O $1_{1\text{-}0}$ - $1_{0\text{-}1}$ line of ortho-water at 556.936 GHz was searched for in the upper sideband of the HIFI band 1a mixer. Although for both asteroids no water signal was detected, very sensitive 3σ upper-limits were obtained in each case.

This talk will summarise the observations carried out, present the results we obtained in each case and finally address the implications of these results on the overall knowledge existing on these asteroids.

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325.23 – Asteroid (16) Psyche: Triaxial Ellipsoid Dimensions and Rotational Pole from Keck II NIRC2 AO Images and Keck I OSIRIS Images

Adaptive optics (AO) images of asteroid (16) Psyche obtained at 4 epochs with the NIRC2 camera at the 10m W. M. Keck Observatory (Keck II) on UT 2015 December 25 lead to triaxial ellipsoid diameters of 279±4 x 230±2 x 195±14 km, and a rotational pole at RA=29° and Dec=-2°. Adding 6 more epochs obtained nearly simultaneously with the OSIRIS system at Keck I, as well as two more epochs from Keck II in 2009, yields diameters of 273±2 x 232±2 x 165±3 km, and a pole at RA=37° and Dec=+1°. (Errors are formal fit parameter uncertainties; an additional 4% uncertainty is possible from systematic biases.) The differing perspectives between 2015 (sub-Earth latitude Θ=-50°) and 2009 (Θ=-6°) improves primarily the *c* dimension and the location of the rotational pole, but illustrates how well images from even a single night can determine the size, shape, and pole of an asteroid. The 2015 observations were obtained as part of a campaign to study Psyche with many techniques over a few months, including radar from Arecibo and images from Magellan.

These handful of images show the same rugged outline as the radius vector model available on the DAMIT website, constructed from many lightcurves and scaled by previous Keck AO images. In fact Psyche has rotated some 125,350 times between the first lightcurve in 1955 and our 2015 AO images, exactly 60 years apart to the day. Since the asteroid has such a high obliquity, these lightcurves have scanned well into both northern and southern hemispheres. The difference between the pole derived from our images and the radius vector model pole is only 7°, and the mean diameters of Psyche are 219 and 211 km, respectively.

Author(s): Jack D. Drummond[2], Al Conrad[1], Vishnu Reddy[3], Katherine R. de Kleer[5], Mate Adamkovics[5], Imke de Pater[5], William J. Merline[4], Peter Tamblyn[4]
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325.24 – Comparing near-surface and bulk densities of asteroids using radar scattering properties

Dual-polarization radar measurements of asteroids provide a joint constraint on the near-surface density and porosity, which can give insights on asteroid composition and evolution. Magri et al. (2001) used (433) Eros radar and spacecraft data as calibration for estimating the near-surface densities and porosities of 45 other radar-detected asteroids (36 main-belt and 9 near-Earth). At that time, only (433) Eros had both radar observations and a measured bulk density. Now that there have been spacecraft observations of several other asteroids and radar measurements of the densities of several binary near-Earth asteroids with various compositions, we can expand the calibration to include those objects. We begin by applying the method of Magri et al. to Ceres, Vesta, Itokawa, 1994 CC, 2001 SN263, 1998 QE2, and 2000 DP107 to explore the differences between the bulk density and the near-surface density measured with radar. We expect significant differences between Ceres and Vesta and the small near-Earth asteroids as the porosities of these objects are expected to be quite different. However, we expect that small binary objects likely have similar internal structures, so that any differences should depend on composition and perhaps surface weathering.

Reference: Magri et al., "Radar constraints on asteroid Properties using 433 Eros as ground truth". Meteoritics & Planetary Science 36, 1697-1709, 2001.

Author(s): Luisa Fernanda Zambrano Marin[3], Michael C. Nolan[2], Patrick A. Taylor[1], Anne Virkki[1]

Institution(s): *1. Arecibo Observatory , 2. U. Arizona, 3. University of Granada*

325.25 – Chemical fractionation resulting from the hypervelocity impact process on metallic targets

In a regime of hypervelocity impact cratering, the internal energy deposited in target + projectile region is large enough to melt and/or vaporize part of the material involved, which expands rapidly away from the impact site. Fast and energetic impact processes have therefore important chemical consequences on the projectile and target rock transformations during major impact events. Several physical and chemical processes occurred indeed in the short duration of the impact, e.g., melting, coating, mixing, condensation, crystallization, redox reactions, quenching, etc., all concurring to alter both projectile and target composition on the irreversible way. In order to document such hypervelocity impact chemical fractionation, we have started a program of impact experiments by shooting doped (27 trace elements) millimeter–sized basalt projectiles on metallic target using a two stages light gas gun. With impact velocity in the range from 0.25 to 7 $km.s^{-1}$, these experiments are aimed i) to characterize chemically and texturally all the post-mortem materials (e.g., target, crater, impact melt, condensates, and ejectas), in order ii) to make a chemical mass balance budget of the process, and iii) to relate it to the kinetic energy involved in the hypervelocity impacts for scaling law purpose. Irrespective of the incident velocities, our preliminary results show the importance of redox processes, the significant changes in the ejecta composition (e.g., iron enrichment) and the systematic coating of the crater by the impact melt [1]. On the target side, characterizations of the microstructure of the shocked iron alloys to better constrain the shielding processes. We also show how these results have great implications in our understanding on the current surface properties of small bodies, and chiefly in the case of M-type asteroids.

[1] Ganino C, Libourel G, Nakamura AM & Michel P (2015) Goldschmidt Abstracts, **2015** 990.

Author(s): Guy Libourel[2], Clément Ganino[2], Patrick Michel[2], Akiko Nakamura[1]

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325.26 – DEEP-South: A New Taxonomic Classification Scheme of Asteroids

Surface mineralogy of asteroids has long been inferred from spectroscopic observations with a range of wavelengths spanning from the ultraviolet to the mid-infrared. Accordingly, their traditional taxonomic classification has been based on spectral slopes and absorption features of the population. In this approach, taxonomic classes are grouped and divided into four broad complexes; silicates (S), carbonaceous (C), featureless (X), Vestoids (V), and the end-members that do not fit well within the S, C, X and V complexes. The extension of the classification scheme has recently been done in the analysis of the SDSS 4th Moving Object Catalog (MOC 4) data. However, the boundaries of each complex and subclass are rather ambiguously defined. Further, there are only few studies on asteroid taxonomy using Johnson-Cousins filters, and those were conducted on a small number of objects, with significant uncertainties. In this paper, we present our preliminary results for a new taxonomic classification of asteroids using SMASS, DeMeo and Carry (2013) and the SDSS MOC 4 datasets. This classification scheme is simply represented by a triplet of photometric colors, either in SDSS, or in Johnson-Cousins photometric systems.

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Institution(s): *1. Korea Astronomy and Space Science Institute*

325.27 – The NEOShield-2 EU Project – The first year of the Italian contribution

The population of Near Earth Asteroids (NEAs) is responsible for a continuous flux of impactors with our planet. To date, more than 14500 NEAs are known, with a current discovery rate of ~1500 objects/year.

The NEA population show a great diversity in terms of composition and physical properties: (different shapes, rotational states, rotational periods...). NEA diversity is also emphasized by the different taxonomic types found within the population that give some hints about the NEA surface composition.

The study of their physical nature is compelling in view of the potential hazard posed to our planet, since it has been acknowledged that whatever the mitigation scenario, it strongly depends upon the composition of the impactor. Unfortunately, only less than 15% of them have been physically characterized, and at the current discovery rate the situation is becoming progressively worse.

Within the framework of the Horizon 2020 program, the European Commission promoted the study of NEAs by approving and financing the NEOShield-2 project (2015-2017). One of the main aims of the NEOShield-2 project is to undertake an extensive observational campaign to provide physical and compositional characterization of a large number of NEAs in the 50-300 m size range.

INAF-OAR and Padova University, the Italian contributors to the NEOShield-2 project, are responsible for the Task 10.2.1 'Colours and Phase function', with the aim to acquire photometric measurements for a wide sample of NEOs. An operational interface is maintained together with the ESA SSA-NEO Coordination Centre (NEOCC) in order to optimize observations devoted to physical characterization.

We will present the results of the first year of the Italian contribution to the project on i) phase function analysis, ii) surface colors and iii) preliminary taxonomical classification and the statistical analysis of the data obtained from several telescopes around the world.

This research has been funded with support from the European Commission (grant agreement no: 640351 H2020- PROTEC-2014 - Access technologies and characterisation for Near Earth Objects (NEOs).

Author(s): Simone Ieva[2], Elisabetta Dotto[2], Elena Mazzotta Epifani[2], Andrea Di Paola[2], Roberto Speziali[2], Monica Lazzarin[5], Ivano Bertini[5], Maria Antonieta Barucci[3], Davide Perna[3], Daniela Lazzaro[4], Sergio Silva[4], Filipe Monteiro[4], Ettore Perozzi[1], Marco Micheli[1], Matteo Cortese[1]

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325.28 – Visualization of Near-Infrared Spectral Data of Eros Using the Small Body Mapping Tool

One of the primary drivers for many missions visiting asteroids is to advance our understanding of their composition beyond what can be (and is) already measured by telescopes. Without sample return or lander missions, this task relies primarily on resolved near-infrared spectroscopic measurements. Scientific analysis using spectral data collected by point spectrometers is not as straightforward as for imaging spectrometers, where the local spatial context is immediately available. In the case of Eros and other highly non-spherical bodies, this problem becomes even more severe when trying to locate spectra that cross a mapped feature that bends over an irregularly shaped surface. Thus, it is often the case that outside of the mission teams, few from the community at large delve into these data sets, as they lack the tools necessary to incorporate the spectral information into geological analyses of the asteroids. Ultimately, we seek to make such spectral datasets, which NASA has invested significant amounts of money to obtain, more widely accessible and user-friendly. The Small Bodies Mapping Tool (SBMT) is a Java-based, interactive, three-dimensional visualization tool written and developed at APL to map and analyze features on irregularly shaped solar system bodies. The SBMT can be used to locate and then "drape" spacecraft images, spectra, and laser altimetry around the shape model of such bodies. It provides a means for rapid identification of available data in a region of interest and allows features to be mapped directly onto the shape model. The program allows the free rotation of a shape model (including any overlain data) in all directions, so that the correlation and distribution of mapped features can be easily and globally observed. We will present the results of our work on the NEAR/Near-Infrared Spectrograph (NIS) data, including improvements to the calibration made by using the geometric information provided by the SBMT and improvements to the SMBT itself to allow spectral visualization, manipulation, and analysis of these data in a spatial context.

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326 – Asteroid Spin States Posters

326.02 – 2013 Apparition of Near-Earth Asteroid (52760) 1998 ML14: Radar and Optical Constraints on Shape and Spin State

Radar images taken by the Arecibo and Goldstone planetary radar systems in 1998 were used by Ostro et al. (Meteoritics & Planetary Science, 36, 1225-1236, 2001) to produce a shape model of the approximately 1-km diameter near-Earth asteroid (52760) 1998 ML14; however, the spin state (pole orientation and rotation period) was not well determined in their modeling. The published shape model was produced using a 14.83 h sidereal rotation period, consistent with the synodic period of 14.98 ± 0.06 h found by optical observations in 1998 (Hicks & Weissman, IAU Circular 6987, 1, 1998). Optical observations in 2013 found a faster synodic period of 14.28 ± 0.01 h (Warner, The Minor Planet Bulletin, 41, 2, 113-124, 2014). Further radar observations at Arecibo in 2013 are inconsistent with the 14.83 h sidereal period. Use of Arecibo radar images from both apparitions, with resolution as fine as 15 m per pixel, are best fit by a sidereal period within 1% of 14.28 h and constrain the pole orientation to within approximately ten degrees. This period is consistent with all radar and lightcurve data. An updated shape model, combining all known observations, will be presented in light of the constraints on ML14's spin state. The model suggests the presence of several smaller topographic features not previously seen, but remains consistent with major features of the previously published model (notably a distinctive saddle-like region).This improved model illustrates the power of multiple radar apparitions for better determining the true shapes and spin states of near-Earth asteroids, as well as the benefits of multiple observers operating at different wavelength regimes.

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326.03 – Rotational properties of L4 Trojan asteroids from K2

Our understanding of solar system formation is undergoing a renaissance as new planetary systems are found, often unlike our own. Many questions now ask how the giant planets and their satellite systems accreted and if there is evidence that they migrated to new orbital positions. One of the keys to understanding these questions within our own solar system is the Jupiter Trojan population which is co-orbital with Jupiter. The two Trojan clouds at the stable L4 and L5 Lagrangian points are in orbits which are stable over the age of the Solar System, unlike many other present epoch small body populations. Planetary migration models suggest that the Trojan asteroids, and the dynamically hot (i.e. "scattered"), population of Kuiper Belt objects originate from the same region in the early solar system. While these objects would have started with the same compositions, establishing compositional linkages is challenging and complicated due to a paucity of distinct and easily identifiable mineralogical features in the optical, where these objects are the brightest. While the surface compositions and colors of the Trojans match objects in the inner solar system, as well as the Kuiper Belt, physical characterization of this large population of objects has been scarce. During Campaign 6 in late 2015, the 115 square degree K2 spacecraft field of view overlapped with the L4 Trojan cloud, allowing for long term monitoring. We report on the fitted rotational periods and lightcurve amplitudes from 56 Trojan asteroids that were observed for an average of 11 days by K2. We find ~20% of objects have rotational periods longer than 50 hours and ~40% of the objects have lightcurves with shapes characteristic of contact binary systems.

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326.04 – Spin Vector Distribution in the Koronis Family for a Sample Complete to IAU *H*=10.88

Because they share the same formation age, asteroid family members have experienced similar evolution for similar lengths of time, offering valuable information to help understand spin evolution processes. Clustered distributions of spin vectors determined from observations of ten of the largest Koronis family members (Slivan 2002) revealed evidence of spin modification by YORP thermal radiation torques (Vokrouhlický et al. 2003). The currently known spin vector sample in the Koronis family (Slivan et al., 2003; Slivan et al., 2009, Hanuš et al., 2011; Hanuš et al., 2013; Durech et al., 2016) clearly shows the two spin groupings observed among the large members: (1) the larger group with low-obliquity retrograde spin and periods between about 3 h and 30 h, and (2) a smaller group with prograde spin obliquity near 45° and periods near 8 h, characteristic of trapping in the s_6 spin-orbit resonance (Vokrouhlický et al. 2003). There's also one "stray" longer-period prograde object with smaller obliquity, perhaps trapped in some other resonance.

A limitation of the existing spin vector sample, which (using IAU *H* as a proxy for size) includes 16 of the brightest 27 members of the family, is that selection biases render it complete only to the brightest 12 members. Slivan et al. (2008) began a lightcurve observing program to increase the sample of Koronis family spin vectors down to about 20 km diameter.

We report pole solutions that were determined for fourteen survey objects using lightcurves recorded from 2005–2016, which complete the Koronis spin vector sample to the brightest 22 members, now including 24 of the brightest 27 members. The larger sample adds several objects to the existing group of low-obliquity retrograde rotators, increasing the period range upward to almost 60 h, and also identifies two companions for the stray longer-period prograde spin object, strengthening the case for the presence of a second cluster of objects trapped in a spin-orbit resonance. The more complete distribution also reveals two new "strays" of its own - one lone fast prograde rotator, and one spin vector of atypical high obliquity, close to the ecliptic plane.

Author(s): Stephen M. Slivan[9], Matt Hosek[7], Alyssa Sokol[8], Sarah Maynard[9], Anna Payne[1], Arden Radford[9], Alessondra Springmann[6], Emily Mailhot[2], Alan Midkiff[3], April Russell[5], Robert D. Stephens[4]
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326.05 – Uncertainty maps for asteroid shape and pole solutions

SAGE (Shaping Asteroids with Genetic Evolution) inversion method is based on genetic algorithm to obtain pole solutions, rotation periods and non-convex shapes of asteroids (Bartczak et.al, 2014). During the process computer graphics methods are used to compare model's synthetic lightcurves to photometric observations. The method is suitable for modelling both single and binary objects. A modelling run starts with a sphere, with no assumptions about the shape, and subsequently it converges to a stable spin and shape solution. Center of mas and moment of inertia are calculated for each model.
Modelling of an asteroid consists of multiple runs of the process, each of them following different path towards a stable solution. As a result we obtain a family of solutions. If enough data is provided, solutions are consistent with each other and can be used for error estimation.

We choose only the best models from a family of solutions, meaning every model that fits 5% threshold above best χ2 found. By comparing them we are able to construct a map of uncertainties for the shape, showing areas in good and poor agreement with chosen models. Such map can then be represented with a 3D visualisation. Moreover, we create a map of errors for pole solutions and periods.

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326.06 – Shaping Asteroid with Genetic Evolution (SAGE) using lightcurve and radar data

We are presenting new module added to SAGE (Shaping Asteroids with Genetic Evolution) algorithm (Bartczak et.al, 2014) which employs radar echo images.
Asteroids can be observed using many ground-based techniques, some of which allow for direct shape observations (eg. stellar occultations, adaptive optics imaging). One interesting, information-rich technique is radar imaging. It provides insights about surface properties, sizes, pole orientations and shapes of asteroids (Ostro, 2012). Radar echo images can be used both for modelling asteroids and testing results from lightcurve inversion methods. We aim to use radar images in SAGE algorithm the same way we use lightcurves.
Genetic algorithm starts with the sphere and random values for pole orientation. Then, by introducing small, random changes to the model parameters, a population of shapes and spin states is created. Subsequently, best model from the population is chosen and process is repeated until stable solution is reached. Assuming even distribution of mass we calculate center of mass and moment of inertia for each model.
For every intermediate step model we calculate synthetic lightcurves and compare it with observations with χ^2 test. Following the same principle, we create simulated radar echo images for a model and compare them with the observed ones. Both χ^2 values for lightcurve and radar are then used as a benchmark for choosing the best model in given population. The best one found serves as a starting model for the next generation of randomly modified models.
We are showing a model of 1996HW1 obtained using the described method.

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326.07 – Distribution of spin axes and shape elongations of main-belt asteroids

Photometric data that are sparse in time (typically few measurements per night over ~15 years) are a potential source of information about shapes and rotational states of asteroids. However, currently available data are usually not accurate enough to derive a unique sidereal rotation period and corresponding shape model by the lightcurve inversion method. To fully utilize sparse-in-time data, we have developed a new simplified model that provides an approximate solution for the orientation of the spin axis (λ, β) and ratios of axes of the ellipsoid, a/b, b/c (asteroids are modelled as geometrically scattering triaxial ellipsoids). The observed values of mean brightness (over one apparition) and the dispersion of brightness are compared with values computed from the model parameters (λ, β, a, b, setting c=1) which are optimized to get the best agreement. The model was applied on the data from Lowell photometric database. We found that the distribution of pole ecliptic longitude λ is nonuniform and that this nonuniformity is larger for asteroids with low inclination of their orbits. The second main result is that small asteroids (D<25 km) are on average more elongated (a/b ~ 1.6) than the large ones (for D>50 km the mean value ofa/b is 1.3).

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326.08 – Small Bodies: Near and Far (SBNAF)

We conduct an EU Horizon2020-funded benchmark study (2016-2019) that addresses critical points in reconstructing physical and thermal properties of near-Earth, main-belt, and trans-Neptunian objects. The combination of the visual and thermal data from the ground and
from astrophysics missions (like Herschel, Spitzer and Akari) is key to improving the scientific understanding of these objects. The development of new tools will be crucial for the interpretation of much larger data sets from WISE, Gaia, JWST, or NEOShield-2, but also for the operations and scientific exploitation of the Hayabusa-2 mission. Our approach is to combine different methods and techniques to get full information on selected bodies: lightcurve inversion, stellar occultations, thermo-physical modeling, radiometric methods, radar ranging and adaptive optics imaging. The applications to objects with ground-truth information from interplanetary missions Hayabusa, NEAR-Shoemaker, Rosetta, and DAWN allows us to advance the techniques beyond the current state-of-the-art and to assess the limitations of each method.
The SBNAF project will derive size, spin and shape, thermal inertia, surface roughness, and in some cases even internal structure and composition, out to the most distant objects in the Solar System. Another important aim is to build accurate thermo-physical asteroid models
to establish new primary and secondary celestial calibrators for ALMA, SOFIA, APEX, and IRAM, as well as to provide a link to the high-quality calibration standards of Herschel and Planck.The target list comprises recent interplanetary mission targets, two samples of main-belt

objects, representatives of the Trojan and Centaur populations, and all known dwarf planets (and candidates) beyond Neptune. Our team combines world- leading expertise in different scientific areas in a new European partnership with a high synergy potential in the field of
small body and dwarf planet characterization, related to astrophysics, Earth, and planetary science. This research project has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 687378.
Author(s): Rene Duffard[2], Thomas G. Mueller[4], Anna Marciniak[1], Toni Santana-Ros[1], Jose-Luis Ortiz[2], Pablo Santos-Sanz[2], Fernandez-Valenzuela Estela[2], Csaba Kiss[3],Verebelyi Erika[3], Przemyslaw Bartczak[1], Butkiewicz-Bak Magda[1], Grzegorz Dudziński[1], Szakáts Robert[3], Takácsné Farkas Aniko[3]
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326.09 – Some (Apparently) Very Wide Binary Asteroids

We present lightcurves for some of the approximately one dozen asteroids that appear to be very widely-separated binaries. Jacobsen et al. (2014, ApJ 780) attribute their formation to a somewhat complex series of events involving BYORP.
The lightcurves consist of two components: Period 1 (P_1) is very long, P_1 = 50-600 h, with amplitudes of A_1 = 0.23-1.0 mag. The second period and amplitudes are similar to the primaries of close binary systems, i.e., P_2 = 2.2-3.6 h, A_2 ~ 0.10 mag. Two candidates have secondary periods in the range of 5-7 hours. The most exceptional example is (19204) Joshuatree, which has values of P_1 = 480 h, A_1 = 0.25 mag and P_2 = 21.25 h, A_2 = 0.08 mag. Based on Jacobson et al. (2014, ApJ 780) and Pravec et al. (2016, Icarus 267), we suggest that P_1 represents the primary (larger) body of the system and P_2 represents the spin rate of the satellite.
Supporting this supposition is that the large amplitude (A_1) must be from the larger body, otherwise the dilution of amplitude would require the smaller body to be unreasonably elongate. The limiting size ratio for binaries is around 0.6 (see Pravec et al. 2010, Nature 466, Fig. 1), or a magnitude difference of about 1.0. For a secondary 1.0 mag fainter than the primary to produce a combined lightcurve amplitude of ~0.4 mag would require that the secondary undiluted amplitude to be several magnitudes (near-infinite elongation) and also a near equatorial aspect. This is not likely.
Given the lack of mutual events, these can be considered to be only possible binaries. Since the orbital period is probably very long, it seems extremely unlikely that mutual events will ever be seen.
The changing landscape of binary asteroid discoveries and theories calls for something beyond descriptive terms such as "suspicious", "possible", "likely", and "confirmed" in order to allow more accurate statistical studies. To this end, we are introducing a new "B" rating in the asteroid lightcurve database (Warner et al., 2009) that will parallel the well-known "U" rating for asteroid lightcurves i.e., it will have values from 0 to 3 with possible ± attributes. Anything rated as B ≥ 2– will be consider a valid binary for statistical studies.
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Institution(s): *1. MoreData!, Inc*

326.10 – YORP-Yarkowski evolution of asteroid families: the effects of collisions

The depletion of objects in the central part of an asteroid family, which can be observed in the absolute magnitude vs. semimajor axis, can be explained in terms of a coupling of the YORP and Yarkovsky effects (Paolicchi and Knezevic, Icarus, 2016). In particular, it can be ascribed to the obliquity evolution caused by YORP and on how it influeces the Yarkovsky drift.
With this work we intend to improve the modeling of YORP-Yarkovsky evolution of asteroid families exploiting a model which tracks the evolution of the spin vector of small asteroids, including also the effects of collisions on the YORP induced obliquity evolution. This allows a better modeling of the asteroid spin evolution.
In these preliminary steps, we will first consider a few model families simulating their time evolution in the magnitude vs. semimajor axis plots. The obtained results will be then compared with observed families to determine and tune the intensity of the effect.
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326.11 – New Approaches For Asteroid Spin State and Shape Modeling From Delay-Doppler Radar Images

Delay-Doppler radar imaging is a powerful technique to characterize the trajectories, shapes, and spin states of near-Earth asteroids; and has yielded detailed models of dozens of objects. Reconstructing objects' shapes and spins from delay-Doppler data is a computationally intensive inversion problem. Since the 1990s, delay-Doppler data has been analyzed using the SHAPE software. SHAPE performs sequential single-parameter fitting, and requires considerable computer runtime and human intervention (Hudson 1993, Magri et al. 2007). Recently, multiple-parameter fitting algorithms have been shown to more efficiently invert delay-Doppler datasets (Greenberg & Margot 2015) – decreasing runtime while improving accuracy. However, extensive human oversight of the shape modeling process is still required. We have explored two new techniques to better automate delay-Doppler shape modeling: Bayesian optimization and a machine-learning neural network.
One of the most time-intensive steps of the shape modeling process is to perform a grid search to constrain the target's spin state. We have implemented a Bayesian optimization routine that uses SHAPE to autonomously search the space of spin-state parameters. To test the efficacy of this technique, we compared it to results with human-guided SHAPE for asteroids 1992 UY4, 2000 RS11, and 2008 EV5. Bayesian optimization yielded similar spin state constraints within a factor of 3 less computer runtime.
The shape modeling process could be further accelerated using a deep neural network to replace iterative fitting. We have implemented a neural network with a variational autoencoder (VAE), using a subset of known asteroid shapes and a large set of synthetic radar images as inputs to train the network. Conditioning the VAE in this manner allows the user to give the network a set of radar images and get a 3D shape model as an output. Additional development will be required to train a network to reliably render shapes from delay-Doppler images.
This work was supported by NASA Ames, NVIDIA, Autodesk and the SETI Institute as part of the NASA Frontier Development Lab program.
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326.12 – Optical observations of NEA 162173 Ryugu (1999 JU3) during the 2016 apparition

Near-Earth asteroid 162173 Ryugu (1999 JU3) is the target of the JAXA's Hayabusa 2 spacecraft which is the first sample return mission to a C-type asteroid. The physical properties of Ryugu were investigated from vigorous ground-based observations conducted during the previous observational opportunities in the 2007 - 2008 and 2011 - 2012 apparitions. However, the pole orientation that is essential for the safety and fuel efficiency of landing and sampling on the asteroid was not precisely constrained due to large uncertainties in photometric data and small variations in the lightcurve amplitude, probably resulting from a spheroidal shape with the axial ratio a/b = 1.12. We carried out the network observations for Ryugu between European and American Continents, and also in Hawaii and Australia, during the end of July to the beginning of the August 2016 nearly simultaneously. We employed several 1-2 m class telescopes: RTT 1.5 m in Turkey, Terksol 2 m in Russia, Rozhen 2 m in Bulgaria, LCOGT 2 m Faulkes Telescopes in US and Australia, McDonald 2.1 m in USA, ZTSh 2.6 m in Crimea, Ukraine. Based on our dataset, we will present the rotational period and the amplitude using the dense lightcurve data.

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327 – Asteroids: Observational Surveys Posters

327.01 – NEOCam: The Near-Earth Object Camera

The Near-Earth Object Camera (NEOCam) is a Discovery mission in Phase A study designed to carry out a large-scale survey of the inner solar system's minor planets. Its primary science objectives are to understand the origins of the solar system's small bodies and the processes that evolved them into their present state. The mission will also characterize the impact hazard from near-Earth objects as well as rare populations such as Earth Trojans and interior-to-Earth objects. In the process, NEOCam can identify targets for future robotic or human exploration. Using a 50 cm telescope operating in two infrared wavelengths (4-5.2 and 6-10 um), the mission is expected to detect and characterize close to 100,000 NEOs and thousands of comets. By achieving high survey completeness in the main belt down to kilometer-scale objects, NEOCam-derived size and albedo distributions can be directly compared to those of the NEOs. The hypotheses that small, dark NEOs and comets are preferentially disrupted at low perihelia can be tested by searching for correlations between size, orbital elements, and albedos. NEOCam's Sun-Earth L1 Lagrange point halo orbit enables a large instantaneous field of regard with a view of low solar elongations, high data rates, and a cold thermal environment. Like its predecessor, WISE/NEOWISE, candidate minor planet detections will be rapidly disseminated to the community via the Minor Planet Center. NEOCam images, source databases, and tables of derived physical properties will be delivered to the community via NASA's Infrared Science Archive and PDS.

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Contributing team(s): NEOCam Science Team

327.02 – NEOWISE diameters and albedos: now available on PDS!

We present the recent PDS release of minor planet physical property data from the WISE/NEOWISE fully cryogenic, 3-band cryo, and post-cryo surveys as well as the first year of the NEOWISE-Reactivation survey. This release includes 165,865 diameters, visible albedos, near-infrared albedos, and/or beaming parameters for 140,493 unique minor planets. The published data include near-Earth asteroids, Main Belt asteroids, Hildas, Jupiter Trojans, Centaurs, active Main Belt objects and irregular satellites of Jupiter and Saturn. We provide an overview of the available data and discuss the key features of the PDS data set. The data are available online at: http://sbn.psi.edu/pds/resource/neowisediam.html.

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327.03 – Asteroid spin and shape modelling using two lightcurve inversion methods

We are conducting an observing campaign to counteract strong selection effects in photometric studies of asteroids. Our targets are long-period (P>12 hours) and low-amplitude (a_max<0.25 mag) asteroids, that although numerous, have poor lightcurve datasets (Marciniak et al. 2015, PSS 118, 256). As a result such asteroids are very poorly studied in terms of their spins and shapes. Our campaign targets a sample of around 100 bright (H<11 mag) main belt asteroids sharing both of these features, resulting in a few tens of new composite lightcurves each year. At present the data gathered so far allowed to construct detailed models for the shape and spin for about ten targets.
In this study we perform spin and shape modelling using two lightcurve inversion methods: convex inversion (Kaasalainen et al. 2001, Icarus, 153, 37) and nonconvex SAGE modelling algorithm (Shaping Asteroids with Genetic Evolution, Bartczak et al. 2014, MNRAS, 443, 1802). These two methods are independent from each other, and are based on different assumptions for the shape.
Thus, the results obtained on the same datasets provide a cross-check of both the methods and the resulting spin and shape models. The results for the spin solutions are highly consistent, and the shape models are similar, though the ones from SAGE algorithm provide more details of the surface features. Nonconvex shape produced by SAGE have been compared with direct images from spacecrafts and the first results for targets like Eros or Lutetia (Batczak et al. 2014, ACM conf. 29B) provide a high level of agreement.
Another way of validation is the shape model comparison with the asteroid shape contours obtained using different techniques (like the stellar occultation timings or adaptive optics imaging) or against data in thermal infrared range gathered by ground and space-bound observatories. The thermal data could provide assignment of size and albedo, but also can help to resolve spin-pole ambiguities. In special cases, the thermal data from Spitzer and Wise/NEOWise might even help in testing specific shape features via thermal infrared lightcurves.

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327.04 – Balloon-Borne Infrasound Detection of Energetic Bolide Events

Infrasound is usually defined as sound waves below 20 Hz, the nominal limit of human hearing. Infrasound waves propagate over vast distances through the Earth's atmosphere: the CTBTO

(Comprehensive Nuclear-Test-Ban Treaty Organization) has 48 installed infrasound-sensing stations around the world to detect nuclear detonations and other disturbances. In February 2013, several CTBTO infrasound stations detected infrasound signals from a large bolide that exploded over Chelyabinsk, Russia. Some stations recorded signals that had circumnavigated the Earth, over a day after the original event. The goal of this project is to improve upon the sensitivity of the CTBTO network by putting microphones on small, long-duration super-pressure balloons, with the overarching goal of studying the small end of the NEO population by using the Earth's atmosphere as a witness plate.
A balloon-borne infrasound sensor is expected to have two advantages over ground-based stations: a lack of wind noise and a concentration of infrasound energy in the "stratospheric duct" between roughly 5 - 50 km altitude. To test these advantages, we have built a small balloon payload with five calibrated microphones. We plan to fly this payload on a NASA high-altitude balloon from Ft Sumner, NM in August 2016. We have arranged for three large explosions to take place in Socorro, NM while the balloon is aloft to assess the sensitivity of balloon-borne vs. ground-based infrasound sensors. We will report on the results from this test flight and the prospects for detecting/characterizing small bolides in the stratosphere.

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327.05 – Non-Vestoid candidates in the inner Main Belt

Most Howardite-Eucrite-Diogenite (HED) meteorites (analogues to V-type asteroids) are thought to originate from asteroid (4) Vesta. However some HEDs show distinct oxygen isotope ratios and therefore are thought to originate from other asteroids. In this study we try to identify asteroids that may represent parent bodies of those mismatching HEDs. In particular the origin of the anomalous Bunburra Rockhole meteorite was traced back to the inner main asteroid belt, showing that there might be asteroids that are not genetically linked to the asteroid (4) Vesta (the main source of V-type asteroids and HED meteorites) in the inner main belt. In this work we identify V-type asteroids outside the dynamical Vesta family whose rotational properties (retrograde vs prograde rotation) suggest the direction of Yarkovsky drift that sets them apart from typical Vestoids and Vesta fugitives. Specificly Nesvorny et al. 2008 simulated escapes paths from the Vesta family and showed that typical Vesta fugitives in the inner main asteroid belt at semi-major axis a < 2.3 AU have to have retrograde rotations and physical and thermal parameters that maximize the Yarkovsky force in order to evolve to scattered orbits within 1-2 Gys (age of the Vesta collisional family). Therefore large asteroids outside the Vesta family and with a < 2.3 AU and having thermal and rotational properties minimizing the Yarkovsky drift or showing Yarkovsky drift direction towards (4) Vesta are the best candidates for non-Vestoidal V-type asteroids and therefore parent bodies of anomalous HED. In this study we have performed accurate photometric observations and determined sense of rotation for several asteroids testing their links to Vesta and anomalous HED. We have found several potential non-Vestoid candidates. Those objects have to be studied in more detail to fully confirm their link to anomalous HEDs.

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327.06 – First results from the rapid-response spectrophotometric characterization of Near-Earth objects using RATIR

We are carrying out a program to obtain rapid-response spectrophotometric characterization of newly discovered Near Earth Objects. Our first results, based on observations made with WFCAM on UKIRT, are presented in Mommert et al. (2016). Here we present a preliminary analysis of the r-i distribution of ~140 small (<500m) NEOs observed with the RATIR instrument on the 1.5-m telescope on San Pedro Martir. The observations are made in queue mode, and the data processing is carried out autonomously. Our goals are to derive coarse taxonomic and therefore compositional classifications for each of these objects, which will allow us to derive composition as a function of NEO size. This work is part of a collaboration in which we will characterize hundreds of NEOs that are generally too faint for other characterization techniques (down to V~21). This work is supported by funding from NASA's Solar System Observations program.

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327.07 – Asteroid thermal modeling in the presence of reflected sunlight

This study addresses thermal modeling of asteroids with a new derivation of the Near Earth Asteroid Thermal (NEATM) model which correctly accounts for the presence of reflected sunlight in short wave IR bands. Kirchhoff's law of thermal radiation applies to this case and has important implications. New insight is provided into the ???? parameter in the NEATM model and it is extended to thermal models besides NEATM. The role of surface material properties on ???? is examined using laboratory spectra of meteorites and other asteroid compositional proxies; the common assumption that emissivity ????=0.9 in asteroid thermal models may not be justified and can lead to misestimating physical parameters. In addition, indeterminacy in thermal modeling can limit its ability to uniquely determine temperature and other physical properties. A new curve-fitting approach allows thermal modeling to be done independently of visible-band observational parameters, such as the absolute magnitude ????.

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327.08 – LSST's Projected Near-Earth Asteroid Discovery Performance

The Large Synoptic Survey Telescope (LSST) is an ambitious project that has the potential to make major advances in Near-Earth Asteroid search efforts. With construction already underway and major optical elements complete, first light is set for 2020, followed by two years of commissioning. Once regular survey operations begin in 2022, LSST will systematically survey the observable sky over a ten-year period from its site on Cerro Pachon, Chile. With an 8.4 m aperture (6.5 m effective), 9.6 square degree field of view, and a 3.2-Gigapixel camera, LSST represents the most capable asteroid survey instrument ever built.
LSST will be able cover over 6000 square degrees of sky per clear night with single visit exposures of 30 s, reaching a faint limit of 24.5 mag in the r band. However the cadence of survey operations is a critical factor for the near-Earth asteroid search performance, and there are multiple science drivers with different cadence objectives that are competing to shape the final survey strategy. We examine the NEA search performance of various LSST search strategies, paying particular attention to the challenges of linking large

numbers asteroid detections in the presence of noise.
Our approach is to derive lists of synthetic detections for a given instantiation of the LSST survey, based on an assumed model for the populations of solar system objects from the main asteroid belt inwards to the near-Earth population. These detection lists are combined with false detection lists that model both random noise and non-random artifacts resulting from image differencing algorithms. These large detection lists are fed to the Moving Object Processing System (MOPS), which attempts to link the synthetic detections correctly without becoming confused or overwhelmed by the false detections.
The LSST baseline survey cadence relies primarily on single night pairs of detections, with roughly 30-60 min separating elements of the pair. The strategy of using pairs is an aggressive and potentially fragile approach, but theoretically represents the most productive NEA search with the minimum impact on other LSST science drivers.
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327.09 – Investigating the contribution of Gaia to orbit improvement and stellar occultation prediction

The ESA Gaia mission, currently surveying the sky from the L2 Lagrangian Point, is providing astrometry of stars and asteroids, at the sub-milliarcsec accuracy. However, the exploitation of this unprecedented capacity of investigation, requires to tackle some specific issues, mostly related to the peculiar properties of the Gaia data.
Orbit determination and improvement have to be tuned at several levels, from the preliminary short-arc solution, up to the most extreme dynamical modeling taking into account observations on a long time span. More specifically, asteroid positions determined by Gaia are very accurate in one direction only, and are affected by a large correlation of the uncertainties in the equatorial coordinates. In order to make the best possible exploitation of Gaia astrometry, we are adapting the software tools to correctly take into account such
correlation. We will discuss preliminary results obtained while validating our approach on some asteroid observations by Gaia, that provide for the first time a quantitative evaluation of the reachable accuracy on
real data.

In particular, we will discuss the contribution of Gaia relative to the whole available record of observations, and the differences found in the accuracy of alerts (daily processing) with respect to the exploitation of better calibrations. The impact of the first Gaia data release (GDR1) and following on the prediction of stellar occultations by asteroids, is also addressed.
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327.10 – Gaia-GOSA: An interactive service for coordination of asteroid observation campaigns

We describe the Gaia–Ground-based Observational Service for Asteroids (www.gaiagosa.eu), which is a website aiming to facilitate asteroid observers in contributing to the Gaia mission by gathering lightcurves of selected targets.
There are many asteroids which lightcurves cannot be covered during one observing run, like slow rotators,
with periods longer than 12 hours. There are also targets with periods commensurate with the Earth's day, so
their lightcurves cannot be covered by observing from one site only. There are also targets of special interest,
like binary objects, where a large amount of data is needed. For all targets like those mentioned above, a
coordination of observers is needed, also to avoid unnecessary duplication of data gathering.
To that end we have created Gaia-GOSA, a web service which allows coordination between observers, focuses
on interesting targets and may avoid observers to unnecessary gather data of the same object at the same
time. Furthermore, it is not necessary to be an advanced observer to contribute to the project. The website
prepares the observing plan, providing all the necessary information to point your telescope. The
subscription is free and observers with any level of experience are welcome.
All the data gathered by Gaia-GOSA users will be reduced and analyzed by astronomers from the Astronomical Observatory of Adam Mickiewicz University in Poznan (AO AMU). The resulting catalogue, containing all the lightcurves obtained, will be used to enhance the results of the Gaia (cornerstone European Space Agency's mission) inversion algorithm.
The project has been developed under funding from the European Space Agency (ESA) and initially was only devoted to help users in planning photometric observations of asteroids. However, in this poster we also present an extended version of the website, which also aims to publish predictions of stellar occultations for selected targets. This work has been done in the framework of the Small Bodies: Near and Far (SBNAF) research project, which has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 687378.
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327.11 – Flagstaff Robotic Survey Telescope (FRoST): Rapid Response for NEOs

The Flagstaff Robotic Survey Telescope (FRoST) is a robotic 0.6m Schmidt telescope that will be used for instant follow-up observations of newly discovered Near Earth Objects (NEOs). Here, we present the progress being made on FRoST as well as the remaining tasks until the telescope is fully operational.
With more than one thousand NEOs being found yearly, more telescopes are needed to carry out follow-up observations. Most NEOs are found at their peak brightness, meaning that these observations need to happen quickly before they fade. By using the Catalina Sky Survey Queue Manager, FRoST will be able to accept interruptions during the night and prioritize observations automatically, allowing instant follow-up observations. FRoST will help refine the orbit of these newly discovered objects while providing optical colors. We will ingest information from the NEOCP and JPL's Scout program at five minute intervals and observe newly discovered targets robotically, process the data automatically, and autonomously generate astrometry and colors. We estimate that will we provide essentially 100% recovery of objects brighter than V~20.
This work was supported by the NSF MRI program as well as by NAU and Lowell Observatory.
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327.12 – Increasing the Output of Spacewatch Astrometry of Near-Earth Asteroids

The Spacewatch Project at the University of Arizona specializes in followup astrometry of Near-Earth Asteroids (NEAs) when they are fainter than most other followup stations can reach. Priority is given to objects on the Confirmation Page of the Minor Planet Center (MPC), potential impactors on the Earth, objects requested by the Jet Propulsion Laboratory (JPL), future targets of radar, objects whose infrared flux or taxonomic properties have been measured, potential destinations of spacecraft, and objects being monitored for Yarkovsky drift. Upgrades in hardware, software, and observing procedures since 2015 Sept have boosted the numbers of observations of NEAs we make with the 0.9-m, 1.8-m, and 2.3-m telescopes on Kitt Peak in Arizona. Targeting specific NEAs with our 0.9-m telescope (site code 691) down to V magnitude 22 has increased the rate of observations of NEAs by a factor of 3.9 compared to the previous survey pattern. Comparing the first three months of 2016 with the same period in 2015 our 1.8-m telescope (site code 291) shows a 25% increase in total images acquired, a 35% increase in shutter-open exposure time, a 68% increase in the number of PHAs observed down to R magnitude 22.5, and a 105% increase in the number of PHAs observed with magnitudes >= 21.5. Installation of our new CCD camera at the Cassegrain focus of the Bok 2.3-meter telescope of Steward Observatory (site code ^695) and better software have allowed 50% more targeted objects per night down to R magnitude 23 and a 303% increase in the number of images taken per night. In the time interval reported, Spacewatch observed 41% of all the NEAs that were observed by anyone and 44% of all the PHAs that were observed by anyone. We also contributed 19% of all the astrometry of PHAs that were fainter than magnitude 22. Support of Spacewatch is from NASA/NEOO grants, the Lunar and Planetary Laboratory, Steward Observatory, Kitt Peak National Observatory, the Brinson Foundation of Chicago, IL, the estates of R. S. Vail and R. L. Waland, and other private donors. We are also indebted to the MPC and JPL for their web services.
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327.13 – Statistical analysis of the astrometric errors for the most productive asteroid surveys

Accurate orbits of minor planets allow reliable predictions of an object's location in time and space. High fidelity ephemerides are crucial for the space missions targeting asteroids and comets, mitigation of Earth impact hazard, study of non-gravitational effects on small bodies and mass determination of encountering objects through mutual perturbations. The length of the observation arc as well as high quality astrometry play an essential role in achieving accurate orbits. In particular, accurate astrometry can allow the recovery of small near-Earth objects that could otherwise be lost. The vast majority of the 715,000 known asteroids have been discovered and observed by major dedicated optical CCD surveys. However, uncertainties of individual astrometric positions are not directly provided by observers yet and so orbit determination traditionally relies on conservative estimates of astrometric errors. We present a statistical study of astrometric residuals of optical CCD astrometry for the nine most prolific past and current asteroid surveys: Pan-STARRS1 (F51), Mt. Lemmon (G96), Catalina (703), LINEAR (704), Spacewatch (691), LONEOS (699), NEAT (644), NEOWISE (C51) and SST (G45). The study was limited to multiple apparition asteroids, which have well-constrained orbits, after correcting for the star catalog position and proper motion biases (Farnocchia et al., 2015). Therefore, the resulting astrometric residuals can be largely attributed to astrometric and timing errors in the reported astrometry. We analyze the behavior of residuals in right ascension, declination, along-track and cross-track, as well as timing errors. Astrometric residuals generally depend on reported magnitude by a quadratic function with astrometric quality degradation near the limiting magnitude and the saturation limit for bright objects. We found no systematic timing errors exceeding one second for the tested surveys. The presented analysis provides useful information to improve the data-weighting schemes and, more in general, the statistical treatment of astrometric observations and to compute more accurate asteroid orbits.

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327.14 – Update on Astrometric Follow-Up at Apache Point Observatory by Adler Planetarium

We began our NEO astrometric follow-up and characterization program in 2014 Q4 using about 500 hours of observing time per year with the Astrophysical Research Consortium (ARC) 3.5m telescope at Apache Point Observatory (APO). Our observing is split into 2 hour blocks approximately every other night for astrometry (this poster) and several half-nights per month for spectroscopy (see poster by M. Hammergren et al.) and light curve studies.
For astrometry, we use the ARC Telescope Imaging Camera (ARCTIC) with an SDSS r filter, in 2 hour observing blocks centered around midnight. ARCTIC has a magnitude limit of V~23 in 60s, and we target 20 NEOs per session. ARCTIC has a FOV 1.57 times larger and a readout time half as long as the previous imager, SPIcam, which we used from 2014 Q4 through 2015 Q3. Targets are selected primarily from the Minor Planet Center's (MPC) NEO Confirmation Page (NEOCP), and NEA Observation Planning Aid; we also refer to JPL's What's Observable page, the Spaceguard Priority List and Faint NEOs List, and requests from other observers. To quickly adapt to changing weather and seeing conditions, we create faint, midrange, and bright target lists. Detected NEOs are measured with Astrometrica and internal software, and the astrometry is reported to the MPC.
As of June 19, 2016, we have targeted 2264 NEOs, 1955 with provisional designations, 1582 of which were detected. We began observing NEOCP asteroids on January 30, 2016, and have targeted 309, 207 of which were detected. In addition, we serendipitously observed 281 moving objects, 201 of which were identified as previously known objects.
This work is based on observations obtained with the Apache Point Observatory 3.5m telescope, which is owned and operated by the Astrophysical Research Consortium. We gratefully acknowledge support from NASA NEOO award NNX14AL17G and thank the University of Chicago Department of Astronomy and Astrophysics for observing time in 2014.
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327.15 – Application of recursive approaches to differential orbit correction of near Earth asteroids

Comparison of three approaches to the differential orbit correction of celestial bodies was performed: batch least squares fitting, Kalman filter, and recursive least squares filter. The first two techniques are well known and widely used (Montenbruck, O. & Gill, E., 2000). The most attention is paid to the algorithm and details of program realization of recursive least squares filter. The filter's algorithm was derived based on recursive least squares technique that are widely used in data processing applications (Simon, D, 2006). Usage recursive least squares filter, makes possible to process a new set of observational data, without reprocessing data, which

has been processed before. Specific feature of such approach is that number of observation in data set may be variable. This feature makes recursive least squares filter more flexible approach compare to batch least squares (process complete set of observations in each iteration) and Kalman filtering (suppose updating state vector on each epoch with measurements).
Advantages of proposed approach are demonstrated by processing of real astrometric observations of near Earth asteroids. The case of 2008 TC3 was studied. 2008 TC3 was discovered just before its impact with Earth. There are a many closely spaced observations of 2008 TC3 on the interval between discovering and impact, which creates favorable conditions for usage of recursive approaches. Each of approaches has very similar precision in case of 2008 TC3. At the same time, recursive least squares approaches have much higher performance. Thus, this approach more favorable for orbit fitting of a celestial body, which was detected shortly before the collision or close approach to the Earth.
This work was carried out at MIIGAiK and supported by the Russian Science Foundation, Project no. 14-22-00197.
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D. Simon, "*Optimal State Estimation: Kalman, H Infinity, and Nonlinear Approaches"*,
1 edition. Hoboken, N.J.: Wiley-Interscience, 2006.
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327.16 – Modeling the joined performance of PanSTARRS1 and PanSTARRS2 telescopes

We have performed detailed simulations of the 1st and the 2nd telescope of the Panoramatic Survey Telescope and Rapid response System (PanSTARRS, Morgan et al. 2012, SPIE Conference Series, Vol. 8444; Chambers et al. 2007, Bulletin of the American Astronomical Society, Vol. 39, #142.06) in order to assess their combined performance and to optimize survey strategy for discovery and follow-up observations of near-Earth asteroids (NEAs). PanSTARRS1 (PS1) is situated on the summit of Haleakala, Maui (observatory code F51) and has been operated by the University of Hawaii since the spring of 2010. PS1 has a 1.8 m diameter primary mirror with an ~7 deg^2 field of view and can survey ~900 deg^2/night for moving objects.
PS2 is located adjacent to PS1, and is similar, but benefits from many improvements coming from our experience with PS1. PS2 will be operational very soon.
We will show how the best and the worst case scenarios of observing conditions (i.e. regarding the weather and the position of the Galactic plane) affect the NEA detection efficiency during a 1-month long survey for several PS1 and PS2 observing and follow-up strategies.
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327.17 – Gaia-GBOT asteroid finding programme *(gbot.obspm.fr)*

The *Ground Based Optical Tracking* group (GBOT) consists of about ten scientists involved in the Gaia mission by ESA. Its main task is the optical tracking of the Gaia satellite itself [1]. This novel tracking method in addition to radiometric standard ones is necessary to ensure that the Gaia mission goal in terms of astrometric precision level is reached for *all*objects. This optical tracking is based on daily observations performed throughout the mission by using the optical CCDs of ESO's VST in Chile, of Liverpool Telescope in La Palma and of the two LCOGT's Faulkes Telescopes in Hawaii and Australia. Each night, GBOT attempts to obtain a sequence of frames covering a 20 min total period and close to Gaia meridian transit time. In each sequence, Gaia is seen as a faint moving object (*R*mag ~ 21, speed > 1"/min) and its daily astrometric accuracy has to be better than 0.02" to meet the Gaia mission requirements. The *GBOT Astrometric Reduction Pipeline* (GARP) [2] has been specifically developed to reach this precision.
More recently, a secondary task has been assigned to GBOT which consists detecting and analysing Solar System Objects (SSOs) serendipitously recorded in the GBOT data. Indeed, since Gaia oscillates around the Sun-Earth L2 point, the fields of GBOT observations are near the Ecliptic and roughly located opposite to the Sun which is advantageous for SSO observations and studies. In particular, these SSO data can potentially be very useful to help in the determination of their absolute magnitudes, with important applications to the scientific exploitation of the WISE and Gaia missions. For these reasons, an automatic SSO detection system has been created to identify moving objects in GBOT sequences of observations. Since the beginning of 2015, this SSO detection system, added to GARP for performing high precision astrometry for SSOs, is fully operational. To this date, around 9000 asteroids have been detected. The mean delay between the time of observation and the submission of the SSO reduction results to the MPC is less than 12 hours allowing rapid follow up of new objects.
[1] Altmann et al. 2014, SPIE, 9149.
[2] Bouquillon et al. 2014, SPIE, 9152.
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327.18 – DEEP-South: Preliminary Lightcurves of Potentially Hazardous Asteroids from the First Year Operation

Deep Ecliptic Patrol of the Southern Sky (DEEP-South) observation is being made during the off-season for exoplanet search. It started in October 2015, using Korea Microlensing Telescope Network (KMTNet), a network of three identical telescopes with 1.6 m aperture equipped with 18K × 18K CCDs located in Chile (CTIO), South Africa (SAAO), and Australia (SSO). The combination of KMTNet's prime focus optics and the 340 million pixel CCD provides four square degree field of view with 0.4 arcsec/pixel plate scale. Most of the allocated time for DEEP-South is devoted to targeted photometry of PHAs and NEAs to increase the number of those objects with known physical properties. It is efficiently achieved by multiband, time series photometry. This Opposition Census (OC) mode targets objects near their opposition, with km-sized PHAs in early stage and goes down to sub-km objects. Continuous monitoring of the sky with KMTNEt is optimized for spin characterization of various kinds of asteroids, including binaries, slow/fast- and non-principal axis- rotators, and hence expected to facilitate the debiasing of previously reported lightcurve observations. We present the preliminary lightcurves of PHAs from year one of the DEEP-South Project.
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327.19 – Characterization of Surface Heterogeneity among Asteroid Taxonomic Classes according to Sloan Digital Sky Survey Observations

This research characterizes the extent of surface heterogeneity among asteroid classes by the extent of Sloan Digital Sky Survey (SDSS) color variance within multiple observations of the same asteroid. The SDSS MOC4 database includes data from 220,101 observations of 104,449 unique objects. The amount of multiple observations of one target makes it ideal for statistically analyzing the surface inhomogeneity of asteroid surfaces. Information from the SDSS MOC4 database (below an error threshold determined from standard error propagation techniques and the interquartile range) is combined with information from the classification in Carvano et al. (2010) to analyze asteroid surface heterogeneity based on taxonomic class. Individual observations are grouped by asteroid, and asteroids are grouped by class. The standard deviation of each normalized SDSS color (i.e. u-r, g-r, r-i, r-z) for each asteroid with multiple observations is calculated. The mean of the standard deviations is then computed for a given class. Comparison of the size of the average standard deviation to the size of the error determines the extent of true variance within a normalized color in a class. The effect of phase angles on SDSS data, as discussed in Carvano et al. (2015), are considered. Additionally, implications for space weathering and evolutionary relationships between taxonomic classes are explored.

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327.20 – High-precision follow-up observations of Near-Earth Objects

We present the latest results of ongoing high-precision astrometric follow-up observations of Near-Earth Objects (NEOs) using the University of Hawaii 2.24 metre telescope (currently 7.5 arcmin FOV), the Canada-France-Hawaii Telescope (CFHT; 1 degree FOV) with MegaPrime, and the Subaru Hyper Suprime-Cam (1.5 degree FOV). The combination of excellent observing conditions at Maunakea, and the use of no filter to maximise our throughput efficiency, allows us to recover targets having V < 24, and sometimes V < 25 under ideal conditions. We frequently achieve astrometric accuracy limited by the reference catalog and plan to improve on this capability with the implementation of the GAIA catalog. This work is funded by NASA grant NXX13AI64G.

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328 – Origin and Evolution of Asteroids Posters

328.01 – Secular representations for the long-term resonant dynamics beyond Neptune

The dynamical structure of the transneptunian region is far from being fully understood, especially concerning high-perihelion objects and their connection to the Oort Cloud. Indeed, even if they undergo very weak orbital perturbations, the observed bodies have large eccentricities, which indicates that they did not form in their current orbital state. Mean-motion resonances with Neptune are a well-known mechanism responsible for large orbital variations, however it is yet unclear what kinds of trajectories can be produced on very long time-scales.
We will present the application of a semi-analytical secular model, designed to describe the long-term dynamics of transneptunian objects in mean-motion resonance with Neptune. A one-degree-of-freedom approximation is obtained by postulating the adiabatic invariance, thereby removing the necessity of any assumption about the resonant angle. That model is used to explore the variety of possible resonant trajectories in the distant Solar System under the effect of the four giant planets. High-amplitude perihelion oscillations are reported and localised in the space of the orbital parameters. It shows that a large perihelion distance is not a sufficient criterion to declare that an object is detached from the planets. We will discuss the possibility for the known transneptunian objects to be driven by such a dynamics, as well as the efficiency of the Oort Cloud as an indirect source for resonant objects trapped in a high-perihelion state.

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329 – Asteroid Dynamics NEO Posters

329.01 – On the rotational motion of NEAs during close encounters with Earth and Venus

"NEAs" stands for Near-Earth Asteroids, and as the name suggests it refers to the asteroids that in its orbital evolution approach the Earth's orbit. During their lifetime, the NEAs suffer numerous close encounters (CE) with Earth, Mars and Venus. These close encounters cause variations in the orbital and rotational angular momentum, changing their dynamic behavior of them. The variation of the rotational angular momentum during the next encounters can increase or decrease the rotation rate depending on the initial condition. In addition to the rotation rate, close encounters cause variation in the movement of precession and nutation of the asteroid. Using a numerical model that takes into account the spin-orbit coupling of a body with ellipsoidal shape, the aim of this study is to analyze the variation and rotacioanal motion (rotation, precession and nutation) of asteroids during CE with earth and Venus for different initial conditions. We computed the variation of the obliquity, the variation of spin period and the spin mode (tumbling or non-tumbling and long-axis mode or short-axis mode) after the CE. We found significant changes in obliquity and spin period only in cases with strong encounters, i.e., those is in cases where the distance of the encounter (d) and the relative velocity (v) (we call encounter parameters) are small. On the other hand we did not find a relation between encounter parameters and the behavior of the spin mode since the body can tumbling in low as well as large values of (d) and (v). For future works we intent to do the same study for a binary asteroid system.

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329.02 – DynAstVO : the Europlanet orbital asteroid database

DynAstVO is a new orbital database dedicated to Near Earth Asteroid orbits, developed within the Europlanet 2020 RI framework.

It provides parameters of asteroid orbits: orbital elements, observational information, minimum distance with Earth and planets, ephemeris and in particular, orbit uncertainty and associated covariance matrix.
This database is updated daily on the basis of the Minor Planet Electronic Circulars.
Orbit determination and improvement is computed as soon as new observations are available or an object is discovered.
This database conforms to EPN-TAP environment (Erard et al. 2015, A&C 7) and is accessible through VO protocols or classical web access. Auxiliary data such as SPICE kernels for their ephemerides are provided.
Finally, we present a comparison with other classical databases such as Astorb or MPCORB.
Acknowledgements: This work is done in the framework of Europlanet 2020 RI which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654208.
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329.03 – General Relativistic Precession in Small Solar System Bodies

Introduction: One of the greatest successes of the Einstein's General Theory of Relativity (GR) was the correct prediction of the precession of perihelion of Mercury. The closed form expression to compute this precession tells us that substantial GR precession would occur only if the bodies have a combination of both moderately small perihelion distance and semi-major axis. Minimum Orbit Intersection Distance (MOID) is a quantity which helps us to understand the closest proximity of two orbits in space. Hence evaluating MOID is crucial to understand close encounters and collision scenarios better. In this work, we look at the possible scenarios where a small GR precession in argument of pericentre (ω) can create substantial changes in MOID for small bodies ranging from meteoroids to comets and asteroids.
Analytical Approach and Numerical Integrations: Previous works have looked into neat analytical techniques to understand different collision scenarios and we use those standard expressions to compute MOID analytically. We find the nature of this mathematical function is such that a relatively small GR precession can lead to drastic changes in MOID values depending on the initial value of ω. Numerical integrations were done with package MERCURY incorporating the GR code to test the same effects. Numerical approach showed the same interesting relationship (as shown by analytical theory) between values of ω and the peaks/dips in MOID values. Previous works have shown that GR precession suppresses Kozai oscillations and this aspect was verified using our integrations. There is an overall agreement between both analytical and numerical methods.
Summary and Discussion: We find that GR precession could play an important role in the calculations pertaining to MOID and close encounter scenarios in the case of certain small solar system bodies (depending on their initial orbital elements). Previous works have looked into impact probabilities and collision scenarios on planets from different small body populations. This work aims to find certain sub-sets of orbits where GR could play an interesting role. Certain parallels are drawn between the cases of asteroids, comets and small perihelion distance meteoroid streams.
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329.04 – The Asteroid 2009 DL46

2009 DL46 was discovered by the Catalina Sky Survey on 2009-February 28. This asteroid has a diameter of about 194 meters (119 to 268 meters) [1], and Brian Warner has obtained a rotation period of at least 10 hours [2]. The asteroid 2009 DL46 flew past Earth on May 24/2016 at a distance of about 6.2 lunar distances (0.0158293668567628 A.U) [3]. The NEOWISE mission had a great likelihood to observing this asteroid in early May. Radiotelescopes of Goldstone and Arecibo had planned to make observations of 2009 DL46. “Using the Goldstone facility, we had planned to make radar observations of 2009 DL46” said Landis, Rob R. (HQ-DG000). This asteroid is on list for possible human mission targets. From our Observatory, located in Pasto-Colombia, we captured several pictures, videos and astrometry data during several hours during three days. Our data was published by the Minor Planet Center (MPC) and also appears at the web page of NEODyS [4]. The pictures and data of the asteroid were captured with the following equipment: CGE PRO 1400 CELESTRON (f/11 Schmidt-Cassegrain Telescope) and STL-1001 SBIG camera.. Astrometry was carried out, and we calculated the orbital elements. Summary and conclusions: We obtained the following orbital parameters: eccentricity = 0.30731 +/- 0.00025, semi-major axis = 1.460279 +/- 0.000532 A.U, orbital inclination = 7.9503 +/- 0.0048 deg, longitude of the ascending node = 63.45053 +/- 0.00034 deg, argument of perihelion = 159.8804 +/- 0.0024 deg, mean motion = 0.558535 +/- 0.000305 deg/d, perihelion distance = 1.01151363 +/- 3.39e-6 A.U, aphelion distance = 1.90904 +/- 0.00106 A.U, absolute magnitude = 22.5. The parameters were calculated based on 83 observations. Dates: 2016 May: 18 to 21 with mean residual = 0.29 arcseconds. The asteroid has an orbital period of 1.76 years (644.53 days).
Acknowledgements: The authors would like to thank to the University of Narino (Pasto, Colombia).
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[4]http://newton.dm.unipi.it/neodys/index.php?pc=2.1.2&o=H78&ab=7
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329.05 – Post-mitigation impact risk assessment for NASA's DART kinetic impactor mission

Field-testing kinetic impactors to deflect potentially hazardous asteroids (PHAs) is essential to better understand the challenges of future asteroid impact threat mitigation. The Asteroid Impact and Deflection Assessment mission (AIDA, Cheng et al. 2016), a collaborative effort between NASA and ESA, offers a timely opportunity to validate kinetic impact deflection strategies. Although the main goal of NASA's kinetic impactor (DART) is to change the circumprimary orbit of (65803) Didymos' moonlet, the imparted momentum will also slightly change the heliocentric orbit of the whole binary asteroid system. Given the high degree of non-linearity of the near-Earth dynamical environment, however, even a small change in initial conditions can affect long term predictions of the encounter distances between Didymos and the Earth. Belonging to the dynamical class of PHAs, (65803) Didymos has several encounters with the Earth over the upcoming decades, some of which are closer than 20 lunar distances. In order to confirm that no planetary safety issues arise as a consequence of DART, we conducted a post-mitigation impact risk assessment (PMIRA, Eggl et al. 2015) for the currently foreseen DART impact trajectories. In this contribution we present the latest PMIRA results and discuss the role of ESA's AIM spacecraft in reducing uncertainties arising in the deflection process.

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Contributing team(s): DART, AIM

329.06 – The disposition of impact ejecta resulting from the AIDA-DART mission to binary asteroid 65803 Didymos: an independent investigation

If all goes as planned, in the year 2020 a joint ESA and NASA mission will be launched that will rendezvous with the near-Earth binary asteroid system 65803 Didymos in the fall of 2022. The European component, the Asteroid Impact & Deflection Assessment (AIDA) spacecraft will arrive first and characterize the system, which consists of a ~800 m diameter primary and a ~160 m diameter secondary, orbiting a common center of mass at a semi-major axis distance of ~1200 m with a orbital period of 11.9 hr. Following system characterization, the AIDA spacecraft will remove to a safe distance while the NASA component, the 300 kg Double Asteroid Redirection Test (DART) spacecraft collides with the trailing edge of the secondary body (with respect to the binary's retrograde mutual orbit). Meanwhile, the AIDA spacecraft will conduct observations of this impact and its aftermath, specifically looking for changes made to the primary, the secondary, and their mutual orbit as a result of the DART collision. Of particular interest is the ballistic flight and final disposition of the ejecta produced by the impact cratering process, not just from the standpoint of scientific study, but also from the standpoint of AIDA spacecraft safety.
In this study, we investigate a series of hypothetical DART impacts utilizing a semi-empirical, numerical impact ejecta plume model originally developed for the Deep Impact mission and designed specifically with impacts on small bodies in mind. The resulting excavated mass is discretized into 7200 individual tracer particles, each representing a unique combination of speed, mass, and ejected direction. The trajectory of each tracer is computed numerically under the gravitational influence of both primary and secondary, along with the effects of solar radiation pressure. Each tracer is followed until it either impacts a body or escapes the system, whereupon tracking is continued in the heliocentric frame using an N-body integrator. Various impact scenarios will be explored, along with a number of ejecta particle sizes, with the aim of characterizing the most likely final ejecta dispositions resulting from the DART impact, and the safest vantages from which the AIDA spacecraft can observe this event.

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329.07 – Arecibo and Goldstone Radar Imaging of Near-Earth Asteroid 2005 WC1

We report radar observations of near-Earth asteroid 2005 WC1 that were obtained at Arecibo (2380 MHz, 13 cm) and Goldstone (8560 MHz, 3.5 cm) on 2005 December 14-15 during the asteroid's approach within 0.020 au (7.7 lunar distances). The asteroid was a strong radar target and we obtained a sequence of delay-Doppler images with resolutions as fine as 7.5 m/pixel. The radar images reveal an angular object with several pronounced facets, radar-dark regions, and an estimated diameter of ~0.4 km. The rotation of the facets in the images gives a rotation period of 2.57 h that is consistent with the estimate of 2.582 h ± 0.002 h reported by Miles et al. (private communication). 2005 WC1 has a circular polarization ratio of 1.12 ± 0.02 that is one of the highest values known, suggesting a structurally-complex near-surface at centimeter decimeter spatial scales. This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

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329.08 – Volatile Survival on Near-Earth Asteroid 2008 EV5

Asteroid 2008 EV5 is currently one of the possible targets of NASA Asteroid Redirect Mission (ARM). The objective of this mission is to recover a boulder from the surface of an asteroid. The selection of the final target requires understanding the physical characteristics of the asteroid such as the size-frequency distribution of boulders on the asteroid's surface, the presence of volatiles on the surface and below, the strength of the surface materials and the degree of their alteration. In our work, we focus on the second criterion, the possibility of volatiles presence on 2008 EV5. These can be expected to survive embedded within the crystal lattice of various phyllosilicates. The positive presence of volatiles on the surface of and inside the asteroid is important especially for ISRU hardware demonstrations. Spectral data suggest that 2008 EV5 is a member of CI chondrite group which is characterized by high phyllosilicate content (~70%) but there is also the possibility of it being a CR chondrite where the phyllosilicate content ranges significantly, from samples with negligible phyllosilicate content to samples with almost 70% phyllosilicate content. If the dynamical history of the asteroid brought it close enough to the Sun, the lattice of phyllosilicates could have disintegrated and released the volatiles (water) and the material could have dehydrated. The depth at which the dehydration might have taken place depends on the characteristic depth of heat wave penetration which in turn depends on material characteristics such as density, heat capacity and heat conductivity. These are in turn are closely linked to the porosity. The characteristic heat penetration depth also depends on orbital geometry and rotational and orbital periods. Besides the temperature itself, the dehydration is also affected by the duration of the crystal lattice breakup temperatures. We use thermal model in conjunction with available experimental data on the dehydration of clays and with the model of near Earth asteroids to determine the possible scenarios of dehydration of 2008 EV5.

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329.10 – Radar observations of near-Earth asteroids from Arecibo Observatory

The Arecibo S-Band (2.38 GHz, 12.6 cm, 1 MW) planetary radar system at the 305-m William E. Gordon Telescope in Arecibo, Puerto Rico is the most active and most sensitive planetary radar facility in the world. Since October 2015, we have detected 56 near-Earth asteroids, of which 17 are classified as potentially hazardous to Earth and 22 are compliant with the Near-Earth Object Human Space Flight Accessible Target Study (NHATS) as possible future robotic- or human-mission destinations. We will present a sampling of the asteroid zoo observed by the Arecibo radar since the 2015 DPS meeting. This includes press-noted asteroids 2015 TB145, the so-called "Great Pumpkin", and 2003 SD220, the so-called "Christmas Eve asteroid".

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329.11 – The Deflector Selector: A Machine Learning Framework for Prioritizing Deflection Technology Development

On 15 February, 2013, a ~15 m diameter asteroid entered the Earth's atmosphere over Russia. The resulting shockwave injured nearly 1500 people, and incurred ~33 million (USD) in infrastructure damages. The Chelyabinsk meteor served as a forceful demonstration of the threat posed to Earth by the hundreds of potentially hazardous objects (PHOs) that pass near the Earth every year. Although no objects have yet been discovered on an impact course for Earth, an impact is virtually statistically guaranteed at some point in the future. While many impactor deflection technologies have been proposed, humanity has yet to *demonstrate* the ability to divert an impactor when one is found. Developing and testing any single proposed technology will require significant research time and funding. This leaves open an obvious question – towards which technologies should funding and research be directed, in order to maximize our preparedness for when an impactor is eventually found?

To help answer this question, we have created a detailed framework for analyzing various deflection technologies and their effectiveness. Using an n-body integrator (REBOUND), we have simulated the attempted deflections of a population of Earth-impacting objects with a variety of velocity perturbations (∂Vs), and measured the effects that these perturbations had on impact probability. We then mapped the ∂Vs applied in the orbital simulations to the technologies capable of achieving those perturbations, and analyzed which set of technologies would be most effective at preventing a PHO from impacting the earth. As a final step, we used the results of these simulations to train a machine learning algorithm. This algorithm, combined with a simulated PHO population, can predict which technologies are most likely to be needed. The algorithm can also reveal which impactor observables (mass, spin, orbit, etc.) have the greatest effect on the choice of deflection technology. These results can be used as a tool to inform funding decisions for both deflection technology development and PHO characterization missions.

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329.12 – SPH simulations of high-speed collisions

Our work is devoted to a comparison of: i) asteroid-asteroid collisions occurring at lower velocities (about 5 km/s in the Main Belt), and ii) mutual collisions of asteroids and cometary nuclei usually occurring at significantly higher relative velocities (> 10 km/s).

We focus on differences in the propagation of the shock wave, ejection of the fragments and possible differences in the resulting size-frequency distributions of synthetic asteroid families. We also discuss scaling with respect to the "nominal" target diameter D = 100 km, projectile velocity 3-7 km/s, for which a number of simulations were done so far (Durda et al. 2007, Benavidez et al. 2012).

In the latter case of asteroid-comet collisions, we simulate the impacts of brittle or pre-damaged impactors onto solid monolithic targets at high velocities, ranging from 10 to 15 km/s. The purpose of this numerical experiment is to better understand impact processes shaping the early Solar System, namely the primordial asteroid belt during during the (late) heavy bombardment (as a continuation of Broz et al. 2013).

For all hydrodynamical simulations we use a smoothed-particle hydrodynamics method (SPH), namely the lagrangian SPH3D code (Benz & Asphaug 1994, 1995). The gravitational interactions between fragments (re-accumulation) is simulated with the Pkdgrav tree-code (Richardson et al. 2000).

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330 – Comets: Chemical Composition Posters

330.01 – A Contextual Comparison of Native Ice Abundances in Comet C/2013 US10 (Catalina) based on Infrared Spectroscopy

The primitive nature of comets makes them the best available carriers of information pertaining to conditions in the early solar system. High-resolution spectrometers operating at IR wavelengths (~ 1 – 5 µm) permit quantifying molecular species (aka "parent volatiles") released into the coma upon sublimation of ices contained in the cometary nucleus (i.e., native ices). Over the past 20 years we used first CSHELL at the IRTF, then NIRSPEC at Keck and CRIRES at the VLT, amassing production rates and abundance ratios in 30-plus comets.

We present a summary of molecular abundances in long period Comet C/2013 US10 (Catalina), which passed perihelion on UT 2015 November 15.7 at heliocentric distance R_h = 0.822 AU. We used CSHELL on UT 2015 November 23 (R_h = 0.84 AU), December 15 – 17 (R_h = 1.0 AU) and 2016 February 28 (R_h = 1.95 AU), and NIRSPEC on 2016 January 24 (R_h = 1.49 AU). We targeted H_2O, CO, H_2CO, CH_3OH, OCS, HCN, NH_3, CH_4, C_2H_2, and C_2H_6, and obtained production rates or stringent upper limits for all of these. This allowed testing for potential changes in relative abundances as a function of R_h. Such IR measurements spanning a range in R_h are still rare, but are very important for testing possible heterogeneous nucleus composition and/or heliocentric dependence of abundances, for example through release from grains heated in the coma. Our measurements will be inter-compared, and also placed in the context of our current (and continually evolving) compositional taxonomy of comets.

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330.02 – Emerging Trends on the Volatile Chemistry in Comets as Measured with High-Resolution Infrared Spectroscopy

A systematic analysis of the mixing ratios with respect to H_2O for eight species (CH_3OH, HCN, NH_3, H_2CO, C_2H_2, C_2H_6, CH_4, and CO) measured with high-resolution infrared spectroscopy is presented. Some trends are beginning to emerge when mixing ratios in individual comets are compared to average mixing ratios obtained for all species within the population. The variation in mixing ratios for all measured species is at least an order of magnitude. Overall, Jupiter-family comets are depleted in volatile species with respect to H_2O compared to long-period Oort cloud comets, with the most volatile species showing the greatest relative depletion. There is a high positive correlation between the mixing ratios of HCN, C_2H_6, and CH_4, whereas NH_3, H_2CO, and C_2H_2 are moderately correlated with each other but generally uncorrelated or show only weak correlation with other species. CO is generally uncorrelated with the other measured species possibly because it has the highest volatility and is therefore more susceptible to thermal evolutionary effects. Molecular mixing ratios for CH_3OH, HCN, C_2H_6, and CH_4 show an expected behavior with heliocentric distance suggesting a dominant ice source, whereas there is emerging evidence that the mixing ratios of NH_3, H_2CO, and C_2H_2 may increase at small heliocentric distances, suggesting the possibility of additional sources related to the thermal decomposition of organic dust. Although this provides information on the composition of the most volatile grains in comets, it presents an additional difficulty in classifying comet chemistry because most comets within this dataset were only observed over a limited range of heliocentric distance. Optical and infrared comparisons indicate that mixing ratios of daughter species and potential parents from cometary ices are sometimes but not always consistent with one another. This suggests that in many comets there are significant sources of C_2 and/or CN from grains, and that the importance of these sources is variable within the comet population.

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330.03 – Survey for Ortho-to-Para Abundance Ratios (OPRs) of NH 2 in Comets: Revisit to the Meaning of OPRs of Cometary Volatiles

Since molecules having identical protons can be classified into nuclear-spin isomers (e.g., ortho-H_2O and para-H_2O for water) and their inter-conversions by radiative and non-destructive collisional processes are believed to be very slow, the ortho-to-para abundance ratios (OPRs) of cometary volatiles such as H_2O, NH_3 and CH_4 in coma have been considered as primordial characters of cometary molecules [1]. Those ratios are usually interpreted as nuclear-spin temperatures although the real meaning of OPRs is in strong debate. Recent progress in laboratory studies about nuclear-spin conversion in gas- and solid-phases [2,3] revealed short-time nuclear-spin conversions for water, and we have to reconsider the interpretation for observed OPRs of cometary volatiles. We have already performed the survey for OPRs of NH_2 in more than 20 comets by large aperture telescopes with high-resolution spectrographs (UVES/VLT, HDS/Subaru, etc.) in the optical wavelength region [4]. The observed OPRs of ammonia estimated from OPRs of NH_2, cluster around ~1.1 (cf. 1.0 as a high-temperature limit), indicative of ~30 K as nuclear-spin temperatures. We present our latest results for OPRs of cometary NH_2 and discuss about the real meaning of OPRs of cometary ammonia, in relation to OPRs of water in cometary coma. Chemical processes in the inner coma may play an important role to achieve un-equilibrated OPRs of cometary volatiles in coma.
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330.04 – Beyond 3 AU from the Sun: "Hypervolatiles" in Distant Comets

Our understanding of inner coma composition in comets has long been biased towards heliocentric distances (R_h) smaller than 2-3 AU. However, observations far from the Sun are also of high value for better understanding the nucleus structure and outgassing of volatiles. Substantial and very important evidence for the activity of distant comets has been accumulated from photometry and analyses of light curves, but direct detections of primary (parent) volatiles are still rare. For example, comet C/2006 W3 (Christensen) remained outside 3.1 AU throughout its apparition, yet it presented the best opportunity since Hale-Bopp (1997) for detailed spectroscopic studies in a distant comet. C/2006 W3 was observed from several space- and ground-based facilities using both infrared and radio techniques. CO, CH_4, and C_2H_6 were measured via infrared spectroscopy at ESO-VLT at R_h = 3.25 AU. Production rates were found to exceed those measured for each of these species in most other comets, despite those comets being observed much closer to the Sun. With its relatively high CO/CO_2 ratio, C/2006 W3 also appears as an outlier in the *AKARI* comet survey of 18 comets. The detections of H_2O (*Herschel* Space Observatory) and CO (ESO-VLT) allow for constraining the coma abundance ratio H_2O/CO at R_h = 5 AU.
We will compare the C_2H_6/CH_4/CO ratios in C/2006 W3 with those in other comets spanning a large range in R_h: from D/2012 S1 ISON (~0.7 AU) to 29P/Schwassmann-Wachmann 1 (~ 6.3 AU). Notably in situ measurements by the *Rosetta* mission were performed in the coma of 67P/Churyumov-Gerasimenko, at a very similar heliocentric distance to C/2006 W3 (3.15 AU). While comparisons of column-integrated remote sensing measurements and abundances from in-situ mass spectrometry (as performed by the ROSINA instrument) are not straightforward, both types of measurement are of high value for constraining models of nucleus outgassing beyond 3 AU from the Sun, where the inferred nucleus structure and differences in volatility among nucleus ices are very important.
We gratefully acknowledge NASA's Planetary Astronomy, Astrobiology, Solar System Observations, and Planetary Atmospheres programs and the NSF Astronomy and Astrophysics Research Grants program.
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330.05 – The OD/OH Isotope Ratio in Comets 8P/Tuttle and C/2012 F6 (Lemmon)

The determination of isotopic ratios in solar system objects is an important source of information about their origin, especially for

comets. Among these ratios the D/H is of particular importance because of its sensitivity to fractionation processes and physical environment, and the abundance of hydrogen in the solar system. The main molecule used to derive this ratio in comets is water. So far, apart water, only HCN has permitted to derive D/H ratio and not only upper limits.
Most of the existing determinations of D/H in water molecules have been obtained by spectroscopic observations of water lines in the sub-mm or near infrared range [1,2]. So far only one measurement has been based on OD/OH emission lines radicals in the near-UV [3] and another one on the Lyman-alpha D emission [4]. In situ measurements have also been obtained in comets 1P/Halley and 67P/Churyumov-Gerasimenko using mass spectrometer [5,6,7,8].
In this work we have used the OH and OD ultraviolet bands at 310 nm observed with the ESO 8-m Very Large Telescope feeding the Ultraviolet-Visual Echelle Spectrograph (UVES) for measuring the D/H ratio in comets 8P/Tuttle and C/2012 F6 (Lemmon). The OH and OD being the photodissociation products of H_2O and HDO such observations allow to derive D/H ratio for water molecules. This work constitutes an independant determination of the D/H ratios already published for these comets and based on observations performed in the sub-mm and near infrared range of H_2O and HDO lines. We present our modeling, data analysis and numerical values obtained for this ratio.
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330.06 – Gaseous activity of distant comets

The activity of most comets within 3AU of the Sun is dominated by the sublimation of frozen water, the most abundant ice in comets. Some comets, however, are active well beyond the water-ice sublimation limit. Studying distantly active comets provides valuable opportunities to explore primitive bodies when water-ice sublimation is largely dormant, which is the case for most of a comet's lifetime. Beyond 4 AU, super-volatiles such as CO or CO_2 are thought to play a major role in driving observed activity. Carbon monoxide is of special interest because it is a major contributor to comae and has a very low sublimation temperature. Three bodies dominate the observational record and modeling efforts for distantly active small bodies: the long-period comet C/1995 O1 Hale-Bopp and the short-period comets (with centaur orbits) 29P/Schwassmann Wachmann 1 and 2060 Chiron. Hale-Bopp's long-period orbit means it has experienced very little solar heating in its lifetime and is analogous to dynamically new comets making their first approach to the Sun. Because Chiron and 29P have much smaller orbits closer to the Sun, they have experienced much more thermal processing than Hale-Bopp and this is expected to have changed their chemical composition from their original state. We point out that the observed CO production rates and line-widths in these three distantly active objects are consistent with each other when adjusted for heliocentric distance. This is particularly interesting for Hale-Bopp and 29P, which have approximately the same radius. The consistent CO production rates may point to a similar CO release mechanism in these objects. We also discuss how observed radio line profiles support that the development and sublimation of icy grains in the coma at about 5-6 AU is probably a common feature in distantly active comets, and an important source of other volatiles within 6 AU, including H_2O, HCN, CH_3OH, and H_2CO.
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330.07 – Spectroscopic observations of $^{14}N/^{15}N$ ratios in both NH_2 and CN in comet C/2013 US10 (Catalina)

Comet is one of the primordial small bodies in the solar system and probably it has kept the information about the evolution of materials from the pre-solar molecular cloud to the solar nebula. Isotopic ratio in volatiles is one of the primordial properties of comets. A heavier isotopes trend to be captured into a molecule by chemical reactions under very low-temperature conditions (called as fractionation). For instance, D/H ratio of water (HDO/H_2O) in comet is enriched in D atom than the elemental abundance ratios of D/H in entire solar system [1]. Based on the observed D/H ratios in cometary water, a presumed temperature is ~20–50 K as the formation temperature of water (most abundant volatiles in cometary nucleus), by assuming water formed in gas-phase chemistry [2].
Besides, the nitrogen isotopic ratios ($^{14}N/^{15}N$) have been determined from CN and HCN (which is believed a dominant "parent" species of CN in the coma) in >20 comets [3,4]. They demonstrated cometary HCN and CN show high ^{15}N-fractionation with respect to the proto-solar value by a factor of ~3 and with a small diversity.
Moreover, $^{14}N/^{15}N$ ratios in NH_3 in comets has been determined from intensity ratios of NH_2 isotopologues [5,6,7], and both ^{15}N-fractionation as much as HCN in comets and a small diversity are seen in those $^{14}N/^{15}N$ ratios in NH_3. However, there is a few reports about $^{14}N/^{15}N$ ratios in both HCN and NH_3 in the same comets, and discussions about the relationship between these $^{14}N/^{15}N$ ratios have not been yet.
We present $^{14}N/^{15}N$ ratios in both NH_2 and CN in comet C/2013 US10 (Catalina). High-resolution optical spectra of the comet were taken with the HDS spectrograph mounted on the Subaru Telescope (Hawaii) on UT 2016 January 2–3. We will discuss about the origins of these volatiles based on the $^{14}N/^{15}N$ ratios.
This work was supported by Graint-in-Aid for JSPS Fellows, 15J10864 (YS).
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331 – Comets: Origins and Theory Posters

331.01 – Unveiling clues from Spacecraft Missions to Comets and Asteroids through Impact Experiments

The Deep Impact Spacecraft mission was the first to boldly face the challenge of impacting the surface of a comet, 9P/Tempel 1, to investigate surface and subsurface 'pristine' materials. The Stardust mission to Comet 81P/Wild 2 brought back an exciting surprise: shocked minerals which were likely altered during the comet's lifetime. Signatures of shock in meteorites also suggest that the

violent past of the solar system has left our small bodies with signatures of impacts and collisions. These results have led to the question: How have impacts affected the evolutionary path taken by comets and asteroids, and what signatures can be observed?
A future planetary mission to a near-Earth asteroid is proposing to take the next steps toward understanding small bodies through impacts. The mission would combine an ESA led AIM (Asteroid Impact Mission) with a JHU/APL led DART (Double Asteroid Redirect Mission) spacecraft to rendezvous with binary near-Earth asteroid 65803 Didymus (1996 G2). DART would impact the smaller asteroid, 'Didymoon' while AIM would characterize the impact and the larger Didymus asteroid.
With these missions in mind, a suite of experiments have been conducted at the Experimental Impact Laboratory (EIL) at NASA Johnson Space Center to investigate the effects that collisions may have on comets and asteroids. With the new capability of the vertical gun to cool targets in the chamber through the use of a cold jacket fed by liquid nitrogen, the effects of target temperature have been the focus of recent studies. Mg-rich forsterite and enstatite (orthopyroxene), diopside (monoclinic pyroxene) and magnesite (Mg-rich carbonate) were impacted. Target temperatures ranged from 25°C to -100°C, monitored by connecting thermocouples to the target container. Impacted targets were analyzed with a Fourier Transform Infrared Spectrometer (FTIR) and Transmission Electron Microscope (TEM). Here we present the evidence for impact-induced shock in the minerals through both spectra and TEM imaging and compare with unshocked samples.
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331.02 – General Comet Traits and Comparison of their Dynamical History

Six comets have been visited by spacecrafts to date (1P/Halley, 19P/Borelly, 81P/Wild 2, 9P/Tempel 1, 103P/Hartley 2, and 67P/Churyumov-Gerasimenko). Very diverse nucleus morphologies are observed, within a
single comet and between them: pits, layered regions, scarps, smooth regions. The relative abundances and extent of these morphologies vary largely between comets. On 81P, pits and layered terrains are particularly abundant, while smooth regions are much less abundant. Conversely, on 9P and 19P, pits are notably less abundant, while smooth areas are abundant and more of greater extent. An evolutionary sequence of comet morphologies has been proposed previously, with the formation of pitted and layered terrains with large topography by early activity, and as activity proceeds, materials are mobilized and eventually form smoother, erosional regions. Observations of 67P seem to place it in between 81P and 9P/19P in this evolutionary sequence. Here we compare nucleus morphologies, outgassing rates, and dynamical history of these comets, in an attempt to test this evolutionary sequence, and to assess whether other properties may also be related to their dynamical history.
This work has been conducted in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.
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331.03 – Modeling the exchange of comets between the Sun and passing stars in a low stellar density environment

We investigated the importance of close encounters between our Sun and its Oort cloud and passing stars with similar Oort clouds in the low stellar density environment of the outer portion of our Galaxy. By constructing a set of interaction cross-sections that describe the interchange of material between the two passing Oort clouds, and then randomly computing sets of encounters that a star would have during its orbit in the Galaxy over a period of time equivalent to the life of the Sun after the dissolution of its birth cluster, we have examined how the ensemble of passing encounters could impact the evolution of our Oort cloud. From the set of 1,000 possible realizations of the interactions over a solar lifetime, we find that the resulting solar Oort cloud is likely to be significantly eroded as a result of the set of encounters, and is also likely today to contain a significant amount of material that was formed in passing extra-solar systems.
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331.04 – Asteroid Family Associations of Main-Belt Comets

We present a population-level analysis of the asteroid family associations of known main-belt comets or main-belt comet candidates (which, to date, have largely just been analyzed on individual bases as they have been discovered). In addition to family associations that have already been reported in the literature, we have identified dynamical relationships between 324P/La Sagra and the Alauda family, P/2015 X6 (PANSTARRS) and the Aeolia family, and P/2016 G1 (PANSTARRS) and the Adeona family. We will discuss the overall implications of these family associations, particularly as they pertain to the hypothesis that members of primitive asteroid family members may be more susceptible to producing observable sublimation-driven dust emission activity, and thus becoming main-belt comets. We will also discuss the significance of other dynamical and physical properties of a family or sub-family as they relate to the likelihood of that family containing one or more currently active main-belt comets.
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331.05 – CO from 67P/C-G: DIurnal and Seasonal Variations

The emission by CO in the coma of comet 67P/Churymov-Gerasimenko varied dramatically over time - episodically in outbursts, diurnally, and seasonally. The interpretation of the observations with the ALICE ultraviolet spectrometer is complicated by the varying viewing geometries from the Rosetta orbiter. It is also complicated by the many unanticipated physical processes leading to formation and excitation, as discussed in other talks and papers. We will focus on regularly executed Deep Volatile Abundance Campaigns, which, for one or more complete rotations of the nucleus, maintained the slit aligned sunward-tailward across the center of the nucleus, with the sunward coma always visible and, when the geometry allowed, the gas in front of the unilluminated parts of the nucleus and also the tailward coma also being visible. For any given geometry, the diurnal variation is generally repeated on successive rotations, thus allowing us to pinpoint the sub-solar longitudes and latitudes at the times of maxima and minima of the CO column density, ultimately enabling identification of the active regions. We also demonstrate the strong seasonal (sub-solar latitude) variation of the CO.

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331.06 – A scenario for the origin of molecular oxygen in comets

The detection of molecular oxygen in the coma of comet 67P/Churyumov-Gerasimenko by the ROSINA-DFMS instrument on board the Rosetta spacecraft raises a number of questions. This observation, showing abundances of O_2 in the 1–10% range with respect to H_2O, seems surprising at first sight, but might be more common than originally thought.

We propose that the radiolysis of icy grains in low-density environments such as the pre-solar cloud or low density regions of the proto-solar nebula (PSN), leads to the production of large amounts of O_2 issued from the destruction of the H_2O environment via different chemical reactions between created fragments. We show that the molecular oxygen produced can be efficiently trapped in the ices formed in the PSN. These molecules would remain embedded in the environing ices, even through a moderate heating that could allow for a phase transition of the amorphous ices to crystalline ones. They are liberated simultaneously with the water ices, leading to the strong correlation observed.

Computational chemistry models based on first principle periodic density functional theory (DFT) have shown to be well adapted to the description of compact ice and capable to provide the quantitative data to support the above scenario: i) no stabilization can be found neither for the *inclusion* of O_2 in the hexagonal ice lattice, neither for the *replacement*of a H_2O by O_2, ii) by contrast, the irradiation of the ice by cosmic rays generates *cavities* in which molecular oxygen is perfectly stable under the form of O_2 or dimers of O_2.

It should be stressed that the formation of one O_2 requires at least the destruction of two H_2O whatever the chemical reactions involved. The present simulation is fully consistent with the aforementioned radiolysis hypothesis, where the irradiation process is at the origin of both the formation of O_2 and the development of the cavities in which it remains sequestered. The possibility of having both, the monomer as well as the dimer, trapped in the cavities also helps with the interpretation of the variations of the proportion O_2/H_2O observed.

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331.07 – Comet Formation in Collapsing Pebble Clouds: Pebble Formation

The formation of comets by gradual growth from (sub-)micron sized ice and dust monomers to km-sized bodies suffers from growth barriers (bouncing, fragmentation, drift). Growth stalls at sizes between mm and m, rendering it considerably difficult to form km-sized objects. However, the streaming instability and subsequent gravitational collapse of clouds of pebbles (particle agglomerates) provide an alternative. The pebbles require Stokes numbers between 0.01 and 3, which corresponds to sizes between mm and dm, unless the pebbles are very porous. Furthermore, the local solid/gas density ratio must be near unity and the local total mass in solids must be >2-3x higher than the minimum mass solar nebula value (1% of gas mass). The gravitational collapse of the pebble clouds then bypasses the growth barriers, forming km-sized bodies directly. The observed bulk properties of comets, e.g. porosity near 80%, are consistent with this scenario. Okuzumi et al. (2012) showed that including porosity comets can form directly via coagulation from sub-micron monomers. However, this relies on using 0.1 micron monomers and pure sticking collisions. Krijt et al. (2015) included erosion and found that highly porous pebbles around 10^9 g in mass can form and might trigger the streaming instability. Drazkowska & Dullemond (2014) showed that compact coagulation can lead to triggering the streaming instability. All those studies include only ice and a simplified collision model. However, a large fraction of a comet's mass is dust. Here, we develop a pebble formation model that includes sticking, bouncing, mass transfer/erosion, and fragmentation, as well as porosity. To take dust and ice into account, we extended the collision model for the treatment of mixed pebbles by linearly interpolating the threshold velocities and compression curves between the cases of pure dust and pure ice based on the fractional abundance of dust monomers. Our simulations show that pebble formation with the full collision model might be a challenging task, because the combination of growth barriers and porosity makes it difficult, but not impossible, for the pebbles to gain suitable Stokes numbers.

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332 – History Posters

332.01 – Historical Trends of Participation of Women Scientists in Robotic Spacecraft Mission Science Teams: Effect of Participating Scientist Programs

Many planetary scientists consider involvement in a robotic spacecraft mission the highlight of their career. We have searched for names of science team members and determined the percentage of women on each team. We have limited the lists to members working at US institutions at the time of selection. We also determined the year each team was selected. The gender of each team member was limited to male and female and based on gender expression. In some cases one of the authors knew the team member and what pronouns they use. In other cases, we based our determinations on the team member's name or photo (obtained via a google search, including institution). Our initial analysis considered 22 NASA planetary science missions over a period of 41 years and only considered NASA-selected PI and Co-Is and not participating scientists, postdocs, or graduate students. We found that there has been a dramatic increase in participation of women on spacecraft science teams since 1974, from 0-2% in the 1970s – 1980s to an average of 14% 2000-present. This, however, is still lower than the recent percentage of women in planetary science, which 3 different surveys found to be ~25%. Here we will present our latest results, which include consideration of participating scientists. As in the case of PIs and Co-Is, we consider only participating scientists working at US institutions at the time of their selection.

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332.02 – The Value of Participating Scientists on NASA Planetary Missions

NASA has a long history of supporting Participating Scientists on its planetary missions. On behalf of the NASA Planetary Assessment/Analysis Groups (OPAG, MEPAG, VEXAG, SBAG, LEAG and CAPTEM), we are conducting a study about the value of Participating Scientist programs on NASA planetary missions, and how the usefulness of such programs might be maximized.
Inputs were gathered via a community survey, which asked for opinions about the value generated by the Participating Scientist programs (we included Guest Investigators and Interdisciplinary Scientists as part of this designation), and for the experiences of those who’ve held such positions. Perceptions about Participating Scientist programs were sought from the entire community, regardless of whether someone had served as a Participating Scientist or not. This survey was distributed via the Planetary Exploration Newsletter, the Planetary News Digest, the DPS weekly mailing, and the mailing lists for each of the Assessment/Analysis Groups. At the time of abstract submission, over 185 community members have responded, giving input on more than 20 missions flown over three decades. Early results indicate that the majority of respondents feel that Participating Scientist programs represent significant added value for NASA planetary missions, increasing the science return and enhancing mission team diversity in a number of ways. A second survey was prepared for input from mission leaders such as Principal Investigators and Project Scientists.
Full results of this survey will be presented, along with recommendations for how NASA may wish to enhance Participating Scientist opportunities into its future missions. The output of the study will be a white paper, which will be delivered to NASA and made available to the science community and other interested groups.

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332.03 – AAS Oral History Project – Seeking Planetary Scientist

Now in its fourth year, the AAS Oral History Project has interviewed over 100 space scientists from all over the world. Led by the AAS Historical Astronomy Division (HAD) and partially funded by the American Institute of Physics Niels Bohr Library and ongoing support from the AAS, volunteers have collected oral histories from space scientists at professional meetings starting in 2015, including AAS, DPS, and the IAU general assembly. Each interview lasts one and a half to two hours and focuses on interviewees’ personal and professional lives. Questions include those about one’s family, childhood, strong influences on one’s scientific career, career path, successes and challenges, perspectives on how astronomy is changing as a field, and advice to the next generation. Each interview is audio recorded and transcribed, the content of which is checked with each interviewee. Once complete, interview transcripts are posted online as part of a larger oral history library at https://www.aip.org/history-programs/niels-bohr-library/oral-histories.
We will present preliminary analysis of those interviewed including characterizing career status, age range, nationality, and primary field. Additionally, we will discuss trends beginning to emerge in analysis of participants’ responses about data driven science and advice to the next generation.
Future analysis will reveal a rich story of space scientists and will help the community address issues of diversity, controversies, and the changing landscape of science. We are actively recruiting individuals to be interviewed at this meeting from all stages of career from undergraduate students to retired and emeritus astronomers. We are especially interested in interviewing 40+E members of DPS. Contact Sanlyn Buxner to schedule an interview or to find out more information about the project (buxner@psi.edu). Contact Jarita Holbrook if you would like to become an interviewer for the project (astroholbrook@gmail.com).

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332.04 – Examples of studies of solar and lunar cycles carried out in Ireland in Neolithic times

Brứ na Bóinn (Newgrange) is the largest member of a group of Neolithic passage graves located in the Boyne Valley, Co. Meath, about 50 km from Dublin in Ireland. According to radio carbon dating, the monument was constructed between about 3200 and 3100 BC and it is thus s about five hundred years older than the current form of Stonehenge as well as older than the Great Pyramid of Giza in Egypt. Also, it predates the Mycenaean culture of ancient Greece. At the Winter Solstice, the rising sun shines through an external architectural feature called the roof box and traverses a 19m long passage to illuminate an inner chamber decorated by an elegant triple spiral and other carvings. This illumination lasts for about 17 minutes. Today, first light enters about four minutes after sunrise, but calculations based on the precession of the Earth show that, 5,000 years ago, first light would have entered exactly at sunrise. The poster presents drawings of the geometrical alignment concerned and places the monument in the context of other Neolithic monuments in Ireland oriented to key dates in the solar calendar. Evidence for the existence in the Boyne Valley of an interest in lunar as well as in solar cycles is discussed and a carving of a lunar cycle, deemed to be the earliest to be identified without serious ambiguity in either Ireland or Britain, is illustrated and described.

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400 – Asteroid Dynamics: Main-belt - Families and Breakups

400.01 – Asteroid clusters similar to asteroid pairs

We study five small, tight and young clusters of asteroids. They are placed around following largest (primary) bodies: (11842) Kap'bos, (14627) Emilkowalski, (16598) 1992 YC2, (21509) Lucascavin and (39991) 1998 HR37. Each cluster has 2-4 secondaries that are tightly clustered around the primary body, with distance in the 5-dimensional space of mean orbital elements mostly within 10 m/s, and always < 23 m/s. Backward orbital integrations indicate that they formed between 10^5 and 10^6 yr ago. In the P_1-q space, where P_1 is the primary's spin period and $q = \Sigma M_j/M_1$ is the total secondary-to-primary mass ratio, the clusters lie in the same range as asteroid pairs formed by rotational fission. We have extended the model of a proto-system separation after rotational fission by Pravec et al. (2010) for application to systems with more than one secondary and found a perfect match for the five tight clusters. We find these clusters to be similar to asteroid pairs and we suggest that

they are “extended pairs”, having 2-4 escaped secondaries rather than just one secondary as in the case of an asteroid pair. We compare them to six young mini-families (1270) Datura, (2384) Schulhof, (3152) Jones, (6825) Irvine, (10321) Rampo and (20674) 1999 VT1. These mini-families have similar ages, but they have a higher number of members and/or they show a significantly larger spread in the mean orbital elements (d_{mean} on an order of tens m/s) than the five tight clusters. In the P_1-q space, all but one of the mini-families lie in the same range as asteroid pairs and the tight clusters; the exception is the mini-family of (3152) Jones which appears to be a collisional family. A possibility that the other five mini-families were also formed by rotational fission as we suggest for the tight clusters (“extended asteroid pairs”) is being explored.
Reference:

Pravec, P., et al. Formation of asteroid pairs by rotational fission. Nature 466, 1085-1088.

Author(s): Petr Pravec[1], David Vokrouhlicky[2], Petr Fatka[1], Peter Kusnirák[1], Kamil Hornoch[1], Adrián Galád[1]
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400.02 – Detection of the YORP effect for small asteroids in the Karin family

The Karin family formed by a collisional breakup of a ~40-km parent asteroid only 5.75 Myr ago. The young age can be demonstrated by numerically integrating the orbits of Karin family members backward in time and showing the convergence of orbital elements. Previous work has pointed out that the convergence is not ideal if the backward integration only accounts for the gravitational perturbations from the Solar System planets. It improves when the thermal radiation force known as the Yarkovsky effect is accounted for. This method can be used to estimate the spin obliquities of Karin family members. Here we show that the obliquity distribution of diameter D=1−2 km asteroids in the Karin family is bimodal, as expected if the YORP effect acted to move obliquities toward extreme values (0 or 180 deg). The measured magnitude of the effect is consistent with the standard YORP model. Specifically, the strength of the YORP effect is inferred to be roughly 70% of the nominal YORP strength obtained for a collection of random Gaussian spheroids. The surface thermal conductivity is found to be 0.07-0.2 W/m/K (thermal inertia 300−500 in the SI units). These results are consistent with surfaces composed of rough and rocky regolith. The obliquity values predicted here for 480 members of the Karin cluster can be validated by the lightcurve inversion method. In broader context, the bimodal distribution of obliquities in the Karin cluster can be thought as an initial stage of dynamical evolution that later leads to a characteristically bi-lobed distribution of family members in the semimajor axis (e.g., Eos, Merxia or Erigone families).

Author(s): David Nesvorny[2], Valerio Carruba[3], David Vokrouhlicky[1]
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400.03 – Dynamics of asteroid family halos constrained by spin/shape models

A number of asteroid families cannot be identified solely on the basis of the Hierarchical Clustering Method (HCM), because they have additional 'former' members in the surroundings which constitute a so called halo (e.g. Broz & Morbidelli 2013). They are usually mixed up with the background population which has to be taken into account too.
Luckily, new photometric observations allow to derive new spin/shape models, which serve as independent constraints for dynamical models. For example, a recent census of the Eos family shows 43 core and 27 halo asteroids (including background) with known spin orientations.
To this point, we present a complex spin-orbital model which includes full N-body dynamics and consequently accounts for all mean-motion, secular, or three-body gravitational resonances, the Yarkovsky drift, YORP effect, collisional reorientations and also spin-orbital interactions. These are especially important for the Koronis family. In this project, we make use of data from the DAMIT database and ProjectSoft Blue Eye 600 observatory.

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400.04 – Yarkovsky V-shape identification of asteroid families

There are only a few known main belt (MB) asteroid families with ages greater than 2 Gyrs. Estimates based on the family producing collision rate suggest that the lack of >2 Gyr-old families may be due to a selection bias in current techniques used to identify families. Family fragments disperse in their orbital elements, semi-major axis, a, eccentricity, e and inclination, i due to secular resonances, close encounters with massive asteroids and the non-gravitational Yarkovsky force. This causes the family fragments to be indistinguishable from the background of the main belt making them more difficult to identify with the hierarchical clustering method (HCM) with increasing family age. The discovery of the Eulalia and Polana families in the inner belt relied on new techniques because they were overlapping families, also, or primarily, because Yarkovsky spreading over their 2 Gyr-old lifetime made them too disperse to be identified using the classical HCM. The techniques used to discover the Polana and Eulalia are modified here to identify asteroid families by searching for correlations between a and absolute magnitude, H, the family's characteristic V-shape. In addition to demonstrating the V-shape technique on known families such as Erigone, Vesta, Flora and Polana, we will present a new investigation of the asteroid belt with this new tool looking for old, previously unidentified families.

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400.05 – SPH/N-body simulations of small (D = 10 km) monolithic asteroidal breakups and improved parametric relations for Monte-Carlo collisional models

Detailed models of asteroid collisions can yield important constrains for the evolution of the Main Asteroid Belt, but the respective parameter space is large and often unexplored. We thus performed a new set of simulations of asteroidal breakups, i.e. fragmentations of intact targets, subsequent gravitational reaccumulation and formation of small asteroid families, focusing on parent bodies with diameters D = 10 km.
Simulations were performed with a smoothed-particle hydrodynamics (SPH) code (Benz & Asphaug 1994), combined with an efficient N-body integrator (Richardson et al. 2000). We assumed a number of projectile sizes, impact velocities and impact angles. The rheology used in the physical model does not include friction nor crushing; this allows for a direct comparison to results of Durda et al. (2007). Resulting size-frequency distributions are significantly different from scaled-down simulations with D = 100 km monolithic targets, although they may be even more different for pre-shattered targets.
We derive new parametric relations describing fragment distributions, suitable for Monte-Carlo collisional models. We also characterize velocity fields and angular distributions of fragments, which can be used as initial conditions in N-body simulations of small asteroid families. Finally, we discuss various uncertainties related to SPH simulations.

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400.06 – Delivery of organics to Mars through asteroid and comet impacts

Despite intensive search, the presence of organic molecules on Mars could only recently be demonstrated, through Curiosity measurements. On the surface of Mars, organics are highly unstable to photodissociation, but may last longer in the subsurface. It is therefore believed that organics observable today were delivered in geologically recent times; possible parent bodies are certain asteroids, comets, and/or
interplanetary dust particles.
We are studying how much organics the known asteroids and comets can deliver to Mars. Comets and certain asteroids (C-class) are known to be organic rich.
To this end we perform numerical gravity simulations to study impact rates on Mars within the past few Myr. We use the N-body integrator RMVS/Swifter to propagate the Sun and the eight planets from their current positions. We separately add comets and asteroids to the simulations as massless test particles, based on their current orbital distributions. In our asteroid simulations we differentiate between organic-rich (C-class) asteroids and other taxonomic types, using WISE albedo as a proxy. We expect to present first results at the meeting.
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401 – Outer Icy and Irregular Satellites I: Dynamics and Orbital Evolution

401.01 – Resonance locking as the source of rapid tidal migration in the Jupiter and Saturn moon systems

The inner moons of Jupiter and Saturn migrate outwards due to tidal energy dissipation within the planets, the details of which remain poorly understood. We demonstrate that resonance locking between moons and internal oscillations of the planet can produce rapid tidal migration. Resonance locking arises due to the structural evolution of the planet and typically produces an outward migration rate comparable to the age of the solar system. Resonance locking predicts a similar migration timescale but a different effective tidal quality factor Q governing the migration of each moon. It also predicts nearly constant migration timescales a function of semi-major axis, such that effective Q values were larger in the past. Recent measurements of Jupiter and Saturn's moon systems find effective Q values that are much smaller than expected (and are different between moons), and which correspond to migration timescales of ~10 Gyr. If confirmed, the measurements are broadly consistent with resonance locking as the dominant source of tidal dissipation in Jupiter and Saturn. Resonance locking also provides solutions to several problems posed by current measurements: it naturally explains the exceptionally small Q governing Rhea's migration, it allows the large heating rate of Enceladus to be achieved in an equilibrium eccentricity configuration, and it resolves evolutionary problems arising from present-day migration/heating rates.
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401.02 – Long-term Evolution of Small Saturnian Satellites: Aegaeon, Methone, Anthe and Pallene

The stability and long-term dynamical evolution of four small saturnian moons, near and gravitationally linked to Mimas and Enceladus, Aegaeon, Methone, Anthe and Pallene, is explored here through a sample of numerical simulations and frequency analysis. The dynamical system is formed by Saturn and its gravity coefficients up to J_6, plus the five biggest satellites of the region, Janus, Epimetheus, Mimas, Enceladus and Tethys.
Along with the small moons, a wide region of phase space surrounding them is explored with thousands of test particles, through frequency analysis maps, to gain a better understanding of the global dynamical stability of the full region.
Previous studies have found that Methone and Anthe are close to a chaotic zone (El Moutamid et. al. 2014), produced by the superposition of corotation and Lindblad eccentricity resonances with Mimas. The same authors found that Aegaeon is far enough of the chaotic zone. On the other hand, based on 6x10^4 yr simulations, Callegari and Yokoyama (2015) suggest that the dynamics of Methone and Anthe is chaotic, while Pallene is non-chaotic and dominated by a quasi secular resonance with Enceladus. Despite their closeness to chaotic regions, some of our preliminary results show, based on 10^5 yr simulations and frequency analysis, that all four small satellites are long-term stable. Finally, we will present additional results for particles near the small moons that are also affected by solar radiation pressure.
Author(s): Marco Antonio Muñoz-Gutiérrez[1], Silvia Giuliatti-Winter[1]
Institution(s): *1. UNESP*

401.03 – Mimas: Constraints on Origin and Evolution from Libration Data

In stark contrast with its neighbor moon Enceladus, Mimas is surprisingly geologically quiet, despite an orbital configuration prone to levels of tidal dissipation 30 times higher. While Mimas' lack of activity could be due to a stiff, frigid interior, libration data from the Cassini spacecraft suggest its interior is not homogeneous [1]. Here, we present 1-D models of Mimas' thermal and structural evolution under two accretion scenarios: primordial, undifferentiated formation in the Saturnian subnebula [2]; and late, layered formation from a debris ring created by the disruption of one or more previous moons [3]. In the primordial scenario, our simulations yield two possible outcomes. If tidal dissipation proceeds at levels higher than those obtained using an Andrade rheology [4], Mimas differentiates and an ocean persists until the present day. This should quickly circularize its orbit, but the current orbit is eccentric. In addition, Mimas lacks surface fractures that should result from strong tidal stresses in an ice shell atop an ocean [5]. If dissipation proceeds at lower levels obtained using a Maxwell rheology, it is too weak to drive differentiation; this does not match the observed libration [1]. In the late accretion scenario, Mimas forms already differentiated. As a result, even its deepest ice is within only 100 km of the frigid surface, and poorly insulated by overlying thermally conductive crystalline ice. Thus, all ice remains cold and poorly dissipative, even if dissipation is an order of magnitude above that provided by the Andrade rheology [4]. If Mimas' rocky core is slightly non-hydrostatic [1], this matches the observed libration. We conclude that Mimas' libration is compatible with a late origin from a debris ring, but not with primordial accretion. Consistent with findings from many authors (e.g. [6]), these models cannot produce an ocean on Enceladus unless its orbital eccentricity is higher than observed.

References:
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[2] Peale (1999) Annu Rev Astron Astrophys 37, 533
[3] Charnoz et al. (2011) Icarus 216, 535
[4] McCarthy & Cooper (2016) EPSL 443, 185
[5] Rhoden et al., JGR: Planets, submitted
[6] Roberts & Nimmo (2008) Icarus 194, 675

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402 – Jovian Planets: Magnetospheres and Aurorae

402.01 – Evolution of Jupiter's auroral-related stratospheric heating and chemistry

Auroral processes on Jupiter are evident over a large range of wavelengths. Emission at X-ray, UV and near-infrared wavelengths highlights the precipitation of charged particles in Jupiter's ionosphere. Jupiter's auroral regions also exhibit enhanced mid-infrared emission of CH_4 (7.8-µm), C_2H_2 (13-µm), C_2H_4 (10.5-µm) and C_2H_6 (12.2-µm), which indicates auroral processes modify the thermal structure and chemistry of the neutral stratosphere at pressures from 10 mbar to 10 µbar. In Sinclair et al., 2016a (submitted), 2016b (in preparation), we investigated these processes further by performing a retrieval analysis of Voyager-IRIS (Infrared Interferometer Spectrometer) observations measured in November 1979, Cassini-CIRS (Composite Infrared Spectrometer) observations measured in January 2001 and IRTF-TEXES (Texas Echelon Cross Echelle Spectrograph on NASA's Infrared Telescope Facility) spectra measured in December 2014. These datasets however captured Jupiter at significantly different epochs and thus the overall global evolution of atmospheric conditions as well as differences in spatial sampling, spectral resolution (and therefore vertical resolution in the atmosphere) have made inferences of the temporal evolution in auroral regions a challenge. However, in April 2016, we acquired IRTF-TEXES observations of Jupiter's high latitudes, using observing parameters very similar to those in December 2014. By performing a similar analysis of these observations and comparing results between December 2014 and April 2016, we can investigate the evolution of the thermal structure and chemistry in Jupiter's auroral regions over a 15 month timescale. The magnitude of temperature/composition changes and the altitudes at which they occur will provide insights into how auroral processes in the ionosphere propagate to the stratosphere. In particular, we can assess whether the evolution of stratospheric conditions in auroral regions is related to the decrease in solar activity from 2014 to 2016. We also hope to obtain further spectra from IRTF-TEXES in December 2016/January 2017 to support the Juno mission.

Author(s): James Sinclair[1], Glenn S Orton[1], Thomas K. Greathouse[2], Leigh N Fletcher[4], Julianne I. Moses[3], Vincent Hue[2], Patrick Gerard Joseph Irwin[5], Henrik Melin[4],Rohini Sara Giles[5]
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402.02 – Juno Ultraviolet Spectrograph (Juno-UVS) Observations of Jupiter during Approach

We present the initial results from Juno Ultraviolet Spectrograph (Juno-UVS) observations of Jupiter obtained during approach in June 2016. Juno-UVS is an imaging spectrograph with a bandpass of 70<λ<205 nm. This wavelength range includes all important ultraviolet (UV) emissions from the H_2 bands and the H Lyman series which are produced in Jupiter's auroras, and also the absorption signatures of aurorally-produced hydrocarbons. The Juno-UVS instrument telescope has a 4 x 4 cm^2 input aperture and uses an off-axis parabolic primary mirror. A flat scan mirror situated near the entrance of the telescope is used to observe at up to ±30° perpendicular to the Juno spin plane. The light is focused onto the spectrograph entrance slit, which has a "dog-bone" shape 7.2° long, in three sections of 0.2°, 0.025°, and 0.2° width (as projected onto the sky). Light entering the slit is dispersed by a toroidal grating which focuses UV light onto a curved microchannel plate (MCP) cross delay line (XDL) detector with a solar blind UV-sensitive CsI photocathode. Tantalum surrounds the spectrograph assembly to shield the detector and its electronics from high-energy electrons. All other electronics are located in Juno's spacecraft vault, including redundant low-voltage and high-voltage power supplies, command and data handling electronics, heater/actuator electronics, scan mirror electronics, and event processing electronics. The purpose of Juno-UVS is to remotely sense Jupiter's auroral morphology and brightness to provide context for in situ measurements by Juno's particle instruments. Prior to Jupiter Orbit Insertion (JOI) on July 5, Juno approach observations provide a rare opportunity to correlate local solar wind conditions with Jovian auroral emissions. Some of Jupiter's auroral emissions (e.g., polar emissions) may be controlled or at least affected by the solar wind. Here we compare synoptic Juno-UVS observations of Jupiter's auroral emissions (~40 minutes per hour, acquired during 2016 June 3-30) with in situ solar wind observations, as well as related Jupiter observations obtained from Earth.

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402.03 – Cassini UVIS Auroral Observations in 2016

In June of 2016, the Cassini Saturn orbiter began a series of high inclination orbits that will continue until September 2017 when the mission ends as Cassini enters the Saturn atmosphere. These orbits present excellent views of Saturn's polar regions suitable for auroral imaging at the closest distances to date, with the additional prospect of simultaneous particle and fields measurements within the sources of Saturn Kilometric Radiation (SKR) associated with ultraviolet auroral emissions and/or acceleration regions likely coinciding with them. We will present new Cassini Ultraviolet Imaging Spectrograph (UVIS) auroral images, spectra and movies obtained during the summer and fall of 2016 and put them in the context of auroral data collected since Cassini orbit insertion in 2004. Included in the new data will be UVIS south polar observations obtained simultaneously with Hubble Space Telescope observations of the north polar region on June 29, 2016 and August 19, 2016.

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Contributing team(s): Cassini UVIS Team

402.04 – Io Plasma Torus Ion Composition: Voyager, Galileo, Cassini

With JAXA's Hisaki spacecraft in orbit around Earth gathering information on the Io plasma torus and NASA's Juno mission measuring plasma conditions in the jovian magnetosphere, the time is ripe for a re-evaluation of earlier observations of the plasma torus to assess evidence for temporal variations. In particular, we are interested in exploring the ion composition of the torus and whether there is evidence of the ultimate source – the volcanic gases from Io – have deviated from SO_2. We use the latest CHIANTI 8.0 atomic database to analyze UV spectra of the torus from Voyager, Galileo and Cassini as well as with the physical chemistry model of Delamere, Steffl and Bagenal (2005). We find that contrary to earlier analyses of Voyager data (e.g. Shemansky 1987; 1988) that produced a composition requiring a neutral source of O/S~4, we find an ion composition that is consistent with the Cassini UVIS data (Steffl et al. 2004) and a neutral O/S~2, consistent with SO_2.

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402.05 – Relative abundance of water-group ions in Saturn's inner magnetosphere

At nineteen different times over seven years, the Cassini Ion Neutral Mass Spectrometer (INMS) measured the relative fractions of water-group ions in the inner magnetosphere of Saturn near the equatorial plane between 3.8 and 6.5 Saturn radii (R_S). INMS samples only a small portion of velocity space in any one measurement, but the measurements span a broad range of velocity space. The data show that H_2O^+ comprises the bulk of the ions near 4.0 R_S, and that its fraction decreases with increasing distance from 4.0 R_S, the source of neutral water at Enceladus. At 4.0 R_S, the fraction of H_2O^+ ranges from 60% to 100%, with an average of 80%. At 6.5 R_S, the three main water-group constituents, H_2O^+, OH^+, and O^+, are nearly equal. H_3O^+, which dominates the water-group ion fractions in the Enceladus plume, is 10% or less in Saturn's magnetosphere outside the plume. The relative ion fractions show other variations that are not clearly linked to any of the studied parameters including velocity, density, and the orbit-phase-dependent activity of Enceladus.

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402.06D – Planetary Magnetosheaths: Role of Compressibility on the Scaling Properties of Turbulence

Compressible turbulence has been a subject of active research within the space physics community for the last three decades especially that it is believed to be essential for understanding the physics of the solar wind (for instance the heating of the fast wind), of the interstellar medium (in cold molecular clouds) and of other astrophysical and space phenomena.
The role of the compressible fluctuations in the energy cascade in the planetary magnetosheaths is investigated with a comparison of a nearly incompressible medium, the solar wind. A focus is put on comparing the energy cascade rates estimated using the exact laws derived for incompressible MHD turbulence [Politano and Pouquet, 1998] (PP98) and for compressible isothermal turbulence recently derived by Banerjee and Galtier, 2013 (BG13).
New features are evidenced using the BG13 model in comparison with the PP98 model. More interestingly, a term-by-term analysis of the compressible model emphasized the relative importance of the new compressible flux terms in the BG13 model w.r.t. to the incompressible (Yaglom) term, and provided new insight into the role played by the compressible fluctuations in the solar wind and the more compressible medium, the planetary magnetosheaths. This observational study can help improving current models of astrophysical turbulence by addressing the role of compressibility behind astrophysical shocks, in the interstellar medium or in supernova remanents.

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403 – Jovian Atmosphere I: Upper Atmosphere

403.01 – Evaluation of the efficiency and accuracy of new methods for atmospheric opacity and radiative transfer calculations in planetary general circulation model simulations

General circulation models often incorporate simple approximations of heating between vertically inhomogeneous layers rather than more accurate but computationally expensive radiative transfer (RT) methods. With the goal of developing a GCM package that can model both solar system bodies and exoplanets, it is vital to examine up-to-date RT models to optimize speed and accuracy for heat transfer calculations. Here, we examine a variety of interchangeable radiative transfer models in conjunction with MITGCM (Hill and Marshall, 1995). First, for atmospheric opacity calculations, we test gray approximation, line-by-line, and correlated-k methods. In combination with these, we also test RT routines using 2-stream DISORT (discrete ordinates RT), N-stream DISORT (Stamnes et al., 1988), and optimized 2-stream (Spurr and Natraj, 2011). Initial tests are run using Jupiter as an example case. The results can be compared in nine possible configurations for running a complete RT routine within a GCM. Each individual combination of opacity and RT methods is contrasted with the "ground truth" calculation provided by the line-by-line opacity and N-stream DISORT, in terms of computation speed and accuracy of the approximation methods. We also examine the effects on accuracy when performing these calculations at different time step frequencies within MITGCM. Ultimately, we will catalog and present the ideal RT routines that can replace commonly used approximations within a GCM for a significant increase in calculation accuracy, and speed comparable to the dynamical time steps of MITGCM. Future work will involve examining whether calculations in the spatial domain can also be reduced by smearing grid points into larger areas, and what effects this will have on overall accuracy.

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403.02 – The Effect of Diurnal Variations on Ionospheric Radio Occultations

Radio occultations are a powerful technique for the study of atmospheres and ionospheres by planetary spacecraft. For missions to the outer solar system, the occultations always probe the terminator region of the planet. The analysis of radio occultations typically assumes symmetry along the ray path in the horizontal direction about the tangent point. While this is an excellent assumption for the neutral atmosphere where the scale length of horizontal gradients is large, it is suspect for the ionosphere where electron densities decrease rapidly from day to night. Diurnal variations in peak electron density are often several orders of magnitude and may occur over a region of a few degrees. We investigate the consequences of diurnal variations on ionospheric occultations with a ray tracing calculation for the angular deflection and frequency residual of the radio wave. The calculations are based on photochemical/diffusion models for the ionospheres of Saturn and Titan. Differences from analysis based on the assumption of horizontal symmetry are most pronounced in the bottom side ionosphere where chemical time constants are short.

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403.03 – UV emissions of Jupiter: exploration of the high-latitude regions through the UV spectrograph on NASA's Juno mission

The Juno mission offers the opportunity to study Jupiter, from its inner structure to its magnetospheric environment. Juno was launched on August 2011 and its Jupiter orbit insertion (JOI) planned for July 4th 2016, will place Juno in a 53.5 days capture orbit. A period reduction maneuver will be performed two orbits later to place Juno into 14-days elliptical orbits for the duration of the nominal mission, which includes 36 orbits. Juno-UVS is a UV spectrograph with a bandpass of $70 \le \lambda \le 205$ *nm*, designed to characterize Jupiter UV emissions. One of the main additions of UVS compared to its predecessors is a 2.54 mm tantalum shielding, to protect it from the harsh radiation environment at Jupiter, and a scan mirror, to allow for targeting specific auroral regions during perijove passes. The scan mirror is located at the front end of the instrument and will be used to look at +/- 30° perpendicular to the Juno spin plane. The entrance slit of UVS has a dog-bone shape composed by three sections with field of views of 0.2°x2.5°, 0.025°x2.0° and 0.2°x2.5°, as projected onto the sky. It will provide new constraints on Jupiter's auroral nightside morphology and spectral features as well as the vertical structure of these emissions. It will bring remote-sensing constraints for the onboard waves and particle instruments (JADE, JEDI, Waves and MAG). The ability to change the pointing will allow relating the observed UV brightness of the regions magnetically connected to where Juno flies with the particles and waves measurements. We will discuss the planned observations and scientific targets for the nominal mission orbital sequence, which will consist of three UV datasets per orbit. We will present the results from the first orbit. As Juno orbit evolves during the mission, we will also present how these objectives evolve over time.

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404 – Mars Atmosphere Composition and Climate

404.01 – Three-dimensional mapping of the water cycle and D/H on Mars with ALMA

Using ALMA, we mapped the vertical distribution of the water D/H across a broad range of terrains and times of days and local seasons on Mars. The observations were done in March/2016 and targeted four lines of isotopic water (H_2O, HDO, $H_2{}^{18}O$, $H_2{}^{17}O$), and one line of isotopic carbon monoxide ($C^{17}O$) used for establishing the thermal structure. The observations allowed us to investigate and separate how the D/H evolves on the planet, since fractionation processes induced by cloud formation would lead to notable variations of D/H along the column.
Isotopic measurements are per-se excellent tracers of water loss/evolution on Mars (Villanueva et al. 2015), yet some of the recently observed variations are striking and reveal a far more complex scenario for the processes acting on the Martian water cycle. They are perhaps indicative of sub-surface water reservoirs interacting with the atmosphere, but the IR measurements did not resolve the vertical structure, limiting the untangling of climatological effects (*e.g.,* cloud formation, Rayleigh distillation). We will present 3D maps of water and D/H and will discuss possible scenarios to explain the observations, in particular, in the context of the upper-atmosphere D/H MAVEN measurements.
Villanueva, G. L., Mumma, M. J., Novak, R. E., et al. 2015, Science, 348, 218

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404.03 – Remote Measurement of Isotopic Carbon Dioxide Over Gale Crater

Accurately determining the relative abundance of carbon dioxide heavy isotopes on Mars is central to estimating the primordial atmospheric inventory on Mars. Groundbased observations of Mars were conducted in April 2016 to measure transitions of oxygen-18 singly-substituted carbon dioxide over the course of several hours of local time on Mars, in comparison to normal-isotope carbon dioxide. These observations used the ultrahigh resolution spectrometer HIPWAC at the NASA Infrared Telescope Facility to measure individual rovibrational transitions of each of the targeted isotopologues as well as thermal continuum from Mars surface. The stable minor isotope O-18 is the most well characterized of the oxygen and carbon minor isotopes, due to strong lines and convenient frequency offset from neighboring normal-isotope lines, as well as being most easily measured on Mars surface through mass spectrometry by the Curiosity rover, Phoenix, and Viking. The average estimated O-18/O-16 isotope ratio in previous spectroscopic measurements using HIPWAC has been found to be approximately consistent with other in situ and remote spectroscopic measurements but radiative-transfer analysis has shown that the retrieved ratio appears to increase with greater ground surface temperature, suggesting mass-dependent fractionation in the adsorption of carbon dioxide onto surface grains, with thermal desorption through the course of the Martian sol as the ground warms.

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404.04D – Constraining the Source of Curiosity's Methane Detections Using the Mars Regional Atmospheric Modeling System (MRAMS)

The putative in situ detection of methane by SAM instrument has garnered significant attention. There are many major unresolved questions regarding this detection: 1) Where is the release location? 2) How spatially extensive is the release? 3) For how long is CH_4 released? In an effort to better address the potential mixing and remaining questions, atmospheric circulation studies of Gale Crater were performed with MRAMS mesoscale model, ideally suited for this investigation using tracer fields to simulate the transport of CH_4 and to understand the mixing of air inside and outside the crater throughout the Martian year. The simulated tracer abundances are compared to gas abundances measured by SAM. Ls270 was shown to be an anomalous season when air within and outside the crater was well mixed by strong, flushing, northerly flow and large amplitude breaking mountain waves: air flowing downslope at night is cold enough to penetrate all the way to the surface. At other seasons, the air in the crater is more isolated from the surrounding environment: the air flowing down the crater rims does not easily make it to the crater floor. Instead, the air encounters very cold and stable air pooled in the bottom of the crater, which forces the air to glide right over the colder, more dense air below. Thus, the mixing of near surface crater air with the external environment is potentially more limited at seasons other than around Ls270. The rise in CH4 concentration was reported to start around Ls336, peaked shortly after Ls82, and then dropped to background values prior to Ls103. Two scenarios are considered in the context of the circulations predicted by MRAMS. The first scenario is the release of CH_4 from somewhere outside the crater. The second is a release of CH_4 within the crater. In both cases, the release is assumed to take place near the season when the rise of concentration was first noted Ls336. This is a transitional time at Gale, when the flushing winds are giving way to the more isolated crater scenario. The objective is to establish the amount of mixing during the limited mixing epochs and to test whether CH_4 releases inside or outside of Gale crater are consistent with observations by SAM.

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Contributing team(s): MSL team, SAM team, REMS team

404.05 – Atmospheric distribution of methane on Mars: A model study

In the past decade, the detection of methane (CH_4) in the atmosphere of Mars has been reported several times. These observations have strongly drawn the attention of the scientific community and triggered a renewed interest in Mars as their implications for the geochemical or biological activities are remarkable. However, given that methane is expected to have a photochemical lifetime of several centuries, the relatively fast loss rates of methane estimated from Earth-based measurements remain unexplained. Although this gave rise to objections against the validity of those observations, recent in situ measurements confirmed that methane is being occasionally released into the atmosphere from an unknown source (possibly from the ground). Additionally, ExoMars/TGO was launched to Mars in March 2016. NOMAD, one of the instruments onboard TGO, will provide the first global detailed observations of methane on Mars. It is in this context that we present a model study of the behavior of methane plumes. A general circulation model for the atmosphere of Mars is applied to simulate surface emission of methane and to investigate its vertical distribution during the first weeks after the release. Such surface emissions were suggested to explain observations of methane. Previous GCM simulations focused on the horizontal evolution of the methane, but the present study focuses on the three-dimensional dispersion of methane throughout the atmosphere after the surface release. It is found that a highly nonuniform vertical distribution, including distinct vertical layers, can appear throughout the atmosphere during the first weeks after the emission. This is explained by the global circulation patterns in the atmosphere at the time of the emission. Large Hadley cells transport the methane rapidly to other locations over the planet, and methane will be stretched out in layers along the general circulation streamlines at heights corresponding to strong zonal jets.
This result changes our understanding of the behavior of atmospheric methane on Mars, and potential implications on the fate of methane will be discussed.

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404.06 – Mars Methane highs unrelated to comets

Until the Curiosity Rover arrived at Mars, all measurements of methane were done by remote sensing, either from Earth or from orbiting spacecraft, using a variety of different instruments and under different observing conditions. The Curiosity Rover's Sample Analysis at Mars (SAM) / Tunable Laser Spectrometer (TLS) has carried out systematic measurements of martian methane from Gale crater for two consecutive martian years (31 - 33, starting in October 2012). Meteoric material interacts with the martian atmosphere when Mars passes through a meteoroid stream left behind by cometary bodies orbiting the Sun. Predictions show that 33 such events are likely to occur during the martian year. It has been suggested that the organics present in this material trigger the formation of methane in the atmosphere, and thus these events could possibly be an explanation for the observed variations in the methane abundance. In a recent paper, Fries et al. [2016] argued that all measurements of high methane concentrations are within 16 days of a predicted meteor shower event, and that as such there is a correlation. We present a new analysis including seven new data points that were not available previously. All these new measurements show low methane values. Some of the new measurements were deliberately taken at the same Ls when high values of methane were measured in the previous martian year, showing that the high methane measurements are likely not seasonal, as would be expected if they were connected to meteor shower events. In our analysis we take into account all the predicted meteor events and search for any correlation drawn between these events and the level of methane in the atmosphere. We conclude that whether we consider individual data points, apply statistical analysis, or consider different time spans between measurements and the occurrence of meteor events, or possible supply of organic material from comets, there is no evidence for such a correlation in the available data.

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404.07 – NOMAD on ExoMars: first results from near Earth commissioning and mid-cruise checking

NOMAD (Nadir and Occultation for MArs Discovery) is a suite of three high-resolution spectrometers on-board the ExoMars Trace Gas Orbiter. The instrument will be able to detect and map a wide variety of Martian gases in unprecedented detail. NOMAD covers the UV-visible (UVIS channel - 200-650nm) and infrared ranges (SO and LNO channels - 2.2-4.3mm), operating in solar occultation, limb and nadir-viewing modes, generating a huge dataset of Martian atmospheric observations during the mission across a wide spectral range.
NOMAD has the resolving power to identify many trace gases that exhibit absorption features within the spectral range of the three channels. The order-of-magnitude increase in spectral resolution over previous instruments will enable spatial and temporal mapping of several isotopologues of methane and water, providing important measurements of the Martian D/H and methane isotope ratios

globally. Sensitivity studies have shown that, using expected SNR values, NOMAD should have the ability to measure methane concentrations down to 25 parts per trillion (ppt) in solar occultation mode, and to 11 parts per billion (ppb) in nadir mode. Using SO and LNO in combination with UVIS, aerosol properties such as optical depth, composition and size distribution can also be derived. NOMAD will also continue to monitor the major seasonal cycles on Mars, extending existing datasets made by successive space missions in the past decade.
NOMAD is now en route to Mars, and has already performed a series of observations, primarily to check the health of the instrument and to begin calibration.

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404.08 – Valley Formation on Early Mars Caused by Carbonate-Silicate Cycle-Induced Climate Cycling

For decades, scientists have tried to explain the evidence for fluvial activity on early Mars, but a consensus has yet to emerge regarding the mechanism for producing it. One hypothesis suggests early Mars was warmed by a thick greenhouse atmosphere. Another suggests early Mars was generally cold but was warmed occasionally by impacts or by episodes of enhanced volcanism. These latter hypotheses struggle to produce the amounts of rainfall needed to form the martian valleys, but are consistent with inferred low rates of weathering compared to Earth. We suggest that both schools of thought are partly correct. Mars experienced dramatic climate cycles with extended periods of glaciation punctuated by warm periods lasting up to 10 Myr. Cycles of repeated glaciation and deglaciation occurred because stellar insolation was low, and because CO2 outgassing could not keep pace with CO2 consumption by silicate weathering followed by deposition of carbonates. In order to deglaciate early Mars , substantial outgassing of molecular hydrogen from Mars' reduced crust and mantle was also required. Our hypothesis can be tested by future Mars exploration that better establishes the time scale for valley formation.

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404.09 – 3D Global Climate Modelling of the environmental effect of meteoritic impacts on Early Mars

There are now robust evidences that liquid water flowed on ancient Mars: dry river beds and lakes, hydrated sedimentary minerals and high erosion rates. Climate models that consider only CO_2/H_2O as greenhouse gases have been unable yet to produce warm climates suitable for liquid water on Early Mars, given the lower solar luminosity at that time. It has been suggested that the warm conditions required to explain the formation of the 3.8 Gyrs old valley networks could have been transient and produced in response to the meteoritic impacts that occured during the contemporaneous Late Heavy Bombardment (LHB). This scenario is appealing because, in a predominately cold climate, the ice tends to accumulate preferentially in the regions where the rivers were sculpted ('Icy Highlands' scenario). This would be a very efficient mechanism of recharge of the valley network water sources between two impact-induced melting events.

Using the LMD Global Climate Model (LMD-GCM) designed for flexible (from cold & dry to warm & wet) conditions, we explored the environmental effect of LHB impact events of various sizes on Early Mars. Our main result is that, whatever the initial impact-induced temperatures and water vapor content injected, warm climates cannot be stable and are in fact short-lived (lifetime of ~ 5 martian years/bar of H_2O injected). Moreover, we will give preliminar estimates of the amount of rainfall/snowmelt that can be produced after impact events depending on their size, following three different approaches:
1) For large impact events ($D_{impactor}$ < 50km, N ~ 40) we initialize the LMD-GCM with warm/moist conditions prescribed with simple scaling laws and assuming energy conservation.
2) For moderate-size events (5km < $D_{impactor}$ < 50km, N ~ $3x10^3$) we use the SOVA hydrocode for short-term modelling of impact cratering. It provides us with post-impact temperature fields, injection of volatiles, ejecta and dust distribution that serve as input for the LMD-GCM.
3) Simultaneously, we derive the cumulated long-term effect of impact events on the geothermal heat fluxes using the StagYY Mantle Convection Model. These are used as input in the LMD-GCM to estimate the effiency of basal melting.

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405 – Asteroids: Observational Surveys I

405.01 – The Catalina Sky Survey for Near-Earth Objects

The Catalina Sky Survey (CSS) operates three telescopes on Mt. Lemmon, Arizona, in support of NASA's effort to detect and catalog near-Earth objects (NEOs). CSS is undergoing a period of significant enhancement, including the installation of two large-format cameras built around monolithic 10k x 10k detectors, which replace our reliable but aging 4k x 4k cameras at the survey telescopes. These new cameras increase the field of view (FoV) of our 0.7-meter Schmidt telescope by a factor of 2.4 (from 8.1 deg^2 to 19.4 deg^2), and the FoV of our 1.5-meter telescope by a factor of 4 (from 1.2 deg^2 to 5.0 deg^2), enabling significantly more sky to be surveyed every night. Other recent improvements include the conversion to a more modern telescope control system, the addition of an image subtraction-based enhancement to our moving object detection software, and the deployment of a custom adaptive queue scheduler.
We will present a brief overview of survey operations, discussing the balance between human-driven decisions and automation. Results from the new camera commissioning will also be presented, and we will introduce a new project to reprocess the CSS archival holdings with an enhanced pipeline, and publicly serve the data via PDS.
CSS is supported by NASA under grant #NNX15AF79G.

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405.02 – Sky-plane discovery rates for Near Earth Object discoveries from Pan-STARRS1 - implications for future search strategies

The Pan-STARRS1 telescope has been spending most of its time for the last 2.5 years searching the sky for Near Earth Objects (NEOs). The surveyed area covers the entire northern sky and extends south to –49 degrees declination. Because Pan-STARRS1 has a large field-of-view, it has been able survey large areas of the sky, and we are now able to examine NEO discovery rates relative to ecliptic latitude.

Most contemporary searches, including Pan-STARRS1, have been spending large amounts of their observing time during the dark moon period searching for NEOs close to the ecliptic. The rationale for this is that many objects have low inclination, and all objects in orbit around the Sun must cross the ecliptic. New search capabilities are now available, including Pan-STARRS2, and the upgraded camera in Catalina Sky Survey's G96 telescope. These allow NEO searches to be conducted over wider areas of the sky, and to extend further from the ecliptic.

We have examined the discovery rates relative to location on the sky for new NEOs from Pan-STARRS1, and find that the new NEO discoveries are less concentrated on the ecliptic than might be expected. This finding also holds for larger objects. The southern sky has proven to be very productive in new NEO discoveries – this is a direct consequence of the major NEO surveys being located in the northern hemisphere.

Our preliminary findings suggest that NEO searches should extend to at least 30 degrees from the ecliptic during the more sensitive dark moon period. At least 6,000 deg^2 should therefore be searched each lunation. This is possible with the newly augmented NEO search assets, and repeat coverage will be needed in order to recover most of the NEO candidates found. However, weather challenges will likely make full and repeated coverage of such a large area of sky difficult to achieve. Some simple coordination between observing sites will likely lead to improvement in efficiency.

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405.03 – Searching for NEO precoveries in the PS1 and MPC databases

The Pan-STARRS (PS1) survey telescope, operated by the University of Hawai`i, covers the sky north of -49 degrees declination with its seven square degree field-of-view. Described in detail by Wainscoat et al. (2015), it has become the leading telescope for new Near Earth Object (NEO) discoveries. In 2015, it found almost half of the new Near Earth Asteroids, as well as half of the new comets.

Observations of potential NEOs must be followed up before they can be confirmed and announced as new discoveries, and we are dependent on the follow-up capabilities of other telescopes for this. However, not every NEO candidate is immediately followed up and linked into a well established orbit, possibly due to the fact that smaller bodies may not be visible at current instrument sensitivity limits for very long, or that their predicted orbits are too uncertain so follow-up telescopes look in the wrong location. But in certain cases, these objects may have been observed during previous lunations.

We present a method to search for precovery detections in both the PS1 database, and the Isolated Tracklet File (ITF) provided by the Minor Planet Center (MPC). This file contains over 12 million detections mostly from the large surveys, which are not associated with any known objects. We demonstrate that multi-tracklet linkages for both known and unknown objects may be found in these databases, including detections for both NEOs and non-NEOs which often appear on the MPC's NEO Confirmation Page.

[1] Wainscoat, R. et al., IAU Symposium 318, editors S. Chesley and R. Jedicke (2015)

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405.04 – ATLAS: Forecasting Falling Rocks

The Asteroid Terrestrial-impact Last Alert System (ATLAS) is a new asteroid survey aimed at detecting small (10-100 meter) asteroids inbound for impact with Earth. Relative to the larger objects targeted by most surveys, these small asteroids pose very different threats to our planet. Large asteroids can be seen at great distances and measured over many years, resulting in precise orbits that enable long-term impact predictions. If an impact were predicted, a costly deflection mission would be warranted to avert global catastrophe -- but a large asteroid impact is very unlikely in the next century. By contrast, impacts from small asteroids are inevitable. Such objects can be detected only during close encounters with Earth -- encounters too brief to yield long-term predictions. Only a few days' warning could be expected for an impactor in the 10-100 meter range, but fortunately the impact of such an asteroid would cause only regional damage. As in the case of a hurricane, a quixotic attempt to deflect or destroy it would be more expensive than the damage from its impact. A better response is to save human lives by evacuating the impact zone, and then rebuild. Only a few days warning are needed for this purpose, and ATLAS is unique among asteroid surveys in being optimized to provide it. While the optimization has many facets, the most important is rapidly surveying the entire accessible sky. A small asteroid could come from any direction and go from invisibility to impact in less than a week: ATLAS must look everywhere, all the time. Sky coverage is more important than exquisite sensitivity to faint objects, because asteroids inbound for impact will eventually become quite bright. This makes ATLAS complementary to other surveys, which scan the sky at a more leisurely pace but are able to detect asteroids at greater distances. We report on ATLAS' first year of survey operations, including the maturing of robotic observation and detection strategies, and asteroid and comet discoveries both expected and unexpected.

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405.06 – The LCOGT NEO Follow-up Network

The LCOGT NEO Follow-up Network is using the telescopes of the Las Cumbres Observatory Global Telescope Network (LCOGT) and a web-based target selection, scheduling and data reduction system to confirm NEO candidates and characterize radar-targeted known NEOs. Starting in July 2014, the LCOGT NEO Follow-up Network has observed over 3,500 targets and reported more than 16,000 astrometric and photometric measurements to the Minor Planet Center (MPC).

The LCOGT NEO Follow-up Network's main aims are to perform confirming follow-up of the large number of NEO candidates and to perform characterization measurements of radar targets to obtain light curves and rotation rates. The NEO candidates come from the NEO surveys such as Catalina, PanSTARRS, ATLAS, NEOWISE and others. In particular, we are targeting objects in the Southern Hemisphere, where the LCOGT NEO Follow-up Network is the largest resource for NEO observations.

LCOGT has completed the first phase of the deployment with the installation and commissioning of the nine 1-meter telescopes at McDonald Observatory (Texas), Cerro Tololo (Chile), SAAO (South Africa) and Siding Spring Observatory (Australia). The telescope

network has been fully operational since 2014 May, and observations are being executed remotely and robotically. Future expansion to a site at Ali Observatory, Tibet is planned for 2017-2018.
We have developed web-based software called NEOexchange which automatically downloads and aggregates NEO candidates from the Minor Planet Center's NEO Confirmation Page, the Arecibo and Goldstone radar target lists and the NASA ARM list. NEOexchange allows the planning and scheduling of observations on the LCOGT Telescope Network and the tracking of the resulting blocks and generated data. We have recently extended the NEOexchange software to include automated data reduction to re-compute the astrometric solution, determine the photometric zeropoint and find moving objects and present these results to the user via the website.
We will present results from the LCOGT NEO Follow-up Network and from the development of the NEOexchange software which is used to schedule, analyze and report observations taken with the LCOGT Network.
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405.07 – Preparing for LSST with the LCOGT NEO Follow-up Network

The Las Cumbres Observatory Global Telescope Network (LCOGT) provides an ideal platform for follow-up and characterization of Solar System objects (e.g. asteroids, Kuiper Belt Objects, comets, Near-Earth Objects (NEOs)) and ultimately for the discovery of new objects. The LCOGT NEO Follow-up Network is using the LCOGT telescope network in addition to a web-based system developed to perform prioritized target selection, scheduling, and data reduction to confirm NEO candidates and characterize radar-targeted known NEOs.
In order to determine how to maximize our NEO follow-up efforts, we must first define our goals for the LCOGT NEO Follow-up Network. This means answering the following questions. Should we follow-up all objects brighter than some magnitude limit? Should we only focus on the brightest objects or push to the limits of our capabilities by observing the faintest objects we think we can see and risk not finding the objects in our data? Do we (and how do we) prioritize objects somewhere in the middle of our observable magnitude range? If we want to push to faint objects, how do we minimize the amount of data in which the signal-to-noise ratio is too low to see the object? And how do we find a balance between performing follow-up and characterization observations?
To help answer these questions, we have developed a LCOGT NEO Follow-up Network simulator that allows us to test our prioritization algorithms for target selection, confirm signal-to-noise predictions, and determine ideal block lengths and exposure times for observing NEO candidates. We will present our results from the simulator and progress on our NEO follow-up efforts.
In the era of LSST, developing/utilizing infrastructure, such as the LCOGT NEO Follow-up Network and our web-based platform for selecting, scheduling, and reducing NEO observations, capable of handling the large number of detections expected to be produced on a daily basis by LSST will be critical to follow-up efforts. We hope our work can act as an example and tool for the community as together we prepare for the age of LSST.
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405.08 – Astrometry of Solar System Objects with Gaia

The Gaia ESA space mission will provide astrometric observations of a large number of celestial bodies, with unprecedented accuracy, and in an homogenous reference frame (to become the optical ICRF). The Gaia satellite is monitoring regularly the whole celestial sphere, with one complete scan in about 6month, down to approximately magnitude V≤20.7. It will provide after its nominal lifetime, (5 years, 2014-2019) about 70 astrometric points for several hundred thousands of solar system objects, asteroids from the Near-Earth region to Centaurs and bright TNOs, as well as planetary satellites and comets. The highly precise astrometric and photometric data is bound to lead to huge advances in the science of small Small Solar System Bodies (e.g. Tanga et al. 2016 P\&SS, Hestroffer et al. 2014 COSPAR #40 ; Mignard et al. 2007 EMP).
The first Gaia data release (GDR#1) is foreseen for Q3-2016 and will provide highly precise positions of selected stars down to mag V≈20. While solar system objets data is foreseen for the next data release (in 2017), science of Solar System will also highly benefit from the Gaia stellar catalogue. We will present the status of the satellite and Gaia mission, and details on the stellar data that will be published in this GDR#1. We discuss the catalogue content, number of stars, parameters and precisions, and the process of cross-matching and validation. We also touch upon the construction of combined Tycho-Gaia TGAS catalogue.
A Gaia data daily processing is devoted to the identification of Solar System Objects. During this process the detection of new (or critical) objects arises and leads to the triggering of scientific alerts to be found on the web gaiafunsso.imcce.fr. We have also set up an international follow-up network called Gaia-FUN-SSO to validate the detection in space. For this goal, in case of detection the observational data must be sent to the MPC by the observers. Besides, Gaia should benefit for the classical astrometric reduction, for future as well as for past observations, which is part of the NAROO project (Robert et al. 2015 A&A). We will also touch upon the next releases steps, and the SSO data from Gaia observations that will be published.
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405.09 – Simulation of the dusty plasma environment of 65803 Didymos for the Asteroid Impact Mission (AIM)

The Asteroid Impact and Deflection Assessment mission (AIDA) is a joint European-US technology demonstrator mission including the DART asteroid impactor (NASA/JHU/APL) and the AIM asteroid rendezvous platform (ESA/DLR/OCA) set to reach Near Earth binary Object 65803 Didymos in October 2022. Besides technology demonstration in the deep space communications domain and the realization of a kinetic impact on the moonlet to study deflection parameters, this asteroid rendezvous mission is an opportunity to carry out in-situ observations of the close environment of a binary system, addressing some fundamental science questions. The MASCOT-2 lander will be released from the AIM platform and operate at the surface of the moonlet of 65803 Didymos, complemented by the ability of the Cubesat Opportunity Payloads (COPINS) to sample the close environment of the binary.
In this context, we have developed an model describing the plasma and charged dust components of the near surface environment of the moonlet (170m in diameter), targeted by the MASCOT-2 lander and of the DART impactor. We performed numerical simulations in order to estimate the electrostatic surface potentials at various

locations of the surface, resulting from its interaction with the solar wind plasma and solar photons. In addition, we describe charging levels, density profiles, and velocity distribution of regolith grains lifted out from the surface up to about 70m above the surface.

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406 – Citizen and Student Engagement in Space Science: The Latest Educational Research and Future Studies

406.01 – Planet Four: Terrains - Pointing the Highest Resolution Camera Ever Sent to Mars with the Help of 10,000 Earthlings

Mars' south pole is sculpted by the never-ending cycle of freezing and thawing of exposed carbon dioxide ice. In the summer, carbon dioxide jets loft dust and dirt through cracks in the thawing carbon dioxide ice sheet to the surface where winds blow the material into the hundreds of thousands of dark fans observed from orbit. Built with the Zooniverse's project builder platform (http://www.zooniverse.org/lab), Planet Four: Terrains (http://terrains.planetfour.org/) is a citizen science project enlisting the general public to review mid-resolution Mars Reconnaissance Orbiter (MRO) Context Camera subimages to identify the channels and pits (dubbed araneiforms) carved during the gas jet formation process, as well as other surface features including craters and carbon dioxide ice pits dubbed 'swiss cheese terrain.'
One of the key goals of the project was to identify jet locations on the Martian south pole and create a set of new targets regions for further detailed monitoring over the next southern Spring and Summer with MRO's HiRISE (High Resolution Imaging Experiment) camera. HiRISE has ~20x higher resolution than CTX, while CTX on the other hand covers more area in a single observation. In less than a year, thanks to the effort of over 10,000 volunteers worldwide, Planet Four: Terrains was able to categorize ~20,000 subimages from 90 CTX images, and identify 20+ regions selected for further HiRISE monitoring to explore the on-going seasonal processes.
We present an overview of Planet Four: Terrains including the project's goals and public engagement. We will also present a summary of the over 20 target regions selected for HiRISE monitoring.
Acknowledgements: This work uses data generated via the Zooniverse.org platform, development of which was supported by a Global Impact Award from Google, and by the Alfred P. Sloan Foundation. We also thank the
HiRISE and MRO Teams for their help in scheduling and acquiring ourrequested observations.

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406.02 – Better the Martian you know? Trust in the crowd vs. trust in the machine when using a Martian Citizen Science platform

Citizen science platforms allow untrained volunteers to take part in scientific research across a range of disciplines, and often involve the analysis of remotely sensed imagery. The data collected by increasingly advanced and automated instruments has made planetary science a prime candidate for, and user of, citizen science online platforms. In order to process this large volume of information, such systems are increasingly performed in conjunction with data-mining analysis software, with varying configurations of computer and volunteer contribution. Despite citizen science being a relatively new approach, there has been a growing field of research considering the practice in its own right beyond the scientific problems they address, with studies involving interface HCI, platform functionality, and motivation particularly adding to a growing body of citizen science scholarship.
Through iterations of the FP7 iMars project's 'Mars in Motion' platform, the work presented studied the effect that guidance information had on volunteers' accuracy and trust. Whilst analysing imagery for change, volunteers were told whether automated change detection software or the consensus of other citizen scientists had found change, with this information varying in terms of accuracy. Results showed that volunteers' ability to both identify change and the type of feature undergoing change was improved when both the software result and crowd opinion guidance information provided had a greater accuracy. However, when guidance information was less accurate volunteers' level of trust fell at a sharper rate when it came from the crowd than when it came from the algorithm, and participants reported more frustration – a counter-intuitive result compared to existing research. Citizen science practitioners need to consider the information they provide to volunteers and how they present it; the results of software analysis or the consensus of a crowd need to be conclusive and above all accurate in order to improve both the performance and engagement of their volunteer community.
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement 607379.

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406.03 – Comet Hunters: A Citizen Science Project to Search for Comets in the Main Asteroid Belt

Fully automated detection of comets in wide-field surveys remains a challenge, as even highly successful comet-finding surveys like Pan-STARRS rely on a combination of both automated flagging algorithms and vetting by human eyes. To take advantage of the long-noted superiority of the human eye over computer algorithms in certain types of pattern recognition, particularly when dealing with a range of target morphologies of interest, we have created a citizen science website with the aim of allowing the general public to aid in the search for active asteroids, which are objects that occupy dynamically asteroidal orbits yet exhibit comet-like dust emission due to sublimation, impact disruption, rotational destabilization, or other effects. Located at comethunters.org, the Comet Hunters website was built using the Zooniverse Project Builder (https://www.zooniverse.org/lab), and displays images of known asteroids obtained either from archival data obtained between 1999 and 2014 by the Suprime-Cam wide-field imager mounted on the 8-m Subaru telescope on Mauna Kea in Hawaii, or more contemporary data obtained by the Hyper Suprime-Cam (HSC) wide-field imager also on the Subaru Telescope as part of the ongoing HSC Subaru Strategic Program (SSP) survey. By using observations from such a large-aperture telescope, most of which have never been searched for solar system objects, much less cometary ones, we expect that volunteers should be able to make genuinely scientifically significant discoveries, and also provide valuable insights into the potential and challenges of searching for comets in the LSST era. To date, over 13,000 registered volunteers have contributed 350,000 classifications. We will discuss the design and construction of the Comet Hunters website, and also discuss early results from the project.
This work uses data generated via the Zooniverse.org platform, development of which was supported by a Global Impact Award

from Google, and by the Alfred P. Sloan Foundation.The HSC SSP collaboration includes the astronomical communities of Japan and Taiwan, and Princeton University. Instrumentation and software for HSC were developed by NAOJ, Kavli IPMU, the University of Tokyo, KEK, ASIAA, and Princeton University.

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406.04 – Assessing Attitudes Towards Science During an Adaptive Online Astrobiology Course: Comparing Online and On-Campus Undergraduates

General-education Science, Technology, Engineering, and Mathematics (STEM) courses are accepted as essential to a college education. An often cited reason is to train a scientifically literate populace who can think critically and make informed decisions about complex issues such as climate change, health care, and atomic energy. Goals of these STEM courses, therefore, go beyond content knowledge to include generating positive attitudes towards science, developing competence in evaluating scientific information in everyday life and understanding the nature of science. To gauge if such non-content learning outcomes are being met in our course, an online astrobiology course called Habitable Worlds, we administered the Classroom Undergraduate Research Experience (CURE) survey to students. The survey was administered before and after completion of the course for three semesters starting with the Fall 2014 semester and ending with the Fall 2015 semester (N = 774). A factor analysis indicated three factors on attitudes: toward science education, toward the interconnectedness of science with non-science fields, and toward the nature of science. Here we present some differences between students enrolled in online degree programs (o-course) and those enrolled in traditional undergraduate programs (i-course). While mean course grades were similar, changes in attitudes toward science differ significantly between o-course and i-course students. The o-course students began the course with more positive attitudes across all three factors than the i-course students. Their attitudes toward science education improved during the course, while the i-course students showed no change. Attitudes toward the other two factors declined in both populations during the course, but declines were smaller among o-course students. These differences may indicate lesser intrinsic motivation among the i-course students. The CURE survey has not been used before in an online course; therefore, we will continue to examine factor analysis, student interviews, and expert review data to validate it for online science courses.

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406.05 – Using Recent Planetary Science Data to Develop Advanced Undergraduate Physics and Astronomy Activities

Teaching science by having students manipulate real data is a popular trend in astronomy and planetary science education. However, many existing activities simply couple this data with traditional "cookbook" style verification labs. As with most topics within science, this instructional technique does not enhance the average students' understanding of the phenomena being studied. Here we present a methodology for developing "science by doing" activities that incorporate the latest discoveries in planetary science with up-to-date constructivist pedagogy to teach advanced concepts in Physics and Astronomy. In our methodology, students are first guided to understand, analyze, and plot real raw scientific data; develop and test physical and computational models to understand and interpret the data; finally use their models to make predictions about the topic being studied and test it with real data.
To date, two activities have been developed according to this methodology: Understanding Asteroids through their Light Curves (hereafter “Asteroid Activity”), and Understanding Exoplanetary Systems through Simple Harmonic Motion (hereafter “Exoplanet Activity”). The Asteroid Activity allows students to explore light curves available on the Asteroid Light Curve Database (ALCDB) to discover general properties of asteroids, including their internal structure, strength, and mechanism of asteroid moon formation. The Exoplanet Activity allows students to investigate the masses and semi-major axes of exoplanets in a system by comparing the radial velocity motion of their host star to that of a coupled simple harmonic oscillator. Students then explore how noncircular orbits lead to deviations from simple harmonic motion. These activities will be field tested during the Fall 2016 semester in an advanced undergraduate mechanics and astronomy courses at a large Midwestern STEM-focused university. We will present the development methodologies for these activities, description of the activities, and results from the pre-tests.

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406.06 – The Arecibo Observatory Space Academy

The Arecibo Observatory Space Academy (AOSA) is an intense fifteen-week pre-college research program for qualified high school students residing in Puerto Rico, which includes ten days for hands-on, on site research activities. Our mission is to prepare students for their professional careers by allowing them to receive an independent and collaborative research experience on topics related to the multidisciplinary field of space science. Our objectives are to (1) supplement the student’s STEM education via inquiry-based learning and indirect teaching methods, (2) immerse students in an ESL environment, further developing their verbal and written presentation skills, and (3) foster in every student an interest in the STEM fields by harnessing their natural curiosity and knowledge in order to further develop their critical thinking and investigation skills. Students interested in participating in the program go through an application, interview and trial period before being offered admission. They are welcomed as candidates the first weeks, and later become cadets while experiencing designing, proposing, and conducting research projects focusing in fields like Physics, Astronomy, Geology, Chemistry, and Engineering. Each individual is evaluated with program compatibility based on peer interaction, preparation, participation, and contribution to class, group dynamics, attitude, challenges, and inquiry. This helps to ensure that specialized attention can be given to students who demonstrate a dedication and desire to learn. Deciding how to proceed in the face of setbacks and unexpected problems is central to the learning experience. At the end of the semester, students present their research to the program mentors, peers, and scientific staff. This year, AOSA students also focused on science communication and were trained by NASA’s FameLab. Students additionally presented their research at this year’s International Space Development Conference (ISDC), which was held in San Juan, Puerto Rico. Funding for this program is provided by NASA SSERVI-LPI: Center for Lunar Science and Exploration through USRA. Supplemental funding for attendance to ISDC was received from the Puerto Rico Science and Technology Trust.

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406.07 – "Where On Mars?": An Open Planetary Mapping Platform for Researchers, Educators, and the General Public

The "Where On Mars?" project is essentially the evolution of an existing outreach product developed in collaboration between ESA and CartoDB; an interactive map visualisation of the ESA's ExoMars Rover candidate landing sites (whereonmars.co). Planetary imagery data and maps are increasingly produced by the scientific community, and shared typically as images, in scientific publications, presentations or public outreach websites. However, this media lacks of interactivity and contextual information available for further exploration, making it difficult for any audience to relate one location-based information to another. We believe that interactive web maps are a powerful way of telling stories, engaging with and educating people who, over the last decade, have become familiar with tools such as Google Maps. A few planetary web maps exist but they are either too complex for non-experts, or are closed-systems that do not allows anyone to publish and share content. The long-term vision for the project is to provide researchers, communicators, educators and a worldwide public with an open planetary mapping and social platform enabling them to create, share, communicate and consume research-based content. We aim for this platform to become the reference website everyone will go to learn about Mars and other planets in our Solar System; just like people head to Google Maps to find their bearings or any location-based information. The driver is clearly to create for people an emotional connection with Mars. The short-term objectives for the project are (1) to produce and curate an open repository of basemaps, geospatial data sets, map visualisations, and story maps; (2) to develop a beautifully crafted and engaging interactive map of Mars. Based on user-generated content, the underlying framework should (3) make it easy to create and share additional interactive maps telling specific stories.

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406.08 – CosmoQuest: Engaging Students in Authentic Research through Science Fairs

CosmoQuest is embarking on a five-year effort to increase student participation in science fairs through nation-wide training of teachers, science educators, and scientists. The program focuses on helping teachers attain the needed content knowledge and skills to support creation of meaningful science fair research projects. . This includes supporting teachers' understanding of how to engage students in age-appropriate projects as young science and engineering professionals. If successful, students will create their own understanding of STEM content through research. This occurs when students are guided into learning where they become involved at a level that makes it possible for them to independently ask questions and investigate answers by seeking patterns, testing, building conceptual models, and/or designing technology.

To support this kind of engagement, we are curating and creating resources to support students of all ages and abilities. Students at different age levels generally have very different developmental reasoning abilities, and engagement and learning are increased when students use age-appropriate reasoning abilities. For instance primary students are effective in observing, communicating, and comparing. As they get older they develop abilities in sequencing and finding relationships. At middle school they add inferring and finally in high school the acquired skills for applying ideas from many disciplines to create more complex understanding.

Through a comprehensive program of curriculum development, educator professional development, and building strategic partnerships, we will increase the number and quality of space science related science fair projects in the United States. CosmoQuest is funded through individual donations, through NASA Cooperative Agreement NNX16AC68A, and through additional grants and contracts that are listed on the About page of our website, cosmoquest.org.

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406.09 – NASA's Universe of Learning: Engaging Learners in Discovery

NASA's Universe of Learning is one of 27 competitively awarded education programs selected by NASA's Science Mission Directorate (SMD) to enable scientists and engineers to more effectively engage with learners of all ages. The NASA's Universe of Learning program is created through a partnership between the Space Telescope Science Institute, Chandra X-ray Center, IPAC at Caltech, Jet Propulsion Laboratory Exoplanet Exploration Program, and Sonoma State University. The program will connect the scientists, engineers, science, technology and adventure of NASA Astrophysics (which includes exoplanets) with audience needs, proven infrastructure, and a network of over 500 partners to advance the objectives of SMD's newly restructured education program. The multi-institutional team will develop and deliver a unified, consolidated suite of education products, programs, and professional development offerings that spans the full spectrum of NASA Astrophysics, including the Exoplanet Exploration theme. Program elements include enabling educational use of Astrophysics mission data and offering participatory experiences; creating multimedia and immersive experiences; designing exhibits and community programs; providing professional development for pre-service educators, undergraduate instructors, and informal educators; and, producing resources for special needs and underserved/underrepresented audiences. This presentation will provide an overview of the program and process for mapping discoveries to products and programs for informal, lifelong, and self-directed learning environments.

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407 – Mission Showcase: Dawn at Ceres Results

407.01 – Fire and ice: GRaND observations of Vesta and Ceres by Dawn

In June of 2016, Dawn completed its primary mission to explore the asteroid (4) Vesta and the dwarf planet (1) Ceres, the largest bodies in the main belt. At both targets, Dawn's Gamma Ray and Neutron Detector (GRaND) acquired several months of global elemental mapping data. Gamma ray and neutron spectra were analyzed to determine the bulk elemental composition of the uppermost meter of the regolith within broad surface regions. Measurements of global Fe/Si, Fe/O, and K/Th ratios buttress the connection between Vesta and the Howardite, Eucrite and Diogenite (HED) meteorites. Their parent body underwent igneous differentiation to form an iron-rich core, ultramafic mantle, and basaltic crust. In some regions, GRaND measurements show that hydrogen is concentrated in Vesta's otherwise anhydrous, basaltic regolith. Multiple lines of evidence support exogenic delivery of hydrogen by the infall of carbonaceous chondrites. In comparison, the regolith of Ceres contains orders of magnitude more hydrogen, which must have originated from within. Near Ceres' equator, the elemental composition of the regolith resembles the aqueously altered CI/CM chondrites (based on H, Fe, K, C and compositional parameters). Increased concentrations of hydrogen observed by GRaND at high latitudes likely result from the presence of extensive near-surface water ice, as anticipated by Fanale and Salvail (1989). GRaND data provide evidence that the action of water altered Ceres on a global scale, resulting in widespread hydrated minerals and residual water ice that has survived to the present day. We describe how GRaND elemental measurements constrain chemical and physical processes that shaped Ceres and discuss implications for the origins of Ceres and similar main belt objects.

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407.02 – Exposed H $_2$O-rich areas detected on Ceres with Dawn Visible and Infrared Mapping Spectrometer

H_2O-rich materials are exposed at the surface of Ceres as discovered from VIR spectra [1] of the Dawn mission [2]. Oxo crater exhibits the most diagnostic absorption bands of the H_2O molecule at 1.65 and 1.28 µm [3]. These features exist in at least four other locations, and they are consistent with H_2O ice mixed with low-albedo components [3,4]. Spectra of mineral hydrates such as salts are also characterized by H_2O absorption overtones, however they do not fit VIR observations as well as H_2O ice spectra. In order to further constrain the composition, the thermophysical and chemical stability of exposed H_2O-rich compounds on Ceres and results from chemical models of Ceres interior are being investigated. One meter of pure H_2O ice exposed to direct sunlight would sublimate within a few tens of years [5-7].The sublimation of a H_2O ice-cemented regolith would leave a low-albedo lag deposit that would also decrease detectability over time [8]. All the reported H_2O exposures occur at latitudes higher than 30°N in fresh craters near rim shadows, have surface area < 3 km^2, and relatively high albedo.The exposed H_2O ice observed by VIR is likely due to a recent impact or a landslide. In some occurrences, high-albedo materials observed within these shadows by the Framing Camera (FC) are contiguous to the observed H_2O; several of them could be in Permanently Shadowed Regions. The surface shape model and history of illumination will allow us to determine whether these areas could be cold traps where H_2O ice could be preserved from sublimation [9].

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Contributing team(s): The VIR Team

407.03 – Icing *in* the Cake: Evidence for Ground Ice in Ceres

Without surface deposits of ice readily visible and few spectral detections of ice, the task of understanding ice on Ceres falls to other investigations. Several decades of thermal models suggest that subsurface ice on Ceres is stable for the lifetime of the solar system. Here, we report geomorphological evidence of silicate-ice mixtures, which we refer to as "ground ice", from careful analysis of the behavior of surface features on Ceres. In particular, we have focused on trends in mass wasting features. Mass wasting on Ceres is pervasive--in over 20% of craters above 10km in size, often with provocative rounded termini. We have identified three "endmember" classes of lobate mass wasting morphologies: tongue-shaped, furrowed flows hundreds of meters thick on steep slopes, tens of meter thick spatulate-sheeted flows on shallow slopes, and cuspate-sheeted flows, also tens of meters thick, but with morphology that indicates fluidization. These features on Ceres are distinct from those on dry Vesta, which shares a similar impactor population and velocity distribution due to their similar locations in the main belt. Thus, differing material properties are implied between the two bodies. Morphologically, each of these feature types possess an analog found in glaciated regions on Earth and Mars or on the surfaces of the icy satellites that help describe how down slope mass motion may be created. In particular, we identify several spectacular features that share commonatlity with rock glaciers and lahars. Moreover, these abundant features increase in number and aerial coverage towards the poles, and show progressively more fluidization towards the low latitudes. We conclude that the geomorphology of these features are evidence that Ceres' subsurface contains significant ground ice and that the ice is most abundant near the poles.

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407.04 – More diversity for volcanism: Ceres' Ahuna Mons from Dawn's Framing Camera data

In the last decades, the exploration of planets and moons by spacecraft revealed a variety of volcanic expressions. The recent visit to dwarf planet Ceres by the Dawn spacecraft is shedding light on a possible new, compositionally different volcanism falling into the cryovolcanism field. The dwarf planet's properties, i.e., low bulk density, low internal temperatures and volatile-rich composition relative to terrestrial planets, would only generate melts composed of brines. On the other hand, Ceres' carbonate- and clay-rich surface mineralogy suggests a cryovolcanism different from that of water-ice dominated icy satellites.

The Dawn Framing Camera (FC) provides a complete global dataset for photo-geological investigations of Ceres, including a 35 m/pixel visible coverage, a 135 m/pixel multi-spectral coverage, and a 135 m/pixel global digital elevation model from stereo-photogrammetry. Domical landforms up to a few kilometers in elevation and tens of kilometers in diameter (referred to as tholi and montes) are found scattered across Ceres' surface. Ahuna Mons is a 4-km topographic high distinct in its shape and morphology from other topographic features on Ceres. The mountain consists of two morphological units: a flank unit of unconsolidated material and a fractured (i.e., consolidated) summit unit. Steep slopes at the angle of repose characterize the flank unit, whereas the summit unit has a convex shape. The flank and summit morphologies and the morphometry of the mountain can be explained by the formation of a cryovolcanic dome, analogous to a silicic volcanic dome found on terrestrial planets. Albedo and crater size-frequency distribution measurements from FC imagery reveal geologically-recent activity on Ahuna Mons, occurring sometime within the last few hundreds Myr. The characteristics of and implications for this possible cryomagma for Ceres thermal and chemical evolution will be discussed.

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407.05 – Ceres' Geophysical Evolution Inferred from Dawn Data

If Ceres formed as an ice-rich body, as suggested by its low density and the detection of ammoniated phyllosilicates [1], then it should have differentiated an ice-dominated shell, analogous to large icy satellites [2]. Instead, *Dawn* observations revealed an enrichment of Ceres' shell in strong materials, either a rocky component and/or salts and gas hydrates [3, 4, 5, 6]. We have explored several scenarios for the emplacement of Ceres' surface. Endogenic processes cannot account for its overall homogeneity. Instead we suggest that Ceres differentiated an icy shell upon freezing of its early ocean that was removed as a consequence of frequent exposure by impacting after the dwarf planet migrated from a cold accretional environment to the warmer outer main belt (or when the solar nebula dissipated, if Ceres formed in situ). This scenario implies that Ceres' current surface represents the interface between the original ice shell and the top of the frozen ocean, a region that is extremely rich chemistry-wise, as illustrated by the mineralogical observations returned by *Dawn* [7]. Thermal modeling shows that the shell could remain warm over the long term and offer a setting for the generation of brines that may be responsible for the emplacement of Ahuna Mons [8] and Occator's bright spots [7] on an otherwise homogeneous surface [9]. An important implication is that Ceres' surface offers an analog for better understanding the deep interior and chemical evolution of large ice-rich bodies.

References: [1] De Sanctis et al., *Nature*, 2015; [2] McCord and Sotin, *Journal of Geophysical Research*, 2005; [3] Park et al., *Nature*, 2016 (in press); [4] Hiesinger et al., *Science*(submitted); [5] Bland et al., *Nature Geoscience*, 2016 (in press); [6] Fu et al., AGU Fall Meeting, 2015*;* [7] De Sanctis et al., *Nature*, 2016 (in press); [8] Ruesch et al., *Science*, in revision; [9] Ammannito et al., *Science*, 2016 (accepted).

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Contributing team(s): The Dawn Team

408 – Jovian Atmosphere II: Giant Planets Interior

408.01 – Molecular abundance profiles characterization of Jupiter'satmosphere using ground-based observations at 5 microns

We report on early results of an observational campaign to support the Juno mission. At the beginning of this year, using TEXES (Texas Echelon cross-dispersed Echelle Spectrograph), mounted on the NASA Infrared Telescope Facility (IRTF), we obtained maps of Jupiter in several spectral ranges between 1800 and 2200 cm^{-1} which probes the atmosphere in the 1-4 bar region, with a spectral resolution of R ≈ 7000 and an angular resolution of ≈ 1.5''. This dataset is analyzed by a code which combines a line-by-line radiative transfer model with a non-linear optimal estimation inversion method. The inversion takes into account the abundance profiles of AsH_3 , CO, GeH_4 and H_2O, as well as clouds contribution, in addtion to the abundance profiles of NH_3 and PH_3 . We will present the inverted abundance profiles, their significance for the understanding of Jupiter's atmospheric dynamics, and how they will be useful for the determination of water abundance up to 200 bars, which is one of the main objectives of the instrument MWR (MicroWave Radiometer) mounted on the Juno spacecraft. This work will also be useful to prepare the analysis of the JIRAM (Jovian InfraRed Auroral Mapper) 5-microns data aboard Juno.

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408.02 – Limits to Determining the Core of Jupiter

Simple, approximate models based on perturbations of the n=1 polytrope are used to identify some general properties of models for nearly-isentropic Jupiter-like planets where the total heavy element mass fraction is small. In these models, it is found that the radius is remarkably insensitive to the distribution of heavy elements and is effectively a measure of total heavy element enrichment (sum of core and envelope). The gravity harmonic J_2 and the normalized moment of inertia $\alpha=I/MR^2$ are almost entirely determined by the density structure outside the core, and this depends on the reduced core mass, defined to be the actual core mass minus the mass of hydrogen and helium that would occupy that region in the absence of the core. The actual core mass or its radius or composition cannot be well determined, even when there is perfect knowledge of the equation of state, thermal state and envelope enrichment by heavy elements. The central concentration of heavy elements is approximately determined, even when the actual core is more massive and contaminated with hydrogen and helium by mixing or erosion (double diffusive convection). At fixed J_2, the dependence of α on core structure is very small, and only exceeds the likely detection limit ~0.1-0.2% for very extended cores. Even though these results are obtained for a simple model, it is argued that they are semi-quantitatively applicable to realistic models. A perturbation scheme is presented for testing this systematically and for assessing the consequences of perturbations to the equation of state, compositional profile and temperature structure for the trade-off between reduced core mass and envelope enrichment.
Author(s): David J. Stevenson[1]
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408.03 – Alternative Evolution and Internal Structure for Jupiter and Saturn

The internal structure of gas giant planets may be more complex than the commonly assumed core-envelope structure with an adiabatic temperature profile. Different primordial internal structures as well as various physical processes can lead to non-homogenous compositional distributions. A non-homogenous internal structure has a significant impact on the thermal evolution and final structure of the planets. Here we present alternative structure and evolution models for Jupiter and Saturn allowing for both adiabatic and non-adiabatic evolution. In convective regions we calculate the mixing of heavy elements by convection, as these planets evolve. We present the thermal and structural evolution of the planets accounting for various initial composition gradients, and in the case of Saturn, include the formation of a helium-rich region as a result of helium rain. We investigate the stability of the structure against convection, and find that the helium shell in Saturn remains stable and does not mix with the rest of the envelope. In other cases, convection mixes the planetary interior despite the existence of compositional gradients, leading to enrichment of the envelope with metals. We show that non-adiabatic structures (and cooling histories) for both Jupiter and Saturn are feasible, and the interior temperatures in that case are much higher that for standard adiabatic models. Moreover, we show that non-adiabatic evolution can suggest more than one mechanism to explain the current structures, including Saturn's high luminosity. We conclude that the internal structure is directly linked to the formation and evolution history of the planet. These alternative internal structures of Jupiter and Saturn should be considered when interpreting the upcoming Juno and Cassini data.
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408.04D – Tidal Response of Jupiter and Saturn from CMS calculationsTidal Response of Jupiter and Saturn from CMS calculations

The *Juno* gravity science system promises to provide observational data from Jupiter's gravitational field at an unprecedented precision. Meanwhile, recent *ab-initio* simulations on mixtures of hydrogen and helium allow for the construction of realistic interior models. The concentric Maclaurin spheroid (CMS) numerical method has been developed for efficient, non-perturbative, self-consistent calculations of shape and gravitational field of a rotating liquid body to this desired precision. Here we present a generalization of the CMS method to three dimensions and included the effect of tides from a satellite. We have identified a number of unexpected features of the static tidal response in the case where a planet's shape is dominated by the rotational bulge. In the general case, there is state mixing of the spherical-harmonic components of the response to the corresponding components of the rotational and tidal excitations. This breaks the degeneracy of the tidal love numbers k_{nm} with m, and introduces a dependence of k_{nm} on the orbital distance of the satellite. Notably for Jupiter and Saturn, the predicted value of k_2 is significantly higher when the planet's high rotation rates are taken into account: k_2=0.413 for Saturn and k_2=0.590 for Jupiter, accounting for an ~13% and 10% increase over the non-rotating case respectively. We have also done preliminary estimates for the off-resonance dynamic response, which may lead to an additional significant increase in k_2. Accurate models of tidal response will be essential for interpreting gravity observations from *Juno* and future studies, particularly for when filtering for signals from interior dynamics in the observed field.
This work was supported by NASA's Juno project. Sean Wahl and Burkhard Militzer acknowledge the support of the National Science Foundation (astronomy and astrophysics research grant 1412646).
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408.05 – Unfolding the atmospheric and deep internal flows on Jupiter and Saturn using the Juno and Cassini gravity measurements

In light of the first orbits of Juno at Jupiter, we discuss the Juno gravity experiment and possible initial results. Relating the flow on Jupiter and Saturn to perturbations in their density field is key to the analysis of the gravity measurements expected from both the Juno (Jupiter) and Cassini (Saturn) spacecraft during 2016-17. Both missions will provide latitude-dependent gravity fields, which in principle could be inverted to calculate the vertical structure of the observed cloud-level zonal flow on these planets. Current observations for the flow on these planets exists only at the cloud-level (0.1-1 bar). The observed cloud-level wind might be confined to the upper layers, or be a manifestation of deep cylindrical flows. Moreover, it is possible that in the case where the observed wind is superficial, there exists deep interior flow that is completely decoupled from the observed atmospheric flow.
In this talk, we present a new adjoint based inverse model for inversion of the gravity measurements into flow fields. The model is constructed to be as general as possible, allowing for both cloud-level wind extending inward, and a decoupled deep flow that is constructed to produce cylindrical structures with variable width and magnitude, or can even be set to be completely general. The deep flow is also set to decay when approaching the upper levels so

it has no manifestation there. The two sources of flow are then combined to a total flow field that is related to the density anomalies and gravity moments via a dynamical model. Given the measured gravitational moments from Jupiter and Saturn, the dynamical model, together with the adjoint inverse model are used for optimizing the control parameters and by this unfolding the deep and surface flows.
Several scenarios are examined, including cases in which the surface wind and the deep flow have comparable effects on the gravity field, cases in which the deep flow is dominating over the surface wind, and an extreme case where the deep flow can have an unconstrained pattern. The method enables also the calculation of the uncertainties associated with each solution. We discuss the physical limitations to the method in view of the measurement uncertainties.
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408.06 – Shape, zonal winds and gravitational field of Jupiter: a fully self-consistent, multi-layered model

We construct a three-dimensional, finite-element, fully self-consistent, multi-layered,non-spheroidal model of Jupiter consisting of an inner core, a metallic electrically conducting dynamo region and an outer molecular electrically insulating envelope. We assume that the Jovian zonal winds are on cylinders parallel to the rotation axis but, due to the effect of magnetic braking, are confined within the outer molecular envelope. Two related calculations are carried out. The first provides an accurate description of the shape and internal density profile of Jupiter; the effect of rotational distortion is not treated as a small perturbation on a spherically symmetric state. This calculation determines the density, size and shape of the inner core, the irregular shape of the 1-bar pressure level, and the internal structure of Jupiter; the full effect of rotational distortion, without the influence of the zonal winds, is accounted for. Our multi-layered model is able to produce the known mass, the known equatorial and polar radii, and the known zonal gravitational coefficient J_2 of Jupiter within their error bars; it also yields the coefficients J_4 and J_6 within about 5% accuracy, and the core equatorial radius $0.09R_J$ containing 3.73 Earth masses.
The second calculation determines the variation of the gravitational field caused solely by the effect of the zonal winds on the rotationally distorted non-spheroidal Jupiter. Four different cases, ranging from a deep wind profile to a very shallow profile, are considered and implications for accurate interpretation of the zonal gravitational coefficients expected from the Juno mission are discussed.
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408.07 – Bayesian thermal evolution models for giant planets: Helium rain and double-diffusive convection in Jupiter

Hydrogen and helium unmix when sufficiently cool, and this bears on the thermal evolution of all cool giant planets at or below one Jupiter mass. Over the past few years, ab initio simulations have put us in the era of quantitative predictions for this H-He immiscibility at megabar pressures. We present models for the thermal evolution of Jupiter, including its evolving helium distribution following one such ab initio H-He phase diagram. After 4 Gyr of homogeneous evolution, differentiation establishes a helium gradient between 1 and 2 Mbar that dynamically stabilizes the fluid to overturning convection. The result is a region undergoing overstable double-diffusive convection (ODDC), whose relatively weak vertical heat transport maintains a superadiabatic temperature gradient. With a general parameterization for the ODDC efficiency, the models can reconcile Jupiter's intrinsic flux, atmospheric helium content, and mean radius at the age of the solar system if the H-He phase diagram is translated to cooler temperatures.
We cast our nonadiabatic thermal evolution models in a Markov chain Monte Carlo parameter estimation framework, retrieving the total heavy element mass, the superadiabaticity of the deep temperature gradient, and the phase diagram temperature offset. Models using the interpolated Saumon, Chabrier and van Horn (1995) equation of state (SCvH-I) favor very inefficient ODDC such that the deep temperature gradient is strongly superadiabatic, forming a thermal boundary layer that allows the molecular envelope to cool quickly while the deeper interior (most of the planet's mass) actually heats up over time. If we modulate the overall cooling time with an additional free parameter, mimicking the effect of a colder or warmer EOS, the models favor those that are colder than SCvH-I; this class of EOS is also favored by shock experiments. The models in this scenario have more modest deep superadiabaticities such that the envelope cools more gradually and the deep interior probably cools monotonically, although more slowly than in the adiabatic case. The two scenarios predict different mass distributions and can be tested using Juno gravity field measurements, and potentially seismology.
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408.08 – Zonal Flow Magnetic Field Interaction in the Semi-Conducting Region of Giant Planets

All four giant planets in the Solar System feature zonal flows on the order of 100 m/s in the cloud deck, and large-scale intrinsic magnetic fields on the order of 1 Gauss near the surface. The vertical structure of the zonal flows remains obscure. The end-member scenarios are shallow flows confined in the radiative atmosphere and deep flows throughout the planet with constant velocity along the direction of the spin-axis. The electrical conductivity increases smoothly as a function of depth inside Jupiter and Saturn, while a discontinuity of electrical conductivity inside Uranus and Neptune cannot be ruled out. Deep zonal flows will inevitably interact with the magnetic field, at depth with even modest electrical conductivity. Here we investigate the interaction between zonal flows and magnetic fields in the semi-conducting region of giant planets. Employing mean-field electrodynamics, we show that the interaction will generate detectable poloidal magnetic field perturbations spatially correlated with the deep zonal flows. Assuming the peak amplitude of the dynamo α-effect to be 0.1 mm/s, deep zonal flows on the order of 0.1 – 1 m/s in the semi-conducting region of Jupiter and Saturn would generate poloidal magnetic perturbations on the order of 0.01 % – 1 % of the background dipole field. These poloidal perturbations should be detectable with the in-situ magnetic field measurements from the upcoming Juno mission and the Cassini Grand Finale. This implies that magnetic field measurements can be employed to constrain the properties of deep zonal flows in the semi-conducting region of giant planets.
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Institution(s): *1. Caltech*

408.09 – Numerical Simulations of Ice Giant Interiors with Radially Varying Electrical Conductivity

The internal dynamics of giant planets are controlled primarily by the interaction of convection, stratification, rotation, and magnetic fields. Within Uranus and Neptune, the ice giants, convection in the ionic ocean generates the planets' magnetic fields through dynamo action, while convection in the molecular envelope may generate the planets' zonal winds. Previous work has hypothesized the influence of rotation on convection to be relatively weak compared to that of buoyancy, leading to fluctuating fluid motions that are characterized by three-dimensional turbulence instead of columns aligned with the rotation axis (Aurnou et al., Icarus 190, 110-126, 2007; Soderlund et al., Icarus 224, 97-113, 2013). In this regime, convection generates a multipolar dynamo and zonal flows with a retrograde equatorial jet and a prograde high latitude jet in each hemisphere that look similar to those observed on the ice giants. However, the magnetic field strength and zonal wind speeds are overestimated in our models with constant electrical conductivity. Towards resolving this discrepancy, we hypothesize that incorporation of an electrically insulating outer molecular envelope will bring the magnetic field and zonal flows into quantitative agreement. We will present new simulations that include radial variations in electrical conductivity based on internal structure models in combination with material property estimates and will discuss the potential for coupling between dynamo action in the ionic ocean and zonal flow generation in the molecular envelope. In addition, we will highlight how these simulations will both contribute to and benefit from the next mission to an ice giant planet.

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409 – Mars Clouds and Aerosols

409.01 – Limb clouds and dust on Mars from VMC-Mars Express images

We have used the large image database generated by the Visual Monitoring Camera (VMC) onboard Mars Express to first search and then study, the properties of projected features (dust and water clouds) on the planet limb. VMC is a small camera serving since 2007 for public education and outreach (Ormston et al., 2011). The camera consists of a CMOS sensor with a Bayer filter mosaic providing color images in the wavelength range 400-900 nm. Since the observations were performed in an opportunistic mode (nor planned on a science base) the captured events occurred in a random mode. In total 17 limb features were observed in the period spanning from April 2007 to August 2015. Their extent at limb varies from about 100 km for the smaller ones to 2,000 km for the major ones. They showed a rich morphology consisting in series of patchy elements with a uniform top layer located at altitudes ranging from 30 to 85 km. The features are mostly concentrated between latitudes 45 deg North and South covering most longitudes although a greater concentration occurs around -90 to +90 deg. from the reference meridian (i.e. longitude 0 degrees, East or West). Most events in the southern hemisphere occurred for orbital longitudes 0-90 degrees (autumnal season) and in the north for orbital longitudes 330-360 (winter season). We present a detailed study of two of these events, one corresponding to a dust storm observed also with the MARCI instrument onboard Mars Reconnaissance Orbiter, and a second one corresponding to a water cloud.

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409.02 – High-resolution mapping of Martian water ice clouds using Mars Express OMEGA observations – Derivation of the diurnal cloud life cycle

The mapping in space and time of water ice clouds can help to explain the Martian water cycle and atmospheric circulation. For this purpose, an ice cloud index (ICI) corresponding to the depth of a water ice absorption band at 3.4 microns is derived from a series of OMEGA images (spectels) covering 5 Martian years. The ICI values for the corresponding pixels are then binned on a high-resolution regular grid (1° longitude x 1° latitude x 5° Ls x 1 h local time) and averaged. Inside each bin, the cloud cover is calculated by dividing the number of pixels considered as cloudy (after comparison to a threshold) to the number of all (valid) pixels
We compare the maps of clouds obtained around local time 14:00 with collocated TES cloud observations (which were only obtained around this time of the day). A good agreement is found.
Averaged ICI compared to the water ice column variable from the Martian Climate Database (MCD) show a correct correlation (~0.5) , which increases when values limited to the tropics only are compared.
The number of gridpoints containing ICI values is small (~1%), but by taking several neighbor gridpoints and over longer periods, we can observe a cloud life cycle during daytime. An example in the the tropics, around the northern summer solstice, shows a decrease of cloudiness in the morning followed by an increase in the afternoon.

Author(s): Andre Szantai[3], Joachim Audouard[2], Jean-Baptiste Madeleine[3], Francois Forget[3], Alizée Pottier[2], Ehouarn Millour[3], Brigitte Gondet[1], Yves Langevin[1], Jean-Pierre Bibring[1]
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409.03 – Fog as a Potential Indicator of a Local Water Source in Valles Marineris

Images from Mars Express suggest that water ice fog may be present in Valles Marineris while absent from the surrounding plateau. Using a regional atmospheric model, we investigate planetary boundary layer processes and discuss the implications of these potential water ice fog. Results from our simulations show that the temperature inside Valles Marineris appears warmer relative to the plateaus outside at all times of day. From the modeled temperatures, we calculate saturation vapor pressures and saturation mixing to determine the amount of water vapor in the atmosphere for cloud formation. For a well-mixed atmosphere, saturated conditions in the canyon imply supersaturated conditions outside the canyon where it is colder. Consequently, low clouds should be everywhere. This is generally not the case. Based on potential fog observations inside the canyon, if we assume the plateau is just sub-saturated, and the canyon bottom is just saturated, the resulting difference in mixing ratios represents the minimum amount of vapor required for the atmosphere to be saturated, and for potential fog to form. Under these conditions, we determined that the air inside the canyon would require a 4-7 times enrichment in water vapor at saturation compared to outside the canyon. This suggests a local source of water vapor is required to explain water ice fog appearing within the confines of Valles Marineris on Mars.

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409.04 – Interplanetary dust particles, not wind blown dust, control high altitude ice clouds on Mars

Water ice clouds on Mars are commonly observed at high altitudes. However, current generation Mars three-dimensional general circulation models (GCM) struggle to reproduce clouds above approximately 20-30 km. On Mars, as on Earth, ice cloud formation likely initiates by heterogeneous nucleation, which requires a population of suspended ice nuclei contiguous with supersaturated atmospheric water vapor. Although supersaturation is observed at high altitudes and has been reproduced in models, models predict very few ice nuclei. The small number of ice nuclei in the upper atmosphere is due to the assumption in Mars GCMs that the only source of ice nuclei is dust from the Martian surface. However, terrestrial mesospheric noctilucent clouds have been shown to form by ice nucleation on particles originating from ablated micrometeoroids. Therefore, it is reasonable to assume that a population of micrometeoric ablation biproducts on Mars exists and can act as a site for cloud nucleation at high altitudes. We present simulations using the Community Atmosphere Model for Mars (MarsCAM) based on the National Center for Atmospheric Research (NCAR) Community Atmosphere Model for Earth,coupled with a physically based, state-of-the-art cloud and dust physics model, the Community Aerosol and Radiation Model for Atmospheres (CARMA) to show that ablating micrometeoroids can yield abundant ice nuclei throughout the upper atmosphere of Mars. We find that simulations including a constant annual micrometeoroid flux allows us to reproduce the observed properties of high altitude water ice clouds including vertical distribution and particle size. In general, effective radius decreases with increasing altitude. We have additionally explored the impact of variable ablation rates. Preliminary results suggest that relatively high ablation rates, near or greater than 50%, are required to reproduce observed cloud features.
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409.05 – Two moment dust and water ice in the MarsWRF GCM
A new two moment dust and water ice microphysics scheme has been developed for the MarsWRF General Circulation Model based on the Morrison and Gettelman (2008) scheme, and includes temperature dependent nucleation processes and energetically constrained condensation and evaporation. Dust consumed in the formation of water ice is also tracked by the model.
The two moment dust scheme simulates dust particles in the Martian atmosphere using a Gamma distribution with fixed radius for lifted particles. Within the atmosphere the particle distribution is advected and sedimented within the two moment framework, obviating the requirement for lossy conversion between the continuous Gamma distribution and discritized bins found in some Mars microphysics schemes. Water ice is simulated using the same Gamma distribution and advected and sedimented in the same way. Water ice nucleation occurs heterogeneously onto dust particles with temperature dependent contact parameters (e.g. Trainer et al., 2009) and condensation and evaporation follows energetic constraints (e.g. Pruppacher and Klett, 1980; Montmessin et al., 2002) allowing water ice particles to grow in size where necessary. Dust particles are tracked within the ice cores as nucleation occurs, and dust cores advect and sediment along with their parent ice particle distributions. Radiative properties of dust and water particles are calculated as a function of the effective radius of the particles and the distribution width. The new microphysics scheme requires 5 tracers to be tracked as the moments of the dust, water ice, and ice core. All microphysical processes are simulated entirely within the two moment framework without any discretization of particle sizes.
The effect of this new microphysics scheme on dust and water ice cloud distribution will be discussed and compared with observations from TES and MCS.
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409.06D – Seasonal Variations in Dust Loading within Gale Crater, Mars
The Mars Science Laboratory rover Curiosity has been exploring Gale Crater for more than two martian years. Such tenure allows seasonal variability of the weather record for the current era to be studied with aid from Mast Cameras (Mastcam), Navigation Cameras (Navcam) and Rover Environmental Monitoring Station (REMS). Dust is a key component in the Martian atmosphere which helps drive atmospheric circulation. As such, these three instruments are integral in the characterization of the dust-loading environment both within and above the crater. This study uses Navcam imagery and a digital terrain model provided from HRSC on Mars Express to derive geographical line-of-sight extinction (LOS-Ext) coefficients, a quantity that assesses dust loading local to the air within the crater and which reveals differences in dust loading along different lines of sight.
We report two martian years worth of LOS-Ext at Gale Crater, covering Ls 210° in Mars year (MY) 31 to Ls 210° in MY33. All seasons have been observed twice with the only significant exception being a gap in data between Ls 270° – 315° in MY31 (early southern summer). Visibility conditions within the crater range from a few tens of km in spring and summer to over 100 km peaking around the winter solstice. The LOS-Ext record is also compared to the column extinction record derived from the Mastcam Tau observations. The first year shows a convergence of the two values around Ls 270° in MY31 and similar values around Ls 350° in MY31 and Ls 135° in MY32. Otherwise, during the first year of observation, the LOS-Ext has lower values than the Mastcam column extinction indicating two non-interacting atmospheric layers. In the second year, not only are similar values observed more frequently, the LOS-Ext coefficients have a global peak and overtake Mastcam column extinction during Ls 270° – 315° in MY32, which correspond to the missing timeframe from the previous year. As this season is prone to high wind speeds, this may be an indication of enhanced suspension of fine grain regolith occurring, coincidentally, at the tail end of a regional dust storm, causing LOS-Ext to be larger than column extinction.
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Contributing team(s): MSL Science Team

409.07D – Temporal evolution of UV opacity and dust particle size at Gale Crater from MSL/REMS measurements
A better characterization of the size, radiative properties and temporal variability of suspended dust in the Martian atmosphere is necessary to improve our understanding of the current climate of Mars. The REMS UV sensor onboard the Mars Science Laboratory (MSL) Curiosity rover has performed ground-based measurements of solar radiation in six different UV spectral bands for the first time on Mars.
We developed a novel technique to retrieve dust opacity and particle size from REMS UV measurements. We use the electrical output current (TELRDR products) of the six photodiodes and the ancillary data (ADR products) to avoid inconsistencies found in the processed data (units of W/m^2) when the solar zenith angle is above 30°. In addition, we use TELRDR and ADR data only in events during which the Sun is temporally blocked by the rover's masthead or mast to mitigate uncertainties associated to the degradation of the sensor due to the deposition of dust on it. Then we use a radiative

transfer model with updated dust properties based on the Monte-Carlo method to retrieve the dust opacity and particle size.
We find that the seasonal trend of UV opacity is consistent with opacity values at 880 nm derived from Mastcam images of the Sun, with annual maximum values in spring and in summer and minimum values in winter. The interannual variability is low, with two local maxima in mid-spring and mid-summer. Finally, dust particle size also varies throughout the year with typical values of the effective radius in the range between 0.5 and 2 µm. These variations in particle size occur in a similar way to those in dust opacity; the smallest sizes are found when the opacity values are the lowest.
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409.08 – Limb Observations of Solar Scattered Light by the Imaging Ultraviolet Spectrograph on MAVEN: New Constraints on Martian Mesospheric Cloud Variability

The Imaging Ultraviolet Spectrograph (IUVS) on NASA's Mars Atmosphere and Volatile Evolution (MAVEN) mission observed the Martian upper atmosphere in late 2015 (Ls ~ 70) and early 2016 (Ls ~ 150). Although designed to measure the dayglow between 90-200 km IUVS also scans the limb down to 60 km, where solar scattered light dominates the mid-ultraviolet (MUV) signal. Occasionally, this MUV light shows enhanced scattering between 60-90 km indicating the presence of aerosols in the mesosphere. We quantify the solar scattering for each daylight scan obtained between October and December, 2015 and between April and June, 2016. We then identify over 100 scans of enhanced scattering between 60-90 km and assemble them both geographically and diurnally. The geographical distribution of the enhancements in 2015 is preferentially located near the equator, consistent with previous observations of mesospheric clouds for this part of the season. A wave three pattern in equatorial cloud occurrence suggests forcing from a non-migrating tide, possibly linked to the longitudinal variation of Mars surface topography. At the same time, there are indications of a diurnal variation such that the clouds seen in 2015 and 2016 are preferentially observed in the early morning, between 0600-0900 local solar time. This suggests an important role for a migrating temperature tide controlling the formation of Martian mesospheric clouds.
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409.09 – Twilight Limb Observations of the Martian North Polar Hood by MAVEN IUVS

In northern winter, a broad distribution of ice aerosols appears in the north polar atmosphere of Mars, commonly referred to as the North Polar Hood (NPH). The NPH is thought to be formed as a result of condensation from lowered temperatures associated with both seasonal and diurnal variations in solar heating. The spatial extent and density of the NPH is highly variable, with a maximum latitudinal extent spanning 30-80°N, and a maximum density at 10-30 km altitude.
The NPH has been extensively observed by both ground-based telescopes and instruments in orbit around Mars. However, the majority of these observations are nadir-pointing. This observation geometry has two significant limitations. Firstly, they poorly probe the vertical structure of the NPH. Secondly, column densities are determined by monitoring the intensity of various spectral features associated with the ice composing the NPH, against a strong background with similar features from the frost that has condensed on the surface in the winter season, resulting in low sensitivities. Limb observations removes both limitations, allowing us to study the vertical distribution of the aerosols that make up the NPH at high sensitivities.
We present new limb observations of the NPH by IUVS (Imaging Ultraviolet Spectrograph) on the MAVEN (Mars Atmospheric and Volatile Evolution) spacecraft. These observations represent the first ultraviolet limb observations of the NPH, opening a new window for understanding the structure and composition of the NPH. The observations are also of the twilight limb, with sunlight being scattered from the dayside into the nightside over large solar zenith angles. This illumination geometry allows us to avoid the high dayside intensities that would drown out the signal from the thinner sections of the NPH. We determine the latitudinal extent of the NPH to be 30-60°N. We also find that an exponential altitude distribution of aerosols is able to reproduce the observed intensities, with a scale height similar to the atmospheric scale height. Finally, we observe an almost mutual exclusion of the NPH and nitric oxide nightglow emissions, an effect of the global circulation that drive both phenomena.
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410 – Asteroids: Observational Surveys II

410.01 – Observations of Near Earth Objects with Spitzer

We are carrying out an Exploration Science Warm Spitzer program entitled NEOSurvey in which we are observing 550 Near Earth Objects in 710 hours of Spitzer time. For each object we use a thermal model to derive diameter and albedo. For each object we also derive a (partial) lightcurve; total elapsed observing times range from 15 minutes to 3.2 hours. This catalog of 500+ NEO lightcurves is a substantial increase over the number of NEO lightcurves presently known. In addition to creating a large catalog of NEO properties, we are also able to study the properties of individual NEOs, including those with low delta V values (i.e., accessible asteroids) and those that might be dead comets. The final observations in this program will be obtained by 30 Sept 2016, so at the DPS meeting we will present a first look at our entire catalog of results. All results are posted at nearearthobjects.nau.edu usually within days of the data being released by the Spitzer Science Center. This work was supported in part by funding from the Spitzer Science Center.
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410.02 – The Mission Accessible Near-Earth Objects Survey (MANOS): spectroscopy results

The Mission Accessible Near-Earth Object Survey (MANOS) is an ongoing physical characterization survey to build a large, uniform catalog of physical properties including lightcurves and visible wavelength spectroscopy. We will use this catalog to investigate the global properties of the small NEO population and identify individual objects that can be targets of interest for future exploration. To accomplish our goals, MANOS uses a wide variety of telescopes (1-8m) in both the northern and southern hemispheres. We focus on targets that have been recently discovered and operate on a regular cadence of remote and queue observations to enable rapid characterization of small NEOs. Targets for MANOS are selected based on three criteria: mission accessibility, size, and observability. With our resources, we observe 5-10 newly discovered sub-km NEOs per month. MANOS has been operating for three years and we have observed over 500 near-Earth objects in that time.

We will present results from the spectroscopy component of the MANOS program. Visible wavelength spectra are obtained using DeVeny on the Discovery Channel Telescope (DCT), Goodman on the Southern Astrophysical Research (SOAR) telescope, and GMOS on Gemini North and South. Over 300 NEO spectra have been obtained during our program. We will present preliminary results from our spectral sample. We will discuss the compositional diversity of the small NEO population and how the observed NEOs compare to the meteorite population.

MANOS is funded by the NASA Near-Earth Object Observations program.

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410.03 – PRIMitive Asteroids Spectroscopic Survey - PRIMASS: Current status

Primitive asteroids are considered transitional objects between rocky and icy bodies. They are characterized by their low-albedo in the visible and a higher content of highly processed materials, and are also expected to be volatile-rich, with a certain amount of hydrated minerals on their surfaces. The study of these bodies is crucial to understand the nature of volatile and organic materials in the early Solar System.

At present, four primitive NEAs are targets of space missions: (101955) Bennu, target of NASA OSIRIS-REx; (162173) Ryugu, target of JAXA Hayabusa 2; (341843) 2008 EV5, proposed target of NASA Asteroid Redirect Mission (ARM); and (65803) Didymos, target of the joint ESA-NASA Asteroid Impact & Deflection Assessment (AIDA) mission. Characterizing the populations from which these NEAs might originate in the main belt will enhance the scientific return of the missions.

In 2010, we started a spectroscopic survey (visible and near-infrared) to characterize primitive asteroids. Our PRIMitive Asteroids Spectroscopic Survey (PRIMASS) uses a variety of ground based facilities. Most of the spectra have been obtained using the 10.4m Gran Telescopio Canarias (GTC), and the 3.6m Telescopio Nazionale Galileo (TNG), both located at the El Roque de los Muchachos Observatory (La Palma, Spain). We also use the 3.0m NASA Infrared Telescope Facility (IRTF) on Mauna Kea (Hawai, USA) and the 4.1m Southern Astrophysical Research Telescope (SOAR) at Cerro Pachón (Chile).

We present here the current status of our on-going survey. Up to now, PRIMASS contains more than 400 spectra, either in the visible (0.4-0.9 microns) or the near-infrared (0.8-2.3 microns). In the inner belt, we have studied the Polana-Eulalia family complex (Pinilla-Alonso et al. 2016; de León et al. 2016), the Erigone family (Morate et al. 2016), and the Sulamitis and Clarissa families (Morate et al., in prep.). In the outer main belt, we have obtained around 60 spectra of asteroids in five different but related groups of primitive bodies: the Hygea, Themis, and Veritas families, and also the Cybeles and Hildas dynamical groups.

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410.04 – Photometry of Main Belt and Trojan asteroids with K2

Due to the failure of the second reaction wheel, a new mission was conceived for the otherwise healthy Kepler space telescope. In the course of the K2 Mission, the telescope is staring at the plane of the Ecliptic, hence thousands of Solar System bodies cross the K2 fields, usually causing extra noise in the highly accurate photometric data. We could measure the first continuous asteroid light curves, covering several days wthout interruption, that has been unprecedented to date. We studied the K2 superstamps covering the M35 and Neptune/Nereid fields observed in the long cadence (29.4-min sampling) mode. Asteroid light curves are generated by applying elongated apertures. We investigated the photometric precision that the K2 Mission can deliver on moving Solar System bodies, and determined the first uninterrupted optical light curves of main-belt and Trojan asteroids. We use thed Lomb-Scargle method to find periodicities due to rotation.

We derived K2 light curves of 924 main-belt asteroids in the M35 field, and 96 in the path of Neptune and Nereid. Due to the faintness of the asteroids and the high density of stars in the M35 field, 4.0% of the asteroids with at least 12 data points show clear periodicities or trend signalling a long rotational period, as opposed to 15.9% in the less crowded Neptune field. We found that the duty cycle of the observations had to reach $\sim$ 60% in order to successfully recover rotational periods.

The derived period-amplitude diagram is consistent to the known distribution of Main Belt asteroids. For Trojan asteroids, the contribution of our 56 objects with newly determined precise period and amplitude is in the order of all previously known asteroids. The comparison with earth-based determinations showed a previous bias toward short periods and has also proven that asteroid periods >20 hour can be unreliable in a few cases because of daylight time and diurnal calibrations. These biases are avoided from the space. We present an unbiased sample of rotation periods and identify a higher rate of slow rotators. We also found multiple periods of large asteroids that has not been observed earlier and still needs explanation.

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410.05 – Results of Observations of Occultations of Stars by Main-Belt and Trojan Asteroids, and the Promise of Gaia

For 40 years, the sizes and shapes of scores of asteroids have been determined from observations of asteroidal occultations, and many hundreds of high-precision positions of the asteroids relative to stars have been measured. Earlier this year, the 3000th observation of an asteroidal occultation was documented. Some of the first evidence for satellites of asteroids was obtained from the early efforts; now, the orbits and sizes of some satellites discovered by other means

have been refined from occultation observations. Also, several close binary stars have been discovered, and the angular diameters of some stars have been measured from analysis of these observations. The International Occultation Timing Association (IOTA) coordinates this activity worldwide, from predicting and publicizing the events, to accurately timing the occultations from as many stations as possible, and publishing and archiving the observations. The first observations were timed visually, but now nearly all observations are either video-recorded, or recorded with CCD drift scans, allowing small magnitude-drop events to be recorded, and resulting in more consistent results. Techniques have been developed allowing one or two observers to set up multiple stations with small telescopes, video cameras, and timers, thereby recording many chords, even across a whole asteroid; some examples will be shown.
Later this year, the first release of Gaia data will allow us to greatly improve the vast star catalog that we use for both predicting and analyzing these events. Although the first asteroidal data will wait until the 4th Gaia release, before that, we can greatly improve the orbits of asteroids that have occulted 3 or more stars in the past so that we can start computing the paths of future occultations by them to few km accuracy. In a couple of years, we'll be able to realistically predict one to two orders of magnitude more events than we can now, allowing efforts to be concentrated on smaller objects of the highest scientific interest, including some comets.

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410.06 – Asteroid phase curve analysis with the *H*, *G* ₁, *G* ₂ photometric phase function: application to the PTF survey observations

Estimation of an asteroid's absolute magnitude *H* from its photometry is extremely important. The absolute magnitude relates the brightness of the asteroid to its size, if the geometric albedo is known. The shape of the phase curve can serve as a proxy for the taxonomic type of the asteroid in cases with no spectral information available [1,2].
In 2012, the IAU adopted the H,G_1,G_2 function to replace the H,G function for phase curve analysis [3]. This new function improves the backscattering behavior of the curve with high- and low-albedo asteroids. The phase function (PF) can be applied to asteroids with multiple high-quality observations. If the number of observations is small, or their accuracy is low, problems may arise. The most apparent problem is that the parameter G or the parameters G_1, G_2 might be poorly estimated. The solution has been to fix to value of G or values of G_1, G_2 and estimate only the H. In our recent work [4], we offer a solution that can improve the current situation with the photometric fits with a small number of low-accuracy observations. We present a constrained nonlinear least-squares method for fitting the H,G_1,G_2 function that can improve the possible bias with low-accuracy data. Then, we revisit the two-parameter PF with new data and offer a new version, the H,G_{12}^* PF. Finally, we assess the problem with fixed G or G_1, G_2 parameters by introducing one-parameter models that relate to five taxonomic asteroid groups. We tie all the models together with three or two parameters, or a single parameter, with a statistical model selection procedure to select the best version for a particular data set.
We have developed practical tools for the abovementioned algorithms. We apply the tools to a dataset of 8,900 asteroids with almost 500,000 photometric observations from the Palomar Transient Factory survey [5]. We report the effect of the revised H estimates on the geometric albedos in cases where WISE-mission size estimates are available.

[1] D.A. Oszkiewicz et al. (2012). Icarus 219, 283–296.
[2] V.G. Shevchenko et al. (2016). PSS 123, 101–116.
[3] K. Muinonen et al. (2010). Icarus 209, 542–555.
[4] A. Penttilä et al. (2016). PSS 123, 117–125.
[5] A. Waszczak et al. (2015). Astron J 150(3).

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411 – Asteroid Spin States I: Rotational Surveys

411.01 – Spin Rate Diversity Amongst Ten-meter Class Near Earth Asteroids

The spin rates of small asteroids can provide insight into their mechanical structure, origin, and subsequent evolution. This is of more than just scientific interest since these are also the objects that will hit the Earth most frequently. Early statistics [Pravec and Harris, 2000] for Near Earth Asteroids (NEAs) with diameters of ~100 meters or less had resulted in the conclusion that many are rotating more rapidly than feasible for a gravitationally bound system of constituent components (i.e, 'rubble piles'). However, more recent studies [Holsapple, 2007; Scheeres et al. 2010] have focused on how non-gravitational cohesion mechanisms do not necessarily rule out a rubble pile structure for fast spin rate bodies. To further study this issue, we will report on the recent spin rate results for the smallest asteroids observed as part of our ongoing NEA target-of-opportunity characterization research [Ryan and Ryan, 2016] conducted using the Magdalena Ridge Observatory's 2.4-meter telescope.
Spin rates determined by this program plus results from the current lightcurve database [Warner et al. 2016] indicate that the very smallest NEAs with H>29 rotate with periods of minutes or less. This implies that these objects possess significant strength, hinting that they are likely examples of truly monolithic fragments. However, our observations also show a great diversity in rotation periods for asteroids that are only slightly larger. In particular, the H~28.6 asteroids 2016 CC136 and 2016 CG18 were observed to rotate with periods approaching or exceeding ~2 hours, with the latter showing a tumbling behavior. In a subset of our database that includes 22 asteroids with H~27.5 (~10 meters) or greater, a full range of periods from less than a minute to greater than 2 hours (close to the minimal period of a self-gravitating system), have been identified. Moreover, at least three of these are in a tumbling state with multiple periods clearly identified, implying constraints on their ages. The overall diversity in the observed spins in our database will be discussed in the context of better understanding internal body strengths required for the smallest asteroids.

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411.02 – The Mission Accessible Near-Earth Objects Survey (MANOS): photometric results

The Mission Accessible Near-Earth Object Survey (MANOS) is a physical characterization survey of Near-Earth Objects (NEOs) to provide physical data for several hundred mission accessible NEOs across visible and near-infrared wavelengths. Using a variety of 1-m to 8-m class telescopes, we observe 5 to 10 newly discovered sub-km NEOs per month in order to derive their rotational properties and taxonomic class.
Rotational data can provide useful information about physical properties, like shape, surface heterogeneity/homogeneity, density, internal structure, and internal cohesion. Here, we present results of

the MANOS photometric survey for more than 200 NEOs. We report lightcurves from our first three years of observing and show objects with rotational periods from a couple of hours down to a few seconds. MANOS found the three fastest rotators known to date with rotational periods below 20s. A physical interpretation of these ultra-rapid rotators is that they are bound through a combination of cohesive and/or tensile strength rather than gravity. Therefore, these objects are important to understand the internal structure of NEOs. Rotational properties are used for statistical study to constrain overall properties of the NEO population. We also study rotational properties according to size, and dynamical class. Finally, we report a sample of NEOs that are fully characterized (lightcurve and visible spectra) as the most suitable candidates for a future robotic or human mission. Viable mission targets are objects with a rotational period >1h, and a delta-v lower than 12 km/s. Assuming the MANOS rate of object characterization, and the current NEO population estimates by Tricarico (2016), and by Harris and D'Abramo (2015), 10,000 to 1,000,000 NEOs with diameters between 10m and 1km are expected to be mission accessible. We acknowledge funding support from NASA NEOO grant number NNX14AN82G, and NOAO survey program.

Author(s): Audrey Thirouin[1], Nicholas Moskovitz[1], Richard Binzel[2], Eric J. Christensen[5], Francesca DeMeo[2], Michael J. Person[2], David Polishook[7], Cristina Thomas[4], David E. Trilling[3], Mark Willman[6], Mary L Hinkle[3], Brian Burt[1], Dan Avner [3]
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411.03 – The Large Super-Fast Rotators and Asteroidal Spin-Rate Distributions With Large Sky-Field Surveys Using iPTF

In order to look for kilometer-sized super-fast rotators (large SFRs) and understand the spin-rate distributions of small (i.e. D of several kilometers) asteroids, we have been conducting asteroid rotation period surveys of large sky area using intermediate Palomar Transient Factory (iPTF) since 2014. So far, we have observed 261 deg^2 with 20 min cadence, 188 deg^2 with 10 min cadence, and 65 deg^2 with 5 min cadence. From these surveys, we found that the spin-rate distributions of small asteroids at different locations in the main-belt are very similar. Moreover, the distributions of asteroids with 3 < D < 15 km show number decrease along with increase of spin rate for frequency > 5 rev/day, and that of asteroids with D < 3 km have a significant number drop at frequency = 5 rev/day. However, we only discover two new large SFRs and 24 candidates. Comparing with the ordinary asteroids, the population of large SFR seems to be far less than the whole asteroid population. This might indicate a peculiar group of asteroid for large SFRs.

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Contributing team(s): iPTF Team

412 – Titan: Views from Cassini

412.01 – Cassini RADARs Penultimate Passes by Titan

The Cassini spacecraft will be in its final year of operation as you read this abstract. The RADAR instrument will observe Titan on passes that occur (or occurred) June 27 (T120), July 25 (T121) and April 22, 2017 (T126), all including SAR imaging. T120 SAR, the only pass received at this writing, has revealed what is arguably the best example of Labrynthic terrain, a unit previously identified on about 2% of the observed surface of Titan (Lopes et al., 2016); extended our observations of "cookie cutter lakes"; seen in SAR the very dark area described by Griffith et al (2012), and given added context to the equatorial wind-streak features (Malaska, 2016). The T121 SAR swath promises similar exciting data as it observes Hotei Regio, an area previously thought to be a candidate cryovolcano; Tui Regio (Barnes et al., 2006); and a last look at Xanadu's eastern flanks. We will review all new findings on T120 and T121 and also preview T126 SAR, where we will get a last look at the northern seas, including Titan's "Magic Island" (Hofgartner et al., 2015).This work was carried out at the Jet Propulsion Laboratory, California Insititue of Technology, under a contract with the National Aeronautics and Space Administration.

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Contributing team(s): Cassini RADAR Science Team

412.02 – The Calm Methane Northern Seas of Titan from Cassini Radio Science Observations

We report on results from 3 bistatic scattering observations of Titan northern seas conducted by the Cassini spacecraft in 2014 (flybys T101, T102, and T106). The onboard Radio Science instrument transmits 3 sinusoidal signals of 0.94, 3.6, and 13 cm wavelengths. The spacecraft is continuously maneuvered to point in incidence direction so that mirror-like reflections from Titan's surface are observed at the ground stations of the NASA Deep Space Network. The corresponding ground-track in all 3 cases crossed different regions of Kraken Mare, and in the case of T101 also crossed Ligeia Mare. A nearly pure sinusoidal reflected signal was clearly detectable in the observed echoes spectra over surface regions identified in the Cassini RADAR images as potential liquid regions. Weaker quasi-specular echoes were also evident over some intermediate dry land and near sea shores. Cassini transmits right-circularly-polarized (RCP) signals and both the RCP and LCP echo components are observed. Their spectral shape, bandwidth, and total power are the observables used to infer/constrain physical surface properties. Presented results are limited to the 3.6 cm wavelength signal which has the largest SNR. The remarkably preserved sinusoidal echo spectral shape and the little detectable Doppler broadening strongly suggest surface that is smooth on scales large compared to 3.6 cm. If long wavelength gravity waves are present, they must be very subtle. The measured RCP/LCP echo power ratio provides direct measurement of the surface dielectric constant and is diagnostic of the liquid composition. The power ratio measurements eliminate possible significant ethane contribution and strongly imply predominantly liquid methane and nitrogen composition. Carefully calibrated measurements of the absolute echo power and the inferred dielectric constant constrain the presence of any capillary waves of wavelength << 3.6 cm. The latter affect wave coherence across the Fresnel region, reducing the reflected sinusoidal component power. When detectable, the reduction implies an RMS ripples height of about 2 mm, otherwise the measurements place an upper bound of about 1 mm. The results appear consistent among the two polarized echo components.

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Contributing team(s): Cassini Radio Science Team

412.03 – Spectral Trends of Titan's Tropical Surface

Titan's surface can be observed most clearly at 8 spectral regions that lie in between the strong methane bands in Titan's spectrum. Within these "windows", between 0.9 to 5 microns, the surface is nonetheless obscured by methane and haze, the latter of which is optically thick at lower wavelengths. Thus studies of Titan's surface must eliminate the effects of atmospheric extinction and extract the

subtle spectral features that underlie the dominant spectral trends. To determine the subtle spectral features of Titan's tropical surface (30S--30N) we conducted a Principal Components Analysis (PCA) of the I/F at the 1.1, 1.3, 1.6 and 2.0 um wavelength windows, recorded by Cassini/VIMS. The PCA analysis identifies the spectral trend that defines the highest variance in the data (the principal component), as well as successively weaker orthogonal trends, without a priori assumptions about the surface composition, e.g. as needed in radiative transfer analyses.
Our analysis derives the spectral features at the four wavelengths that describe Titan's tropical surface. We detect a large almost contiguous region that extends roughly 160 degrees in longitude and which exhibits absorption features at 1.6 and 2.0, as well as 2.8 um (characteristic of water ice). This vast and perhaps tectonic feature is, in part, associated with terrain that is hypothesized to be some of the oldest surfaces on Titan. In addition, the PCA analysis indicates at least 2 separate organic spectra signatures, potentially due to the separation of liquid and refractory sediments or to their chemically alteration over time. Here we discuss the PCA analysis and compare our derived compositional maps of Titan's surface with Radar maps of the topography and morphology, to entertain questions regarding the geology of Titan's surface the age of its atmosphere.
Author(s): Caitlin Ann Griffith[4], Paulo F. Penteado[2], Jake Turner[5], Nicholas Montiel[4], Ashley Schoenfeld[3], Rosaly M.C Lopes[2], Laurence A. Soderblom[7], Catherine Neish[6],Jani Radebaugh[1]
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412.04 – Compositional mapping of Titan's North Pole with VIMS

Titan's methane lakes and seas are almost exclusively found at the moon's north polar region. The factors that drive this distribution are not yet well understood. The poles are generally lower in elevation and a few Kelvin colder than the equator. But the south pole looks very different from the north with only one large lake and a few smaller bodies. To further illuminate what processes might make the north pole unique, we investigate the region's compositional variability and the connection to morphology by analyzing the entirety of the publically available data from Cassini's Visual and Infrared Mapping Spectrometer (VIMS) that cover the north pole. Because VIMS can only observe the surface in seven IR windows, we identify the relative composition ("spectral units") of the north polar terrain (90N - 45N) and compare our results to those of Birch et al. (Icarus, in revision), who defined geomorphological units in Cassini RADAR north polar data. We find interesting correlations and examples of distinct composition boundaries in VIMS that aren't reflected in the RADAR data. These results provide a more complete context for lake formation/retention hypotheses as well as identify features for further study.
Author(s): Shannon MacKenzie[6], Jason W Barnes[6], Christophe Sotin[2], Jason M. Soderblom[1], Stéphane Le Mouélic[4], Sebastien Rodriguez[5], Kevin Baines[7], Bonnie J. Buratti[2], Roger Nelson Clark[3]
Institution(s): *1. Massachusetts Institute of Technology, 2. Jet Propulsion Laboratory California Institute of Technology, 3. Planetary Science Institute, 4. Universite de Nantes, 5. Universite de Paris 7, 6. University of Idaho, 7. University of Wisconsin-Madison*

412.05 – Sounding Titan's Lakes and Seas: Bathymetry, Composition, and Role in the Hydrologic Cycle

One of the most surprising discoveries of the Cassini Solstice Mission is the microwave transparency of Titan's lakes and seas. Coherent processing of altimetry echoes acquired over Ligeia Mare in May 2013 revealed bottom reflections and allowed construction of a bathymetric profile as well as an estimation of the liquid loss tangent. Following the successful detection of subsurface echoes at Ligeia, the RADAR team organized a campaign to acquire altimetry over the remaining Mare. Altimetry over Kraken and Punga Maria were obtained in August 2014 and January 2015, respectively, and also show detectable subsurface echoes. Using new analysis techniques, subsurface returns were also recovered from data acquired over Ontario Lacus in 2008. The final Titan flyby (T126, April 2017) will acquire altimetry over several of the smaller lakes in Titan's north, permitting comparative studies between the Mare and lakes. In this presentation, we will report on the latest results from this ongoing campaign.
Assuming a ternary composition of CH_4, C_2H_6, and N_2, the best-fit loss tangent at Ligeia Mare is consistent with 71% CH_4, 12% C_2H_6, and 17% N_2 by volume. The best-fit loss tangent Ontario Lacus is consistent with 47% CH_4, 40% C_2H_6, and 13% N_2. The higher loss tangent at Ontario Lacus could result from an increased abundance of more involatile hydrocarbons and/or nitriles; these species could be concentrated as a consequence of orbitally-driven insolation cycles that may have slowly transported volatile components (methane/ ethane) to the north over the past several tens of millennia. Initial analysis of Kraken and Punga Maria suggest liquid absorptivity similar to Ligeia Mare. In total, the bathymetric results suggest that the total volume of Titan's lakes and seas is >70,000 km^3. If this liquid were evenly spread across the surface it would be equivalent to a global ocean depth of 1 m. This is equivalent to 300 times the mass of Earth's proven natural gas reserves. Unlike Earth, where the total water content in the atmosphere ($1.29x10^4$ km^3) is only a fraction of the surficial reservoir ($1.35x10^9$ km^3), the moisture content in Titan's atmosphere is approximately seven times larger than the volume found in its lakes and seas.
Author(s): Alexander Hayes[1], Marco Mastrogiuseppe[1], Jonathan I. Lunine[1], Valerio Poggiali[5], Ralph Lorenz[3], Alice Le Gall[4], Karl L. Mitchell[2]
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Contributing team(s): Cassini RADAR Science Team

412.06D – Equatorial belt of Titan: Aaru Region as seen by VIMS/Cassini

Since eleven years of observation, near-infrared imaging data from the Visual and Infrared Mapping Spectrometer (VIMS) onboard Cassini[1] reveal a variety of surface units that are compositionally and structurally distinct[2, 3]. The analysis of these units enables constraining the surface composition of Titan, which is of prime importance for modelling Titan's interior, surface, and atmosphere, particularly in the search for an endogenic methane source. For this study, we investigate a selection of units of interest seen in VIMS data by comparatively applying an empirical correction[4, 5] and a radiative transfer code[6-8] in order to correct for atmospheric contributions and retrieve surface albedo. SAR swaths from the Radar instrument are also used for geomorphological mapping purposes. We focus on the region of Aaru, located in the equatorial belt and centered at 10°N and 340°W, where several geological features have been identified: (1) infrared-brown dunes material; (2) a strongly eroded impact crater named Paxsi[9]; (3) mountainous and infrared-bright plateaus; and (4) infrared-blue areas devoid of dunes (similar to those seen in other regions probably enriched in water-ice, such as Chusuk Planitia[10]). By using our radiative transfer model, we estimate the surface albedo of regions of our interest within different infrared units of the Aaru region and compare with spectra of surface candidates, starting with water-ice and tholins. As seen in the similar study over Sinlap crater and its surroundings[11], this method of analysis allows understanding of the compositional and structural relations between the different spectral units.

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Author(s): Jeremy Florian Brossier[1], Sébastien Rodriguez[3], Luca Maltagliati[2], Stéphane Le Mouélic[4], Anezina Solomonidou[2], Athena Coustenis[2], Mathieu Hirtzig[2], Ralf Jaumann[1], Robert H. Brown[5]

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412.07 – Constraints on the nature of various Titan Geomorphological Units with Cassini/VIMS and SAR

We investigate the lower atmosphere of Titan from Visual and Infrared Mapping Spectrometer (VIMS) spectro-imaging data by use of a recently updated radiative transfer code in the near-IR range and RADAR/SAR data for the distinction of geomorphological units. We focus here on the geological major units identified in [1;2] and [3]: mountains, plains, labyrinths, dune fields, and possible cryovolcanic and/or evaporitic features (the latter two are albedo features, [4;5;6]). We infer surface properties (like absolute surface albedo and morphology) and atmospheric contributions, in particular the haze content. We find that the Huygens landing site and the candidate evaporitic regions pair compositionally with the variable plains, thus indicating that units of significant geomorphological differences seem to consist of very similar materials. Similarly for the labyrinth terrains and the undifferentiated plains. On the contrary, many regions from the same geomorphological unit show compositional variations depending on location (i.e. undifferentiated plains). These differences provide implications on the endogenic or exogenic origin of the various units. In previous studies we showed that the processes most likely linked to the formation of the various geomorphological units are aeolian, fluvial, sedimentary, and lacustrine, in addition to the deposition of organics through the atmosphere. Currently, we are working on deriving information on the chemical composition of the aforementioned regions from the extracted surface albedos using an extensive library of ices and tholins [e.g. 7]. This will shed light on the potential formation processes (Solomonidou et al. in prep.). Preliminary results on the chemical composition of the regions that have shown temporal changes (i.e. Tui Regio and Sotra Patera; [6]) are also presented.

References: [1] Lopes, R.M.C., et al.: Icarus, 205, 540-558, 2010; [2] Lopes, R.M.C., et al.: Icarus, 270, 162-182, 2016; [3] Malaska, M., et al.: Icarus, 270, 130-161, 2016; [4] Barnes, J., et al.: Pl. Scie., 2:1, 2013; [5] Solomonidou, A., et al.: JGR, 119, 1729-1747, 2014; [6] Solomonidou, A., et al.: Icarus, 270, 85-99, 2016; [7] Schmitt, B., et al.: GhoSST database (ghosst.osug.fr).

Author(s): Anezina Solomonidou[6], Athena Coustenis[4], Rosaly M.C Lopes[6], Sébastien Rodriguez[3], Bernard Schmitt[2], Sylvain Philippe[2], Michael Malaska[6], Kenneth J. Lawrence[6], Michael A. Janssen[6], Alice Le Gall[8], Ralf Jaumann[1], Frank Sohl[1], Katrin Stephan[1], Pierre Drossart[4], Robert H. Brown[5], Luca Maltagliati[3], Emmanuel Bratsolis[7],Christos Matsoukas[7]

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412.08 – Geomorphological map of the South Belet region of Titan: An exploration of Mid-Latitude-to-Pole transition zones

We carried out detailed geomorphological mapping of Titan's mid-latitude region south of the Belet Sand Sea. We used radar data collected by Cassini's Synthetic Aperture Radar (SAR) as our basemap, supplemented by spectro-images from VIMS, images from ISS, SARtopo, and microwave emissivity datasets. We mapped at a scale of 1:800,000 in all areas of the South Belet region covered by SAR swaths, taking into consideration the 300 m/pixel resolution of the swaths. For the mid-latitudes, we have defined five broad classes of terrains following Malaska et al. (2016). These terrain classes are craters, hummocky/mountainous, labyrinth, plains, and dunes. We have found that the hummocky/mountainous terrains are the oldest, with a radiometric signature consistent with icy materials. Dunes are the youngest units and return a radiometric signature consistent with organic sediments. The South Belet region of Titan is primarily covered by the dune and plain units (specifically the undifferentiated plains) typical of the mid-latitudes (Malaska et al. 2016). Previous mapping efforts of the mid-latitude regions of Titan (Lopes et al. 2016; Malaska et al. 2016) have indicated that these regions are predominately modified and influenced by aeolian activities. A plain unit designated "scalloped plains" is prominently featured between the 50°S and 60°S latitudes of this region. In this area we also find a terrain unit (dark irregular plains) that has been interpreted as damp materials saturated with liquid hydrocarbons (Malaska et al 2016; Hayes et al. 2008). We also note a higher identification of fluvial channels starting at this latitude zone and extending poleward. We suggest that these features demark the transition zone between mid-latitude/equatorial aeolian-dominated processes and fluvial-dominated processes prevailing at the poles.

References: Lopes, R.M.C., et al.: *Icarus*, *270*, 162-182, 2016; Malaska, M., et al.: *Icarus*, *270*, 130-161, 2016; Hayes, A. et al.: *Geophys. Res. Lett. 35*, L09204, 2008.

Author(s): Ashley Marie Schoenfeld[4], Rosaly M.C Lopes[4], Michael Malaska[4], Anezina Solomonidou[4], Samuel Birch[3], Alexander Hayes[3], David A. Williams[2], Michael A. Janssen[4], Alice Le Gall[5], Elizabeth P. Turtle[1]

Institution(s): *1. Applied Physics Laboratory, John Hopkins University, 2. Arizona State University , 3. Cornell, 4. Jet Propulsion Laboratory, 5. University of Versailles-Saint Quentin*

Contributing team(s): The Cassini RADAR Team

412.09D – Fluvial transport on Titan: formation and evolution of river deltas

The Cassini-Huygens mission provided numerous observations indicating that processes of sediment transport are currently operating on the surface of Titan. We performed numerical simulations of flow and sediment transport on Titan with particular emphasis on formation of sedimentary landforms in Titan's lakes. We compared the morphology and evolution of landforms formed in Titanian and terrestrial conditions, under various discharges and with different dominant grain sizes. The processes are similar in both environments; in some cases we observed bifurcation of the flow and switching of the active distributaries. Such processes may lead to abandonment of some delta lobes, as hypothesized for the delta observed in Ontario Lacus on Titan. The lower gravity of Titan and higher buoyancy of the most plausible kinds of sediment result in higher efficiency of transport and generally faster evolution of the deltaic deposits. Our results suggest also that the flat, lobate river deltas may form in narrower range of parameters than on Earth.

Author(s): Piotr Przemyslaw Witek[1], Leszek Czechowski[1]
Institution(s): *1. University of Warsaw*

414 – Farinella Prize Lecture: Flavors of Chaos in the Asteroid Belt, Kleomenis Tsiganis (Aristotle University of Thessaloniki)

414.01 – Flavors of Chaos in the Asteroid Belt

The asteroid belt is a natural laboratory for studying chaos, as a large fraction of asteroids actually reside on chaotic orbits. Numerous studies over the past 25 years have unveiled a multitude of dynamical chaos-generating mechanisms, operating on different time-scales and dominating over different regions of the belt. In fact, the distribution of chaotic asteroids in orbital space can be largely understood as the outcome of the combined action of resonant gravitational perturbations and the Yarkovsky effect – two topics on which Paolo Farinella has made an outstanding contribution! – notwithstanding the fact that the different "flavors" of chaos can give rise to a wide range of outcomes, from fast escape (e.g. to NEA space) to slow (~100s My) macroscopic diffusion (e.g. spreading of families) and strange, stable-looking, chaotic orbits (ultra-slow diffusion). In this talk I am going to present an overview of these mechanisms, presenting both analytical and numerical results, and their role in understanding the long-term evolution and stability of individual bodies, asteroid groups and families.

Author(s): Kleomenis Tsiganis[1]
Institution(s): *1. Aristotle University of Thessaloniki*

415 – Harold C. Urey Prize Lecture: In for the Long Haul: Exploring Atmospheric Cycles on the Giant Planets, Leigh Fletcher (University of Leicester)

415.01 – In for the Long Haul: Exploring Atmospheric Cycles on the Giant Planets

Timing is everything. The churning, dynamic atmospheres of the four giant planets exhibit spectacular variability on timescales that are poorly understood, largely due to the challenges involved in acquiring multi-spectral time series over their long, slow orbits. With the notable exception of Cassini, planetary missions rarely provide more than a snapshot of the climate at a particular moment – the vast gaps between spacecraft encounters must be filled by regular Earth-based observations. Archives of infrared observations, essential for characterising the changing environmental conditions in the troposphere and stratosphere (temperatures, winds, composition and clouds), now span three Jovian years, a single Saturnian year, and only one Uranian season. Nevertheless, these have revealed the thermochemical changes associated with Jupiter's belt/zone life cycles (e.g., the 2009-10 fade and revival of the South Equatorial Belt); the seasonal evolution of Saturn's atmosphere (including the 2010 springtime storm) and polar vortices; the rise in storm activity on Uranus, and the development of a seasonal polar vortex on Neptune. Such records are vital for placing the results of new missions (NASA/Juno and ESA/JUICE) in their wider temporal context, and for disentangling the myriad radiative, dynamical and chemical processes shaping gas giant climate. The importance of moist convection has been explored via ground-based infrared observations of large cumulonimbus complexes, surrounded by broad, dry downdrafts, during both Saturn's 2010 storm and Jupiter's 2010 SEB revival. This convection spawns waves that couple the tropospheric weather to the stable stratosphere, generating longitudinal thermal waves or, in the extreme case, Saturn's enormous infrared stratospheric "beacon." But what of the distant ice giants? Long-lived orbital missions, able to provide multi-spectral sounding and in situ sampling of Uranus and/or Neptune, should be a top priority for our community. And these ambitious missions will only be possible through international collaboration between agencies. To truly understand our diverse collection of giant planet systems, we have to be in it for the long haul.

Author(s): Leigh N Fletcher[1]
Institution(s): *1. University of Leicester*

416 – Plenary Talk: The Ancient Habitability of Gale Crater, Mars, after Four Years of Exploration by Curiosity, Ashwin Vasavada (Jet Propulsion Laboratory)

416.01 – The Ancient Habitability of Gale Crater, Mars, after Four Years of Exploration by Curiosity

The Mars Science Laboratory (MSL) Curiosity rover landed in August 2012 with the goal of assessing the habitability of environments dating from the Noachian-Hesperian boundary, a time when Mars was undergoing a major climatic change from wetter to drier conditions. The stratified and mineralogically diverse foothills of Gale crater's central mound, Aeolis Mons, retain a record of this key period. Prior to reaching Aeolis Mons, ancient habitable environments were found on the surrounding plains. At Yellowknife Bay, geological, geochemical, and mineralogical analyses of the lacustrine Sheepbed mudstone indicated a near-neutral pH and low salinity environment with the key chemical elements required by life and potential sources of energy to fuel microbial metabolism. As the rover traversed across the plains, evidence for ancient fluvial and deltaic systems pointed toward the hypothesis that lower Aeolis Mons was built up from sediments deposited within a series of lakes that once filled the central basin of the crater. Upon reaching the mountain in September 2014, Curiosity found an array of fluvial, lacustrine, and aeolian strata that also show a complex pattern of post-depositional alteration. The basal outcrops that form the lowest stratigraphic unit of Aeolis Mons, the Murray formation, are characterized predominantly by mudstones with minor intercalated sandstones. The mudstone facies show abundant fine-scale planar laminations throughout the Murray formation succession and are interpreted to record deposition in an ancient lacustrine system in Gale crater. Curiosity has explored 40 m of the ~ 200-m thick Murray formation. If the entire section is lacustrine, it would imply that lakes were stable in Gale crater over a period of at least millions of years, challenging present climate models that cannot account for the temperate and humid conditions needed to sustain long-lived open lakes on early Mars. This presentation will review how Curiosity's geological and atmospheric (e.g., methane and isotopic signatures) observations have changed our view of the ancient habitability of Mars.

Author(s): Ashwin R Vasavada[2], Sanjeev Gupta[1]
Institution(s): *1. Imperial College London, 2. Jet Propulsion Laboratory*
Contributing team(s): Mars Science Laboratory Science Team

417 – Capacity Building in Formal and Informal Education Posters

417.01 – Engaging Scientists with the CosmoQuest Citizen Science Virtual Research Facility

NASA Science Mission Directorate missions and research return more data than subject matter experts (SMEs – scientists and engineers) can effectively utilize. Citizen scientist volunteers represent a robust pool of energy and talent that SMEs can draw upon to advance projects that require the processing of large quantities of images, and other data. The CosmoQuest Virtual Research Facility has developed roles and pathways to engage SMEs in ways that advance the education of the general public while producing science results publishable in peer-reviewed journals, including through the CosmoQuest Facility Small Grants Program and CosmoAcademy. Our Facility Small Grants Program is open to SMEs to fund them to work with CosmoQuest and engage the public in analysis. Ideal projects have a specific and well-defined need for additional eyes and minds to conduct basic analysis and data collection (such as crater counting, identifying lineaments, etc.) Projects selected will undergo design and implementation as Citizen Science Portals, and citizen scientists will be recruited and trained to complete the project. Users regularly receive feedback on the quality of their data. Data returned will be analyzed by the SME and the CQ Science Team for joint publication in a peer-reviewed journal. SMEs are also invited to consider presenting virtual learning courses in the subjects of their choice in CosmoAcademy. The audience for CosmoAcademy are lifelong-learners and education professionals. Classes are capped at 10, 15, or 20 students. CosmoAcademy can also produce video material to archive seminars long-term. SMEs function as advisors in many other areas of CosmoQuest, including the Educator's Zone (curricular materials for K-12 teachers), Science Fair Projects, and programs that partner to produce material for podcasts and planetaria. Visit the CosmoQuest website at cosmoquest.org to learn more, and to investigate current opportunities to engage with us. CosmoQuest is funded through individual donations, through NASA Cooperative Agreement NNX16AC68A, and through additional grants and contracts that are listed on the About page of our website, cosmoquest.org.

Author(s): Jennifer A. Grier[2], Pamela L. Gay[3], Sanlyn Buxner[2], Jacob Noel-Storr[1]
Institution(s): *1. InsightSTEM, 2. Planetary Science Institute, 3. SIUE*
Contributing team(s): CosmoQuest Team

417.02 – Career and Workforce Impacts of the NASA Planetary Science Summer School: TEAM X model 1999-2015

Sponsored by NASA's Planetary Science Division, and managed by the Jet Propulsion Laboratory (JPL), the Planetary Science Summer School prepares the next generation of engineers and scientists to participate in future solar system exploration missions. PSSS utilizes JPL's emerging concurrent mission design "Team X" as mentors. With this model, participants learn the mission life cycle, roles of scientists and engineers in a mission environment, mission design interconnectedness and trade-offs, and the importance of teamwork. Applicants are sought who have a strong interest and experience in careers in planetary exploration, and who are science and engineering post-docs, recent PhDs, doctoral or graduate students, and faculty teaching such students. An overview of the program will be presented, along with results of a diversity study conducted in fall 2015 to assess the gender and ethnic diversity of participants since 1999. PSSS seeks to have a positive influence on participants' career choice and career progress, and to help feed the employment pipeline for NASA, aerospace, and related academia. Results will also be presented of an online search that located alumni in fall 2015 related to their current occupations (primarily through LinkedIn and university and corporate websites), as well as a 2015 survey of alumni.

Author(s): Leslie L. Lowes[1], Charles Budney[1], Karl Mitchell[1], Alice Wessen[1]
Institution(s): *1. JPL*
Contributing team(s): JPL Education Office, JPL Team X

417.03 – Leadership Workshops for Adult Girl Scout Leaders

This year, the University of Arizona is conducting its first two Leadership Workshops for Girl Scout adult leaders. These workshops are being supported by a five-year NASA Collaborative Agreement, *Reaching for the Stars: NASA Science for Girl Scouts (www.seti.org/GirlScoutStars)*, through the SETI Institute in collaboration with the University of Arizona, Girl Scouts of the USA (GSUSA), the Girl Scouts of Northern California, the Astronomical Society of the Pacific, and Aries Scientific, Inc. These workshops are an outgrowth of *Astronomy Camp for Girl Scout Leaders*, a 14-year "Train the Trainer" program funded by NASA through the James Webb Space Telescope's Near Infrared Camera (NIRCam) education and outreach team. We are continuing our long-term relationship with all Girl Scout Councils to engage girls and young women not only in science and math education, but also in the astronomical and technological concepts relating to NASA's scientific mission. Our training aligns with the GSUSA Journey: *It's Your Planet-Love It!* and introduces participants to some of the activities that are being developed by the Girl Scout Stars team for GSUSA's new space science badges for all Girl Scout levels being developed as a part of *Reaching for the Stars: NASA Science for Girl Scouts.*

The workshops include hands-on activities in basic astronomy (night sky, stars, galaxies, optics, telescopes, etc.) as well as some more advanced concepts such as lookback time and the expansion of the Universe. Since the inception of our original Astronomy Camp in 2003, our team has grown to include nearly 280 adult leaders, staff, and volunteers from over 79 Councils in 43 states and the District of Columbia so they can, in turn, teach young women essential concepts in astronomy, the night sky environment, applied math, and engineering. Our workshops model what astronomers do by engaging participants in the process of science inquiry, while equipping adults to host astronomy-related programs with local Girl Scouts.

Reaching for the Stars: NASA Science for Girl Scouts is supported by NASA Science Mission Directorate's Education Cooperative Agreement # NNX16AB90.

Author(s): Larry A. Lebofsky[2], Donald McCarthy[2], Edna DeVore[1], Pamela Harman[1]
Institution(s): *1. SETI Institute, 2. University of Arizona*
Contributing team(s): The Reaching for the Stars Team

417.04 – Collaborating with Scientists in Education and Public Engagement

The Education and Public Engagement team at the Lunar and Planetary Institute (LPI) is developing a scientific advisory board, to gather input from planetary scientists for ways that LPI can help them with public engagement, such as connecting them to opportunities, creating useful resources, and providing training. The advisory board will assist in outlining possible roles of scientists in public engagement, provide feedback on LPI scientist engagement efforts, and encourage scientists to participate in various education and public engagement events.

LPI's scientists have participated in a variety of education programs, including teacher workshops, family events, public presentations, informal educator trainings, and communication workshops. Scientists have helped conduct hands-on activities, participated in group discussions, and given talks, while sharing their own career paths and interests; these activities have provided audiences with a clearer vision of how science is conducted and how they can become engaged in science themselves.

This poster will share the status and current findings of the scientist advisory board, and the lessons learned regarding planetary scientists' needs, abilities, and interests in participating in education and public engagement programs.

Author(s): Christine Shupla[1], Andrew Shaner[1], Amanda Smith Hackler[1]
Institution(s): *1. Lunar and Planetary Institute*

417.05 – Reaching Rural Canadian Communities in the Yukon and Alberta

Canada is very large geographically, so many rural communities are very far from major centers. People in such communities are at a severe disadvantage when it comes to in-person interaction with science or scientists because resources tend to be directed at large population centers, where more people can be reached for the same amount of effort. While this geographic distance can be mitigated by doing outreach over the internet, there is at some level no substitute for showing up in person with e.g. meteorites in hand. Due to where various members of my family are located, I have occasion to visit Whitehorse, YT and Andrew, AB (~1.5 hour drive north-east of Edmonton) and have taken advantage of trips to these locations to do astronomy outreach in both schools and public libraries. I will discuss how I arranged school and library visits and general observations from my experience doing outreach in rural Canadian communities.

Author(s): Christa L. Van Laerhoven[1]
Institution(s): *1. Canadian Institute for Theoretical Astrophysics*

417.06 – Crowdfunding To Support University Research and Public Outreach

Crowdfunding involves raising (usually small) monetary contributions from a large number of people, often performed via the internet. Several universities have adopted this model to support small-dollar, high-profile projects and provide the seed money for research efforts. By contrast with traditional scientific funding, crowdfunding provides a novel way to engage the public in the scientific process and sometimes involves donor rewards in the form of acknowledgments in publications and direct involvement in the research itself.
In addition to Kickstarter.com and Indiegogo.com that support a range of enterprises, there are several organizations tailored to scientific research and development, including Experiment.com and the now-defunct PetriDish.org. Private companies are also available to help universities establish their own crowd-funding platforms. At Boise State University, we recently engaged the services of ScaleFunder to launch the PonyUp platform (https://ponyup.boisestate.edu/), inaugurated in Fall 2015 with requests of support for projects ranging from the health effects of organic food during pregnancy to censuses of hummingbirds.
In this presentation, I'll discuss my own crowdfunding project to support the rehabilitation of Boise State's on-campus observatory. As the first project launched on PonyUp, it was an enormous success -- we met our original donation goal of $8k just two weeks into the four-week campaign and so upped the goal to $10k, which we achieved two weeks later. In addition to the very gratifying monetary support of the broader Boise community, we received personal stories from many of our donors about their connections to Boise State and the observatory. I'll talk about our approach to social and traditional media platforms and discuss how we leveraged an unlikely cosmic syzygy to boost the campaign.

Author(s): Brian Jackson[1]
Institution(s): *1. Boise State University*

417.07 – Reaching the Public in 2016

Travelers in the Night is a series of 2 minute audio programs whose topics include Catalina Sky Survey discoveries as well as other current research in astronomy and the space sciences. Each episode is first published on Public Radio Exchange [PRX] which makes it available to NPR and Community Radio Stations free of charge. After about 3 weeks it is published as an audio podcast on the internet via spreaker.com, iHeart Radio, Stitcher, iTunes and a few other outlets. The most interesting aspect of the Travelers In The Night experiment is the insight it provides into the rapidly changing means by which people obtain information in 2016. The demographics, and devices used to obtain more than 175,000 plays and downloads are presented in this poster.

Author(s): Albert D. Grauer[1]
Institution(s): *1. University of Arizona*
Contributing team(s): Catalina Sky Survey

417.08 – CosmoQuest Collaborative: Galvanizing a Dynamic Professional Learning Network

The CosmoQuest Collaboration offers in-depth experiences to diverse audiences around the nation and the world through pioneering citizen science in a virtual research facility. An endeavor between universities, research institutes, and NASA centers, CosmoQuest brings together scientists, educators, researchers, programmers—and citizens of all ages—to explore and make sense of our solar system and beyond. Leveraging human networks to expand NASA science, scaffolded by an educational framework that inspires lifelong learners, CosmoQuest engages citizens in analyzing and interpreting real NASA data, inspiring questions and defining problems.

The Question

Linda Darling-Hammond calls for professional development to be: "focused on the learning and teaching of specific curriculum content [i.e. NGSS disciplinary core ideas]; organized around real problems of practice [i.e. NGSS science and engineering practices] …; [and] connected to teachers' collaborative work in professional learning community...." (2012) In light of that, what is the unique role CosmoQuest's virtual research facility can offer NASA STEM education?

A Few Answers

The CosmoQuest Collaboration actively engages scientists in education, and educators (and learners) in science. CosmoQuest uses social channels to empower and expand NASA's learning community through a variety of media, including science and education-focused hangouts, virtual star parties, and social media. In addition to creating its own supportive, standards-aligned materials, CosmoQuest offers a hub for excellent resources and materials throughout NASA and the larger astronomy community.
In support of CosmoQuest citizen science opportunities, CQ initiatives (Learning Space, S-ROSES, IDEASS, Educator Zone) will be leveraged and shared through the CQPLN. CosmoQuest can be present and alive in the awareness its growing learning community. Finally, to make the CosmoQuest PLN truly relevant, it aims to encourage partnerships between scientists and educators, and offer "just-in-time" opportunities to support constituents exploring emerging NASA STEM education, from diverse educators to the curious learner of any age.

Author(s): Whitney Cobb[3], Georgia Bracey[5], Sanlyn Buxner[4], Pamela L. Gay[1], Jacob Noel-Storr[2]
Institution(s): *1. CosmoQuest, 2. InSight STEM, 3. McREL International, 4. Planetary Science Institute, 5. University of Southern Illinois, Edwardsville*
Contributing team(s): CosmoQuest Team

417.09 – Exploration Science Opportunities for Students within Higher Education

The NASA Solar System Exploration Research Virtual Institute (SSERVI) is a virtual institute focused on exploration science related to near-term human exploration targets, training the next

generation of lunar scientists, and education and public outreach. As part of the SSERVI mission, we act as a hub for opportunities that engage the public through education and outreach efforts in addition to forming new interdisciplinary, scientific collaborations. SSERVI provides opportunities for students to bridge the scientific and generational gap currently existing in the planetary exploration field. This bridge is essential to the continued international success of scientific, as well as human and robotic, exploration.
The decline in funding opportunities after the termination of the Apollo missions to the Moon in the early 1970's produced a large gap in both the scientific knowledge and experience of the original lunar Apollo researchers and the resurgent group of young lunar/NEA researchers that have emerged within the last 15 years. One of SSERVI's many goals is to bridge this gap through the many networking and scientific connections made between young researchers and established planetary principle investigators. To this end, SSERVI has supported the establishment of NextGen Lunar Scientists and Engineers group (NGLSE), a group of students and early-career professionals designed to build experience and provide networking opportunities to its members. SSERVI has also created the LunarGradCon, a scientific conference dedicated solely to graduate and undergraduate students working in the lunar field. Additionally, SSERVI produces monthly seminars and bi-yearly virtual workshops that introduce students to the wide variety of exploration science being performed in today's research labs. SSERVI also brokers opportunities for domestic and international student exchange between collaborating laboratories as well as internships at our member institutions. SSERVI provides a bridge that is essential to the continued international success of scientific, as well as human and robotic, exploration.

Author(s): Brad Bailey[1], Joseph Minafra[1], Gregory Schmidt[1]
Institution(s): *1. Solar System Exploration Research Virtual Institute*

417.10 – Effective Models for Scientists Engaging in Meaningful Education and Outreach

We present a central paradigm, extending the model of "Teacher-Scientist" partnerships towards a new philosophy of "Scientist-Instructor-Learner-Communicator" Partnerships. In this paradigm modes of, and expertise in, communication, and the learners themselves, are held is as high status as the experts and teachers in the learning setting.
We present three distinctive models that rest on this paradigm in different educational settings. First a model in which scientists and teachers work together with a communications-related specialist to design and develop new science exploration tools for the classroom, and gather feedback from learners. Secondly, we present a model which involves an ongoing joint professional development program helping scientists and teachers to be co-communicators of knowledge exploration to their specific audience of learners. And thirdly a model in which scientists remotely support classroom research based on online data, while the teachers and their students learn to become effective communicators of their genuine scientific results.
This work was funded in part by the American Association for the Advancement of Science, and by NASA awards NNX16AC68A and NNX16AJ21G. All opinions are those of the authors.

Author(s): Jacob Noel-Storr[1]
Institution(s): *1. InsightSTEM*
Contributing team(s): InsightSTEM SILC Partnership Team

417.11 – Teachers as researchers: An experiment to introduce high school science teachers to how science is done

Scientists know that the power of science lies in thinking like a scientist, rather than in a list of facts and figures, but few science teachers have any personal experience "doing science". They merely encounter science at the level of rote memorization, then teach it to their students in the same way. To break this vicious cycle, two teachers from local public high schools spent 5 weeks conducting research at Boston University on the ionosphere of Venus. They experienced the joys and frustrations of research, which will enable them to better explain to their students the true nature of the process of science. This presentation will summarize how the research program was created and implemented, what worked well and what did not, and how the teachers have made use of their summer research experiences back in the classroom.

Author(s): Paul Withers[1], Kathryn J. Fallows[1], Marlene King[3], Ken Magno[2]
Institution(s): *1. Boston Univ., 2. Norwell High School, 3. Wilmington High School*

417.12 – Outreach and Education with Europlanet 2020 RI

Since 2005, Europlanet has provided a framework to bring together Europe's widespread planetary science community. The project has evolved through a number of phases, and currently comprises a Research Infrastructure (RI) funded through the European Commission's Horizon 2020 program, as well as a self-sustaining membership organization. Launched in September 2015, Europlanet 2020 RI provides support, services, access to facilities, new research tools and a virtual planetary observatory. Europlanet 2020 RI's outreach and education program aims to engage members of the public, schools, teachers, policy makers and industrial partners across Europe with planetary science and the opportunities that it provides for innovation, inspiration and job creation. Europlanet's outreach and education activities are led by Science Office Ltd, a Portuguese-based SME, and a network of partners spread across nine countries including University College London, the University of Leiden, University of Latvia, Vilnius University, the Institute of Accelerating Systems and Applications, the Observatoire de Paris, CAB-INTA and the Austrian Space Forum.
Europlanet supports educators and outreach providers within the planetary science community by organizing meetings, best practice workshops and communication training sessions, offering a seed-funding scheme for outreach activities, and awarding an annual prize for public engagement. Europlanet is also developing its own education and outreach resources, including an animation on 'Jupiter and its Icy Moons' (the first in a series of video "shorts") and kits for hands-on comparative planetology activities. The Europlanet Media Centre uses traditional and social media channels to communicate newsworthy results and activities to diverse audiences in Europe and worldwide. Using tools like Google Hangouts, the project connects planetary researchers directly with the public and school groups. In addition, Europlanet engages with policy makers in the European Parliament and the European Commission, as well as high-level representatives of ESA, NASA and other space agencies, through an active programme of individual briefings, events and exhibitions.

Author(s): Anita R Heward[1], Mariana Barrosa[1]
Institution(s): *1. Europlanet 2020 RI*
Contributing team(s): Europlanet 2020 RI

417.13 – Europlanet Prize for Public Engagement

The Europlanet Prize for Public Engagement with Planetary Science is awarded annually. Through the Prize, Europlanet aims to recognise achievements in engaging European citizens with planetary science and to raise the profile of outreach within the scientific community. It is awarded to individuals or groups who have developed innovative practices in planetary science communication and whose efforts have significantly contributed to a wider public engagement with planetary science.

Author(s): Thierry Fouchet[1]
Institution(s): *1. Observatoire de Paris*

418 – Large-scale Opportunities for Citizen Engagement Posters

418.01 – Seven Years of World-Wide Participation in International Observe the Moon Night

International Observe the Moon Night (InOMN) is an annual worldwide public event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA planetary science and exploration. Everyone on Earth is invited to join the celebration by hosting or attending an InOMN event - and uniting on one day each year to look at and learn about the Moon together. This year marks the seventh year of InOMN, which will be held on October 8, 2016. Between 2010 and 2015, a total of 3,275 events were registered worldwide, 49% of which were held in the United States. In 2015, a total of 545 events were registered on the InOMN website from around the world. These events were scheduled to be held in 54 different countries, 43% of which were registered in the United States from 40 states and the District of Columbia. InOMN events are hosted by a variety of institutions including astronomy clubs, observatories, schools, and universities and hosted at a variety of public and private institutions all over the world including museums, planetaria, schools, universities, observatories, parks, and private businesses and private homes. Evaluation of InOMN is led by the Planetary Science Institute who assesses the success of InOMN through analysis of event registrations, facilitator surveys, and visitor survey. Current InOMN efforts demonstrate success in meeting the overall goals of the LRO E/PO goals including raising visitors' awareness of lunar science and exploration, providing audiences with information about lunar science and exploration along with access to LRO data and science results, and inspiring visitors to want to learn more about the Moon and providing connections to opportunities to do so. InOMN is sponsored by NASA's Lunar Reconnaissance Orbiter, NASA's Solar System Exploration Research Virtual Institute (SSERVI), and the Lunar and Planetary Institute. Learn more at http://observethemoonnight.org/.

Author(s): Sanlyn Buxner[4], Andrea J. Jones[4], Lora Bleacher[3], Matthew Wenger[4], Andrew Shaner[1], Emily C. S. Joseph[4], Brian Day[2], Marti Canipe[4]
Institution(s): *1. Lunar and Planetary Institute, 2. NASA Ames Research Center, 3. NASA Goddard Space Flight Center, 4. Planetary Science Institute*
Contributing team(s): InOMN Coordinating Committee

418.02 – CosmoQuest: Training Educators and Engaging Classrooms in Citizen Science through a Virtual Research Facility

CosmoQuest is a Citizen Science Virtual Research Facility that engages scientists, educators, students, and the public in analyzing NASA images. Often, these types of citizen science activities target enthusiastic members of the public, and additionally engage students in K-12 and college classrooms. To support educational engagement, we are developing a pipeline in which formal and informal educators and facilitators use the virtual research facility to engage students in real image analysis that is framed to provide meaningful science learning. This work also contributes to the larger project to produce publishable results. Community scientists are being solicited to propose CosmoQuest Science Projects take advantage of the virtual research facility capabilities. Each CosmoQuest Science Project will result in formal education materials, aligned with Next Generation Science Standards including the 3-dimensions of science learning; core ideas, crosscutting concepts, and science and engineering practices. Participating scientists will contribute to companion educational materials with support from the CosmoQuest staff of data specialists and education specialists. Educators will be trained through in person and virtual workshops, and classrooms will have the opportunity to not only work with NASA data, but interface with NASA scientists. Through this project, we are bringing together subject matter experts, classrooms, and informal science organizations to share the excitement of NASA SMD science with future citizen scientists. CosmoQuest is funded through individual donations, through NASA Cooperative Agreement NNX16AC68A, and through additional grants and contracts that are listed on our website, cosmoquest.org.

Author(s): Sanlyn Buxner[5], Georgia Bracey[6], Theresa Summer[1], Whitney Cobb[4], Pamela L. Gay[6], Keely D. Finkelstein[7], Suzanne Gurton[1], Lisa Felix-Strishock[6], Brian Kruse[1], Larry A. Lebofsky[5], Andrea J. Jones[5], Ann Tweed[4], Paige Graff[3], Susan Runco[3], Jacob Noel-Storr[2]
Institution(s): *1. Astronomical Society of the Pacific, 2. InsightSTEM, 3. Johnson Space Center, 4. McREL International, 5. Planetary Science Institute, 6. Southern Illinois University Edwardsville, 7. University Texas*
Contributing team(s): CosmoQuest Team

418.03 – CosmoAcademy Training and Certification for Scientists and Engineers

CosmoQuest is a virtual research facility bringing together scientists, citizens, and learners of all ages. CosmoQuest offers classes, training, and learning opportunities online through CosmoAcademy, offering opportunities for all kinds of learners to become more connected to the science of the Universe. In this poster we describe CosmoAcademy opportunities for Subject Matter Experts (SMEs), scientists and engineers who are interested in broadening their impact of their work by providing learning opportunities for those outside of the scientific community. CosmoAcademy offers SME programs at a variety of levels and across a variety of topics in formal and informal education and outreach -- ranging from sharing the results of your work on social media, through delivering an online class series, to partnering with teachers and schools. SMEs may combine sequences of training to earn certification at various levels for their participation in the CosmoAcademy programs. SMEs who have been trained may also apply to teach CosmoAcademy classes for the community on subjects of their expertise to build a rich and engaging learning resource for members of society who wish to understand more about the Universe.

Author(s): Jacob Noel-Storr[1], Sanlyn Buxner[2], Jennifer A. Grier[2], Pamela L. Gay[3]
Institution(s): *1. InsightSTEM, 2. Planetary Science Institute, 3. Southern University of Illinois Edwardsville*
Contributing team(s): CosmoQuest Team

418.04 – The Pro-Am Collaborative Astronomy (PACA) Project

The PACA Project is an ecosystem of several social media platforms (Facebook, Pinterest, Twitter, Flickr, Vimeo) that takes connects professional and amateur astronomers in a common observing campaign. It takes advantage of immediate connectivity amongst amateur astronomers worldwide, that can be galvanized to participate in a given observing campaign and provide observations/data that helps provide a long temporal backdrop for professional data. To date, The PACA Project has participated in organized campaigns such as NASA Comet ISON Observing Campaign in 2013; NASA Comet Integrated Observations Campaign to observe Comet Siding Spring flyby of Mars on 19 October 2014, and currently is participating in the ESA/Rosetta mission's ground-based amateur observing campaign, soon to finish. With several bright comets well placed in the sky, the PACA Project has focused groups for each comet of interest to its members. The PACA Project is now extending its observing campaigns to include planets, namely, Jupiter, Saturn and Mars. The 2014 observing campaign of comet Siding Spring included both comet and Mars amateur astronomers. With Mars, just past its recent opposition and heading towards its perihelic opposition, when it will be its largest size as viewed from Earth, in 2018; with NASA's JUNO spacecraft arrival at Jupiter on 4 July 2016 and NASA/ESA Cassini mission ending its mission to Saturn in 2017, all three planets are targets of amateur observers. The synergy between The PACA Project goals, amateur and professional astronomers translates well into a cohesive paradigm to monitor and observe comets and planets to increase the data on these targets for crowdsourcing. I shall highlight the results from the various campaigns, including various comets, Jupiter, Saturn and Mars and propose various science observing campaigns, resulting in both scientific research and citizen science.

Author(s): Padma A. Yanamandra-Fisher[1]
Institution(s): *1. Space Science Institute*

418.05 – Eclipse 2017: Through the eyes of NASA

The August 21, 2017 eclipse will be the first time a total solar eclipse has traversed the Continental US since June 8th, 1918. Anticipation y for energy for this eclipse is off the charts. Over 500 million in North America alone will catch the eclipse in either partial or total phase. Parts of South America, Africa, and Europe will see a partial eclipse as well.

NASA is planning to take full advantage of this unique celestial event as an education and public engagement opportunity by leveraging its extensive networks of partners, numerous social media platforms, broadcast media, and its significant unique space assets and people to bring the eclipse to America and the world as only NASA can.

This talk will outline NASA's education plans in some detail replicating our many Big Events successes including the 2012 Transit of Venus and the MSL/Curiosity landing and show how scientists and the public can get involved.

Author(s): Louis Mayo[1]
Institution(s): *1. NASA's GSFC*
Contributing team(s): NASA/GSFC Heliophysics Education Consortium

418.06 – Revival of the "Sun Festival": An educational and outreach project

In ancient times, past civilisations used to celebrate both the winter and summer solstices, which represented key moments in the periodical cycle of seasons and agricultural activities. In 1904, the French astronomer Camille Flammarion, the engineer Gustave Eiffel, the science writer Wilfrid de Fonvielle and the Spanish astronomer Josep Comas i Solà decided to celebrate the summer solstice with a festival of science, art and astronomical observations opened to the public at the Eiffel tower in Paris. For ten consecutive years (1904-1914) on the day of the summer solstice, the "Sun Festival" (*Fête du Soleil* in French) included scientific and technological lectures and demostrations, celestial observations, music, poetry, danse, cinema, etc. This celebration was interrupted by the First World War, just to resume in Barcelona, Spain, between 1915 and 1937, and in Marseille, France, in the 1930s. It was the founders' dream to extend this celebration to all cities in France and elsewhere.

It is only during the International Year of Astronomy in 2009, to our knowledge, that the "Sun Festival" was given another chance in France, thanks to the joint effort of several scientific and cultural centers (*Centres de Culture Scientifique, Technique et Industrielle*, CCSTI) and the timely support of the European Space Agency (ESA). In this occasion again, the festival was characterized by the combination of science, art and technological innovation around a common denominator: our Sun!

We have recently revived the idea of celebrating the summer solstice with a "Sun Festival" dedicated to scientific education and outreach about our star and related topics. This project started last year in Aix-les-Bains, France, with the "Sun and Light Festival" (2015 was the International Year of Light), attended by about 100 people. This year's second edition was in Le Bourget-du-Lac, France. Following the COP21 event, the specific theme was the "Sun and Climate Festival", and we had about 250 attendees. We plan to hold a "Sun and Planets Festival" next year in the city of Chambery, France, for which we are actively looking for partnerships and support, in order to make this event a recurrent education and outreach project at increasing scale.

Author(s): Luca Montabone[1]
Institution(s): *1. Space Science Institute*

418.07 – Public Engagement with the Lunar and Planetary Institute

The Lunar and Planetary Institute's (LPI) public engagement programs target audiences of all ages and backgrounds; in 2016 LPI has expanded its programs to reach wider, more diverse audiences. The status, resources, and findings of these programs, including evaluation results, will be discussed in this poster.

LPI's Cosmic Explorations Speaker Series (CESS) is an annual public speaker series to engage the public in space science and exploration. Each thematic series includes four to five presentations held between September and May. Past series' titles have included *"Science" on the Silver Screen*, *The Universe is Out to Get Us and What We Can (or Can't) Do About It*, and *A User's Guide to the Universe: You Live Here. Here's What You Need to Know*. While the presentations are available online after the event, they are now being livestreamed to be accessible to a broader national, and international, audience.

Sky Fest events, held four to five times a year, have science content themes and include several activities for children and their parents, night sky viewing through telescopes, and scientist presentations. Themes include both planetary and astronomy topics as well as planetary exploration topics (e.g., celebrating the launch or landing of a spacecraft). Elements of the Sky Fest program are being conducted in public libraries serving audiences underrepresented in STEM near LPI. These programs take place as part of existing hour-long programs in the library. During this hour, young people, typically 6-12 years old, move through three stations where they participate in hands-on activities. Like Sky Fest, these programs are thematic, centered on one over-arching topic such as the Moon or Mars.

Beginning in Fall 2016, LPI will present programs at a revitalized park in downtown Houston. Facilities at this park will enable LPI to bring both the Sky Fest and CESS programs into the heart of Houston, which is one of the most diverse cities in the US and the world.

Author(s): Andrew Shaner[1], Christine Shupla[1], Amanda Smith Hackler[1], Sanlyn Buxner[2], Matthew Wenger[2], Emily C. S. Joseph[2]
Institution(s): *1. Lunar and Planetary Institute, 2. Planetary Science Institute*

418.08 – Preparing the Public for the James Webb Space Telescope and its Exploration of the Solar System

The James Webb Space Telescope (JWST) is the successor to the Hubble Space Telescope. STScI and the Office of Public Outreach are committed to bringing awareness of the technology, the excitement, and the future science potential of this great observatory to the public and to the scientific community, prior to its 2018 launch. The challenges in ensuring the high profile of JWST (understanding the infrared, the vast distance to the telescope's final position, and the

unfamiliar science territory) requires us to lay the proper background. We currently engage the full range of the public and scientific communities using a variety of high impact, memorable initiatives, in combination with modern technologies to extend reach, linking the science goals of Webb to the ongoing discoveries being made by Hubble. We have injected Webb-specific content into ongoing outreach programs: for example, simulated, scientifically-inspired but aesthetic JWST scenes (illustrating the differences between JWST and previous missions); partnering with high impact science communicators such as MinutePhysics to produce timely and concise content; incorporating JWST science into activities at large scale events. JWST has unique observational capabilities that optimize its ability ot study the Solar System: monitoring weather, tracking and measuring dusty objects, collaborative parallax observations with other observatories, and more. We discuss some of the ways we engage the public on these concepts.
Author(s): Joel D. Green[1], Denise A. Smith[1], Bonnie K. Meinke[1], Hussein Jirdeh[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): Office of Public Outreach

419 – Tools and Resources for Education Posters

419.01 – DPS Discovery Slide Sets for the Introductory Astronomy Instructor

The DPS actively supports the E/PO needs of the society's membership, including those at the front of the college classroom. The DPS Discovery Slide Sets are an opportunity for instructors to put the latest planetary science into their lectures and for scientists to get their exciting results to college students.
In an effort to keep the astronomy classroom apprised of the fast moving field of planetary science, the Division for Planetary Sciences (DPS) has developed "DPS Discoveries", which are 3-slide presentations that can be incorporated into college lectures. The slide sets are targeted at the Introductory Astronomy undergraduate level. Each slide set consists of three slides which cover a description of the discovery, a discussion of the underlying science, and a presentation of the big picture implications of the discovery, with a fourth slide that includes links to associated press releases, images, and primary sources. Topics span all subdisciplines of planetary science, and 26 sets are available in Farsi and Spanish. We intend for these slide sets to help Astronomy 101 instructors include new developments (not yet in their textbooks) into the broader context of the course. If you need supplemental material for your classroom, please checkout the archived collection:
http://dps.aas.org/education/dpsdisc
More slide sets are now in development and will be available soon! In the meantime, we seek input, feedback, and help from the DPS membership to add fresh slide sets to the series and to connect the college classroom to YOUR science. It's easy to get involved – we'll provide a content template, tips and tricks for a great slide set, and pedagogy reviews. Talk to a coauthor to find out how you can disseminate your science or get involved in E/PO with your contributions.
Author(s): Bonnie K. Meinke[3], Brian Jackson[1], Sanlyn Buxner[4], Sarah Horst[2], David Brain[5], Nicholas M. Schneider[5]
Institution(s): *1. Boise State University, 2. Johns Hopkins University, 3. STScI, 4. University of Arizona, 5. University of Colorado, Boulder*

419.02 – AAS Nova and Astrobites: Making current astronomy research accessible

AAS Nova and Astrobites are two resources available for astronomers, astronomy students, and astronomy enthusiasts to keep up with some of the most recent research published across the field of astronomy. Both supported by the AAS, these two daily astrophysical literature blogs provide accessible summaries of recent publications on the arXiv and in AAS journals. We present the goals, content, and readership of AAS Nova and Astrobites, and discuss how they might be used as tools in the undergraduate classroom.
Author(s): Susanna Kohler[1]
Institution(s): *1. American Astronomical Society*
Contributing team(s): Astrobites Team

419.03 – DPS Planetary Science Graduate Programs Database for Students and Advisors

Several years ago the DPS Education committee decided that it should have an online resource that could help undergraduate students find graduate programs that could lead to a PhD with a focus in planetary science. It began in 2013 as a static page of information and evolved from there to a database-driven web site. Visitors can browse the entire list of programs or create a subset listing based on several filters. The site should be of use not only to undergraduates looking for programs, but also for advisers looking to help their students decide on their future plans.
The reason for such a list is that "planetary science" is a heading that covers an extremely diverse set of disciplines. The usual case is that planetary scientists are housed in a discipline-placed department so that finding them is typically not easy—undergraduates cannot look for a Planetary Science department, but must (somehow) know to search for them in all their possible places. This can overwhelm even determined undergraduate student, and even many advisers!
We present here the updated site and a walk-through of the basic features as well as some usage statistics from the collected web site analytics. We ask for community feedback on additional features to make the system more usable for them. We also call upon those mentoring and advising undergraduates to use this resource, and for program admission chairs to continue to review their entry and provide us with the most up-to-date information.
The URL for our site is http://dps.aas.org/education/graduate-schools.
Author(s): David R. Klassen[1], Anthony Roman[2], Bonnie K. Meinke[2]
Institution(s): *1. Rowan Univ., 2. Space Telescope Science Institute*

419.04 – Astronomy4Kids: Utilizing online video forums to teach basic planetary concepts to children (pre-K to 2nd-grade)

We have developed **Astronomy4Kids** to help cultivate the next generation of scientists by using technology to reach every interested child in both formal and informal learning environments. This online video series fills the void of effective STEM education tools for children under the age of 8. Our first collection of videos discuss many planetary topics, including the following: planet and moon formation theories, solar and lunar eclipses, and the seasonal effect of the Earth's tilt. As education and outreach become a larger focus of groups such as AAS and NASA, it is imperative to include programs such as **Astronomy4Kids** to extend these initiatives to younger age groups.
Traditionally, this age group has been viewed as too young to be introduced to physics and astronomy concepts. However, child development research is consistently demonstrating the amazing plasticity of a young child's mind: the younger one is introduced to a complex concept, the easier it is to grasp later on. Following the philosophies of Fred Rogers, we present children with a real, relatable, instructor allowing them to focus on the concepts being presented.
The format of **Astronomy4Kids** includes short instruction video clips that usually include a hands-on activity that is easily reproduced at home or in the classroom. This permits flexibility in how the video

series is utilized. Within formal classroom or after-school situations, teachers and instructors can lead the discussion and activity with help from the video and supplemental materials (e.g. worksheets, concept outlines, etc.). Informal environments permit the viewer to complete the tasks on their own or simply enjoy the presentation. The video series can be found on YouTube (under "Astronomy 4 Kids") or Facebook (at www.facebook.com/astronomy4kids); we have also expanded to Instagram (www.instragram.com/astronomy4kids) and Pinterest (www.pinterest.com/astronomy4kids).

Author(s): Richard L Pearson[1]
Institution(s): *1. Astronomy4Kids*

419.05 – An Undergraduate Endeavor: Assembling a Live Planetarium Show About Mars

Viewing the mysterious red planet Mars goes back thousands of years with just the human eye but in more recent years the growth of telescopes, satellites and lander missions unveil unrivaled detail of the Martian surface that tells a story worth listening to. This planetarium show will go through the observations starting with the ancients to current understandings of the Martian surface, atmosphere and inner-workings through past and current Mars missions. Visual animations of its planetary motions, display of high resolution images from the Hi-RISE (High Resolution Imaging Science Experiment) and CTX (Context Camera) data imagery aboard the MRO (Mars Reconnaissance Orbiter) as well as other datasets will be used to display the terrain detail and imagery of the planet Mars with a digital projection system. Local planetary scientists and Mars specialists from the Lunar and Planetary Lab at the University of Arizona (Tucson, AZ) will be interviewed and used in the show to highlight current technology and understandings of the red planet. This is an undergraduate project that is looking for collaborations and insight in order gain structure in script writing that will teach about this planetary body to all ages in the format of a live planetarium show.

Author(s): Allison M. McGraw[1]
Institution(s): *1. Lunar and Planetary Lab*

419.06 – Utilizing a scale model solar system project to visualize important planetary science concepts and develop technology and spatial reasoning skills

Scale model solar systems have been used for centuries to help educate young students and the public about the vastness of space and the relative sizes of objects. We have adapted the classic scale model solar system activity into a student-driven project for an undergraduate general education astronomy course at the University of Arizona. Students are challenged to construct and use their three dimensional models to demonstrate an understanding of numerous concepts in planetary science, including: 1) planetary obliquities, eccentricities, inclinations; 2) phases and eclipses; 3) planetary transits; 4) asteroid sizes, numbers, and distributions; 5) giant planet satellite and ring systems; 6) the Pluto system and Kuiper belt; 7) the extent of space travel by humans and robotic spacecraft; 8) the diversity of extrasolar planetary systems. Secondary objectives of the project allow students to develop better spatial reasoning skills and gain familiarity with technology such as Excel formulas, smart-phone photography, and audio/video editing. During our presentation we will distribute a formal description of the project and discuss our expectations of the students as well as present selected highlights from preliminary submissions.

Author(s): Stephen J. Kortenkamp[1], Laci Brock[1]
Institution(s): *1. University of Arizona*

419.07 – The LAPS Project : A live 1D Radiative-Convective Model to explore the possible climates of terrestrial planets and exoplanets.

The LAPS (Live Atmospheres-of-Planets Simulator) is a live 1D version of the LMD Global Climate Model that provides an accelerated and interactive simulation of the climate of terrestrial planets and exoplanets.
This tool was designed for students to explore the «Classical Habitable Zone», defined as the range of orbital distances within which a planet can maintain liquid water on its surface. The model faithfully reproduces both the inner edge and the outer edge limits of the Habitable Zone, and their dependencies to the type of star and the gas composition.
Furthermore, it provides a "hands on" experiment by showing how the surface and atmospheric temperatures as well as the profile of water vapor evolve through time when the external forcing (insolation, star spectrum, ...) or the planet (quantity of CO2, initial amount of water reservoir, ...) is modified.
The tool is available at http://laps.lmd.jussieu.fr/ .

Author(s): Martin Turbet[2], Francois Forget[2], Cédric Schott[1]
Institution(s): *1. Labex ESEP (Exploration Spatiale des Environnements Planétaires), 2. LMD, IPSL, UPMC*

419.08 – The OpenPlanetary initiative

"Open" has become attached to several concepts: science, data, and software are some of the most obvious. It is already common practice within the planetary science community to share spacecraft missions data freely and openly [1]. However, this is not historically the case for software tools, source code, and derived data sets, which are often reproduced independently by multiple individuals and groups. Sharing data, tools and overall knowledge would increase scientific return and benefits [e.g. 2], and recent projects and initiatives are helping toward this goal [e.g. 3,4,5,6].
OpenPlanetary is a bottom-up initiative to address the need of the planetary science community for sharing ideas and collaborating on common planetary research and data analysis problems, new challenges, and opportunities. It started from an initial participants effort to stay connected and share information related to and beyond the ESA's first Planetary GIS Workshop [7]. It then continued during the 2nd (US) Planetary Data Workshop [8], and aggregated more people.
Our objective is to build an online distributed framework enabling open collaborations within the planetary science community. We aim to co-create, curate and publish resource materials and data sets; to organise online events, to support community-based projects development; and to offer a real-time communication channel at and between conferences and workshops.
We will present our current framework and resources, developing projects and ideas, and solicit for feedback and participation.
OpenPlanetary is intended for research and education professionals: scientists, engineers, designers, teachers and students, as well as the general public that includes enthusiasts and citizen scientists. All are welcome to join and contribute at openplanetary.co

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419.09 – The Design and Use of Planetary Science Video Games to Teach Content while Enhancing Spatial Reasoning Skills

Traditional teaching of Planetary Science requires students to possess well developed spatial reasoning skills (SRS). Recent research has demonstrated that SRS, long known to be crucial to math and science success, can be improved among students who lack these skills (Sorby et al., 2009). Teaching spatial reasoning is particularly valuable to women and minorities who, through societal pressure, often doubt their abilities (Hill et al., 2010). To address SRS deficiencies, our team is developing video games that embed SRS training into Planetary Science content. Our first game, on Moon Phases, addresses the two primary challenges faced by students trying to understand the Sun-Earth-Moon system: 1) visualizing the system (specifically the difference between the Sun-Earth orbital plane and the Earth-Moon orbital plane) and 2) comprehending the relationship between time and the position-phase of the Moon. In our second video game, the student varies an asteroid's rotational speed, shape, and orientation to the light source while observing how these changes effect the resulting light curve. To correctly pair objects to their light curves, students use spatial reasoning skills to imagine how light scattering off a three dimensional rotating object is imaged on a sensor plane and is then reduced to a series of points on a light curve plot. These two games represent the first of our developing suite of high-interest video games designed to teach content while increasing the student's competence in spatial reasoning.

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419.10 – Using Virtual Reality For Outreach Purposes in Planetology

2016 has been a year marked by a technological breakthrough : the availability for the first time to the general public of technologically mature virtual reality devices. Virtual Reality consists in visually immerging a user in a 3D environment reproduced either from real and/or imaginary data, with the possibility to move and eventually interact with the different elements. In planetology, most of the places will remain inaccessible to the public for a while, but a fleet of dedicated spacecraft's such as orbiters, landers and rovers allow the possibility to virtually reconstruct the environments, using image processing, cartography and photogrammetry. Virtual reality can then bridge the gap to virtually "send" any user into the place and enjoy the exploration.

We are investigating several type of devices to render orbital or ground based data of planetological interest, mostly from Mars. The most simple system consists of a "cardboard" headset, on which the user can simply use his cellphone as the screen. A more comfortable experience is obtained with more complex systems such as the HTC vive or Oculus Rift headsets, which include a tracking system important to minimize motion sickness. The third environment that we have developed is based on the CAVE concept, were four 3D video projectors are used to project on three 2x3m walls plus the ground. These systems can be used for scientific data analysis, but also prove to be perfectly suited for outreach and education purposes.

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420 – Inner Planets: Magnetospheres Posters

420.01 – Solar cycle dynamic of the Martian induced magnetosphere. Planetary ions acceleration zones and escape.

This work presents a massive statistical analysis of the ion flows in the Martian induced magnetosphere. We performed this analysis using Mars Express ion mass spectrometer data taken during 2008 - 2013 time interval. This data allows to make an enhanced study of the induced magnetosphere variations as a response of the solar activity level. Since Mars Express has no onboard magnetometer, we used the hybrid models of the Martian plasma environment to get a proper frame to make an adequate statistics of the magnetospheric response. In this paper we present a spatial distribution of the planetary plasma properties in the planetary wake as well as the ionosospheric escape as a function of the solar activity.

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420.02 – On the Earth's paleo-magnetosphere for the late Hadean eon

Simulations of the terrestrial paleo-magnetosphere for early stages of the solar system are of particular importance for studying the evolution and mass loss of the Earth's atmosphere. Within this presentation, we will present simulations of the paleo-magnetosphere of the Earth for the late Hadean, i.e. for ~4.1 billion years ago. These were performed with an adapted version of the Paraboloid Magnetospheric Model (PMM) of the Skobeltsyn Institute for Nuclear Physics of the Moscow State University, which serves as an ISO standard for the magnetosphere . As an input parameter, the new measurements of the paleomagnetic field strength by Tarduno et al., 2015, are taken. These data from zircons between 3.3 billion and 4.2 billion years old vary between 1.0 and 0.12 of today's equatorial field strength. Available data at ~4.1 billion years ago are among the lowest field strength values. Another input into the adapted PMM is the solar wind pressure, which was derived from a newly developed solar/stellar wind evolution model, which is strongly dependent on the rotation rate of the early Sun. Our simulations of the terrestrial paleo-magnetosphere with the adapted PMM show that for the most extreme case of a fast rotating Sun and a paleomagnetic field strength with 0.12 of today's value, the stand-off distance of the magnetopause r_s shrinks significantly down from today's 10-11 R_E to 3.43 R_E (i.e. 2.43 R_E above the Earth's surface, where R_E is the Earth's surface). Even for the least extreme case – i.e. the same magnetic field strength as that of today and a slow rotating Sun - r_s shrinks down to 8.23 R_E. Another outcome of the modelling is that the polar cap was significantly broader ~4.1 billion years ago than today.

These results have implications for the early terrestrial atmosphere. Since the EUV flux during the late Hadean eon was significantly higher, the exobase of a nitrogen dominated atmosphere would most probably have reached the magnetopause, leading to enhanced atmospheric erosion. However, a significantly higher amount of CO_2 during the late Hadean than at present-day may have prevented atmospheric loss in such a scenario. First results of these erosion processes will be presented within this presentation.

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420.03 – The Martian paleo-magnetosphere during the early Naochian and its implication for the early Martian atmosphere

During the late 1990's the Mars Global Surveyor MAG/ER experiment detected crustal remanent magnetization at Mars indicating an ancient internal magnetic dynamo. The location of this remanent magnetization and in particular its absence at the large Martian impact craters like Hellas suggests a cessation of the dynamo during the early Naochian epoch, i.e. ~ 4.1 to 4 billion years ago. The strength of the remanent magnetization together with dynamo theory are indicating an ancient dipole field strength lying in the range of ~0.1 and ~1.0 of the present-day dipole field of the Earth, making the Martian paleo-magnetosphere comparable with the terrestrial paleo-magnetosphere. This also has implication for the early Martian atmosphere.
In this poster we will present simulations of the paleo-magnetosphere of Mars for the early Naochian, just before cessation (i.e. for ~4.1 to ~4.0 billion years ago). These were performed with an adapted version of the Paraboloid Magnetospheric Model (PMM) of the Skobeltsyn Institute of Nuclear Physics of the Moscow State University, which serves as an ISO standard for the magnetosphere. Here the ancient magnetic field was assumed to be a dipole field (with dipole tilt ψ=0). The ancient solar wind ram pressure as important input parameter was derived from a newly developed solar/stellar wind evolution model, which is strongly dependent on the rotation rate of the early Sun. These simulations show that for the most extreme case of a fast rotating Sun and a paleomagnetic field strength of 0.1 of the present-day Earth value, the Martian magnetopause was located at ~5.5 R_M(i.e. ~2.9 R_E) above the Martian surface. Assuming a strong dipole field (i.e. 1.0 of present-day Earth) and a slow rotating Sun – our least extreme case - would lead to a standoff-distance of r_s~16 R_M (i.e. ~8.5 R_E).
Our simulations also have implications for the early Martian atmosphere, which will be demonstrated within this poster. These first results on the erosion of the early Martian atmosphere take into account the paleo-magnetosphere, the enhanced EUV-flux and solar wind conditions during the early Naochian epoch.

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421 – Jovian Planets: Atmospheres and Interiors Posters

421.01 – Investigating Wave Structures in Jupiter's Atmosphere using HST Images

Hubble Space Telescope images taken in 2015 and 2016 as part of the Outer Planet Atmosphere Legacy (OPAL) program are used to create zonal wind profiles for Jupiter's atmosphere. These jet profiles are then analyzed for longitudinal variations in latitude or velocity, which can be indicators of wave features in the atmosphere. To create the zonal wind profiles, two image sections, separated in time by Δt (typically about one jovian rotation), are correlated at every latitude from -80° to +80°, and the physical displacement Δx between features in each image is found. This yields a velocity for each latitude. The image sections have dimensions of 80° latitude by 80° longitude, but smaller longitude bins were used in the correlations. That allows each velocity profile to be specific to one longitudinal region on the planet. Variations between profiles thus represent variations in the jet's velocity with longitude. This analysis was performed on images taken in visible wavelengths with HST. Here, we focus on two latitudinal regions, ~17°N and ~7°S, which are locations of prominent westward and eastward jets, respectively. At ~17°N, we find a dichotomy in wind speeds: from 165° to 300°W the wind speeds are roughly -13 m/s, in stark contrast with the -23 m/s velocities measured at all other longitudes. In the 7°S jet, we observe quasi-periodic behavior, with longitude regions alternating between ~148 m/s and ~154 m/s, which is possibly related to chevron activity in the region. With a velocity resolution of a few m/s, we argue that the variations in both jets are significant, and suggest possible wave-related explanations for their existence. This research was supported by the NASA EPSCoR JIVE in NM project awarded to NMSU and NMT and a New Mexico Space Grant awarded to NMT.

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421.02 – Photochemistry in Saturn's Ring-Shadowed Atmosphere: Modulation of Hydrocarbons and Observations of Dust Content

Cassini has been orbiting Saturn for over twelve years now. During this epoch, the ring shadow has moved from covering much of the northern hemisphere with solar inclination of 24 degrees to covering a large swath south of the equator and it continues to move southward. At Saturn Orbit Insertion in 2004, the projection of the A-ring onto Saturn reached as far as 40N along the central meridian (52N at the terminator). At its maximum extent, the ring shadow can reach as far as 48N/S (58N/S at the terminator). The net effect is that the intensity of both ultraviolet and visible sunlight penetrating through the rings to any particular latitude will vary depending on both Saturn's axis relative to the Sun and the optical thickness of each ring system. In essence, the rings act like semi-transparent venetian blinds.
Previous work examined the variation of the solar flux as a function of solar inclination, i.e. for each 7.25-year season at Saturn. Here, we report on the impact of the oscillating ring shadow on the photolysis and production rates of hydrocarbons (acetylene, ethane, propane, and benzene) and phosphine in Saturn's stratosphere and upper troposphere. The impact of these production and loss rates on the abundance of long-lived photochemical products leading to haze formation are explored. We assess their impact on phosphine abundance, a disequilibrium species whose presence in the upper troposphere can be used as a tracer of convective processes in the deeper atmosphere.
We will also present our ongoing analysis of Cassini's CIRS, UVIS, and VIMS datasets that provide an estimate of the evolving haze content of the northern hemisphere and we will begin to assess the implications for dynamical mixing. In particular, we will examine how the now famous hexagonal jet stream acts like a barrier to transport, isolating Saturn's north polar region from outside transport of photochemically-generated molecules and haze.
The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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421.03 – Models of aerosol and methane distributions on Uranus based on 2015 HST/STIS observations

On 10 October 2015 we acquired new HST/STIS spectral imaging observations of Uranus, with supporting WFC3 imaging on 11 October and Keck near-IR imaging on 29 August 2015. Our objectives were to better define the latitudinal and temporal variation of methane and characterize the brightening north polar region. Our prior analyses of similar 2002 and 2012 observations (Sromovsky et al. 2014, Icarus 238, 137-155) used a simplified model of the 815-835 nm spectral region, where hydrogen and methane produce comparable absorption, to define their relative variation with latitude. The scale factor converting to absolute methane volume mixing ratios (VMR) was established by full radiative transfer models at three latitudes, using a linked methane and thermal structure model consistent with radio occultation observations. Since that analysis, Orton et al. (2014, Icarus 243, 494-513) used Spitzer Infrared Spectrometer observations to define a new global average thermal profile for Uranus that was not consistent with radio occultation results. Our new STIS analysis thus considered a wider range of options in both thermal and methane profiles, instead of forcing consistency with occultation results. We also carried out a limited spectral analysis covering the 730 - 850 nm region, where we could constrain both the vertical aerosol structure and the methane/hydrogen ratio, retaining full radiative transfer effects to obtain absolute values directly. We found that the new analysis allows a wider range of methane mixing ratios, with generally lower values at low latitudes (0.03 instead of 0.04), but a larger fractional decrease from low to high latitudes, by a factor of three, with some dependence on the thermal profile and aerosol model that is used. We found that most aerosol layers did not change dramatically versus latitude in 2015, and that the relatively bright polar region is a result of reduced methane absorption at high latitudes. However, the increased polar brightness relative to 2012 is due to increased aerosol scattering, not to any changes in the methane mixing ratio. This research was supported by grants from the Space Telescope Science Institute.

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421.04 – Atmospheric Dynamics on Uranus in the millimeter and sub-millimeter

Characterizing the atmospheric dynamics of Uranus is important to understand its structure, evolution, and energetics. In addition, most of the exoplanets discovered to date are roughly the same size and mass as our solar system's ice giants, therefore a fuller understanding of Uranus will aid in the study of exoplanets. Most observations of Uranus's atmospheric dynamics are derived from infrared observations, but these observations probe to a depth of only a few bars. In contrast, radio wavelength observations can probe up to tens of bars. Early cm-wavelength observations in the 1980's and 1990's from the Very Large Array (VLA) showed enhanced brightness temperatures at the South Pole [1], inferred to be due to a deep Hadley cell circulation [2]. Observations with the Submillimeter Array (SMA) hinted at similar structure, but the signal-to-noise ratio was limiting [3]. The vertical extent of this Hadley cell is an important parameter and can help our understanding of the circulation itself and the chemical species involved in that circulation; mm-wavelength observations similar to those from the VLA would help determine this. Using the Atacama Large Millimeter Array (ALMA), a sensitive array for mm and submm-wavelength observations, the vertical extent of this circulation can be constrained. We utilized publicly available calibration data at wavelengths of 0.8 and 1.3 mm from October 2011 to December 2012 and combined them to make the most sensitive images of Uranus to date at these wavelengths. Due to the sensitivity of these wavelengths at the 1-5 bar depth on Uranus, and the ability to express variations of brightness temperature latitudinally, we see clear brightness temperature enhancements at the North Pole at both wavelengths and hints of similar enhancements at far southern latitudes. This indicates that the circulation penetrates at least as high as 1 bar. We will discuss the observed features' implications for the composition and temperature structure of the atmosphere. Anna Schonwald would like to thank the NRAO and the NSF REU program for support during this research. [1] Hofstadter & Muhleman (1988); [2] Hofstadter & Butler (2003); [3] Hofstadter et al. 2009.

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421.05 – Resistive Heating in Saturn's Thermosphere

The thermospheres of the jovian planets are several times hotter than solar heating alone can account for. On Saturn, resistive heating appears sufficient to explain these temperatures in auroral regions, but the particular mechanism(s) responsible for heating the lower latitudes remains unclear. Smith et al. (2005) suggested that electrodynamics of the equatorial region—particularly resistive heating caused by strong electrojet currents—might explain the observed temperatures at low latitudes. Müller-Wodarg et al. (2006) found that their circulation model could reproduce low-latitude temperatures only when they included resistive heating at the poles and applied a uniform, generic heating source globally. Smith et al. (2007) concluded that heating at the poles leads to meridional circulation that cools low latitudes and argued that in-situ heating is required to explain the temperatures at low latitudes.
Resistive heating at low latitudes, arising from enhanced current generation driven by thermospheric winds, is a potentially important in-situ heating mechanism. Ion drag caused by low-latitude electrodynamics can modify global circulation and meridional transport of energy. We present an axisymmetric, steady-state formulation of wind-driven electrodynamics to investigate these possibilities throughout Saturn's thermosphere. At present, we assume a dipole magnetic field and neglect any contributions from the magnetosphere. We use ion mixing ratios from the model of Kim et al. (2014) and the observed temperature-pressure profile from Koskinen et al. (2015) to calculate the generalized conductivity tensor as described by Koskinen et al. (2014). Our model solves the coupled equations for charge continuity and Ohm's law with tensor conductivity while enforcing zero current across the boundaries. The resulting partial differential equation is solved for the current density throughout the domain and used to calculate the net resistive heating rate. We demonstrate the dependence of the resulting current density and heating profile on the input wind profile. We compare the heating profile with the observed temperature profiles from Koskinen et al. (2015) and previous calculations by Müller-Wodarg et al. (2006, 2012).

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421.06 – Modeling the Potential Effects of Virga on the Microwave Emission from the Jovian Atmosphere in Support of the Juno Microwave Radiometer (MWR)

The Juno Microwave Radiometer (MWR) has six channels ranging from 1.36-50 cm, and has the ability to peer deep into the Jovian atmosphere. With the potential to probe as deep as 1000 bars, the Juno MWR will probe well beneath the water clouds. To support necessary cloud depletion, precipitation will likely occur at some time and location over the Jovian disk. A model for potential precipitation effects has been developed and the resulting effects have been analyzed. The studies show a potential for identifying precipitation below the aqueous ammonia cloud using the MWR onboard the Juno spacecraft.

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421.07 – Investigating aspects of dark spot structure and environment in relation to vortex drift on the Ice Giants

Geophysical vortices called Dark Spots, whether directly observed like the original Great Dark Spot (GDS-89) or inferred as with "The Berg" cloud feature, that drift meridionally are distinctive atmospheric features of Uranus and Neptune. Numerical simulations of GDS-89 suggest a possible link between the environmental gradient of potential vorticity and the vortex drift rate (starting with LeBeau and Dowling, 1998). This mechanism could be similar to the "beta gyre" concept proposed for hurricane drift (Fiorino and Elsberry, 1989) in which the advection of environmental potential vorticity by and about the vortex generates a residual vortex dipole, effectively propelling the original vortex away or towards the equator. In the case of hurricanes, this effect is considered one part of the overall environmental wind that forms the steering flow driving hurricane drift. For the dark spots, such a gyre might be the dominant mechanism for north-south motions.

Similar numerical simulations of vortices on Uranus have not been fully consistent with the GDS-89 results. Some vortices like the original Uranus Dark Spot (UDS) do appear to favor regions of low environmental PV gradients, which in simulations suggest increased stability (Hammel et al., 2009). However, even near-zero PV gradients result in significant drift on Uranus in contrast to Neptune. The effect of companion clouds on vortex drift also requires greater understanding, particularly on Uranus.

To better understand these vortex dynamics, a parametric approach is now being applied in which vortex characteristics such as size and wind strength as well as environmental conditions are varied through a range of possible values. While these simulations are not necessarily designed to capture a particular known dark spots, the goal of these simulations is to determine what conditions lead to what types of vortex behavior.

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R.P. LeBeau and T.E. Dowling. Icarus 132:239-265, 1998

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421.08 – A Cloud Microphysics Model for the Gas Giant Planets

Recent studies have significantly increased the quality and the number of observed meteorological features on the jovian planets, revealing banded cloud structures and discrete features. Our current understanding of the formation and decay of those clouds also defines the conceptual modes about the underlying atmospheric dynamics. The full interpretation of the new observational data set and the related theories requires modeling these features in a general circulation model (GCM). Here, we present details of our bulk cloud microphysics model that was designed to simulate clouds in the Explicit Planetary Hybrid-Isentropic Coordinate (EPIC) GCM for the jovian planets. The cloud module includes hydrological cycles for each condensable species that consist of interactive vapor, cloud and precipitation phases and it also accounts for latent heating and cooling throughout the transfer processes (Palotai and Dowling, 2008. Icarus, 194, 303–326). Previously, the self-organizing clouds in our simulations successfully reproduced the vertical and horizontal ammonia cloud structure in the vicinity of Jupiter's Great Red Spot and Oval BA (Palotai et al. 2014, Icarus, 232, 141–156). In our recent work, we extended this model to include water clouds on Jupiter and Saturn, ammonia clouds on Saturn, and methane clouds on Uranus and Neptune. Details of our cloud parameterization scheme, our initial results and their comparison with observations will be shown. The latest version of EPIC model is available as open source software from NASA's PDS Atmospheres Node.

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421.09 – Saturn's Doppler velocimetry wind measurements with VLT/UVES

We present Doppler wind velocity results of Saturn's zonal flow at ~0.4 mbar pressure level. Our aim is help to constrain the characterization of the equatorial jet at the referred altitude and the latitudinal variation of the zonal winds, to contribute to monitor the spatial and temporal variability in order to achieve a better understanding of the dynamics of Saturn's zonal winds, which Sánchez-Lavega et al. (2003, Nature, 423, 623) have found to have strongly changed in recent years, as the planet approached southern summer solstice.

The UVES/VLT instrument has been used, which simultaneously achieves high spectral resolving power and high spatial resolution. The field has been derotated in order to have the aperture aligned perpendicularly to Saturn's rotation axis. In this configuration, spatial information in the East-West direction is preserved in a set of spectra in the direction perpendicular to dispersion.

The technique of absolute accelerometry (AA, Connes, 1985, ApSS 110, 211) has been applied to the backscattered solar spectrum in order to determine the Doppler shift associated with the zonal circulation. Our measurements have been made in the wavelength range of 480-680 nm. Previously we successfully adapted this Doppler velocimetry technique for measuring winds at Venus cloud tops (Machado et al. 2012).

The observations consisted of 4 blocks of 15 exposures of 90 sec, plus two shorter blocks of 9 exposures, totalling 7.3 hours of telescope time. In order to cover the whole disk the aperture has been offset by 1 arcsec in the North-South direction between consecutive exposures. Most of the northern hemisphere was covered by the rings. Saturn's diameter was 17.4 arcsec, and the slit aperture was 0.3x25 arcsec. The aperture offset between consecutive exposures was 1 arcsec. Two observations blocks of 9 exposures only covered the central part of the disk, and four others covered the whole disk. The sub-terrestrial point was at -26.1 degrees South. The presence of the rings lead to severe order superposition.

Finally, we will compare our Doppler wind velocity results with the first cloud tracked winds based on Cassini's observations, providing an independent set of observations.

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421.10 – Retrieval of water, ammonia and dynamics using microwave spectra: With application to Juno Microwave Radiometer

The Juno Microwave Radiometer (MWR) is designed to measure the thermal emission of Jupiter's atmosphere from the cloud tops at about 1 bar pressure to as deep as hundreds of bars pressure, with unprecedented accuracy and spatial resolution. Unlike infrared spectroscopy, microwave observations of giant planetary atmospheres are difficult to interpret due to the absence of spectral features and broad weighting functions. The observed quantity is an intricate consequence of thermodynamic and dynamic processes. To unravel the mystery, we introduce two scalar parameters (stretching and cooling) that describe the alteration of the atmospheric thermal and compositional structure by dynamics. Using the above parameters, we are able to fit the Galileo Probe results as well as model the spectral differences between hot spots, zones and belts in Jupiter's atmosphere observed by VLA (de Pater et al., 2016). Finally, we make use of the state-of-the-art retrieval method – Markov Chain Monte Carlo – to determine the joint probability distribution of all parameters of interest. This approach fully calibrates error, assesses covariance between parameters, and explores the widest possible types of atmospheric conditions as opposed to traditional trial-and-error method. We apply this method to simulated Juno/MWR observations. We show that the water abundance is constrained to +3.1/-1.5 times solar for a normal situation and is constrained to an upper limit for an extreme situation.

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421.11 – The long-term evolution of hydrocarbons in Jupiter's stratosphere

We present the global distribution of hydrocarbons in Jupiter's stratosphere using ground-based mid-infrared R~15,000 TEXES observations from the NASA Infrared Telescope Facility (IRTF), obtained between 2013 and 2016. Ethane and acetylene are the primary products of methane photolysis in Jupiter's stratosphere, and their spatial distribution can be used to trace atmospheric circulation and the lifetimes of chemical constituents. Zonal mean distributions of these species have been previously studied from the Voyager and Cassini spacecraft (Nixon et al., 2010, doi: 10.1016/j.pss.2010.05.008), but the TEXES dataset now provides the opportunity to track the evolution of the hydrocarbons from Earth (Fletcher et al., 2016, doi:10.1016/j.icarus.2016.06.008). Global spectral maps of methane, ethane and acetylene emission are used to characterize the temporal evolution of large scale features in Jupiter's stratosphere (0.5-20 mbar?), including: equator to pole contrasts driven by large-scale stratospheric overturning; mid-latitude bands of elevated hydrocarbon emission; small-scale wave phenomena driven by meteorological activity in the underlying troposphere; and the tropical changes in emission related to Jupiter's Quasi-Quadrennial Oscillation. The NEMESIS spectral inversion tool (Irwin et al., 2008, doi: 10.1016/j.jqsrt.2007.11.006) is used to derive stratospheric temperatures and hydrocarbon abundances from spatially-resolved spectra at 744, 819, and 1247 cm-1. We use these to investigate the changes in the vertical temperature and ethane and acetylene distributions over time, with the aim of providing the global and temporal context for Juno's exploration of the jovian atmosphere in 2016/17.

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421.12 – The Sleepy Anticyclonic Eye of the Great Storm on Saturn as seen by Cassini/VIMS

The Great Storm that erupted at 34^{o} N on Saturn in late 2010 obliterated the String of Pearls feature in that region and left a lasting remnant – a clear 5-µm bright zone around the entire globe inhabited by a lone anticyclone that persists to the present time. We have observed this enduring oval with Cassini/VIMS since 2011 and note that it exhibits a somewhat latitudinally oscillatory nature as it bobs in Saturn's zonal currents. Centered at 35.9^{o} planetocentric latitude in May 2011, it drifted northward to 37.8^{o} in 2012, floated near 37^{o} through 2013, settled as far south as ~36.5^{o} in 2014, bobbed northward to ~37^{o} in 2015, and now appears to reside at about ~36.3^{o} in early 2016. It has also periodically bumped up against the dark band above it, spinning off material in 2013 and 2015. We measured a prograde zonal drift speed of ~22 m/s in 2012, increasing as much as 60% through 2013, then relaxing back to a more moderate ~15 m/s in 2014 and 2015. Early indications are that it has slowed considerably in 2016 to about ~4.7 m/s, which would be the slowest drift rate we've yet measured for it, but still consistent with the Voyager Wind Profile for this region. The feature has varied in size over time as it spins, spanning 4.9^{o} x 3.2^{o} in 2011, elongating to 7.3^{o} x 2.9^{o} by 2013, contracting to 5.5^{o} x 2.9^{o} in 2014, enlarging again to ~9^{o} x ~4^{o} in 2015, and currently averaging ~6.6^{o} x ~3.5^{o} in 2016. It currently is symmetrically oval in shape. It has varied in terms of cloudiness, being ~ 90% 5-µm dark (obscured) in 2011, whereas by 2013 it was mostly bright (clear) with a thin dark edge, returning to ~90% dark in 2015, and currently about 98% obscured. We have used night observations to isolate thermal flux, and found that the mean 5-µm flux coming from the anticyclone has diminished steadily by about 50% since 2013. We are monitoring this trend. The entire storm latitude of ~34^{o} N itself has remained persistently 5-µm bright since 2011, but is slowly dimming as it fills in. We are continuing to monitor the evolution of the anticyclone and the Storm Region over time with Cassini/VIMS.

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421.13 – HITRAN2016 : new and improved data and tools towards studies of planetary atmospheres

The HITRAN2016 molecular spectroscopic database is scheduled to be released this year. It will replace the current edition, HITRAN2012 [1], which has been in use, along with some intermediate updates, since 2012.
We have added, revised, and improved many transitions and bands of molecular species and their isotopologues. Also, the amount of parameters has also been significantly increased, now incorporating, for instance, broadening by He, H_2 and CO_2 which are dominant in different planetary atmospheres [2]; non-Voigt line profiles [3]; and other phenomena. This poster will provide a summary of the updates, emphasizing details of some of the most important or drastic improvements or additions.
To allow flexible incorporation of the new parameters and improve the efficiency of the database usage, the whole database has been reorganized into a relational database structure and presented to

the user by means of a very powerful, easy-to-use internet program called HITRAN*online* [4] accessible at <www.hitran.org>. This interface allows the user many queries in standard and user-defined formats. In addition, a powerful application called HAPI (HITRAN Application Programing Interface) [5] was developed. HAPI is a set of Python libraries that allows much more functionality for the user. Demonstration of the power of the new tools will also be offered. This work is supported by the NASA PATM (NNX13AI59G), PDART (NNX16AG51G) and AURA (NNX14AI55G) programs.

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[4] C. Hill *et al*, JQSRT **177**, 4 (2016)
[5] R.V. Kochanov *et al*, JQSRT **177**, 15 (2016)

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421.14 – On the NH3 absorption depression observable at Northern low latitudes of Jupiter

From February to April of 2016, we carried out a special series of spectrophotometric observations of Jupiter to study the current behavior of the ammonia absorption at the low latitudes of the Northern hemisphere, where in 2004 we have found a well-defined depression of the 787 nm NH3 absorption band intensity (V.Tejfel et al., Bull.AAS, 2005, Vol. 37, p.682). In subsequent years, an existence of this depression was annually confirmed by spectral observations, although we were noticing its variable character. During observations of 2016 we obtained more than 2,500 CCD-spectrograms, including the spectra of the central meridian, the GRS, and 12 scans of Jovian disk on different dates (70 zonal spectra in each scan). The 787 nm NH3 absorption band was extracted with using of ratios of the Jovian spectra to the Saturn's disk spectrum that was taken as a reference. The depression of absorption in this band begins almost from the equator, and its maximum occurs at the planetographic latitude of 10^0N; then the absorption increases again approaching to the latitude of 20^0N. The equivalent bandwidths corresponding to these latitudes are equal to 18.7 ± 1.4 A, 14.4 ± 1.0 A and 17.8 ± 0.8A. The 645 nm NH3 absorption band also shows depletion at the low latitudes of the Northern hemisphere, but it is less pronounced. At the temperate latitudes of the Northern hemisphere this band's absorption is systematically lower than the Southern Hemisphere's ones. We will continue research in this direction, especially because recently a significant depletion of gaseous NH_3 has also been found with using of the VLA with high resolution (I. de Pater et al., Science, 2016, Vol. 352, Issue 6290, p.1290-1294) at the low latitudes of the Northern hemisphere in the region of the NEB.

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421.15 – Vertical Wind Shear in Neptune's Atmosphere Explained with a Modified Thermal Wind Equation

We present observations of Neptune taken in H-(1.4-1.8 µm) and K'-(2.0-2.4 µm) bands on the nights of July 3, 2013 and August 20, 2014 from the 10-m W.M. Keck II Telescope using NIRC2 coupled to the Adaptive Optics (AO) system. We track the positions of about 100 bright atmospheric features over a 4-5 hour window on each night to derive zonal velocities and wind profiles.

Our results deviate from the smooth Voyager zonal wind profile from Sromovsky et al. (1993), often by 100-200 m/s, and often by 3-10 times their estimated uncertainties. Besides what appears to be a random dispersion, there is also a systematic deviation that is wavelength dependent. The H-band profile is best described with a 73-106 m/s shift towards the east for a retrograde flow from the Voyager profile at the equator. The K'-band profile is consistent with Voyager on both nights. Comparing K'/H intensity versus latitude and zonal velocity variation suggests equatorial H-band features are, on average, deeper and have greater eastward velocities than K'-band features. Assuming the average variations in the zonal wind profiles result from wind shear over 3-5 scale heights, we predict vertical wind shears between -1.0 and -2.2 m/(s x km) at the equator.

The standard thermal wind equation and meridional thermal profile for Neptune given by Voyager/IRIS spectra predict wind shear of the wrong sign relative to the observations. We consider two effects that reconcile this inconsistency. First, we calculate the meridional temperature gradients at pressures outside the Voyager/IRIS sensitivity window required to match our predicted wind shears. Second, we generalize to a thermal wind equation that considers global methane variations and re-derive the temperature structure needed to match the observed wind shear. If methane is uniformly distributed or weakly-varying, the equator must be 2-15 K cooler than the mid latitudes below 1 bar. If methane is strongly-varying, the equator can be 2-3 K warmer than the mid latitudes below 1 bar, consistent with observed temperature contrasts. These findings may imply a stacked-celled circulation pattern in Neptune's atmosphere.

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421.16 – A Study of Saturn's Normal Mode Oscillations and Their Forcing of Density Waves in the Rings

Analysis of Cassini Visual and Infrared Mapping Spectrometer (VIMS) ring occultation profiles has revealed the presence of spiral density waves in Saturn's C ring that are consistent with being driven by gravitational perturbations associated with normal-mode oscillations of the planet [1]. These waves allow the C ring to serve as a sort of seismometer, since their pattern speeds (i.e., azimuthal phase speeds) can in principle be mapped onto the frequencies of the predominant normal oscillations of the planet. The resonant mode frequencies in turn are sensitive to Saturn's internal structure and rotational state. Characterization of the normal modes responsible for the forcing holds the potential to supply important new constraints on Saturn's internal structure and rotation. We perform numerical calculations to determine the resonant frequencies of the normal modes of a uniformly rotating planet for various assumptions regarding its internal stratification and compare the implied pattern speeds to those of density waves observed in the C ring. A question of particular interest that we address is whether quasi-toroidal modes are responsible for exciting a mysterious class of slowly propagating density waves in the ring. We also explore the implications of avoided crossings between modes for explaining observed fine splitting in the pattern speeds of spiral density waves having the same number of spiral arms, and weigh the role that convective overstability may play in exciting large-scale quasi-toroidal modes in Saturn. [1] Hedman, M.M. and Nicholson, P.D. 2014. MNRAS 444, 1369.

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421.17 – Pre-Juno Optical Analysis of Jupiter's Atmosphere with the NMSU Acousto-optic Imaging Camera

Jupiter's upper atmosphere is a highly dynamic system in which clouds and storms change color, shape, and size on variable timescales. The exact mechanism by which the deep atmosphere affects these changes in the uppermost cloud deck is still unknown. With Juno's arrival at Jupiter in July 2016, the thermal radiation from the deep atmosphere will be measurable with the spacecraft's Microwave Radiometer. By taking detailed optical measurements of Jupiter's uppermost cloud deck in conjunction with Juno's microwave observations, we can provide a context in which to better understand these observations. This data will also provide a complement to the near-IR sensitivity of the Jovian InfraRed Auroral Mapper and will expand on the limited spectral coverage of JunoCam. Ultimately, we can utilize the two complementary datasets in order to thoroughly characterize Jupiter's atmosphere in terms of its vertical cloud structure, color distribution, and dynamical state throughout the Juno era. In order to obtain high spectral resolution images of Jupiter's atmosphere in the optical regime, we use the New Mexico State University Acousto-optic Imaging Camera (NAIC). NAIC contains an acousto-optic tunable filter, which allows us to take hyperspectral image cubes of Jupiter from 450-950 nm at an average spectral resolution (λ/dλ) of 242. We present an analysis of our pre-Juno dataset obtained with NAIC at the Apache Point Observatory 3.5-m telescope during the night of March 28, 2016. Under primarily photometric conditions, we obtained 6 hyperspectral image cubes of Jupiter over the course of the night, totaling approximately 2,960 images. From these data we derive low-resolution optical spectra of the Great Red Spot and a representative belt and zone to compare with previous work and laboratory measurements of candidate chromophore materials. Future work will focus on radiative transfer modeling to elucidate the Jovian cloud structure during the Juno era. This work was supported by NASA through award number NNX15AP34A.

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421.19 – Jupiter before Juno: State of the atmosphere at cloud level in 2016 from PlanetCam observations in the 0.4-1.7 microns wavelength range and amateur observations in the visible

The arrival of Juno to Jupiter provides a unique opportunity to link findings of the inner structure of the planet with astronomical observations of its meteorology at cloud level. Long time base observations of Jupiter's atmosphere before and during the Juno mission are critical in providing context to Junocam observations and may benefit the interpretation of the MWR data on the lower atmosphere structure as well as Juno data on the depth of the zonal winds. We have performed a long campaign of observations in the visible with the PlanetCam lucky imaging instrument in the 2.2m telescope at Calar Alto Observatory in Spain with observations obtained in December 2015 and in March, May, June and July 2016. In observations under good atmospheric seeing, the instrument allows to obtain images with a spatial resolution of 0.05'' in the visible and 0.1'' from 1.0 to 1.7 microns. The later is an interesting range of wavelengths for observing Jupiter because of the existence of several strong and weak methane absorption bands not generally used in high-resolution ground-based observations of the planet. A combination of images using narrow filters centered in methane absorption bands and their adjacent continuum allows studying the vertical structure of the clouds at horizontal spatial scales of 350-1000 km over the planet depending on the atmospheric seeing and filter used. The best images can be further processed showing features at spatial resolutions of about 150 km. We have also monitored the state of the atmosphere with images obtained by amateur astronomers contributing to the Planetary Virtual Observatory Laboratory database (http://pvol.ehu.eus). Based on both datasets we present zonal winds from -70 to +75 deg with an accuracy of 10 m/s in the low latitudes and 25 m/s in subpolar latitudes. Relative altitude maps of features observed in bands J, H and others with different methane absorption will be presented.

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Contributing team(s): PVOL-IOPW Team

421.20 – Jets, eddies & waves in Saturn's troposphere and stratosphere from multi-annual high-resolution Global Climate Modeling

A mission as richly instrumented as Cassini has brought a new impulse to the studies of Saturn's atmospheric fluid dynamics, to be further extended to Jupiter by the Juno mission.
We recently built an innovative Global Climate Model (GCM) for giant planets by coupling our complete seasonal radiative model [Guerlet Icarus 2014] with a new hydrodynamical solver using an original icosahedral mapping of the planetary sphere to ensure excellent conservation and scalability properties in massively parallel computing resources [Dubos GMD 2015].
Here we describe the insights gained from GCM simulations for Saturn with both unprecedented horizontal resolutions (reference at 1/2° latitude/longitude, and tests at 1/4° and 1/8°), integrated time (up to ten simulated Saturn years), and large vertical extent (from the troposphere to the stratosphere).
Starting from a windless initial state, our 10-year-long GCM simulation for Saturn reproduce alterned tropospheric mid-latitude jets bearing similarities with the observed jet system (numbering, intensity, width). We demonstrate that those jets are eddy-driven with a conversion rate from eddies to mean flow in agreement with Cassini estimates. Before reaching equilibrium, mid-latitude jets experience poleward migration, which can be ascribed to a self-destabilization of the jets by barotropic and baroclinic instabilities.
Our Saturn GCM also predicts in the equator the presence of eastward-propagating Rossby-gravity (Yanai) and westward-propagating Rossby waves, reminiscent of similar waves in the terrestrial tropics. Furthermore, our GCM simulations exhibit a stratospheric meridional circulation from one tropic to the other, with a seasonal reversal, which allows us to investigate the possible dynamical control on the observed variations of hydrocarbon species.
In contrast to observations, in our GCM simulations the equatorial jet is only weakly super-rotating and the polar jet is strongly destabilized by meandering. Moreover, in spite of predicting stacked stratospheric eastward and westward jets, our GCM does not reproduce the observed propagation of the equatorial oscillation by Cassini. We will discuss how to address those remaining challenges in future simulations.

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421.23 – Improving the Planetary Ephemeris with VLBA Astrometry of Spacecraft

Improvements to the planetary ephemeris support dynamical studies of the solar system, pulsar timing, tests of general relativity, occultation and eclipse predictions, and interplanetary spacecraft navigation. We have been observing the Cassini spacecraft orbiting Saturn for over a decade using the NRAO Very Long Baseline Array to obtain positions with nano-radian precision. These radio positions are tied to the extragalactic International Celestial Reference Frame (ICRF), and are combined with solutions for Cassini's orbit about Saturn from DSN Doppler tracking to obtain ICRF positions for the Saturn system barycenter. These observations have improved our knowledge of the orientation of Saturn's orbital plane, which had been the dominant error in Saturn's orbit, to a level of 0.25 milli-arcseconds. This is comparable to the accuracy of inner planet orbits in the ephemeris, and an order of magnitude improvement over Saturn's pre-VLBA orbit accuracy. We will continue periodic VLBA astrometric observations of Cassini until the end of mission in late 2017.

We are about to begin a series of similar VLBA observations of the Juno spacecraft while it orbits Jupiter. As with Cassini and Saturn, Juno will provide the first long-term series of high precision position measurements of Jupiter. (Although the Galileo spacecraft orbited Jupiter for several years, the loss of its high gain antenna prevented high precision VLBI astrometry.) Combining Juno observations with a single-epoch position measurement from the Ulysses spacecraft flyby in 1992 will allow us to cover nearly a quarter of Jupiter's orbit. We expect to obtain a factor of several improvement in the accuracy of Jupiter's orbit from VLBA observations of Juno.

This work has been supported by NASA grant NNX15AJ11G to the Space Science Institute in Boulder, CO. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. The VLBA is part of the National Radio Astronomy Observatory, which is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

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421.24 – ALMA Observation of Neptune's Spatially-resolved Stratospheric HCN (*J* = 4-3)

Neptune's stratospheric HCN(J = 4 - 3) rotational transition was observed by Atacama Large Millimeter-submillimeter Array (ALMA). 19 12-m antennas with the Band-7 receivers spatially resolved Neptune's 2.3'' diameter disk with 0.4'' times 0.6'' synthesized beam. The HCN emission line was clearly detected on the entire disk. The wind velocity map of the stratosphere was illustrated by the Doppler-shift analysis of the HCN emission, and the structured zonal wind whose maximum velocity reaches as high as 600 m/s in the high latitude region of the southern hemisphere was detected. Respective the westward and eastward zonal winds were observed for the northern and southern hemisphere.

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421.25 – Identifying the source of colours in the Jovian atmosphere

We wish to identify the source of Jupiter's colours through spectral analysis of images of Jupiter in the visible-to-near-infrared in conjunction with observations made by Juno in the mid-infrared and at super-high frequency. Three sets of observations were made of Jupiter by the MUSE integral-field spectrograph between 2014-2016 in the spectral range 0.48-0.93um, and reduced using a standard pipeline. Some large high-altitude hazes were observed in 2014 in the North Tropical Zone and the North Temperate Belt which appeared to have vanished by 2016. A single spectral image cube from 2014 was selected for analysis, and attempts at retrieving vertical cloud profiles, imaginary refractive indices and single-scattering albedos using the Nemesis radiative transfer model were made in different locations on Jupiter corresponding to the most prominent features close to the Equatorial region. Differences in lower tropospheric cloud altitude and opacity were found between the zones and the belts, and the belt cloud particles were seen to be significantly more blue-absorbing than the zone particles. Attempts were made at retrieving the real refractive index of the cloud particles in the upper tropospheric haze, where the majority of the colour-producing particles, or 'chromophores', are thought to be located, and values of refractive index greater than that of ammonia ice were observed, indicating the presence of a foreign substance. Further ground-based observations from MUSE in the visible and from TEXES in the mid-Infrared combined with localised observations from Juno later this year should shed more light on the origin of the colour-producing substance in the Jovian clouds, as well as of any seasonal changes in colour.

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421.26 – Infrared Absorption Spectrum of Matrix-Isolated Phenanthrene

The far-to-mid Infrared absorption spectrum of phenanthrene ($C_{14}H_{10}$), one of the polycyclic aromatic hydrocarbons (PAHs), has been measured in an argon matrix at 5 K. Thirty two fundamental bands for phenanthrene have been observed; one of them is detected for the first time (v_{54} = 1398.0 cm^{-1}) and eight of them are detected for the first time at temperatures below room temperature (v_{43} = 233.8 cm^{-1}, v_{42} = 425.2 cm^{-1}, v_{66} = 441.6 cm^{-1}, v_{65} = 499.0 cm^{-1}, v_{21} = 546.3 cm^{-1}, v_{63} = 714.5 cm^{-1}, v_{18} = 1033.7 cm^{-1} and v_{55} = 1362.5 cm^{-1}). The relative intensities of these 32 bands have been measured; three (v_{21}, v_{18}, v_{54}) of which are measured for the first time and six (v_{43}, v_{42}, v_{66}, v_{65}, v_{63}, and v_{55}) of which are measured for the first time at temperatures below room temperature. Our low temperature study of the vibrational bands for phenanthrene provides important information for the spectral analysis of the Composite Infrared Spectrometer (CIRS) aboard the Cassini Spacecraft.

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Contributing team(s): Stanley P. Sander

421.27 – Laboratory Studies of Phosphine Chemistry Relevant to the Jovian and Saturnian Atmospheres

The photochemistry of phosphine (PH_3) in the tropospheres of Saturn and Jupiter is initiated by ultraviolet (UV) radiation and then follows a cascade of chemical reactions that result in P-H hydrides as well as the condensed chromophore red phosphorus (P_4). A key intermediate in this pathway is diphosphine (P_2H_4). The rate constants for the photodissociation of phosphine into initial phosphino radicals and consequently into formation of diphosphine are currently unavailable, limiting their applicability to observational measurements. The condensation of diphosphine to ice in the cold tropospheres is also poorly understood due to the difficulties in

synthesizing, handling, and analyzing the compound.
Our presentation will describe two experiments at SRI International to produce rate constants for the photochemistry initiated by UV light interacting with phosphine and diphosphine and properties related to the condensed phases of these species. One study seeks to produce property values for application in photochemical and cloud/haze models. Specifically, we extend the measured vapor pressure curve for diphosphine to temperatures relevant to temperatures of Saturn and Jupiter. A sophisticated vapor pressure cell has been constructed and tested and is coupled to a Fourier transform infrared (FTIR) and mass spectrometer for high-fidelity species diagnostics. A companion study investigates phosphine photochemistry to measure the rate constants of key intermediate species related to the loss of PH_3 and the formation of P_2H_4. The experiments employ laser photolysis at 193 nm followed by time-resolved mid-IR laser-based species detection of reactants, and the products provide basic chemical kinetic data useful for interpreting phosphine photochemistry in planetary atmospheres.
These two studies are intended to supply basic physical measurements to aid in the interpretation of outer planet atmospheric observations. For both studies, we will present our latest laboratory results and discuss their atmospheric implications.
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422 – Jovian Planets: Magnetospheres and Aurorae Posters

422.01 – Jovian Mid-Infrared Aurora, Hydrocarbon Abundances and Temperature Prior to Juno's Arrival

We report on ground-based measurements of Jupiter's thermal infrared aurora, ethane abundances and temperature prior to Juno's arrival at Jupiter in July 2016. Measurements covering spectral and altitude regions that will complement Juno observational capabilities were made April 18-22, 2016, with the GSFC Heterodyne Instrument for Planetary Wind And Composition (HIPWAC) on the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. The ultra-high spectral resolution infrared heterodyne spectroscopy (IRHS) measures fully resolved individual spectral lines whose shape provides unique information on variability of temperature and abundance. Ethane line spectra near 12-micrometer wavelength will be used to determine the intensities of auroral emission from Jupiter's polar regions and retrieve ethane abundance and temperature changes on and off the north polar "hot spot" region. Results will be compared to a 30-year study of this thermal infrared aurora with ground-based IRHS and with Voyager IRIS and Cassini CIRS measurements. Additional measurements during Juno's orbital mission phase are also planned. Analyses of the variability of the earlier measurements suggest that the thermal IR auroral emission may be low during the Juno –Jupiter encounter. Results will be useful for the Juno mission, since it does not have instrumentation in this spectral region and this work provides complementary information and diagnostic for studying Jupiter in a spectral region and altitude range not directly probed by Juno.
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422.02 – Cool Temperatures near the Homopause of the 8-µm North Polar Hot Spot of Jupiter

We have observed the 8-µm north-polar hot spot (8NPHS) of Jupiter at 3 µm with GNIRS, the Gemini Near-Infrared Spectrograph at Gemini North on January 13, 2013(UT), and at 8 µm on Feburary 6, 2013(UT) with TEXES, the Texas Echelon Cross Echelle Spectrograph at the NASA IRTF. We have derived rather cool homopause temperatures of 180 - 250 K for the 8NPHS by fitting CH_4 emission models to 3- and 8-µm spectra of the 8NPHS. From the fits, we also found that CH_4 mixing ratios at the 8NPHS are consistent with those reported by Kim et al. (Icarus, 237, 42, 2014) in equatorial regions. We will discuss possible implications of the relatively cool 8NPHS homopause, which was unexpected.
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422.03 – Solar wind influence on Jupiter's aurora

Jupiter's main auroral emission is driven by a system of corotation enforcement currents that arises to speed up outflowing Iogenic plasma and is not due to the magnetosphere-solar wind interaction like at Earth. The solar wind is generally expected to have only a small influence on Jupiter's magnetosphere and aurora compared to the influence of rotational stresses due to the planet's rapid rotation. However, there is considerable observational evidence that the solar wind does affect the magnetopause standoff distance, auroral radio emissions, and the position and brightness of the UV auroral emissions. Using the Michigan Solar Wind Model (mSWiM) to predict the solar wind conditions upstream of Jupiter we have identified intervals of high and low solar wind dynamic pressure in the Galileo dataset, and use this information to quantify how a magnetospheric compression affects the magnetospheric field configuration. We have developed separate spatial fits to the compressed and nominal magnetic field data, accounting for variations with radial distance and local time. These two fits can be used to update the flux equivalence mapping model of Vogt et al. (2011), which links auroral features to source regions in the middle and outer magnetosphere. The updated version accounts for changing solar wind conditions and provides a way to quantify the expected solar wind-induced variability in the ionospheric mapping of the main auroral emission, satellite footprints, and other auroral features. Our results are highly relevant to interpretation of the new auroral observations from the Juno mission.
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422.04 – Birotor dipole model for Saturn's inner magnetic field from CASSINI RPWS measurements and MAG data

The radio and plasma wave science (RPWS) experiment on board the Cassini spacecraft, orbiting around Saturn since July 2004, revealed the presence of two distinct and variable rotation periods in the Saturnian kilometric radiation (SKR). These two periods were attributed to the northern and southern hemispheres respectively. The existence of a double period makes the study of the planetary magnetic field much more complicated and the building of a field model, based on the direct measurements of the MAG experiment from the magnetometers embarked on board Cassini, turns out to be uncertain. The first reason is the difficulty for defining a longitude system linked to the variable period, because the internal magnetic field measurements from MAG are not continuous. The second reason is the existence itself of two distinct periods which could imply the existence of a double rotation magnetic structure generated by Saturn's dynamo. However, the radio observations from the RPWS experiment allow a continuous and accurate follow-up of the rotation phase of the variable two periods, since the SKR emission is permanently observable and produced very close to the planetary surface. A wavelet transform analysis of the intensity of the SKR signal received at 290 kHz was performed in order to calculate the rotation phase of each Saturnian hemisphere. A dipole model was proposed for Saturn's inner magnetic field: this dipole presents the particularity to rotate around Saturn's axis at two different angular velocities; it is tilted and not centered. Then it is possible to fit the MAG data for each Cassini's revolution around the planet the periapsis of which is less than 5 Saturnian radii. This study suggests that Saturn's inner magnetic field is neither stationary nor fully axisymmetric. Such a result can be used as a boundary condition for modelling and constraining the planetary dynamo.

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422.05 – Constraining the Europa Neutral Torus

"Neutral tori" consist of neutral particles that usually co-orbit along with their source forming a toroidal (or partial toroidal) feature around the planet. The distribution and composition of these features can often provide important, if not unique, insight into magnetospheric particles sources, mechanisms and dynamics. However, these features can often be difficult to directly detect. One innovative method for detecting neutral tori is by observing Energetic Neutral Atoms (ENAs) that are generally considered produced as a result of charge exchange interactions between charged and neutral particles.
Mauk et al. (2003) reported the detection of a Europa neutral particle torus using ENA observations. The presence of a Europa torus has extremely large implications for upcoming missions to Jupiter as well as understanding possible activity at this moon and providing critical insight into what lies beneath the surface of this icy ocean world. However, ENAs can also be produced as a result of charge exchange interactions between two ionized particles and in that case cannot be used to infer the presence of neutral particle population. Thus, a detailed examination of all possible source interactions must be considered before one can confirm that likely original source population of these ENA images is actually a Europa neutral particle torus. For this talk, we examine the viability that the Mauk et al. (2003) observations were actually generated from a neutral torus emanating from Europa as opposed to charge particle interactions with plasma originating from Io. These results help constrain such a torus as well as Europa source processes.

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422.06 – Particle Environment Package (PEP) for the ESA JUICE mission

PEP is a suite of six (6) sensors arranged in 4 units to measure charged and neutral particles in the Jupiter magnetospheres and at the moons to answer four overarching science questions:
1. How does the corotating magnetosphere of Jupiter interact with the complex and diverse environment of Ganymede?
2. How does the rapidly rotating magnetosphere of Jupiter interact with the seemingly inert Callisto?
3. What are the governing mechanisms and their global impacts of release of material into the Jovian magnetosphere from seemingly inert Europa and active Io?
4. How do internal and solar wind drivers cause such energetic, time variable and multi-scale phenomena in the steadily rotating giant magnetosphere of Jupiter?
PEP measures positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms present in all domains of the Jupiter system over nine decades of energy from < 0.001 eV to > 1 MeV with full angular coverage.
PEP provides instantaneous measurements of 3D flow of the ion plasma and composition to understand the magnetosphere and magnetosphere-moon interactions. It also measures instantaneously 3D electron plasma to investigate auroral processes at the moon and Jupiter. Measurements of the angular distributions of energetic electrons at sub-second resolution probe the acceleration mechanisms and magnetic field topology and boundaries.
PEP combines global imaging via remote sensing using energetic neutral atoms (ENA) with in-situ measurements and performs global imaging of Europa/Io tori and magnetosphere combined with energetic ion measurements. Using low energy ENAs originating from the particle – surface interaction PEP investigate space weathering of the icy moons by precipitation particles. PEP will first-ever directly sample of the exospheres of Europa, Ganymede, and Callisto with extremely high mass resolution ($M/\Delta M > 1100$).
The PEP sensors are (1) an ion mass analyzer, (2) an electron spectrometer, (3) a low energy ENA imager, (4) a high energy ENA and energetic ions imager, (5) an energetic electron sensor, and (6) a neutral gas and ions mass spectrometer.

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422.07 – Model Predictions and Ground-based Observations for Jupiter's Magnetospheric Environment: Application to the JUICE and Juno Missions

The advent of new missions to the Jovian system such as Juno (recently arrived) and JUICE (scheduled for 2022 launch) makes timely the provision of model-based predictions for the physical conditions to be encountered by these spacecraft; as well as the planning of simultaneous, ground-based observations of the Jovian system.
Using the UCL Jovian magnetodisc model, which calculates magnetic field and plasma distributions
according to Caudal's (1986) force-balance formalism, we provide predictions of the following quantities along representative Juno / JUICE orbits through the middle magnetosphere: (i) Magnetic field strength and direction; (ii) Density and / or pressure of the 'cold' and 'hot' particle populations; (iii) Plasma angular velocity.
The characteristic variation in these parameters is mainly influenced by the periodic approaches towards and recessions from the magnetodisc imposed on the 'synthetic spacecraft' by the planet's rotating, tilted
dipole field. We also include some corresponding predictions for ionospheric / thermospheric conditions at the magnetic footpoint of the spacecraft, using the JASMIN model (Jovian Atmospheric Simulator
with Magnetosphere, Ionosphere and Neutrals).
We also present preliminary imaging results from 'IoSpot', a planned, ground-based programme of observations based at the University College London Observatory (UCLO) which targets ionized sulphur emissions from the Io plasma torus. Such programmes, conducted simultaneously with the above missions, will provide valuable context for the overall physical conditions within the Jovian magnetosphere, for which Io's volcanoes are the principal source of plasma.

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422.08 – Study of Jovian synchrotron emission with the NASA's Deep Space Network for Juno mission

We are monitoring Jupiter's synchrotron emission with the purpose of connecting the measurements of the Juno mission's MicroWave Radiometer (MWR) experiment to the historical baseline of non-thermal emission, using NASA's Deep Space Network (DSN). The DSN has the most sensitive network of antennas dedicated to tracking spacecraft that are exploring deep space, whose state-of-the-art receivers are considered among the best radio telescopes in the world. Availability for radio astronomy studies is subject to demand from space projects using the DSN. These antennas have previously contributed to the study of the Jovian non-thermal synchroton emission [1].

NASA's New Frontiers Juno mission was placed into a nominal orbit on the 4^{th} of July, 2016, allowing it to begin a detailed exploration of Jupiter. Among its scientific objectives is the characterization and exploration of the 3D structure of Jupiter's polar magnetosphere and auroras. It is important to provide a means to connect these detailed MWR measurements with the historical record of synchrotron emission. Ideally, these measurements should be performed on a regular basis during the whole extent of the mission. The DSN has the advantage of being able to perform uninterrupted 24-hour observations using antennas from the different complexes located in USA, Australia and Spain.

Additionally, this monitoring program links with and validates the Jupiter observations currently performed by the triplet of educational programs GAVRT, STARS and PARTNeR in USA, Australia and Spain, respectively. These educational programs are partially supported by the DSN and use some of its antennas for teaching purposes, involving students in professional research and exploration.

We will describe the DSN single-dish continuum observations of Jupiter in detail: the antennas, receivers and the equipment used to collect the data, the observing procedure, and the data-reduction process. Preliminary results of the Jupiter beaming curve will also be presented.

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423 – Outer Icy and Irregular Satellites Posters

423.01 – Concept Doped-Silicon Thermopile Detectors for Future Planetary Thermal Imaging Instruments

Presently, uncooled thermopiles are the detectors of choice for thermal mapping in the 4.6-100 µm spectral range. Although cooled detectors like Ge or Si thermistor bolometers, and MgB2 or YBCO superconducting bolometers, have much higher sensitivity, the required active or passive cooling mechanisms add prohibitive cost and mass for long duration missions. Other uncooled detectors, like pyroelectrics, require a motor mechanism to chop against a known reference temperature, which adds unnecessary mission risk. Uncooled vanadium oxide or amorphous Si microbolometer arrays with integrated CMOS readout circuits, not only have lower sensitivity, but also have not been proven to be radiation hard >100 krad (Si) total ionizing dose, and barring additional materials and readout development, their performance has reached a plateau. Uncooled and radiation hard thermopiles with D* ~$1x10^9$ cm√Hz/W and time constant τ ~100 ms have been integrated into thermal imaging instruments on several past missions and have extensive flight heritage (Mariner, Voyager, Cassini, LRO, MRO). Thermopile arrays are also on the MERTIS instrument payload on-board the soon to be launched BepiColombo Mission.

To date, thermopiles used for spaceflight instrumentation have consisted of either hand assembled “one-off” single thermopile pixels or COTS thermopile pixel arrays both using Bi-Sb or Bi-Te thermoelectric materials. For future high performance imagers, thermal detector arrays with higher D*, lower τ, and high efficiency delineated absorbers are desirable. Existing COTS and other flight thermopile designs require highly specialized and nonstandard processing techniques to fabricate both the Bi-Sb or Bi-Te thermocouples and the gold or silver black absorbers, which put limitations on further development.

Our detector arrays will have a D* ≥ $3x10^9$ cm√Hz/W and a thermal time constant ≤ 30 ms at 170 K. They will be produced using proven, standard semiconductor and MEMS fabrication techniques, which will enable the future integration of other ancillary structures like high efficiency broadband absorbers, which will result in D* ≥ $5x10^9$ cm√Hz/W.

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423.02 – OPUS – Outer Planets Unified Search with Enhanced Surface Geometry Parameters – Not Just for Rings

In recent years, with the massive influx of data into the PDS from a wide array of missions and instruments, finding the precise data you need has been an ongoing challenge. For remote sensing data obtained from Jupiter to Pluto, that challenge is being addressed by the Outer Planets Unified Search, more commonly known as OPUS. OPUS is a powerful search tool available at the PDS Ring-Moon Systems Node (RMS) – formerly the PDS Rings Node. While OPUS was originally designed with ring data in mind, its capabilities have been extended to include all of the targets within an instrument’s field of view. OPUS provides preview images of search results, and produces a zip file for easy download of selected products, including a table of user specified metadata. For Cassini ISS and Voyager ISS we have generated and include calibrated versions of every image. Currently OPUS supports data returned by Cassini ISS, UVIS, VIMS, and CIRS (Saturn data through June 2010), New Horizons Jupiter LORRI, Galileo SSI, Voyager ISS and IRIS, and Hubble (ACS, WFC3 and WFPC2).

At the RMS Node, we have developed and incorporated into OPUS detailed geometric metadata, based on the most recent SPICE kernels, for all of the bodies in the Cassini Saturn observations. This extensive set of geometric metadata is unique to the RMS Node and enables search constraints such as latitudes and longitudes (Saturn, Titan, and icy satellites), viewing and illumination geometry (phase, incidence and emission angles), and distances and resolution.

Our near term plans include adding the full set of Cassini CIRS Saturn data (with enhanced geometry), New Horizons MVIC Jupiter encounter images, New Horizons LORRI and MVIC Pluto data, HST STIS observations, and Cassini and Voyager ring occultations. We also plan to develop enhanced geometric metadata for the New Horizons LORRI and MVIC instruments for both the Jupiter and the Pluto encounters.

OPUS: http://pds-rings.seti.org/search/

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423.03 – The near-surface electron radiation environment of Saturn's moon Mimas

Introduction: Saturn's inner mid-size moons are exposed to a number of external weathering processes, including charged particle bombardment and UV photolysis, as well as deposition of E ring grains and interplanetary dust. While optical remote sensing observations by several instruments onboard the Cassini spacecraft have revealed a number of weathering patterns across the surfaces of these moons, it is currently not entirely clear which external process is responsible for which observed weathering pattern. Here we focus on Saturn's moon Mimas and model the effect of energetic electron bombardment across its surface. Our results are discussed in the context of previously reported Cassini remote sensing observations of Mimas.
Methods: To model the access of energetic electrons to different surface locations we used a guiding center, bounce-averaged approach which has previously been employed for the Jovian and Saturnian moons. The electron spectrum at the orbit of Mimas was implemented according to the fit functions provided by, which are based on averaged measurements from the Cassini Magnetospheric Imaging Instrument (MIMI) Low Energy Magnetospheric Measurement System (LEMMS) at a narrow corridor near the orbit of Mimas (~3.08 Rs) during the period 2004-2013. The interaction of electrons with the surface of Mimas was implemented using the PLANETOCOSMICS code, which is based on the Geant4 toolkit.
Results: We predict a lens-shaped electron energy deposition pattern which extends down to ~cm depths at low latitudes near the center of the leading hemisphere. These results are consistent with previous remote sensing observations of a lens-shaped color anomaly [4] as well as a thermal inertia anomaly at this location. At the trailing hemisphere, we predict a similar lens-shaped electron energy deposition pattern, which to date has not been observed by the Cassini optical remote sensing instruments. We suggest that no corresponding lens-shaped weathering pattern has been observed on the trailing hemisphere due the comparatively short range of lower energy (<1 MeV) electrons into surface ice, as well as competing effects from cold plasma bombardment.

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423.04 – Modeling Spectra of Icy Satellites and Cometary Icy Particles Using Multi-Sphere T-Matrix Code

The Multi-Sphere T-matrix code (MSTM) allows rigorous computations of characteristics of the light scattered by a cluster of spherical particles. It was introduced to the scientific community in 1996 (Mackowski & Mishchenko, 1996, JOSA A, 13, 2266). Later it was put online and became one of the most popular codes to study photopolarimetric properties of aggregated particles. Later versions of this code, especially its parallelized version MSTM3 (Mackowski & Mishchenko, 2011, JQSRT, 112, 2182), were used to compute angular and wavelength dependence of the intensity and polarization of light scattered by aggregates of up to 4000 constituent particles (Kolokolova & Mackowski, 2012, JQSRT, 113, 2567). The version MSTM4 considers large thick slabs of spheres (Mackowski, 2014, Proc. of the Workshop ``Scattering by aggregates``, Bremen, Germany, March 2014, Th. Wriedt & Yu. Eremin, Eds., 6) and is significantly different from the earlier versions. It adopts a Discrete Fourier Convolution, implemented using a Fast Fourier Transform, for evaluation of the exciting field. MSTM4 is able to treat dozens of thousands of spheres and is about 100 times faster than the MSTM3 code. This allows us not only to compute the light scattering properties of a large number of electromagnetically interacting constituent particles, but also to perform multi-wavelength and multi-angular computations using computer resources with rather reasonable CPU and computer memory. We used MSTM4 to model near-infrared spectra of icy satellites of Saturn (Rhea, Dione, and Tethys data from Cassini VIMS), and of icy particles observed in the coma of comet 103P/Hartley 2 (data from EPOXI/DI HRII). Results of our modeling show that in the case of icy satellites the best fit to the observed spectra is provided by regolith made of spheres of radius ~1 micron with a porosity in the range 85% - 95%, which slightly varies for the different satellites. Fitting the spectra of the cometary icy particles requires icy aggregates of size larger than 40 micron with constituent spheres in the micron size range.

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423.05 – Besieged by Trojans: Material Exchange between Tethys and its Coorbital Moons

Two small Trojan moons are coorbital with the Saturnian moon Tethys: Calypso (20-km diameter) resides in the trailing L5 Lagrangian point of Tethys' orbit around Saturn, while Telesto (25-km diameter) occupies the leading L4 Lagrangian point. Due to their fixed location with respect to Tethys, consistent material transfer to Tethys occurs whenever there is a primary impact on either of the Trojan moons. Here we investigate this material exchange, and its implications for the cratering history of Tethys.
Multiple craters in excess of 1-km in diameter are seen on both Trojan moons [1]. We model the evolution of ejecta escaping from the largest five and seven craters on Calypso and Telesto respectively. The Maxwell Z-model [2] is used, with an implicit gravity-regime cratering assumption, to approximate outbound ejecta velocity distributions. The smallest craters considered on Calypso and Telesto are 1.35 and 1.9 km in diameter respectively; these impacts would have generated a significant amount of sesquinary ejecta [3] in orbits coorbital to that of Tethys. We model the evolution of these sesquinary ejecta in the Saturnian gravity system across 100 years and track their impact locations [e.g. 4]. Our results show that a large fraction of sesquinary ejecta created by primary impacts to either Trojan is likely to impact Tethys; the coorbital nature of the source bodies results in a significant fraction of this ejecta being incident at low impact velocities and low (oblique) impact angles.
We present results of ongoing work to convolve these results with observed crater populations and morphologies on Tethys. The persistence of sesquinary impactors inbound to Tethys suggests that such impacts are a relatively frequent process. Additional sources of impactor material, such as from material excavated by primary impacts to Tethys and later reaccreted, will also be discussed.
[1] Thomas et al., 2013, *Icarus*; [2] Melosh, 1989, *Oxford Univ. Press*; [3] Zahnle et al., 2008, *Icarus*; [4] Nayak and Asphaug, 2016, *Nature Communications.*

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423.06 – Dione flybys in the view of energetic particles

We report on the results of energetic electron measurements above 15 keV from the Low Energy Magnetospheric Measurement System

LEMMS, part of the Magnetospheric Imaging Instrument MIMI onboard Cassini during the five close Dione flybys combined with measurements of the magnetometer instrument MAG - an update of the paper by Krupp et al. 2013. We found particles in the vicinity of Dione bouncing and drifting in Saturn's magnetosphere and eventually are lost onto the surface of the moon. The location and depth of the absorption signature depends on species, their energy and on the geometry of the flyby. For the upstream encounter D1 energy-dependent ion absorption signatures were measured with the evidence that protons present in the upstream region can explain the observed dropout features. The flybys D2 and D3 went through the moon's geometrical wake and we observed energy dependent asymmetric absorption signatures in the fluxes of electrons between the planetward and anti-planetward sectors of the moon's wake at energies above about 100 keV. The most recent flybys D4 and D5 went directly over the north pole of the moon and showed absorption signatures when connected with the moon's flux tube. Trajectory tracings in a simulated environment of Dione's magnetospheric interaction using the Adaptive hybrid model for space plasma simulations (A.I.K.E.F.) indicate that the magnetic and electric field perturbations in Dione's interaction region, as well as magnetospheric diffusion need to be taken into account in order to explain the features in the data.

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423.07 – Color Survey of the Irregular Planetary Satellites

Irregular satellites are characterized by their larger orbital distance from their planet, their high eccentricity and their high inclination, all indicating that they were captured. However, the mechanism of capture and the location of origin of the satellites remain unknown. We are conducting a photometric survey of the irregular satellites of the giant planets using the LRIS instrument on the 10-meter telescope at the Keck Observatory in Hawaii. The measured colors will be compared to other planetary bodies in search for similarities and differences that may reflect upon the origin of the satellites. For example, if irregular satellites were captured from the Kuiper Belt then some should contain the ultrared material that is common in the trans-Neptunian and Centaur populations. If the irregular satellites of Jupiter were captured from the same source population as the Jovian Trojans, then it is natural to expect that the surface properties of satellites and Trojans should be the same. We will present initial results of this work.

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424 – Titan Atmosphere Posters

424.01 – The atmospheric circulation and methane cycle in the TitanWRF and Titan MITgcm models

We use the TitanWRF and Titan MITgcm to simulate the formation of stratospheric superrotation on Titan. The stratospheric wind speed reaches 180 m/s around both solstices. The MITgcm results appear similar to those from Titan WRF (Newman et al., 2011). However, despite the similar physics parameterizations such as radiative transfer and PBL mixing, the MITgcm produces a consistent minimum (about 5 to 15m/s depending on the season) near 50km above the surface. This result is comparable to the wind profile obtained by Huygens, though the observed wind minimum was between 75km and 80km above the surface. Attempts have been made to investigate what produces the wind minimum, e.g., turning off the diurnal cycle and removing surface thermal inertia. The wind minimum persists despite the effort, suggesting the feature may originate from interactions between zonal wind and downward propagating waves.

We further examine the effect of topography on the wind structure. The stratospheric superrotation in these simulations is significantly slower than that in the simulations without topography, with maximum speed of 110m/s as opposed to previously simulated 180m/s. The wind minimum near 50km, however, still exists in the MITgcm. Also, results suggest that the near surface winds are primarily guided by topography, and are less affected by solar heating on the surface. Another distinct result, compared to the cases without topography in both TitanWRF and the MITgcm, is that the near surface winds in the equatorial region exhibit strong eastward components, which may help to explain the combination of dune orientations and transport directions inferred from imaging. Lastly, we introduce an active methane cycle using a simplified Betts-Miller scheme (similar to Mitchell et al, 2009) to represent moist convection associated with the methane cycle in the troposphere. We will explore the impact of the new scheme on the methane cycle, and compare its realism to that of the large-scale condensation scheme previously used in TitanWRF (Newman et al., 2016).

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424.02 – Distribution and escape of the major neutral species from Titan's atmosphere

Titan possesses the most significant atmosphere among all satellites in the Solar system, and is an important source of material for the Saturn's magnetosphere. Understanding of the neutral species distribution and escape is important for further understanding of the Titan's atmosphere evolution and loss.

The first in situ observations of the Titan's atmosphere were performed by Voyager and continued by Cassini, which measured the atmospheric composition, velocity and temperature, as well as the energy spectra of neutral species, ions and electrons. Analysis and interpretation of the acquired data involves coupled modeling of the Saturn magnetosphere and Titan's atmosphere.

Having that in mind we have undertaken numerical modeling of the major neutral species (N_2 and CH_4) in Titan's upper atmosphere to investigate the effect of the solar EUV and magnetospheric ion energy deposition on the neutral species atmospheric distribution and escape. This modeling combines MHD simulation of the Saturn's magnetosphere plasma interacting with Titan's atmosphere, fluid type simulation of the neutral species in Titan's lower atmosphere, and kinetic modeling of the upper atmosphere and exosphere. Here we present estimations of the neutral species escape rate, and discuss the effect of the magnetospheric ion energy deposition on the atmospheric escape concluded from the results of our modeling. This work was supported by NASA Outer Planet Research grant NNX13AL04G.

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424.03 – A new description of Titan's aerosol optical properties from the analysis of VIMS Emission Phase Function observations

The Huygens probe gave unprecedented information on the properties of Titan's aerosols (vertical distribution, opacity as a function of wavelength, phase function, single scattering albedo) by in-situ measurements (Tomasko et al. 2008). Being the only existing

in-situ atmospheric probing for Titan, this aerosol model currently is the reference for many Titan studies (e.g. by being applied as physical input in radiative transfer models of the atmosphere). Recently a reanalysis of the DISR dataset, corroborated by data from the Downward-Looking Visible Spectrometer (DLVS), was carried out by the same group (Doose et al. 2016), leading to significant changes to the indications given by Tomasko et al. (2008).
Here we present the analysis of the Emission Phase Function observation (EPF) performed by VIMS during the Cassini flyby T88 (November 2012). An EPF observes the same spot on the surface (and thus the same atmosphere) with the same emergence angle but with different incidence angles. In this way, our EPF allows, for the first time, to have direct information on the phase function of Titan's aerosols, as well as on other important physical parameters of the aerosols as the behavior of their extinction as a function of wavelength and the single scattering albedo (also as a function of wavelength) for the whole VIMS range (0.8-5.2 µm). The T88 EPF is composed of 25 VIMS datacubes spanning a scattering angle range approximately from 0°to 70°.
We used the radiative transfer model described in Hirtzig et al. (2013) as baseline, updated with improved methane (+ related isotopes) spectroscopy. By changing the aerosol description in the model, we found the combination of aerosol optical parameters that fits best a constant aerosol column density over the whole set of the VIMS datacubes. We confirmed that the new results from Doose et al. (2016) do improve the fit for what concerns the vertical profile and the extinction as a function of wavelength. However, a different phase function with respect to what they propose must be employed, especially in the trend towards the backscattering peak. We also find that darker aerosols are needed in order to reproduce the value of the column opacity measured in-situ by Huygens.
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424.04 – Photoreactivity of condensed species on Titan's aerosols analogues

Titan's aerosols formation is initiated in the upper atmospheric layers at about 1000 km by the dissociation and the ionization of N_2 and CH_4 by the VUV solar photons [1]. Then, they aggregate and sediment to the surface. The temperatures of the stratosphere and the troposphere [3] (measured by the HASI instrument onboard the Huygens probe [2]) allow the condensation of many volatile organics on the solid aerosols, forming organic ice coating on the aerosol polymers. We will present an experimental study simulating this process and discuss the photoreactivity of condensed species on Titan's aerosols analogues in the atmosphere and on the surface. We demonstrated experimentally that the organic aerosols, which cover the Titan's surface, drive the photoreactivity of condensed species such as acetylene when they are irradiated with long wavelength photons (λ > 300 nm). This result highlights that Titan's surface remains active despite the absorption of the most energetic photons by the atmosphere.
Acknowledgments
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424.05 – Are protonated ions efficient sequestration agents for noble gases in the primitive nebula context?

One explanation for the deficiencies of argon, krypton and xenon observed in the atmosphere of Titan might be related to a scenario of sequestration by H_3^+ in the gas phase at the early evolution of the solar nebula. The chemical process implied is a radiative association, evaluated as rather efficient in the case of H_3^+, especially for krypton and xenon. In fact, this mechanism of chemical trapping might not be limited to H_3^+ only, considering that the protonated ions produced in the destruction of H_3^+ by its main competitors, namely H_2O, CO and N_2, present in the primitive nebula, might also give stable complexes with the noble gases.
Here, the reactivity of the noble gases Ar, Kr, Xe, with all the protonated ions issued from H_2O, CO and N_2, expected to be present in the nebula with reasonably high abundances, i.e. H_3O^+, HCO^+, HOC^+, N_2H^+, has been studied with quantum simulation methods, quantum dynamics included. All of them give stable complexes; the rate coefficients of their radiative associations have been calculated as a function of temperature between 10 and 100 °K and found ranging from 10^{-18} to 10^{-16} cm^3s^{-1}, which can be considered as high for this type of reactions and are comparable to the rates obtained with H_3^+.
Consequently, we can consider this process as universal for all protonated ions, which, if present in the primitive nebula as astrophysical models predict, should act as efficient sequestration agents for all three noble gases, in addition to the original H_3^+ captor.
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424.06 – Carbon Monoxide Affecting Planetary Atmospheric Chemistry

Atmospheric hazes are present in a range of solar system and extrasolar planetary atmospheres, and organic hazes, such as that in Titan's atmosphere, could be a source of prebiotic molecules.[1] However, the chemistry occurring in planetary atmospheres and the resulting chemical structures are still not clear. Numerous experimental simulations[2]have been carried out in the laboratory to understand the chemistry in N_2/CH_4 atmospheres, but very few simulations[4] have included CO in their initial gas mixtures, which is an important component in many N_2/CH_4 atmospheres including Titan, Triton, and Pluto.[3] Here we have conducted a series of atmosphere simulation experiments using AC glow discharge (cold plasma) as energy source to irradiate reactions in gas mixtures of CO, CH_4, and N_2 with a range of CO mixing ratios (from 0, 0.05%, 0.2%, 0.5%, 1%, 2.5%, to 5%) at low temperature (~100 K). Gas phase products are monitored during the reaction by quadrupole mass spectrometer (MS), and solid phase products are analyzed by solution-state nuclear magnetic resonance spectroscopy (NMR). MS results show that with the increase of CO in the initial gases, the production of nitrogenous organic molecules increases while the production of hydrogen molecules decreases in the gas phase. NMR measurements of the solid phase products show that with the increase of CO, hydrogen atoms bonded to nitrogen or oxygen in unsaturated structures increase while those bonded to saturated carbon decrease, which means more unsaturated species and less saturated species formed with the addition of CO. MS and NMR results demonstrate that the inclusion of CO affects the compositions of both gas and solid phase products, indicating that CO has an important impact on the chemistry occurring in our experiments and probably in planetary atmospheres.

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424.07 – Reaction Profiles and Molecular Dynamics Simulations of Cyanide Radical Reactions Relevant to Titan's Atmosphere

Titan's atmosphere is arguably the atmosphere of greatest interest that we have an abundance of data for from both ground based and spacecraft observations. As we have learned more about Titan's atmospheric composition, the presence of pre-biotic molecules in its atmosphere has generated more and more fascination about the photochemical process and pathways it its atmosphere. Our computational laboratory has been extensively working throughout the past year characterizing nitrile synthesis reactions, making significant progress on the energetics and dynamics of the reactions of ·CN with the hydrocarbons acetylene (C_2H_2), propylene (CH_3CCH), and benzene (C_6H_6), developing a clear picture of the mechanistic aspects through which these three reactions proceed. Specifically, first principles calculations of the reaction profiles and molecular dynamics studies for gas-phase reactions of ·CN and C_2H_2, ·CN and CH_3CCH, and ·CN and C_6H_6 have been carried out. A very accurate determination of potential energy surfaces of these reactions will allow us to compute the reaction rates which are indispensable for photochemical modeling of Titan's atmosphere.

The work at University of Puerto Rico at Cayey was supported by Puerto Rico NASA EPSCoR IDEAS-ER program (2015-2016) and DTPR was sponsored by the Puerto Rico NASA Space Grant Consortium Fellowship. *E-mail: juan.lopez15@upr.edu

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424.08 – Infrared and X-ray Absorption Near Edge Structure Spectroscopy Analyses of the Titan Haze Simulation (THS) Aerosols Produced at Low Temperature (200 K)

We present our latest results on the Titan Haze Simulation (THS) experiment developed on the COSmIC simulation chamber at NASA Ames. In Titan's atmosphere, a complex organic chemistry induced by UV radiation and electron bombardment occurs between N_2 and CH_4 and leads to the production of larger molecules and solid aerosols. In the THS, Titan's chemistry is simulated by pulsed plasma in the stream of a supersonic expansion, at Titan-like temperature (200 K). The residence time of the gas in the pulsed plasma discharge is ~3 µs, hence the chemistry is truncated allowing us to probe the first and intermediate steps of the chemistry, by adding heavier precursors into the initial N_2-CH_4 gas mixture. Experiments have been performed in different gas mixtures from the simpler N_2-CH_4 (98:2 and 95:5), to more complex mixtures: N_2-CH_4-C_2H_2 (91:5:4 and 94.5:5:0.5), N_2-CH_4-C_6H_6 (90:5:5) and N_2-CH_4-C_2H_2-C_6H_6 (86:5:4:5). Both the gas and solid phases have been analyzed using a combination of *in situ* and *ex situ* diagnostics.
A recent mass spectrometry analysis of the gas phase demonstrated that the THS is a unique tool to monitor the different steps of the N_2-CH_4 chemistry [1]. The results of the solid phase study are consistent with the chemical growth evolution observed in the gas phase. The solid phase products are in the form of grains produced in volume and not from interaction on the substrate's surface. Scanning Electron Microscopy images have shown that more complex mixtures produce larger aggregates (100-500 nm in N_2-CH_4, up to 5 µm in N_2-CH_4-C_2H_2-C_6H_6). Moreover, the morphology of the grains seems to depend on the precursors, a finding that could have an impact on Titan haze microphysical models. We will present the latest results of the infrared and x-ray absorption near edge structure spectroscopic measurements that have been performed on all four mixtures. These results provide information on the nature of the different functional groups present in our samples as well as the C/N ratio, and give insight on the specific chemical pathways associated with the presence of acetylene and benzene.

Reference: [1] Sciamma-O'Brien et al., 2014, *Icarus* 243, 325.

Acknowledgements: The authors acknowledge the support of NASA SMD.

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424.09 – XUV complex refractive indices of aerosols in the atmospheres of Titan and the primitive Earth

The complex refractive indices of tholins, simulating aerosols in the atmosphere of Titan and the primitive earth, have been measured over a wide spectral range, including the soft X-ray, vacuum-ultraviolet (VUV), and UV-Visible. The soft X-ray and VUV spectral ranges are in particular relevant to radiative transfer models of solar irradiation of primitive atmospheres (Lammer et al. 2008) and may elucidate the (anti-)greenhouse potential of photochemical aerosols. Thin films were grown using the PAMPRE capacitively coupled plasma setup (Szopa et al. 2006; Carrasco et al. 2009). Gas mixtures consisting of CH_4/N_2 with 5:95 ratios were used to simulate Titan's atmospheric composition. For the primitive Earth, gas mixtures of $N_2/CO_2/H_2$ and $N_2/CO_2/CH_4$ were used as described in Fleury et al. (2014).
State-of-the-art laboratory techniques were used to determine the refractive indices of such tholin films. These include VUV ellipsometry (performed in collaboration with the Metrology Light Source in Berlin) and synchrotron X-ray spectroscopy (performed at the SEXTANTS beamline of the SOLEIL synchrotron). While VUV spectroscopy reveals new electronic transitions due to plasmon resonances in tholins, X-ray spectra reveal the C and O absorption edges of these solids. The refractive indices are compared to results from Khare et al. (1984). Implications on the optical properties of these aerosol analogs on the radiative modeling of primitive atmospheres will be discussed.

Author(s): Lisseth Gavilan[4], Nathalie Carrasco[4], Maciej Neumann[2], Norbert Esser[2], Benjamin Fleury[1], Pierre-Richard Dahoo[4], Horia Popescu[3], Nicolas Jaouen[3]
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424.10 – Recent Progress in Planetary Laboratory Astrophysics achieved with NASA Ames' COSmIC Facility

We describe the characteristics and the capabilities of the laboratory facility, COSmIC, that was developed at NASA Ames to generate,

process and analyze interstellar, circumstellar and planetary analogs in the laboratory [1]. COSmIC stands for "Cosmic Simulation Chamber" and is dedicated to the study of neutral and ionized molecules and nanoparticles under the low temperature and high vacuum conditions that are required to simulate various space environments such as planetary atmospheres. COSmIC integrates a variety of state-of-the-art instruments that allow forming, processing and monitoring simulated space conditions for planetary, circumstellar and interstellar materials in the laboratory. The COSmIC experimental setup is composed of a Pulsed Discharge Nozzle (PDN) expansion, that generates a plasma in the stream of a free supersonic jet expansion, coupled to two high-sensitivity, complementary *in situ* diagnostics: a Cavity Ring Down Spectroscopy (CRDS) and laser induced fluorescence (LIF) systems for photonic detection [2, 3], and a Reflectron Time-Of-Flight Mass Spectrometer (ReTOF-MS) for mass detection [4].
Recent results obtained using COSmIC will be highlighted. In particular, the progress that has been achieved in an on-going study investigating the formation and the characterization of laboratory analogs of Titan's aerosols generated from gas-phase molecular precursors [5] will be presented. Plans for future laboratory experiments on planetary molecules and aerosols in the growing field of planetary laboratory astrophysics will also be addressed, as well as the implications of studies underway for astronomical observations.

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424.11 – Progress in the measurement of temperature-dependent N_2–N_2 collision-induced absorption and H_2-broadening of cold and hot CH_4

We report preliminary measurements from two separate laboratory studies: (A) collision-induced absorption (CIA) of nitrogen in the far-infrared at temperatures between 78 and 130 K; and (B) temperature dependence of H_2-broadening of CH_4 in the near infrared at temperatures between 100 and 370 K.
(A) Nitrogen collision-induced absorption provides the primary opacity of Titan at long wavelengths, thereby playing a critical role in determining the heat balance as well as the atmospheric composition and dynamics. Our new measurements of the nitrogen absorption spectrum at temperatures from 78 to 130 K are consistently ~20% higher than predictions made using theoretical models of Borysow and Frommhold (1986) [ApJ, 311, 1043] and of Karman et al. (2015)[J Chem Phys, 142, 084306]. However, the new data are consistent with the previous measurements at 78 K by the UBC group (Wishnow et al. 1996)[J Chem Phys, 104, 3511]. We present preliminary results for the N_2-N_2 CIA coefficients and their temperature dependence between 78 and 130 K, and comparisons with the above theoretical calculations.
(B) In support of the Jovian and exoplanet atmospheric remote sensing in the near infrared, we have measured the temperature dependence of H_2-broadened half width and pressure shift coefficients of CH_4, both of which are known to be rotational quantum number dependent. We studied both cold and hot CH_4 in the *K* band (~2.2 µm) with the focus on a) weaker lines in the v_2+v_3 band at low temperatures for cold giant planets and b) stronger lines in the v_3+v_4 band at elevated temperatures for extra-solar planets (*e.g.*, hot-Jupiters). Three custom-built gas absorption cells (two cold and one hot) were used to obtain the spectra of CH_4 and H_2 mixtures at temperatures between 100 and 370 K. We will discuss our on-going spectrum analysis for a few select J manifolds and provide comparisons with published values, which are available only at room temperature.

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424.12 – The Effect of Aerosol Formation on Stable Isotopes Ratio in Titan's Atmosphere

The formation of large amounts of aerosol in Titan atmosphere induces a significant sink for carbon and nitrogen in the atmosphere. Due to the high complexity of the chemistry leading to aerosol formation, there may be isotopic fractionation along the formation pathways of the aerosol. So far several stable isotopes have been measured in Titan atmosphere including the $^{13}C/^{12}C$, $^{15}N/^{14}N$ and D/H ratios for different gaseous species. However, the fractionation effect of the aerosol formation and its impact on atmospheric stable isotope ratios has yet to be fully understood. Two experimental studies were recently published on the stable carbon [1] and nitrogen [1,2] isotope fractionation during aerosol formation in N_2-CH_4 reactant mixture. To better constrain the fractionation effect of aerosol formation on the Titan atmosphere we have measured the isotopic fractionation induced in laboratory aerosol analogues produced exploring the space of parameters that are expected to have an effect on fractionation processes. Parameters studied include pressure and temperature of aerosol formation and the reactant gas phase composition, including the standard "Titan" mixture of CH_4/N_2 as well as other trace species such as benzene (C_6H_6).

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Author(s): Thomas Gautier[1], Melissa G Trainer[1], Joshua Sebree[2], Allison Wold[2], Jennifer Stern[1]
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424.13 – Optical properties of Titan's aerosols: comparison between DISR/Huygens observations and VIMS/Cassini solar occultation observations

Titan, the only satellite with a dense atmosphere, presents a hydrocarbon cycle that includes the formation and sedimentation of organic aerosols. The optical properties of Titan's haze inferred from measurement of the Huygens probe were recently revisited by Doose et al. (Icarus, 2016). The present study uses the solar occultation observations in equatorial regions of Titan that have been acquired by the Visual and Infrared Mapping Spectrometer

(VIMS) onboard the Cassini spacecraft to infer similar information in a broader wavelength range. Preliminary studies have proven the interest of those solar occultation data in the seven atmospheric windows to constrain the aerosol number density, but could not directly compare with the Descent Imager and Spectral Radiometer (DISR) data because models predict that the density profile vary with latitude. The present study compares the DISR measurements of aerosol extinction coefficients and the solar occultation data acquired by the VIMS instrument onboard Cassini. These sets of data differ in their acquisition method and time, spectral range, and altitude: the DISR measurements have been taken in 2005, along a vertical line of sight, in the visible spectral range (490-950nm) and under 140km of altitude. The relevant solar occultation data at equator have been acquired in 2009, along a horizontal line of sight, in the IR range (0.9-5.1µm), with sun light scanning all altitudes for a long enough wavelength, namely in the five-micron atmospheric window. These sets of data have been analyzed previously, separately and using different models. Here, we present a cross analysis of these sets of data, that allows us to test the different models describing the density profile of aerosols. In addition to providing wavelength dependence of the extinction coefficient, the comparison allows us to assess the impact of refraction in Titan's atmosphere. It also provides optical depth and scattering properties that are crucial information for defining the characteristics of high-resolution infrared cameras to be embarked on future missions to Titan.

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425 – Titan Surface and Interior Posters

425.01 – Global mapping of the surface of Titan through the haze with VIMS onboard Cassini

The Visual and Infrared Mapping Spectrometer (VIMS) onboard Cassini observes the surface of Titan through the atmosphere in seven narrow spectral windows in the infrared at 0.93, 1.08, 1.27, 1.59, 2.01, 2.68-2.78, and 4.9-5.1 microns. We have produced a global hyperspectral mosaic at 32 pixels per degrees of the complete VIMS data set of Titan between T0 (July 2004) and T120 (June 2016) flybys. We merged all the data cubes sorted by increasing spatial resolution, with the high resolution images on top of the mosaic and the low resolution images used as background. One of the main challenge in producing global spectral composition maps is to remove the seams between individual frames taken throughout the entire mission. These seams are mainly due to the widely varying viewing angles between data acquired during the different Titan flybys. These angles induce significant surface photometric effects and a strongly varying atmospheric (absorption and scattering) contribution, the scattering of the atmosphere being all the more present than the wavelength is short. We have implemented a series of empirical corrections to homogenize the maps, by correcting at first order for photometric and atmospheric scattering effects. Recently, the VIMS' IR wavelength calibration has been observed to be drifting from a total of a few nm toward longer wavelengths, the drift being almost continuously present over the course of the mission. Whereas minor at first order, this drift has implications on the homogeneity of the maps when trying to fit images taken at the beginning of the mission with images taken near the end, in particular when using channels in the narrowest atmospheric spectral windows. A correction scheme has been implemented to account for this subtle effect.

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425.02 – Forming of single-thread channels and multiple channel rivers on Titan and Earth

In our research we use numerical model of the river to determine the limits of different fluvial parameters that play important roles in evolution of the rivers on Titan and on Earth. We have found that transport of sediments as suspended load is the main way of transport for Titan [1]. We also determined the range of the river's parameters for which multiple channel rivers are developed rather than single channel. This work is aimed to investigate the similarity and differences between these processes on Titan and the Earth.

Numerical model

The dynamical analysis of the considered rivers is performed using the package CCHE modified for the specific conditions on Titan. The package is based on the Navier-Stokes equations for depth-integrated two dimensional, turbulent flow and three dimensional convection-diffusion equation of sediment transport. We use the same numerical package that in our previous work [1] and [2], i.e. CCHE2D package.

Parameters of the model

For Titan we consider liquid corresponding to a Titan's rain (75% methane, 25% nitrogen) and water ice as material transported in rivers, for Earth the water and the quartz. We model evolution of the river for at least 100-200 days.

Results and Conclusions

Our preliminary results indicate that suspended load is the main way of transport in simulated Titan's conditions. We also indicate that multiple channel rivers appears for larger range of slope on Titan (e.g. S=0.01-0.04) than on Earth (e.g. S=0.004-0.009). Also, for the same type of river, the grain size on Titan is at least 10 times larger than on Earth (1 cm for Titan versus 1 mm for the Earth). It is very interesting that on Titan multiple channel rivers appear even for very little discharge (e.g. Q=30m3/s) and for very large grain size (e.g. 10 cm). In the future we plan the experimental modelling in sediment basin to confirm results from computer modelling.

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425.03 – Quantifying Density, Water Adsorption and Equilibration Properties of Wind Tunnel Materials

Aeolian processes are found on various planetary bodies including Earth, Venus, Mars, Titan, Triton, Pluto, and Comet 67P. Wind tunnels can simulate aeolian processes under different planetary parameters, with the robustness of results relying on experimental conditions and understanding of experimental materials. Threshold wind speed, the minimum wind speed to initiate saltation, is one

parameter that can be investigated in wind tunnels. Liquid water adsorbed on wind tunnel materials could greatly enhance the threshold wind speed by increasing the interparticle force, density, and effective size of particles. Previous studies have shown that this effect could increase the threshold by 100% by putting 0.3-0.6% of water into typical dry quartz sand (Fecan et al. 1998). In order to simulate the weight of particles on other planetary bodies where gravity is significantly lower than on Earth, low-density materials are used in planetary wind tunnels, including walnut shells, activated charcoal, iced tea, and instant coffee.
We first quantified the densities for all wind tunnel materials using a pycnometer and updated the density for low-density materials (e.g., walnut shells have density of 1.4 g/cm^{3}instead of 1.1 g/cm^3 in the literature (Greeley et al. 1980)). Then we present a set of measurements that quantify water adsorption for both low and high-density materials (sand, basalt, and chromite). We first measured the water content and equilibration timescales for the materials through gravimetric measurements. We found low-density materials tend to have much more water (>5%) compared to high-density materials (<1%). Low-density materials also tend to equilibrate with air over much longer timescales (> 6 hrs) compared to high-density materials (10–50 minutes). Since only water adsorbed on the particle surface would change the interparticle force, we then separate the surface and internal water using thermo-gravimetric analysis, and found that >80% of the water is still on the surface. Thus we assume water adsorption for low-density materials could greatly enhance the threshold wind speed. A set of Titan Wind Tunnel (TWT) runs using wet and dry walnut shells are ongoing and would provide insight into the effect.
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425.04 – Searching for shoreline change at Titan's north pole

Titan, Saturn's largest moon, is the only other place in the solar system with an active "hydrological" cycle. The conditions in Titan's thick, hazy atmosphere are suitable for methane to play that same role that water does here on Earth. In the ‘’hydrological cycle”, methane rains down, flows across the surface into lakes, and eventually evaporates back into the atmosphere. As such, Titan's surface is dynamic: Cassini has found evidence for fluvial and pluvial activity and erosion. Additionally, evaporites (leftover solid hydrocarbon “salts”) along the shores of some lakes demonstrate that lake levels have changed. The question of how fast lake filling or desiccation might happen is still unanswered. Hayes et al. (2011) found that Ontario Lacus experienced up to 9-11 km of shoreline retreat in 4 years on the southwestern margin, but Cornet et al. (2012) found no change in their analysis of the same data. Our project aims to clarify the discrepancy and search for shoreline changes in the north polar lakes during the extent of the Cassini mission. We survey lakes with multiple good resolution images in two Cassini datasets (those of the Visual and Infrared Mapping Spectrometer and RADAR). Our results inform a better understanding of the local and global climate, and constrain the timescale for lake-level changes on Titan.
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425.05 – Transient Broad Specular Reflections from Titan's North Pole

In 2014, Cassini observed rough patches or transient broad specular reflections on one of Titan’s seas, Punga Mare. These observations were made by the Visual and Infrared Mapping Spectrometer (VIMS). The rough patches were interpreted to be waves on the surface of the hydrocarbon sea with slopes of $6^0 \pm 1^0$. Although long anticipated, this was an important observation since there was no detection of waves in the initial flybys of north polar lakes and seas until the northern summer approached.
We have analyzed several recent VIMS flybys of Titan’s north pole looking for these rough surfaces. Our observations are classified as clouds, mudflats, specular reflections, or waves based on VIMS color composites. We observe waves in at least two seas at the north pole, Ligeia Mare and Kraken Mare. In addition, we also observe specular reflections from the shoreline or land, indicating the wet sidewalk effect or mudflat in other flybys. Wet sidewalk observations indicate a recent rainfall event causing diffuse specular reflection.
These new observations help us understand more about the weather conditions and sea-wind interaction generating waves on the seas.
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425.06 – SRTC++: a New Monte Carlo Radiative Transfer Model for Titan

Titan's vertically extended and highly scattering atmosphere poses a challenge to interpreting near-infrared observations of its surface. Not only does Titan's extended atmosphere often require accommodation of its spherical geometry, it is also difficult to separate surface albedos from scattering or absorption within low-altitude atmospheric layers. One way to disentangle the surface and atmosphere is to combine observations in which terrain on Titan is imaged from a range of viewing geometries. To address this type of problem, we have developed a new algorithm, Spherical Radiative Transfer in C++ or SRTC++.This code is written from scratch in fast C++ and designed from the ground up to run efficiently in parallel. We see SRTC++ as complementary to existing plane-parallel codes, not in competition with them as the first problems that we seek to address will be spatial in nature. For example, we will be able to investigate spatial resolution limits in the various spectral windows, discrimination of vertical atmospheric layers, the adjacency effect, and indirect illumination past Titan's terminator.
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425.07 – Carbon dioxide chemistry on the surface of Titan

Titan possesses many of the basic elements of habitability, including a rich organic chemistry. However, the thick atmosphere of Titan shields the surface from radiation, which makes the incorporation of oxygen into organic compounds difficult, due to a reducing environment and low temperatures that slow chemical reactions. These obstacles may be overcome by impacts or cryovolcanic heating of ice, which would mix organics with liquid water and allow chemical reactions that can incorporate oxygen. However, reactions involving oxygen can occur on Titan without invoking such unusual conditions. We show that the reaction of carbon dioxide with amines can lead to oxygenated organics at Titan’s surface without the need for external energy input, via the carbamation reaction: $R\text{-}NH_2 + CO_2 \rightarrow R\text{-}NH\text{-}COOH$. Using a combination of micro-Raman spectroscopy and UHV FTIR spectroscopy, we examine the reaction products and kinetics of the carbamation reaction for a variety of primary and secondary amines. We have observed carbamic acid formation in mixtures of methylamine, ethylamine and dibutylamine with CO_2 at cryogenic temperatures. This indicates that both primary and secondary amines can undergo carbamation at low temperatures. Reaction was observed with methylamine as low as 40 K, and with ethylamine at 100 K, demonstrating that carbamation is fast at Titan surface temperatures. We will present data on the kinetics of the carbamation reaction for a variety of amines, as well as estimates of the quantity of carbamic acids that may be produced on Titan's surface and in the atmosphere.

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425.08 – A Mid-Latitude Geomorphologic Map of Titan

We investigated the geologic history of Titan through mapping and analyzing the distribution of observed geomorphic features using a combination of Cassini data collected by RADAR, VIMS, and ISS. Determining the spatial and superposition relationships between geomorphologic units on Titan leads to an understanding of the likely time evolution of the landscape and gives insight into the process interactions that drive its evolution. We have used all available datasets to extend the mapping initially done by Lopes et al. [1]. We now have the mid-latitudes (60N to 60S) of Titan mapped at 1:800,000 scale in all areas covered by Synthetic Aperture Radar (SAR). A map of the polar regions has been done by Birch et al. [2]. For the mid-latitudes, we have defined five broad classes of terrains following Malaska et al. [3], largely based on prior mapping [1]. These broad classes are: craters, hummocky/mountainous, labyrinth, plains, and dunes. We have found that the hummocky/mountainous terrains are the oldest units on the surface and appear radiometrically cold, indicating icy materials [5]. Dunes are the youngest units and appear radiometrically warm, indicating organic sediments. VIMS analysis shows that compositional variations can also exist within the same class of unit [6, 7]. Future work aims to combine the polar maps of Birch et al. [2] with the mid-latitude maps presented here and harmonize the units at the 60 degrees boundaries. We also plan to extend the map in regions not covered by SAR to produce a 1:1,500,000 scale map compatible with USGS standards.

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425.09 – The rotation of Titan and Ganymede

The rotation rates of Titan and Ganymede, the largest satellites of Saturn and Jupiter, are on average equal to their orbital mean motion. Here we discuss small deviations from the average rotation for both satellites and evaluate the polar motion of Titan induced by its surface fluid layers. We examine different causes at various time scales and assess possible consequences and the potential of using librations and polar motion as probes of the interior structure of the satellites.

The rotation rate of Titan and Ganymede cannot be constant on the orbital time scale as a result of the gravitational torque of the central planet acting on the satellites. Titan is moreover expected to show significant polar motion and additional variations in the rotation rate due to angular momentum exchange with the atmosphere, mainly at seasonal periods. Observational evidence for deviations from the synchronous state has been reported several times for Titan but is unfortunately inconclusive. The measurements of the rotation variations are based on determinations of the shift in position of Cassini radar images taken during different flybys. The ESA JUICE (JUpiter ICy moons Explorer) mission will measure the rotation variations of Ganymede during its orbital phase around the satellite starting in 2032.

We report on different theoretical aspects of the librations and polar motion. We consider the influence of the rheology of the ice shell and take into account Cassini measurements of the external gravitational field and of the topography of Titan and similar Galileo data about Ganymede. We also evaluate the librations and polar motion induced by Titan's hydrocarbon seas and use the most recent results of Titan's atmosphere dynamics. We finally evaluate the potential of rotation variations to constrain the satellite's interior structure, in particular its ice shell and ocean.

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425.10 – Phase behavior in the system tetrahydrofuran-water-ammonia from calorimetry and Raman spectroscopy

From geochemical models and Cassini-Huygens mission data it can be postulated that the icy crust of Titan is composed by water ice, clathrate hydrates and ammonia hydrates. When the shell evolves thermically, the first minerals in dissociating are the ammonia hydrates. Ammonia is a powerful antifreeze, promoting the drop of the equilibrium curves of both water ice and clathrates to values as low as 170 K and 203 K respectively. Calorimetry, using a Setaram BT 2.15 Calvet calorimeter, has allowed to identify the different phases formed in the system THF-H_2O-NH_3 when the molar ratio H_2O:THF is 1:X <, = or > 17, which corresponds with the THF-clathrate stoichiometric ratio, and at NH_3 concentrations up to 30 wt%. When X < 17, THF is in excess; all the H_2O forms clathrates, no ammonia hydrates are observed, and the excess THF interacts with NH_3 to form a NH_3-THF phase. When X > 17, the H_2O is in excess; the formation of ammonia hydrates, water ice and THF-clathrate is observed. Since under this condition, all available THF is trapped in the clathrate, no THF-NH_3 phase is observed. In all the scenarios, the release of NH_3 (from the melting of THF-NH_3 solid or ammonia hydrates) promotes partial dissociation of THF clathrates, which start at much lower temperature the equilibrium dissociation of the clathrates. This research is supported by an appointment to the NASA Postdoctoral Program at the Jet Propulsion Laboratory, California Institute of Technology, administered by Universities Space Research Association (USRA) through a contract with NASA. Support from the NASA Outer Planets Research program and government sponsorship acknowledged.

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425.12 – Polyimine and its potential significance for prebiotic chemistry on Titan

Hydrogen cyanide (HCN), a key reagent in prebiotic chemistry, is being generated in large amounts in the atmosphere of Titan. Contradictions between Cassini–Huygens measurements of the atmosphere and the surface of Titan, suggest that HCN is undergoing reaction chemistry, despite the frigid temperatures of 90-94 K. We will discuss computational results [1] investigating polyimine as one potential explanation for this observation.

Polyimine is a polymer identified as the major component of polymerized HCN in laboratory experiments. It is flexible, which aids low temperature mobility, and it is able to form intermolecular and intramolecular =N–H...N hydrogen bonds, allowing for different polymorphs. Polymorphs have been predicted and explored by density functional theory coupled with a structure-searching algorithm. We have calculated the thermodynamics of polymerization, and show that polyimine is capable of absorbing light in a window of relative transparency in Titan's atmosphere. Light absorption and the possible catalytic functions of polyimine are suggestive of it driving photochemistry on the surface, with potential prebiotic implications.

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426 – Mars: Surface Posters

426.01 – Mars in Motion: An online Citizen Science platform looking for changes on the surface of Mars

The European FP7 iMars project has developed tools and 3D models of the Martian surface through the co-registration of NASA and ESA mission data dating from the Viking missions of the 1970s to the present day, for a much more comprehensive interpretation of the geomorphological and climatic processes that have taken and do take place. We present the Citizen Science component of the project, 'Mars in Motion', created through the Zooniverse's Panoptes framework to allow volunteers to look for and identify changes on the surface of Mars over time. 'Mars in Motion', as with many other current citizen science platforms of a planetary or other disciplinary focus, has been developed to compliment the results of automated data mining analysis software, both by validation through the creation of training data and by adding context – gathering more in-depth data on the type and metrics of change initially detected.

Through the analysis of initial volunteer results collected in the second half of 2016, the accuracy and ability of untrained participants to identify geomorphological changes is considered, as well as the impact of their position in the system. Volunteer contribution, either as a filter for poor quality imagery pre-algorithm, validation of algorithmic analysis, or adding context to pre-detected change, and their awareness and interpretation of its importance, can directly influence engagement with the platform and therefore ultimately its success. Understanding the effect of the volunteer and software's role in the system on both the results of and engagement with planetary science citizen science platforms will be an important lesson for the future, especially as the next generation of planetary missions will likely collect data orders of magnitude greater in volume. To deal with the data overload, it is likely that human or software solutions alone will not be sufficient, and that a combination of the two working together in a complimentary system that combines and exploits their strengths could provide a viable solution.

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426.02 – EU-FP7-iMARS: analysis of Mars multi-resolution images using auto-coregistration, data mining and crowd source techniques: A Status Report

There has been a revolution in 3D surface imaging of Mars over the last 12 years with systematic stereoscopy from HRSC and the production for almost 50% of the Martian surface of DTMs and ORIs. The iMars project has been exploiting this unique set of 3D products as a basemap to co-register NASA imagery going back to the 1970s. DLR have produced 3D HRSC mosaic products for large regions with c. 100 individual strips/region (MC-11E/W). UCL have developed an automated processing chain for CTX and HiRISE 3D processing to densify this global HRSC dataset with DTMs down to 18m and 75cm respectively [1].

A fully Automated Co-Registration and Orthorectification (ACRO) system has been developed at UCL and applied to the production of around 8,000 images co-registered to a HRSC pixel (typically 12.5m) and orthorectified to HRSC DTMs of 50-150m spacing [2]. These images are viewable through an OGC-compliant webGIS developed at FUB including tools for viewing sequences over the same area [3]. Corresponding MARSIS and SHARAD data can be viewed through the QGIS plugin available [4]. An automated data mining system is being developed at UCL [5] for change detection to search and classify features in images going back to Viking Orbiter of IFoV ≤100m. In parallel, a citizen science project at Nottingham University [6] is defining training samples for classification of change features and eventually for verification of change [7]. Scientific applications include change mapping over the SPRC [8], mass movements near the North Pole [9]; dark streaks [10] CRISM mapping of mineralogy of dust in the SPRC "Swiss cheese" layers [11] and mapping of dune movement [12].

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426.03 – Automatic detection of surface changes on Mars - a status report

Orbiter missions have acquired approximately 500,000 high-resolution visible images of the Martian surface, covering an area approximately 6 times larger than the overall area of Mars. This data abundance allows the scientific community to examine the Martian surface thoroughly and potentially make exciting new discoveries. However, the increased data volume, as well as its complexity, generate problems at the data processing stages, which are mainly related to a number of unresolved issues that batch-mode planetary data processing presents. As a matter of fact, the scientific community is currently struggling to scale the common ("one-at-a-

time" processing of incoming products by expert scientists) paradigm to tackle the large volumes of input data. Moreover, expert scientists are more or less forced to use complex software in order to extract input information for their research from raw data, even though they are not data scientists themselves.
Our work within the STFC and EU FP7 i-Mars projects aims at developing automated software that will process all of the acquired data, leaving domain expert planetary scientists to focus on their final analysis and interpretation. Moreover, after completing the development of a fully automated pipeline that processes automatically the co-registration of high-resolution NASA images to ESA/DLR HRSC baseline, our main goal has shifted to the automated detection of surface changes on Mars. In particular, we are developing a pipeline that uses as an input multi-instrument image pairs, which are processed by an automated pipeline, in order to identify changes that are correlated with Mars surface dynamic phenomena. The pipeline has currently been tested in anger on 8,000 co-registered images and by the time of DPS/EPSC we expect to have processed many tens of thousands of image pairs, producing a set of change detection results, a subset of which will be shown in the presentation.
The research leading to these results has received funding from the STFC "MSSL Consolidated Grant under "Planetary Surface Data Mining" ST/K000977/1 and partial support from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement number 607379
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426.04 – SWIR spectral mapping of the Martian South Polar Residual Cap using CRISM

The Martian South Polar Residual Cap (SPRC) exhibits unique CO_2 ice sublimation features that cover the surface. These flat floored, circular depressions are highly dynamic, with scarp retreat rates of up to 8m per Martian Year. As the scarps sublimate in Martian Southern Hemisphere spring, they expose dust particles previously trapped within the ice during winter. This allows a window of opportunity to analyse the dust for fragile organic molecules that might otherwise be rapidly destroyed when subjected to ultraviolet radiation at the Martian surface. Polycyclic aromatic hydrocarbons (PAHs) are one such type of organic compound that have not yet been reported as detected on Mars. PAHs are considered to be important in astrobiology as they potentially play a role in abiogenesis, and are a biomarker for extant life. PAHs are abundant on Earth, in deep space and in recent years have been identified on the Saturnian moons Iapetus and Phoebe.
Utilising data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on board NASA's Mars Reconnaissance Orbiter (MRO), SPRC features have been spectrally mapped, the effects of H_2O and CO_2 ice on infrared spectra eliminated, and regions with obvious dust particles analysed to establish their mineral composition, and signatures indicative of PAHs compared to Mars data.
Spectral mapping has identified compositional differences between depression rims and the majority of the SPRC, allowing regions of spectral interest to be selected for in-depth analysis. CRISM spectra have been compared with known Martian mineralogy and PAH laboratory data, with results suggesting Magnesium Carbonate dust content in depression rims, and rims have been found to have higher water content than regions of featureless ice. CO_2 ice has been found to be the most limiting factor in looking for PAH diagnostic signatures on the SPRC. Further work is being undertaken with more detailed results to be presented in the future.
The research leading to these results has received partial funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement no. 607379.
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426.05 – Analysis of Dark Slope Streaks on Mars based on Multitemporal Imagery and Digital Elevation Model derived from HRSC Data

Recurring slope lineae (RSL) on Mars are dark and narrow downhill oriented surface features found in equatorial regions (1) associated with water or hydrated salt flows (2). On the other hand there are Dark Slope Streaks which seem to be dry avalanches on dust covered slopes (3). The origin of both ist still under discussion. We found linear features in eastern Noctis Labyrinthus region (6°S, 265°E) with lengths of up to several kilometres and lateral extensions of 20-30 metres. RSL fade and
recur in the same location over multiple Mars years (4). Similarly, Dark Slope Streaks form on at least annual to decade-long timescales (5). During 10 years of HRSC observation time (2005-2015) several linear features in Noctis Labyrinthus changed in visibility. Slope
parameters and seasonal illumination conditions are investigated based on
a DTM derived from HRSC data. Also particle flow along streaks has been modelled. Feature and change identification is presented involving spatial filtering and DTM analysis.
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement n° 607379.
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426.06 – Analysis of Spatial and Temporal Coverage of Multi-Instrument Optical Images for Change Detection Research on the Mars South Polar Residual Cap

Interest in Mars' surface started in 1965 with Mariner 4. Since then cameras on other fly-by satellites, such as the NASA Mariner 6 (1965), Mariner 7(1971), Mariner 9 (1972) and then orbiting satellites from Viking 1 and 2 (1975-1980), MGS MOC-NA and MOC-WA (1997-2006), Mars Odyssey THEMIS-VIS (2001-present), ESA Mars Express HRSC and SRC (2003-present), NASA MRO HiRISE and CTX (2006-present) and the latest ExoMars TGO CaSSIS launched in March 2016. Both poles of Mars are very fascinating because of their seasonal changes, such as Carbon Dioxide ice layers staying even in summer on South Polar Residual Cap (SPRC). On which features like so-called Swiss Cheese Terrain, spiders, polar dune flow and dust

deposition under layers of ice have been identified. To detect changes between images, we need two or more co-registered images of the same area, and from different time periods, for seasonal features. We have studied the spatial and temporal coverage of images over SPRC. Using a single instrument, full SPRC spatial coverage is available for Viking, HRSC, and CTX images. Images from 25cm HiRISE and ≤10m MOC-NA however, are necessary to detect changes at sufficiently high resolution. The longest period for images from one instrument is 5 MY (for CTX and HiRISE, from MY 28-32). Combining multi-instrument images, we can lengthen the period to 10 MY (from MY 23-32, N.B. we are in MY 33 as present). We can compare the surface images over the 10 MY with the surface from MY 12 from Viking Orbiters. Using multi-instrument images we can increase the number of overlapping images over an area. Overlap information for a single instrument is important to obtain stereo-pairs to be used in DTM production. Overlap information from HRSC images and its DTMs can be used to map changes not only horizontally, but also vertically. We will demonstrate in this study the areas which can be most fruitfully employed for change detection research.
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426.07 – Formation of the Martian Polar Layered Terrains: Quantifying Polar Water Ice and Dust Surface Deposition during Current and Past Orbital Epochs with the NASA Ames GCM

Structural and compositional variability in the layering sequences comprising Mars' polar layered terrains (PLT's) is likely explained by orbital-forced climatic variations in the sedimentary cycles of water ice and dust from which they formed [1]. The PLT's therefore contain a direct, extensive record of the recent climate history of Mars encoded in their structure and stratigraphy, but deciphering this record requires understanding the depositional history of their dust and water ice constituents. 3D Mars atmosphere modeling enables direct simulation of atmospheric dynamics, aerosol transport and quantification of surface accumulation for a range of past and present orbital configurations. By quantifying the net yearly polar deposition rates of water ice and dust under Mars' current and past orbital configurations characteristic of the last several millions of years, and integrating these into the present with a time-stepping model, the formation history of the north and south PLT's will be investigated, further constraining their age and composition, and, if reproducible, revealing the processes responsible for prominent features and stratigraphy observed within the deposits. Simulating the formation of the deposits by quantifying net deposition rates during past orbital epochs and integrating these into the present, effectively 'rebuilding' the terrains, could aid in understanding deeper stratigraphic trends, correlating between geographically-separated deposits, explaining the presence and shapes of large-scale polar features, and correlating stratigraphy with geological time. Quantification of the magnitude and geographical distribution of surface aerosol accumulation will build on the work of previous GCM-based investigations [3]. Construction and analysis of hypothetical stratigraphic sequences in the PLT's will draw from previous climate-controlled stratigraphy methodologies [2,4], but will utilize GCM-derived net deposition rates to model orbital influences on sedimentation and erosion.
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426.08 – Interpretation of collapsed terrain on Mars

On the images from HiRISE camera within volcanoes and circumpolar areas there are depressions that can be explained in two ways, either by melting subsurface layer of ice or by cooling of lava which forms branch intrusion and flank craters underneath. On many pictures from Mars similar cavities are found on the slopes of Martian craters on Arsia Mons , Pavonis Mons on northern hemisphere and Alba Patera on southern hemisphere. Such cavities can be compared to a Hawaiian type volcanoes. At the top of Mauna Loa linearly arranged craters can be seen, strikingly similar to those on Arsia Mons . Basing on map ice content measured by Odyssey GRS apparatus, in this place of the volcanic cone, quite small ice content can be observed that varies in the range of 2-4% hydrogen abundance. It is therefore difficult to explain these collapses by unfreezing of subsurface ice. In an infrared spectrum of these areas there are no bands of water in the CRISM spectra, although it does not say that the water in the form of ice couldn't have been there before. In the central part of Chryse, there are series of chains depressions caused most likely by the collapse of land. These forms have been associated with an open pingo type system additionally with assisted topography of the area or tectonics and internal cracks in the rocks. These are noticed on the slopes of craters or wherever the area decline. Then flowing subsurface water or brine coming from the ice layer could while freezing accumulate and create a longitudinal hill that collapsed due to seasonal thawing forming gullies or canyons . At the end of these gullies remaining trace of the leak can be seen, as if there was a crack in the ground and liquid flew out on the surface. Cryosubsurface processes on Mars can support the hypothesis of geochemical origin of water, which separates from the magma, and its primary source comes from the protoplanetary disk. The water separated from the magma migrates up to the surface and if the temperature is below zero the water deposits as a layer of ice in the case of Mars as a subsurface layer or in the case of moons of gas giants as an eruption through the surface.
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426.09 – Resurfacing history of the Harmakhis Vallis channel, Mars

Harmakhis Vallis is one of the four major outflow channel systems (Dao, Niger, Harmakhis and Reull Valles) which cut the eastern rim region of the Hellas basin, the largest well-preserved impact structure of Mars. The structure of Harmakhis Vallis and the volume of its head depression, as well as the earlier dating studies suggest that the channel formed during the Hesperian period by collapsing when a large amount of subsurface fluids was released. Thus Harmakhis Vallis, as well as the other nearby outflow channels, represent a significant stage of the fluvial activity in the regional history. On the other hand, the channel lies on the Martian mid-latitude zone, where there are several geomorphologic indicators of past and possibly also contemporary ground ice. The floor of Harmakhis also displays evidence of a later-stage ice-related activity as the channel has been covered by lineated valley fill deposits and debris apron material.
The eastern rim region of the Hellas impact basin has been the subject of numerous geologic mapping studies at various scales and

using different imaging data sets. However, the Harmakhis Vallis channel itself has received less attention, or the studies on the channel have focused only on different geologic events as a separate subject. In this work, we present our mapping and dating results of the Harmakhis Vallis floor based on the Mars Reconnaissance Orbiter's ConTeX camera imagery (CTX; ~5 m/pixel), which covers the entire Harmakhis channel system from its head depression to the beginning of the terminus. The purpose of the study is to outline how the floor of the Harmakhis Vallis channel has been modified after its formation, what kind of geologic processes have occurred on the channel and when, and by doing so, provide further understanding of the channel evolution and changes in the Martian climate. This work also gives information about the crater counting age determination method and its usability in the cases where only high resolution data is in use.

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426.10 – Characterization of rocks buried in the subsurface by the GPR WISDOM/ExoMars 2020

The search for evidence of past life on Mars is the main objective of the ESA-Roscosmos ExoMars Rover mission. Given the hostile environment at the surface, if such evidence is to be found anywhere, it will most likely be in the subsurface. This is why the ExoMars rover mission has been optimized to investigate the subsurface. Among the instruments accommodated onboard the Rover, the polarimetric ground penetrating radar WISDOM (Water Ice Subsurface Deposits Observation On Mars, Ciarletti et al., 2011) has been designed to investigate the shallow subsurface and search for the most favorable locations where to drill and collect samples for analysis. WISDOM is able to probe down to a depth of few meters with a vertical resolution of a few centimeters, and will provide key information on the geological context of the environment.
In particular, insights into density, size and shape of the rocks buried beneath the rover would be clues for a better understanding of the geological and hydrological history of the Rover site. In addition, the density and size of the buried rocks will have to be taken into account for the safety of the drilling operations.
In this paper, we will focus on the ability of WISDOM to detect, localize and characterize (in terms of size and shape), rocks in the shallow subsurface of Mars. More specifically, we use a 3D numerical code based on the Finite Difference in Time Domain method to model the antenna system of WISDOM and simulate the instrument operations on realistic environments with buried rocks. In this approach, size-frequency distribution of rocks in agreement with observations from orbit and by cameras operated from the Martian surface will be considered. We will present results of simulations for different density and shape of buried rocks, including critical configurations where the density of rocks is too high to allow individual detection of rocks. In addition, we will present experimental data for comparison with the simulated data.
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426.11 – Long distance observations with the ChemCam Remote Micro-Imager: Eroded Mount Sharp deposits on Gale Crater floor?

Curiosity's ChemCam includes a Remote Micro-Imager (RMI) to provide context for the laser pits, to obtain long-range images, and for passive reflectance spectra (400-840 nm). Use of the RMI has been enhanced by a new autofocus algorithm using onboard analysis of RMI images. The RMI has the finest pixel scale on the rover with 19.6 µrad/pixel (1024x1024 grayscale), compared to Mastcam M100 color images (74 µrad/pixel). The pixel scale for RMI images is ~2 cm at 1 km, and ~26 cm at 12 km, beyond which HiRISE orbital resolution (25 cm/pixel) is better. Note: useful resolution of geological features requires 3-5 pixels. A major question for Gale Crater (age 3.6 BY), is whether the presently truncated deposits on Mt. Sharp originally extended across the crater floor, prior to the deposition of Peace Vallis and other fans at 3.2 BY? HiRISE imagery shows early, partly eroded deposits in the vicinity of the Peace Vallis fan, but the materials could have been impact related. Long distance RMI images of the deposits, however, confirm the presence of eroded buttes with at least 8-10 horizontal layers (0.8–1.6 m thick) in one example, consistent with a sedimentary origin. The layered buttes rise as much as 12 meters above the surrounding deposits. The later deposits embay the lower portions of the buttes and are probably a phase of the later Peace Vallis fan. The RMI images show the presence of blocks in this fan unit of about 50-80 cm, consistent with an enhanced retention of craters that has been noted for this unit. Another RMI observation just above the Peace Vallis channel shows an eroded bench or series of layered hills at the same level, that could also indicate early sediment deposits prior to Peace Vallis fan. Conclusions - The RMI images (and HiRISE images of other crater floor deposits) suggest at least some deposits possibly related to Mt. Sharp were present on the crater floor near the Peace Vallis fan and now are highly eroded, but their original thickness is still unknown. The RMI rover perspective and high resolution provide a powerful new tool for geological analysis at Gale Crater.

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Contributing team(s): MSL Science Team

426.12 – Potential sources of artifacts and backgrounds generated by the sample preparation of the SAM experiment aboard the Curiosity Rover on Mars

Sample Analysis at Mars (SAM) is one of the instruments of the MSL mission. Three analytical devices are onboard SAM: the Tunable Laser Spectrometer (TLS), the Gas Chromatography (GC) and the Mass Spectrometer (MS). To adapt the nature of a sample to the analytical devices used on SAM, a sample preparation and gas processing system is implemented with (a) a pyrolysis system, (b) wet chemistry: MTBSTFA and TMAH (c) the hydrocarbon trap (silica beads, Tenax® TA and Carbosieve G) which is employed to concentrate volatiles released from the sample prior to GC-MS analysis [1].
Volatile compounds and abundant chlorinated hydrocarbons have been detected with SAM when analyzing samples collected in several sites explored by Curiosity rover. Some volatile compounds (chlorinated and non-chlorinated) come from the degradation of the MTBSTFA under high temperature or by the reaction of Martian oxychlorine compounds (present in the samples) with terrestrial carbon coming from the derivatization agent (MTBSTFA) used in SAM [2,3]. But other chlorinated compounds do not follow this pathway. For example, Chlorobenzene has been detected by SAM but it cannot be formed by the reaction of MTBSTFA and

perchlorates. Then, two other reaction pathways for chlorobenzene were therefore proposed: (1) reactions between the volatile thermal degradation products of perchlorates (e.g. O_2, Cl_2 and HCl) and Tenax® and (2) the interaction of perchlorates (T>200°C) with organic material from Mars's soil such as benzenecarboxylates. However, even if major part of the chlorobenzene detected has been identified as Martian origin [4] it is important to list all the potential byproducts able to be released from the Tenax®.
Thus, this study inventory all the possible compounds which are originated from Tenax®, MTBSTFA and their interaction with perchlorate.

References: [1] Buch, A. et al. (2009) J chrom. A, 43, 143-151. [2] Glavin, D., A. et al. (2013), LPSC. [3] Eigenbrode, J. et al. (2013), LPSC. [4] Freissinet, C. et al., JGR (2015)

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Contributing team(s): MSL Science Team

426.13 – In Situ Sedimentological Evidence for Climate Change in Early Mars Provided by the Curiosity Rover in Gale Crater

The Striated formation is one of the rock units that was deposited in Gale crater, Mars, during the Late Noachian to Hesperian time (4.2 to 3.6 billion years ago). It crops out for 3 km along the Curiosity's traverse. The Striated formation strikes N65°E and has a depositional dip of 10° - 20° to SE. It consists of 500 m to 1000 m of highly rhythmic layers each 1 m to 4 m in thickness. Study of MAHLI and MastCam images provided by the Curiosity Rover indicates that layers form fining-upward cycles consisting of thick-bedded to massive conglomerate at the base that grades upward to thinly bedded conglomerate, then to pebbly sandstone, and topped by laminated, fine grained sandstone. Layers show slump folds, soft sediment deformation, and cross-beddings.
The highly rhythmic occurrence and the fining-upward grain size characteristic indicate that each layer within the Striated formation is a coarse-grained turbidite: a type of rock that forms when sediments move down-hill by gravity-driven turbidity flows and deposit in deep waters. We propose that turbidite layers of the Striated formation are related to delivery of sediments to Gale crater by megafloods through its northern rim. Upon entering Gale crater, sediments moved down-hill and deposited as turbidite layers when the crater may have been filled to the rim with water. About 1000 to 3000 turbidite layers are present suggesting the occurrences of as many megafloods during hothouse climatic intervals when Mars was warmer than the Present and had plenty of liquid water. Floods were generated by one or a combination of the following processes: (1) torrential rain along the margins of Mars's Northern Ocean, 500 km to 1000 km to the north, (2) rapid melting of ice in highland areas, and (3) tsunamis formed by impacts on the Northern Ocean. Cold and/or dry climate of icehouse intervals may have followed each warming episode. Mars's climate forcing mechanism and periodicities of climate change are not clear at this point. However, the highly regular and rhythmic nature of turbidite layers point to an orbital triggering mechanism, possibly driven by changes in obliquity.

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426.14 – The Mars Orbital Catalog of Hydrated Alteration Signatures (MOCHAS) - Initial release

Aqueous minerals have been identified from orbit at a number of localities, and their analysis allowed refining the water story of Early Mars. They are also a main science driver when selecting current and upcoming landing sites for roving missions.
Available catalogs of mineral detections exhibit a number of drawbacks such as a limited sample size (a thousand sites at most), inhomogeneous sampling of the surface and of the investigation methods, and the lack of contextual information (e.g. spatial extent, morphological context).
The MOCHAS project strives to address such limitations by providing a global, detailed survey of aqueous minerals on Mars based on 10 years of data from the OMEGA and CRISM imaging spectrometers. Contextual data is provided, including deposit sizes, morphology and detailed composition when available. Sampling biases are also addressed.
It will be openly distributed in GIS-ready format and will be participative. For example, it will be possible for researchers to submit requests for specific mapping of regions of interest, or add/refine mineral detections.
An initial release is scheduled in Fall 2016 and will feature a two orders of magnitude increase in sample size compared to previous studies.

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Contributing team(s): The OMEGA and CRISM teams

426.15 – Using THEMIS and TES to conduct a mineral analysis on Olympus Mons

Olympus Mons is the largest shield volcano in our known solar system. In previous studies, the composition of the basaltic lava flows on Olympus Mons was shown to be similar to the composition of those lava flows of Earth's shield volcanoes. It has been suggested that basalt located near volcanoes contained bacteria living below the surface of the Earth. In this pilot study, the effect of Olympus Mons' aspect (i.e. north- vs. south-facing slope) on its mineral composition was examined. Imagery from Thermal Emission Imaging System (THEMIS), onboard the Mars Odyssey spacecraft, were used because Olympus Mons' size and surface roughness hinder rover exploration. After removing transmission errors and performing an atmospheric correction, the THEMIS images were ready to be analyzed via a mineral spectral library. Using Arizona State University's Thermal Emission Spectrometer (TES) derived mineral spectral library, the images were classified in ENVI. These classifications were verified using ASU's GIS tool, Java Mission-planning and Analysis for Remote Sensing (JMARS) and TES. Results show differences in the mineral composition and in the geological features on Olympus Mons' surface. The mineral vanadinite was shown to be prevalent on the sampled southern portions of Olympus Mons, but was sparse on the sampled northern portions. Previous studies suggested that the mineral ilmenite, which this study found in high concentrations on the sampled northern portions of Olympus Mons, might serve as a food source for iron-oxidizing and iron-scavenging bacteria. Future research should focus on better understanding the concentrations of vanadinite and ilmenite on Olympus Mons to see if these minerals have a role in the potential presence of bacteria on Olympus Mons.

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426.16 – Thermal Reactivity of Organic Molecules in the Presence of Chlorates and Perchlorates and the Quest for Organics on Mars with the SAM Experiment Onboard the Curiostiy Rover

One of the main objectives of the Sample Analysis at Mars (SAM) experiment is the in situ molecular analysis of gases evolving from

solid samples collected by Curiosity when they are heated up to ~850°C. With this aim **SAM** uses a gas-chromatograph coupled to a mass spectrometer (GC-MS) able to detect and identify both inorganic and organic molecules released by the samples.
During the pyrolysis, chemical reactions occur between oxychlorines, probably homogeneously distributed at Mars's surface, and organic compounds SAM seeks for. This was confirmed by the first chlorohydrocarbons (chloromethane and di- and trichloromethane) detected by SAM that were entirely attributed to reaction products occurring between these oxychlorines and organics from instrument background. But SAM also detected in the Sheepbed mudstone of Gale crater, chloroalkanes produced by reaction between oxychlorines and Mars indigenous organics, proving for the first time the presence of organics in the soil of Mars. However, the identification of the molecules at the origin of these chloroalkanes is much more difficult due to the complexity of the reactivity occurring during the sample pyrolysis. If a first study has already been done recently with this aim, it was relatively limited in terms of parameters investigated.
This is the reason why, we performed a systematic study in the laboratory to help understanding the influence of oxychlorines on organic matter during pyrolysis. With this aim, different organic compounds from various chemical families (e.g. amino and carboxylic acids) mixed with different perchlorates and chlorates, in concentrations compatible with the Mars soil from estimations done with SAM measurements, were pyrolyzed under SAM like conditions. The products of reaction were analyzed and identified by GC-MS in order to show a possible correlation between them and the parent molecule. Different parameters were tested for the pyrolysis to evaluate their potential influence on the products of reaction obtained. This work present the results of this series of experiments and the conclusions that can be done about the SAM measurements, but also about future analyses to be done by the MOMA experiment of the Exomars 2020 mission.

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426.17 – A Potential Mechanism for Perchlorate Formation on Mars: Surface-Radiolysis-Initiated Atmospheric Chemistry

Perchlorate (ClO_4^-) is prevalent on Earth, and with observations of perchlorate on lunar samples and chondrite meteorites, along with recent observations indicating the presence of perchlorate (ClO_4^-) in the Martian surface by the Phoenix lander and the Sample Analysis at Mars (SAM) on the Mars Science Laboratory (MSL) rover, it appears that the existence of perchlorate is widespread throughout the solar system. However, the abundance and isotopic composition of Martian perchlorate suggest that the perchlorate formation mechanism on Mars may involve a different path than perchlorate found elsewhere in the solar system. Motivated by this, we employ a one-dimensional chemical model to investigate the viability of perchlorate formation in the atmosphere of Mars, instigated by the radiolysis of the Martian surface by galactic cosmic rays. The surface-atmosphere interaction to produce Martian perchlorate involves the sublimation of chlorine oxides into the atmosphere, through surface radiolysis, and their subsequent synthesis to form perchloric acid ($HClO_4$), followed by surface deposition and mineralization to form surface perchlorates. Considering the chlorine oxide, OClO, we find an OClO surface flux as low as 3.2×10^7 molecules cm^{-2} s^{-1}, sublimated into the atmosphere from the surface could produce sufficient $HClO_4$ to explain the perchlorate concentration on Mars, assuming an accumulation depth of 30 cm and integrated over the Amazonian period. Radiolysis provides an efficient pathway for the oxidation of chlorine, bypassing the efficient Cl/HCl recycling mechanism that characterizes $HClO_4$ formation mechanisms proposed for the Earth but not Mars.

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426.18 – Attenuation of UV Light in Mars Analog Minerals: Implications for Organic Detection with the SHERLOC Mars 2020 Instrument

SHERLOC is an instrument that is part of the Mars 2020 payload. It utilizes a deep UV laser (248.6 nm) to induce Raman and fluorescence in organics and minerals [1]. Samples of interest are spatially scanned with the laser to stimulate fluorescence emissions and Raman scattering from the sample. Specifically, fluorescence is generated from electronic transitions in aromatic organics and Raman scatter is generated from vibrational bonds in both organics and minerals [2]. SHERLOC will be used on Mars to identify, in situ, interesting samples for sample caching and potential subsequent return to Earth.
The mineral transparency at the wavelengths of interest (~250-400 nm) for both the incident laser light and the sample specific photons from fluorescence emission or Raman scattering will affect the interrogation volume of analysis and thus constrain the limits of detection.
The attenuation rates of UV photons in bulk mineral samples have been determined as a function of mineral layer thickness for Mojave Mars Simulant basalt (MMS), gypsum (calcium sulfate), kaolinite (a clay mineral) and Bishop Tuff (a rhyolitic tuff). UV attenuation curves were determined by placing mineral pellets of varying thickness between a 1000-W Xe arc lamp and a radiometrically calibrated UV spectrometer. Results show that although UV transmission drops off quickly as a function of depth, there is some penetration of UV photons even at depths of several hundred microns.
We have also used a SHERLOC-like laser system to detect aromatic and aliphatic organics under thin layers of these minerals at different depths below the surface. Results indicate that detection of certain organics may be possible at depths of 250um or greater below the mineral surface, allowing for a greater interrogation volume than previously assumed for SHERLOC.

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426.19 – ExoMars 2016 arrives at Mars

The Trace Gas Orbiter (TGO) and the Schiaparelli Entry, descent and landing Demonstrator Model (EDM) will arrive at Mars on 19 October 2016. The TGO and the EDM are part of the first step of the ExoMars Programme. They will be followed by a Rover and a long lived Surface Platform to be launched in 2020.

The EDM is attached to the TGO for the full duration of the cruise to Mars and will be separated three days before arrival at Mars. After separation the TGO will perform a deflection manoeuvre and, on 19 October (during the EDM landing), enter into a highly elliptical near equatorial orbit. TGO will remain in this parking orbit until January 2017, when the orbital plane inclination will be changed to 74 degrees and aerobraking to the final 400 km near circular orbit will start. The final operational orbit is expected to be reached at the end of 2017.

The TGO scientific payload consists of four instruments. These are: ACS and NOMAD, both infrared spectrometers for atmospheric measurements in solar occultation mode and in nadir mode, CASSIS, a multichannel camera with stereo imaging capability, and FREND, an epithermal neutron detector for search of subsurface hydrogen. The mass of the TGO is 3700 kg, including fuel. The EDM, with a mass of 600 kg, is mounted on top of the TGO as seen in its launch configuration. The main objective of the EDM is to demonstrate the capability of performing a safe entry, descent and landing on the surface, but it does carry a descent camera and a small battery powered meteorological package that may operate for a few days on the surface.

The ExoMars programme is a joint activity by the European Space Agency(ESA) and ROSCOSMOS, Russia. ESA is providing the TGO spacecraft and Schiaparelli (EDM) and two of the TGO instruments and ROSCOSMOS is providing the launcher and the other two TGO instruments. After the arrival of the ExoMars 2020 mission at the surface of Mars, the TGO will handle the communication between the Earth and the Rover and Surface Platform through its (NASA provided) UHF communication system. The 2016 mission was launched by a Russian Proton rocket from Baikonur on 14 March 2016.

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Contributing team(s): ExoMars Team

426.20 – Statistical scaling properties of planetary topographic fields

The massive acquisition of altimetric data in the solar system has motivated numerous analysis of the topography of planets, in particular the surface roughness. Many statistical indicators have been proposed and widely explored in order to study the surface of plantets. Useful informations have been obtained by the use of those indicators but they often have the disadvantage of been defined at a given scale. By construction, they do not directly take into account the well-established scale symmetry that generally occurs in the case of natural surfaces. Indeed, topography can not be interpreted as a stationary field, meaning that statistical parameters like the mean or the standard deviation exhibit a dependence toward scales. This subject has been widely studied in the past, parallel to the development of the notion of fractals. It is now well established that topography is often efficiently modelled by fractal simulations. More interestingly, the fractal theory provides a mathematical formalism to describe the scale dependence of statistical parameters toward scales. It turns out that simple power-law relations efficiently approach the variability of planetary surfaces.

However, The observed intermittency (spatial dependance of the scaling laws) apparently rejects the idea of a global description of any topographic field at the planetary scale. Still, modern developments in the fractal theory might be able to give full account to the observed variability and intermittency. It is possible to extent the fractal interpretation of topography to a multifractal statistical object requiring an infinite number of fractal dimensions (one for each statistical moment order). In the present study, we analyse the global scaling laws of topography for different body in the solar system in order to test the multifractal formalism. We then compare the fractal and multifractal parameters form a body to the other. We demonstrate that a change of processes governing the global topography of planets occurs at 10 km. A multiplicative cascade process is occurring at scale higher than 10 km but a simpler monofractal scaling process is occurring a small scale.

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426.21 – Raman Laser Spectrometer internal Optical Head current status: opto-mechanical redesign to minimize the excitation laser trace

Raman Laser Spectrometer (RLS) is the Pasteur Payload instruments of the ExoMars mission, within the ESA's Aurora Exploration Programme, that will perform for the first time in an out planetary mission Raman spectroscopy. RLS is composed by SPU (Spectrometer Unit), iOH (Internal Optical Head), and ICEU (Instrument Control and Excitation Unit). iOH focuses the excitation laser on the samples (excitation path), and collects the Raman emission from the sample (collection path, composed on collimation system and filtering system). The original design presented a high laser trace reaching to the detector, and although a certain level of laser trace was required for calibration purposes, the high level degrades the Signal to Noise Ratio confounding some Raman peaks. The investigation revealing that the laser trace was not properly filtered as well as the iOH opto-mechanical redesign are reported on. After the study of the Long Pass Filters Optical Density (OD) as a function of the filtering stage to the detector distance, a new set of filters (Notch filters) was decided to be evaluated. Finally, and in order to minimize the laser trace, a new collection path design (mainly consisting on that the collimation and filtering stages are now separated in two barrels, and on the kind of filters to be used) was required. Distance between filters and collimation stage first lens was increased, increasing the OD. With this new design and using two Notch filters, the laser trace was reduced to assumable values, as can be observed in the functional test comparison also reported on this paper.

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Contributing team(s): Instituto Nacional de Técnica Aeroespacial (INTA), Universidad de Valladolid (UVa), Ingeniería de Sistemas para la Defesa de España S.A. (ISDEFE)

426.22 – Raman Laser Spectrometer for 2020 ExoMars

The Raman Laser Spectrometer (RLS) is one of the Pasteur Payload instruments, within the ESA's Aurora Exploration Programme, ExoMars mission.

ExoMars 2020 main scientific objective is "Searching for evidence of past and present life on Mars".

Raman Spectroscopy is used to analyze the vibrational modes of a substance either in the solid, liquid or gas state. It relies on the inelastic scattering (Raman Scattering) of monochromatic light produced by atoms and molecules. The radiation-matter interaction

results in the energy of the exciting photons to be shifted up or down. The shift in energy appears as a spectral distribution and therefore provides an unique fingerprint by which the substances can be identified and structurally analyzed.
The RLS is being developed by an European Consortium composed by Spanish, UK, French and German partners. It will perform Raman spectroscopy on crushed powdered samples, obtained from 2 meters depth under Mars surface, inside the Rover's Analytical Laboratory Drawer.
After a wide campaign for evaluating Instrument performances by means of simulation tools and development of an instrument prototype, Instrument Structural and Thermal Model was successfully delivered on February 2015, and the Engineering and Qualification Model has been manufactured and is expected to be delivered by November 2016, after a testing campaign developed during Q2 & Q3 of 2016.
A summary of main Instrument performances obtained during the last months, achieving high levels of spectral resolution and accuracy in the obtained spectra.
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426.23 – Metacatalog of Planetary Surface Features for Multicriteria Evaluation of Surface Evolution: the Integrated Planetary Feature Database

We have created a metacatalog, or catalog or catalogs, of surface features of Mars that also includes the actual data in the catalogs listed. The goal is to make mesoscale surface feature databases available in one place, in a GIS-ready format. The databases can be directly imported to ArcGIS or other GIS platforms, like Google Mars. Some of the catalogs in our database are also ingested into the JMARS platform.
All catalogs have been previously published in a peer-reviewed journal, but they may contain updates of the published catalogs. Many of the catalogs are "integrated", i.e. they merge databases or information from various papers on the same topic, including references to each individual features listed.
Where available, we have included shapefiles with polygon or linear features, however, most of the catalogs only contain point data of their center points and morphological data.
One of the unexpected results of the planetary feature metacatalog is that some features have been described by several papers, using different, i.e., conflicting designations. This shows the need for the development of an identification system suitable for mesoscale (100s m to km sized) features that tracks papers and thus prevents multiple naming of the same feature.
The feature database can be used for multicriteria analysis of a terrain, thus enables easy distribution pattern analysis and the correlation of the distribution of different landforms and features on Mars. Such catalog makes a scientific evaluation of potential landing sites easier and more effective during the selection process and also supports automated landing site selections.
The catalog is accessible at
https://planetarydatabase.wordpress.com/.
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426.24 – Seismic signals from Dust Devils on Mars

We modeled the long-period seismic signals generated by Dust Devils and convective vortices on Mars. To characterize the source term, we used Large-Eddy Simulations with a spatial resolution of 50 m that resolve large turbulent and convective structures of the Martian atmosphere. The corresponding surface pressure fluctuations induce a quasi-static ground displacement and thus a tilt of the surface, which over weak soils can be detected by sensitive seismometers, as shown in terrestrial field experiments. Typical convective vortices on Mars have core-pressure drops of 2-5 Pa and generate tilt accelerations of 10-20 nm/s^2 over a regolith halfspace, and of a few nm/s^2 in the presence of a layer of harder rock at shallow depth. This signals are strong enough to be detected by the Very-Broad Band seismometer of the InSight/SEIS experiment up to a distance of several tens of meters from the vortex. The results of numerical simulations are compared to meteorological data from previous mission to Mars, and they give estimates of the encounter frequencies, showing how convective vortices will be routinely detected during the central hours of the day. A joint analysis of meteorological and seismic data will permit to distinguish atmospheric episodes from internal seimic sources and to investigate the structure and the elastic properties of the near surface at the InSight landing site.
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427 – Mars: Interior Posters

427.01 – Signatures of the Martian rotation parameters in the Doppler and range observables

Because of Mars rotation, the position of a lander on Mars' surface is affected by different motions: the nutations, the precession, the length-of-day variations and the polar motion.
We derive first-order expressions of the signature of these different rotation parameters in a Doppler observable between a lander and the Earth. These expressions are function of the diurnal rotation of Mars, the lander position (its latitude and its longitude), the planet radius and the amplitude of the rotation parameter. The nutation signature is proportional to the Earth declination with respect to Mars.
For an equatorial lander, the largest signatures in the Doppler observable are for the length-of-day variations, precession rate and rigid nutations. The polar motion and the liquid core signature have a much smaller amplitude.
All the signatures, with the exception of the polar motion, decrease as the lander gets closer to the pole, while the polar motion signature decreases if the lander is closer to the equator.
Similarly, we also derive expressions for the signatures of the rotation parameters in the lander-Earth range observable.
These expressions are useful in order to find when these signatures are maximal during one day or on a longer timescale, therefore to identify the times during a geodesy mission where the signatures can be maximized.
Numerical values for these signatures are given for the future InSight and ExoMars landers.
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427.02 – The Martian rotation from Doppler measurements: Simulations of future radioscience experiments

The radioscience experiment onboard the future InSight and ExoMars missions consists in two-way Doppler shift measurement

from a X-band radio link between a lander on Mars and the ground stations on Earth. The Doppler effect on the radio signal is related to the revolution of the planets around the Sun and to the variations of the orientation and the rotation of Mars. The variations of the orientation of the rotation axis are the precession and nutations, related to the deep interior of Mars and the variations of the rotation rate are the length-of-day variation, related to the dynamic of the atmosphere.
We perform numerical simulations of the Doppler measurements in order to quantify the precision that can be achieved on the determination of the Mars rotation and orientation parameters (MOP). For this purpose, we use the GINS (Géodésie par Intégrations Numériques Simultanées) software developed by the CNES and further adapted at the Royal Observatory of Belgium for planetary geodesy applications. This software enables to simulate the relative motion of the lander at the surface of Mars relative to the ground stations and to compute the MOP signature on the Doppler shift. The signature is the difference between the Doppler observable estimated taking into account a MOP and the Doppler estimated without this parameter.
The objective is to build a strategy to be applied to future data processing in order to improve our estimation of the MOP. We study the effect of the elevation of the Earth in the sky of the lander, of the tracking duration and number of pass per week, of the tracking time, of the lander position and of Doppler geometry on the signatures. Indeed, due to the geometry, the Doppler data are highly sensitive to the position variations along the line of sight.
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427.03 – Planetary Seismology : Lander- and Wind-Induced Seismic Signals

Seismic measurements are of interest for future geophysical exploration of ocean worlds such as Europa or Titan, as well as Venus, Mars and the Moon. Even when a seismometer is deployed away from a lander (as in the case of Apollo) lander-generated disturbances are apparent. Such signatures may be usefully diagnostic of lander operations (at least for outreach), and may serve as seismic excitation for near-field propagation studies. The introduction of these 'spurious' events may also influence the performance of event detection and data compression algorithms. Examples of signatures in the Viking 2 seismometer record of lander mechanism operations are presented. The coherence of Viking seismometer noise levels and wind forcing is well-established : some detailed examples are examined. Wind noise is likely to be significant on future Mars missions such as InSight, as well as on Titan and Venus.
Author(s): Ralph Lorenz[1]
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428 – Mars Satellites: Phobos and Deimos Posters

428.01 – Precise radio Doppler and interferometric tracking of spacecraft in service of planetary science

The Planetary Radio Interferometry and Doppler Experiments (PRIDE) project is designed as a multi-purpose, multidisciplinary enhancement of the space missions science return by means of Doppler and phase-referenced Very Long Baseline Interferometry (VLBI) tracking of spacecraft. These measurements can be used in a multitude of scientific applications, both fundamental and applied, where an accurate estimate of the spacecraft state vector is essential. In particular, the gravitational field of planetary moons can be sampled with close spacecraft flybys, allowing to probe the moons' interior.
In this presentation, we will describe the principles of PRIDE data collection, processing, and analysis. We will present the results of demonstrational observations of a Phobos flyby conducted by ESA's Mars Express spacecraft.
Author(s): Dmitry Duev[1]
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Contributing team(s): PRIDE team

428.02 – Formation of Phobos and Deimos in a giant collision scenario facilitated by a large transient moon

Mars has two natural satellites, Phobos and Deimos, similar to asteroids but whose current orbital parameters are not consistent with those of captured objects. We present an alternative scenario, backed by numerical simulations, in which Phobos and Deimos are formed in situ from a disc of debris resulting from a giant impact which gave Mars its spin and its north-south dichotomy. In this, a small number of large inner moons spawn at the Roche limit of the inner disc and then migrate outwards. Smaller debris in the outer, less dense part of the disc tend to accumulate at mean motion orbital resonances generated by these moons, hence facilitating their accretion. Our numerical simulations robustly reproduce the current Martian system of one more massive satellite lying just below the synchronous orbit and one less massive satellite above it. The large inner moons eventually fall back onto Mars as the inner disc itself empties, leaving the two small satellites to evolve under tidal dissipation to their current orbits. Our scenario offers an explanation for why Mars did not end up with one single large Moon like Earth, nor with numerous small moons like the giant planets. It also implies that Phobos and Deimos may be composed of material from both Mars and the impactor.
Author(s): Pascal Rosenblatt[5], Sébastien Charnoz[3], Kevin Dunseath[4], Mariko Terao-Dunseath[4], Antony Trinh[5], Ryuki Hyodo[2], Hidenori Genda[1], Steven Toupin[5]
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428.03 – Physical librations and possible homogeneity of natural moons from astrometry

Astrometry is the discipline that aims to provide positions of celestial objects in space with the highest accuracy. Thanks to recent space missions like Mars Express and Cassini, astrometric measurements of moons have allowed the probing of the gravity environment of their systems with unprecedented resolution. Here we focus on the possible determination of physical librations on the rotation of the moons, by modelling their effects on the moons' orbits. Assuming a homogeneous density, a theoretical expectation of the main libration can be computed and compared with possible observed values obtained indirectly from the orbit. In this work, we obtain for Phobos a physical libration of 1.04 +/- 0.02 degrees, in agreement with a homogeneous interior. The case of some of the inner moons of Saturn will be addressed, also.
Author(s): Valery Lainey[3], Nicholas Cooper[4], Carl Murray[4], Benoît Noyelles[6], Andreas Pasewaldt[1], Vincent Robert[2], Pascal Rosenblatt[5], William Thuillot[3]
Institution(s): *1. DLR, 2. IPSA, 3. Paris Observatory, 4. QMUL, 5. ROB, 6. UNamur*

428.04 – Thermal Infrared Observations and Thermophysical Modeling of Phobos

Mars-observing spacecraft have the opportunity to study Phobos from Mars orbit, and have produced a sizeable record of observations using the same instruments that study the surface of the planet below. However, these observations are generally infrequent, acquired only rarely over each mission.
Using observations gathered by Mars Global Surveyor's (MGS) Thermal Emission Spectrometer (TES), we can investigate the fine layer of regolith that blankets Phobos' surface, and characterize its thermal properties. The mapping of TES observations to footprints on the Phobos surface has not previously been undertaken, and must consider the orientation and position of both MGS and Phobos, and TES's pointing mirror angle. Approximately 300 fully resolved observations are available covering a significant subset of Phobos' surface at a variety of scales.
The properties of the surface regolith, such as grain size, density, and conductivity, determine how heat is absorbed, transferred, and reradiated to space. Thermophysical modeling allows us to simulate these processes and predict, for a given set of assumed parameters, how the observed thermal infrared spectra will appear. By comparing models to observations, we can constrain the properties of the regolith, and see how these properties vary with depth, as well as regionally across the Phobos surface. These constraints are key to understanding how Phobos formed and evolved over time, which in turn will help inform the environment and processes that shaped the solar system as a whole.
We have developed a thermophysical model of Phobos adapted from a model used for unresolved observations of asteroids. The model has been modified to integrate thermal infrared flux across each observed portion of Phobos. It will include the effects of surface roughness, temperature-dependent conductivity, as well as radiation scattered, reflected, and thermally emitted from the Martian surface. Combining this model with the newly-mapped TES observations will reveal variations of thermophysical parameters across the surface. We will present our results on what parameters best reproduce TES's measurements.
Author(s): Nathan Michael Smith[1], Christopher Scott Edwards[3], Michael Mommert[1], David E. Trilling[1], Timothy Glotch[2]
Institution(s): *1. Northern Arizona University, 2. Stony Brook University, 3. U.S. Geological Survey*

428.05 – Phobos spectral clustering: comparison between the 0.5-0.9 micron slope on OMEGA and CRISM data sets

We analyzed the MEX-OMEGA (8) and MRO-CRISM (1) visible multispectral data sets of Phobos using I/F values at 0.5 and 0.9 micron and derived spectral slope from these. The purpose is to understand surface spectral variablity on Phobos. Combining the multispectral data sets provides nearly complete coverage for Phobos surface. Different observing scales ranging from 110 to 2000 m/px, with a range of phase angles from 37° to 101°.
We applied an unsupervised K-means partitioning algorithm to evaluate the variability of the two I/F values. Each resulting cluster is characterized by an average, and its associated variability. This approach has been validated by application to different Solar System objects, e.g. asteroids, Mars, and Iapetus. The algorithm is agnostic of the physical meaning of the resulting clusters, and scientific interpretation is required for their subsequent evaluation.
Using this techinque, 7 clusters were identified for each of the 9 Phobos data sets. For each cluster, we calculated the 0.5-0.9 micron slope within each Phobos data set. The calculated slopes change from a minimum of 0.1% to a maximum of 14.7%. These results indicate that Phobos surface may be more variable than previously suggested, however the exact cause of these variations remains to be determined. In this context, the OMEGA and CRISM data sets are fundamental for expanding our knowledge about Phobos.
Author(s): Maurizio Pajola[3], Ted L. Roush[2], Giuseppe Marzo[1]
Institution(s): *1. ENEA, 2. NASA Ames Research Center, 3. NASA Ames Research Center (NPP)*

428.06 – 12 years of Phobos observations by Omega and Spicam on board MEX

Mars Express made several encounters with Phobos and a few with Deimos since 2004. Observations with SPICAM and OMEGA imaging spectrometers on board Mars Express covers the range from UV (110-312 nm) to visible and mid IR up to 5 µm. In the following we consider the ultraviolet (UV) channel of SPICAM and only the visible channel of OMEGA and its small UV extension down to 390 nm, in order to compare with SPICAM. Preliminary results were presented already in the past [1]. Since then, a more detailed analysis was carried out, subtracting some internally scattered light affecting the SPICAM UV retrieved reflectance.
The combined spectrum of Radiance Factor from SPICAM and OMEGA suggests the presence of a deep absorption feature. Both instruments, taken separately, support also this absorption feature. In the visible part of CRISM [2] on board MRO and recently confirmed by Omega, one feature is centered at 0.65 µm, with an absorption depth varying from 0 to 4%, an other one is centered at 2.8µm. These two Visible IR features were interpreted [2] either to highly desiccated Fe-phyllosilicate minerals indigenous to the bodies, or to a surface process involving Rayleigh scattering and absorption of small iron particles formed by exogenic space weathering processing.
In this rather uncertain situation, the UV band detected by SPICAM and OMEGA on board Mars Express is of great importance to attempt discriminating between the two scenarios proposed above to explain the Visible-IR reflectance spectra of Phobos.
[1] Bertaux J.L. et al. (2011) *EPSC/DPS conference abstract,* Nantes, November 2011. [[2] Freaman A.A. et al. (2014) *Icarus, 229 ,* 196–205.
Author(s): Brigitte Gondet[1], Jean-Loup Bertaux[2]
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Contributing team(s): Omega team, Spicam team

429 – Galilean Satellites Posters

429.01 – The contribution of JUICE-PRIDE to Jovian system ephemerides

The European Space Agency (ESA) Jupiter Icy Moons Explorer (JUICE) mission will perform detailed measurements of the properties of the Galilean moons, with a nominal mission duration of 4 years (2030-2033). Using both radio tracking data, and (Earth- and JUICE-based) optical astrometry, the dynamics of these moons can be derived to unprecedented accuracy. This will provide key input to the creation of ephemerides and the determination of physical properties of the Jovian system. We perform a general analysis of the Galilean moon dynamics that could be observable from JUICE data. Moreover, we specifically analyze the contribution to the ephemerides of VLBI data, obtained with the Planetary Radio Interferometry and Doppler Experiment (PRIDE) experiment.
We perform a sensitivity analysis of the influence on the dynamics of the Galilean system for a wide array of undertainties in gravitational, tidal and rotational characteristics, and analyze the capabilities of the nominal (unperturbed) dynamical model to absorb the influence of these perturbations. Our results indicate that this nominal model can mostly absorb the influence of current uncertainties of the Galilean system's characteristics. A key exception is the dissipation in Io, which will likely be observable in the JUICE tracking data.
The VLBI data from PRIDE will provide measurements of the motion of the moons perpendicular to their orbital planes. We perform a

covariance analysis of the ephemeris generation for a broad range of mission and system characteristics, providing key input for the further development of the PRIDE observational planning and ground segment development.
The results of the covariance analysis show that the VLBI data are crucially important for constraining the out-of-plane dynamics of Ganymede and Callisto. Also, the VLBI data make the ephemerides less dependent on the error in the orbit determination of the JUICE spacecraft itself. Furthermore, we find that optical astrometry data of Europa and Io using the JANUS instrument and/or the navigational camera will be crucial in stabilizing the solution of the normal equations.

Author(s): Dominic Dirkx[1], Leonid Gurvits[3], Valery Lainey[2], Giuseppe Cimo[3], Tatiana Bocanegra-Bahamon[3], Pieter N.A.M Visser[1], Niccolò Gastaldello[1]
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429.02 – Photometry and Astrometry of the Jovian satellites Amalthea and Thebe

During the 2014-2015 campaign of mutual events, we realized ground-based observations of Amalthea (JV) and Thebe (JXIV). We recorded two eclipses of Amalthea and, for the first time, one of Thebe by the Galilean moons. We used the 1-m telescope at Pic du Midi Observatory with an IR filter and a mask placed over the planetary image to reduce thelight intensity of Jupiter. A third observation of Amalthea was taken at Saint-Sulpice Observatory with a 60-cm telescope using a methane filter (890 nm) and a deep absorption band to decrease the contrast between the planet and the satellites. We provide astrometric results derived from the photometry with an overall accuracy of 34 mas, or 100 km at Jupiter. In the same time, we realized 45 astrometric observations of Amalthea and 41 of Thebe to compare the photometric technique with direct astrometry, using the UCAC4 reference star catalog. We provide astrometric results with an overall accuracy of 100 mas for Amalthea, or 300 km at Jupiter, and 90 mas for Thebe, or 270 km at Jupiter. These results are better than those from previous ground-based and old reduced space measurements.

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429.03 – Angular Scattering Reflectance and Polarization Measurements of Candidate Regolith Materials Measured in the Laboratory

The reflectance and polarization of light reflected from a solar system object indicates the chemical and textural state of the regolith. Remote sensing data are compared to laboratory angular scattering measurements and surface properties are determined. We use a Goniometric Photopolarimeter (GPP) to make angular reflectance and polarization measurements of particulate materials that simulate planetary regoliths. The GPP employs the Helmholtz Reciprocity Principle (2, 1) – the incident light is linearly polarized - the intensity of the reflected component is measured. The light encounters fewer optical surfaces improving signal to noise. The lab data are physically equivalent to the astronomical data.
Our reflectance and polarization phase curves of highly reflective, fine grained, media simulate the regolith of Jupiter's satellite Europa. Our lab data exhibit polarization phase curves that are very similar to reports by experienced astronomers (4). Our previous reflectance phase curve data of the same materials agree with the same astronomical observers (5). We find these materials exhibit an increase in circular polarization ratio with decreasing phase angle (3). This suggests coherent backscattering (CB) of photons in the regolith (3). Shkuratov et al.(3) report that the polarization properties of these particulate media are also consistent with the CB enhancement process (5). Our results replicate the astronomical data indicating Europa's regolith is fine-grained, high porous with void space exceeding 90%.

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Author(s): Robert M. Nelson[4], Mark D. Boryta[3], Bruce W. Hapke[5], Yuriy Shkuratov[2], Kurt Vandervoort[1], Christina L. Vides[3]
Institution(s): *1. California Polytechnic State Univeristy at Pomona, 2. Karazin University, 3. Mt. San Antonio College, 4. Planetary Science Institute, 5. University of Pittsburgh*

429.04 – ESA radiation and micro-meteoroid models applied to Space Weathering of atmosphere-less bodies: icy moons and asteroids

The Galilean moons reveal large albedo variations on their surfaces, in particular between their leading and trailing hemispheres. The differences observed are likely the results of a balance between various weathering processes of the surface, determined by the moons' local environment. Chemical and physical alterations occur at the surface, triggered by multiple exogenic energy deposit processes (radiolysis, plasma sputtering, micro-meteoroids impacts, …).
The observed variations are probably due to anisotropy in the energy fluxes received on each hemisphere and due to to a different relative contribution of the weathering agents (plasma, dust…) as function of the distance to Jupiter. We will be testing this hypothesis by estimating quantitatively the kinetic energy flux impacting different part of the surfaces of the Galilean moons. This work is essential in the context of the future missions to the Jovian moons, such as the JUICE ESA mission, as a proper understanding of the moons' surface history can be achieved only if one is able to constrain the balance between exogenic and endogenic alteration processes.
Impacts of dust particles coming from the Galilean moons and evolving dynamically in the Jovian system will be simulated using the Jovian Micrometeoroid Environment Model (JMEM) [1]. Direct interplanetary dust impacts are simulated using the prediction of the Interplanetary Micrometeoroid Environment Model (IMEM) [2] computed at Jupiter's Hill radius, taking into account gravitational focusing by the planet. Finally, electron and ion fluxes interacting with different parts of the moons' surfaces can be estimated using the Jovian Specification Environment model (JOSE) [3].
In parallel, signature of surface weathering will be assessed using reflectance maps based on the Galileo imaging data.
Those models will also be applied, for comparison, to other atmosphere-less bodies of the solar system such as the asteroids Ceres, Vesta and Pallas.

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Author(s): Claire Vallat[7], Nicolas Altobelli[2], Thomas Cornet[2], Jürgen Schmidt[6], Sara Navarro[1], Christian Erd[3], Olivier Witasse[3], Jens Rodmann[5], Alexey Mints[4]

Institution(s): *1. Complutense University of Madrid, 2. ESA/ESAC, 3. ESA/ESTEC, 4. Max-Planck Institute for Solar System Research, 5. University of Göttingen, 6. University of Oulu, 7. VEGA/ESA*

429.05 – Re-evaluation of Galileo Energetic Particle Detector data - a correction model and comparison to semiconductor detector dead-layer sensitivity losses using SRIM

The Energetic Particle Detector launched in 1989 on the Galileo satellite took data on the Jovian Particle environment for 8 years before its demise. Over the course of the mission the detectors in the Composition Measurement System (CMS) have visibly decayed with higher mass particles, specifically oxygen and sulphur, reading far lower energies at later epochs. By considering the non-steady accumulation of damage in the detector, as well as the operation of the priority channel data recording system in place on the EPD, an evolving correction can be made. The recalibration significance can be validated using a model of dead layer build-up in semiconductor detectors, based on SRIM results. The final aim is to assign an estimation dead-layer depth during the mission data recordings.

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429.07 – Photon-induced electro-chemical processes in airless icy bodies analogues

Previous laboratory studies have shown that radiation-induced ionization of impurities in water-rich ices drives the formation of ionized species resulting in charge generation and accumulation in ices [1-3]. It is expected that some of these impurity ions are decomposed into smaller volatile species and ejected into the vacuum. These processes are relevant to the chemical composition of the near-surface tenuous (thin) atmosphere of icy bodies such as the Jovian satellites like Europa.
Our work aims at investigating photocurrents from organic impurity embedded water ices of several microns thick and understanding how these measurements correlate with the desorption of volatiles during UV and electron irradiation. These experiments are performed in an ultrahigh vacuum chamber around Europa's surface temperature (100 – 150 K) conditions using a low-pressure hydrogen flow-discharge lamp emitting primarily at Lyα (121.6 nm), a 2 keV electron source, and a substrate-less electrode. Photoionization of organic impurities in the water matrix results in charge pair (electron and ion) separation within the ice, and hence in detectable currents that are measured as a function of the applied bias and the temperature (5 K – 200 K). Photodesorption products are also identified by a quadrupole mass spectrometer (QMS) and correlated with conductivity measurements. We will discuss these results in the context of expected Europa's surface photoconductivity and near-surface volatile production.
References:
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This work has been carried out at Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration, and funded by NASA under Planetary Atmospheres Program Grant "Understanding the Near-Surface Atmospheres of Icy Bodies: Role of Photoionization of Organic Impurities in Icy Surfaces"
Author(s): Demian Marchione[2], Murthy Gudipati[1]
Institution(s): *1. Jet Propulsion Laboratory, 2. JPL/Caltech*

429.08 – Sputtering of the Europa surface by thermal ions from the torus and pickup ions in a diverted flow

Europa's atmosphere is very tenuous and is mainly composed of O_2. It is thought to be produced by ion bombardment of its icy surface. Several ion populations may contribute to this sputtering:
1) The thermal plasma of the torus (~ 1keV including ram velocity), which may be partially diverted around the moon by the ionospheric currents
2) The energetic sulfur and hydrogen ions (~10 keV-MeV), which diffuse inward toward Europa's orbit
3) and possibly the newly ionized O_2 molecules that are picked up by the torus flow and hit the surface.
The relative contribution of each sputtering ion population has been debated for more than three decades with estimated O_2 sputtering rates varying by ~2 order of magnitude. Modelers have historically focused on a single piece of the puzzle: plasma modelers assume a static atmosphere and tend not to check that their sources and losses are consistent with their prescribed atmosphere; while atmospheric modelers neglect the electro-dynamic interaction that diverts torus plasma around the moon, and limits the ion flux to the surface.
In this work, we present a first step to compute self-consistently the atmospheric production by the bombardment of the thermal plasma and pickup O2+ ions.
1) We calculate the plasma flow around Europa with a MHD model
2) We use this flow in a multi-species physical chemistry model of the plasma-atmosphere interaction to compute the ion fluxes into Europa's surface.
3) We compute the production rate of O2 resulting from the ice sputtering by thermal and pickup ions and compare the resulting atmospheric source rate to previously published results.

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429.09 – 3D multispecies collisional model of Ganymede's atmosphere

Ganymede's atmosphere is produced by the interaction of the Sun and of the Jovian magnetosphere with its surface. It is a reflection of Ganymede's surface properties, but also of the complex interaction between the Ganymede and Jupiter magnetospheres. The Exospheric Global Model (EGM) has been developed in order to be able to integrate surface and magnetosphere processes with those in Ganymede's atmosphere. It is a 3D parallelized multi-species collisional model, coupled with LatHys, a hybrid multi-grid 3D multi-species model of Ganymede's magnetosphere (Leclercq et al., Geophys. Res. Let., Submitted, 2016). EGM's description of the species-dependent spatial distribution of Ganymede's atmosphere, its temporal variability during rotation around Jupiter, its connection to the surface, the role of collisions, and respective roles of sublimation and sputtering in producing Ganymede's exosphere, illustrates how modeling combined with in situ and remote sensing of Ganymede's atmosphere can contribute to our understanding of this unique surface-atmosphere-magnetosphere integrated system.

Author(s): Francois Leblanc[1], Ludivine Leclercq[2], Apurva Oza[1], Carl Schmidt[1], Ronan Modolo[2], Jean-Yves Chaufray[2], Robert E. Johnson[3]
Institution(s): *1. LATMOS/CNRS, UPMC Univ. Paris 06 Sorbonne Universités, UVSQ, 2. LATMOS/IPSL, UVSQ Université Paris-Saclay, UPMC Univ. Paris 06,, 3. University of Virginia*

429.10 – Mid-IR Spectral Search for Salt SIgnatures on Europa

We present mid-IR spectra of Europa's leading and trailing hemispheres obtained with the NASA IRTF/TEXES instrument on March 28 and March 30, 2015. The observations span from ~10 – 11 microns with a resolving power of R ~2500. Few observations of Europa have been made at these wavelengths, and the high spectral resolution of the instrument enables the identification of distinguishing spectral features in this relatively unexplored bandpass. While the leading hemisphere of Europa consists of relatively pure water ice, the trailing hemisphere's surface contains a mix of ice and some other component, causing the surface to appear reddish at visible wavelengths. We compare the spectra from the trailing hemisphere with those from the leading, pure-ice hemisphere and with recent laboratory measurements of chlorinated salts, which have distinct spectral signatures at these wavelengths. We find that the signal obtained from Europa's leading hemisphere is 5-10 times lower than the signal obtained from the trailing hemisphere, likely due to a temperature difference between the hemispheres. We discern several spectral features that are present in the trailing hemisphere but not in the spectra of the leading hemisphere, though the explanation for these features is not yet apparent.

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429.11 – Chemistry and Spectroscopy of Frozen Chloride Salts on Icy Bodies

Currently, our understanding of the chemical composition of Europa's surface is our best means of inferring constraints on the subsurface ocean composition and its subsequent habitability. The bulk of our knowledge of Europa surface chemistry can be traced to near infrared spectra recorded by the Near Infrared Mapping Spectrometer on the Galileo spacecraft. However, the usefulness of this and other remote sensing data is limited by the availability of spectral libraries of candidate materials under relevant conditions (temperature, thermal/radiation history, etc.). Chloride salts are expected to exist on the surface of Europa, and other icy bodies, based on geochemical predictions of the ocean composition. In order to help improve our understanding of Europa's surface composition, we have conducted a study of frozen chloride-salt brines prepared under simulated Europa surface conditions (vacuum, temperature, and UV irradiation) using both near IR and Raman spectroscopies. Specifically, Raman spectroscopy was used to determine the hydration states of various chloride salts as a function of temperature. Near IR spectroscopy of identically prepared samples was used to provide reference reflectance spectra of the identified hydrated salts. Our results indicate that at temperatures ranging from 80 K to 233 K, hydrohalite is formed from the freezing of NaCl brines, while the freezing of KCl solutions does not form KCl hydrates. In addition, the freezing of $MgCl_2$ solutions forms a stable hexahydrate, and the freezing of $CaCl_2$ solutions forms a hexahydrate, a tetrahydrate, and a dihydrate. Dehydration of the salts was observed as temperatures were increased, leading to a succession of hydration states in the case of $CaCl_2$.

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429.12 – MAJIS (Moons and Jupiter Imaging Spectrometer): the VIS-NIR imaging spectrometer of the JUICE mission

MAJIS is the VIS-NIR imaging spectrometer of JUICE. This ambitious mission of ESA's « cosmic vision » program will investigate Jupiter and its system with a specific focus on Ganymede. After a tour of more than 3 years including 2 fly-bys of Europa and up to 20 flybys of Ganymede and Callisto, the end of the nominal mission will be dedicated to an orbital phase around Ganymede with 120 days in a near-circular, near-polar orbit at an altitude of 5000 km and 130 days in a circular near-polar orbit at an altitude of 500 km. MAJIS will adress 17 of the 19 primary science objectives of JUICE, investigating the surface and exosphere of the Galilean satellites (Ganymede during the orbital phase, Europa and Callisto during close flybys, Io from a minimum distance of 570,000 km), the atmosphere / exosphere of Jupiter, small satellites and rings, and their role as sources and sinks of particles in the Jupiter magnetosphere.
The main technical characteristics are the following:
Spectral range : 0.5 – 5.7 µm with two overlapping channels (VIS-NIR : 0.5 – 2.35 µm ; IR : 2.25 – 5.7 µm)
Spatial resolution : 0.125 to 0.15 mrad
Spectral sampling (VIS-NIR channel) : 2.9 to 3.45 nm
Spectral sampling (IR channel) : 5.4 to 6.45 nm
The spectral and spatial resolution will be finalized in october 2016 after the selection of the MAJIS detectors.Passive cooling will provide operating temperatures < 130 K (VIS-NIR) and < 90 K (IR) so as to limit the impact of dark current on performances.
The SNR as determined from the photometric model and the noise model will be larger than 100 over most of the spectral range except for high resolution observations of icy moons at low altitude due to limitations on the integration time even with motion compensation provided by a scanner and for exospheric observations due to intrinsic low signal levels.

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Contributing team(s): MAJIS team

429.14 – Exploring A Thermal-Orbital Feedback Mechanism At Europa

We present a geophysical model of the Europa system to describe it's structural, orbital, and thermal states. In doing so, we examine the potential for feedback mechanisms to occur which can produce oscillatory behavior in shell thickness, eccentricity, and heat flux, due to the coupled nature of the relevant processes. We implement a tidal heating model to describe the heat flux into the body. This model depends primarily on the shell structure as well as the orbital eccentricity. The model has the capacity to consider multilayered bodies for which the interior structure can evolve over time. Furthermore, the tidal heating model is fully three dimensionally resolved, having the ability to predict radial and lateral variations in heating throughout Europa. This allows us to predict particular locations on Europa that should have the maximum surface heat flux. This heating model is coupled to the orbital evolution as well. Tidal dissipation pulls energy out of the orbit, effectively reducing the semi-major axis and eccentricity, circularizing the orbit. This would slow, and even shut down, the tidal heating at Europa, however, the Galilean Satellites' Laplace resonance continuously transfers energy back into Europa's orbit, keeping the tidal dissipation active. We compare the tidal heat input to the heat conducted out of the ice shell, which is a function of shell thickness, among other things. Heat transfer into or out of the ice compensates any imbalance of heat. This heating, in turn, leads to structural variations of the shell. For example, if tidal heating is greater than the heat conducted out of the shell, the remaining balance goes into sensible and latent heats which thin the shell (thus increasing the surface heat output to balance that which is tidally input). Oppositely, when conducted heat output is greater than the tidal heating, the shell thickens. Shell thickness variations then result in global extension or contraction, due to the density difference between the ice and water. We predict the timescales for these variations and the strain and stress expected from such mechanisms. We further report the eccentricity of Europa's orbit over time, as well as the satellites surface heat flux history.

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429.15 – DIY EOS: Experimentally Validated Equations of State for Planetary Fluids to GPa Pressures, Tools for Understanding Planetary Processes and Habitability

Sound speeds are fundamental to seismology, and provide a path allowing the accurate determination of thermodynamic potentials. Prior equations of state (EOS) for pure ammonia (Harr and Gallagher 1978, Tillner-Roth et al. 1993) are based primarily on measured densities and heat capacities. Sound speeds, not included in the fitting, are poorly predicted.

We couple recent high pressure sound speed data with prior densities and heat capacities to generate a new equation of state. Our representation fits both the earlier lower pressure work as well as measured sound speeds to 4 GPa and 700 K and the Hugoniot to 70 GPa and 6000 K.

In contrast to the damped polynomial representation previously used, our equation of state is based on local basis functions in the form of tensor b-splines. Regularization allows the thermodynamic surface to be continued into regimes poorly sampled by experiments. We discuss application of this framework for aqueous equations of state validated by experimental measurements. Preliminary equations of state have been prepared applying the local basis function methodology to aqueous NH_3, Mg_2SO_4, NaCl, and Na_2SO_4. We describe its use for developing new equations of state, and provide some applications of the new thermodynamic data to the interior structures of gas giant planets and ocean worlds.

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429.16 – Slush Fund: Ice's Multiphase Evolution and Its Role in Shaping Europa

The role of Europa's ice shell in mediating ocean-surface interaction, constraining potential habitability of the underlying hydrosphere, and dictating the surface morphology of the moon has been discussed in the literature for years, yet the dynamics and characteristics of the shell itself remain largely unconstrained. These discrepancies likely arise from underrepresented physics and varying *a priori* assumptions built into the current ice shell models. Presented here is a two-phase reactive porous media model of Europa's ice shell evolution, inspired by successful contemporary sea ice models, designed to capture the multiphase nature of forming ice as well as eliminate the need for *a priori* assumptions about ice shell structure and properties. The design of the model is such that it temporally and spatially constructs the ice shell from a first principles approach, allowing for accurate simulation of the shell's thermodynamic and compositional properties from the beginning of its formation up to its current state. This methodology provides explicit predictions of the ice's two-phase behavior, including heat and mass transfer, which ultimately dictate the shell's composition, density, and eutectic properties. All of which have been suggested as key factors in facilitating ocean-surface interaction, understanding the ocean's potential habitability, and shaping the moons surface. Preliminary results and their potential impact on how we understand Europa's evolution and dynamics will be discussed.

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429.17 – Radar attenuation in Europa's ice shell: obstacles and opportunities for constraining shell thickness and thermal structure

With its strikingly young surface and possibly recent endogenic activity, Europa is one of the most exciting bodies within our Solar System and a primary target for spacecraft exploration. Future missions to Europa are expected to carry ice penetrating radar instruments which are powerful tools to investigate the subsurface thermophysical structure of its ice shell.

Several authors have addressed the 'penetration depth' of radar sounders at icy moons, however, the concept and calculation of a single value penetration depth is a potentially misleading simplification since it ignores the thermal and attenuation structure complexity of a realistic ice shell. Here we move beyond the concept of a single penetration depth by exploring the variation in two-way radar attenuation for a variety of potential thermal structures of Europa's ice shell as well as for a low loss and high loss temperature-dependent attenuation model. The possibility to detect brines is also investigated.

Our results indicate that: (i) for all ice shell thicknesses investigated (5-30 km), a nominal satellite-borne radar sounder will penetrate between 15% and 100% of the total thickness, (ii) the maximum penetration depth strongly varies laterally with the deepest penetration possible through the cold downwellings, (iii) the direct detection of the ice/ocean interface might be possible for shells of up to 15 km if the radar signal travels through the cold downwelling, (iv) even if the ice/ocean interface is not detected, the penetration through most of the shell could constrain the deep shell structure through the loss of signal, and (v) for all plausible ice shells the two-way attenuation to the eutectic point is ≤30 dB which shows a robust potential for longitudinal investigation of the ice shell's shallow structure.

Part of this work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. K.K. acknowledges support by the Grant Agency of the Czech Republic through project 15-14263Y.

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429.18 – Modeling planetary seismic data for icy worlds and terrestrial planets with AxiSEM/Instaseis: Example data and a model for the Europa noise environment

Seismology is one of our best tools for detailing interior structure of planetary bodies, and seismometers are likely to be considered for future lander missions to other planetary bodies after the planned landing of InSight on Mars in 2018. In order to guide instrument design and mission requirements, however, it is essential to model likely seismic signals in advance to determine the most promising data needed to meet science goals. Seismic data for multiple planetary bodies can now be simulated rapidly for arbitrary source-receiver configurations to frequencies of 1 Hz and above using the numerical wave propagation codes AxiSEM and Instaseis (van Driel et al., 2015) using 1D models derived from thermodynamic constraints (e.g. Cammarano et al., 2006). We present simulations for terrestrial planets and icy worlds to demonstrate the types of seismic signals we may expect to retrieve. We also show an application that takes advantage of the computational strengths of this method to construct a model of the thermal cracking noise environment for Europa under a range of assumptions of activity levels and elastic and anelastic structure.

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429.19 – New global maps of Europa's lineaments

Physical models have been developed to successfully explain the orientations and locations of many fractures observed on Europa's surface. Between the different fractures located on the surface of the icy satellite global-scale lineaments are present. These features are correlated with tidal stress suggesting that they initiated at tensile cracks in response to non-synchronous rotation (Geissler et al., 1998, Geissler et al. 1999). In this work we completed a global map of all type of lineaments presented on the surface of Europa, including also cycloidal lineaments that are interpreted to be tensile cracks that form due to diurnal stresses from Europa's orbital eccentricity (Hoppa et al., 1999).

We enhanced the mapping of lineaments in comparison to what previously published, tracking about 5500 lineaments located everywhere on the surface of the icy satellite. We analyze these features in terms of their orientation and location using 2D methods, such as stereo plots and rose diagrams, showing that our preliminary results are in agreement with previous studies (McEwen et al. 1986). In addition, we visualize our results taking into account the 3D information to perform a detailed analysis of lineaments constraining their orientation and behavior. The aim of this work is to characterize the mapped lineaments and investigate the timing of their formation in order to correlate our results with proposed stress pattern models.

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429.20 – The Effect of Bands and Ridges on Chaos Formation on Europa

Europa presents a dynamic and varied surface, but the most enticing component is arguably its chaos structures. With it, the surface and subsurface can interact, but in order to fully understand if this is occurring we have to properly parameterize the surface structural integrity. We consider the Schmidt et al. (2011) method of classifying icebergs by feature type to study what features remained intact in the chaos matrix. In this work we expand on this idea. We hypothesize that ridges and bands exhibit higher structural strengths than plains. Subsequently, less of the stronger band or ridge material is destroyed during chaos formation than plains material, leaving behind large blocks of ice (i.e. icebergs) comprised mainly of ridges and bands, with matrix formed predominantly from plains materials. We begin by mapping the surface at and near Murias chaos including surrounding chaos regions. Maps are used to infer what paleo-topographic features existed before each chaos formed. We perform a multivariate regression to correlate the amount of icebergs present to the amount of surface that was covered by either bands, plains, or ridges. We find ridges play the biggest role in the production of icebergs with a weighted value of 40%. Bands may play a smaller role (13%), but plains show little to no correlation (5%). Further mapping will better reveal if this trend holds true in other regions. This statistical analysis supports our hypothesis, and further work will better quantify what is occurring. We will address the energy expended in the chaos regions via movement and rotation of icebergs during the formation event and through ice-melt.

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429.21 – Jupiter and Mutual Satellite Occultations of Io from 1985 to 2015

Occultations of Io by Jupiter and by other satellites provide a long-term record of the brightness of individual volcanic hotspots. They also provide our highest spatial resolution observations of individual volcanic centers such as Loki. We are in the process of reanalyzing observations spanning the years 1985 through 2015 for submission to the NASA Planetary Data System. The Jupiter occultation observations have spatial resolution limited to roughly the Jupiter atmospheric scale height (22 km) but as these events occur every Io orbit we have data on over 100. They include observations from the NASA-IRTF, WIRO, Lowell, and other telescopes on Mauna Kea. Part of this data set originally revealed the semi-periodic nature of the activity at Loki (Rathbun et al. 2002). A series of mutual satellite occultations occurs only every six years but the sharp limb of the other satellite allows for much higher spatial resolution. The original analysis was limited by inaccuracies in the satellite ephemerides but improvements now allow us to more reliably assign brightnesses to individual hotspots. They also allow improved image reconstructions of individual spots from mutual events. We will report on our tests of that better ephemeris, the improved assignment of hotspot brightnesses, and the reconstructed mutual event images.

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429.22 – Monitoring the Near-infrared Volcanic Flux from Io's Jupiter-facing Hemisphere from Fan Mountain Observatory

Fan Mountain Observatory, near Charlottesville, Virginia, is a dark-sky site that supports a number of telescopes including a 31-inch reflecting telescope equipped with a 1024x1024 HgCdTe 1-2.5 um (YJHK) imager. Reflected sunlight ordinarily overwhelms Io's comparatively weak K-band (2.0-2.4 um) volcanic emission in unresolved observations, however when Io is eclipsed in Jupiter's shadow even a small infrared-equipped telescope can detect Io's volcanic emission. The Fan Mountain Infrared Camera observed Io in eclipse at regular intervals, typically weekly, during the few months before and after Jupiter's March 2016 opposition. When in eclipse Io's Jupiter-facing hemisphere is oriented toward Earth with sub-Earth longitudes at the time of observation ranging from 345 - 360 degrees (pre-opposition) to 0 - 15 degrees (post-opposition). A K-band filter (2.04-2.42 um) provided a bulk measurement of Io's volcanic flux weighted largely toward the 2.4 um end of this filter given the typical 500K color temperature of the volcanic emission. Most epochs also included observation in a narrowband filter centered at 2.12 um that, when combined with the broadband "long" wavelength measurement, provided a proxy for color temperature. The K-band flux of Io varied by more than 2 magnitudes during the 7 month observation interval. The [2.12 um - K-band] color of the emission strongly correlated with the K-band flux in the expected sense that the color temperature of the emission increased when Io's broadband volcanic flux was the greatest. One epoch of TripleSpec near-IR Io eclipse spectroscopy (0.90 - 2.45 um; R~3000) from the Apache Point Observatory 3.5-meter telescope provided ground truth for transforming the filter photometry into quantitative temperatures.

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429.23 – Quantitative measurements of active Ionian volcanoes in Galileo NIMS data

Io is the most volcanically active body in our solar system. The spatial distribution of volcanoes a planetary body's surface gives clues into its basic inner workings (i.e., plate tectonics on earth). Tidal heating is the major contributor to active surface geology in the outer solar system, and yet its mechanism is not completely understood. Io's volcanoes are the clearest signature of tidal heating and measurements of the total heat output and how it varies in space and time are useful constraints on tidal heating. Hamilton et al. (2013) showed through a nearest neighbor analysis that Io's hotspots are globally random, but regionally uniform near the equator. Lopes-Gautier et al. (1999) compared the locations of hotspots detected by NIMS to the spatial variation of heat flow predicted by two end-member tidal heating models. They found that the distribution of hotspots is more consistent with tidal heating occurring in asthenosphere rather than the mantle. Hamilton et al. (2013) demonstrate that clustering of hotspots also supports a dominant role for asthenosphere heating. These studies were unable to account for the relative brightness of the hotspots. Furthermore, studies of the temporal variability of Ionian volcanoes have yielded substantial insight into their nature. The Galileo Near Infrared Mapping Spectrometer (NIMS) gave us a large dataset from which to observe active volcanic activity. NIMS made well over 100 observations of Io over an approximately 10-year time frame. With wavelengths spanning from 0.7 to 5.2 microns, it is ideally suited to measure blackbody radiation from surfaces with temperatures over 300 K. Here, we report on our effort to determine the activity level of each hotspot observed in the NIMS data. We decide to use 3.5 micron brightness as a proxy for activity level because it will be easy to compare to, and incorporate, ground-based observations. We fit a 1-temperature blackbody to spectra in each grating position and averaged the results to get a temperature and area (with uncertainties) for each pixel. From these results, we calculate 3.5 micron brightness (with uncertainties).

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429.24 – Deconvolution of IRTF Observations of Jupiter's Moon Io

Io is a active volcanic world with a heat output more than 40 times that of earth. While spacecraft have been used to study Io's volcanoes, their high level of variability requires Earth-based observations to reveal their eruptions in the absence of spacecraft data. Our nearly 20 years of observations from the NASA InfraRed Telescope Facility (IRTF) have been used to monitor volcanic eruptions on Io. Our observations allow us not only to better understand the eruption properties of Ionian volcanoes, but also how the volcanic eruptions affect the rest of the Jovian system, such as the Io plasma torus, sodium clouds, Jovian magnetosphere, and aurorae. While our Jupiter occultation lightcurves of an eclipsed Io have been the focus of this program, due to their ability to determine volcano brightnesses and 1D locations, those observations only allow us to measure volcanic eruptions on the sub-Jovian hemisphere. We also observe Io in reflected sunlight so that we can observe other longitudes on Io. But, brighter eruptions are required for us to be able to distinguish them above the reflected sunlight. We are able to increase the spatial resolution of these images of in order to detect and locate fainter hotspots. We have employed shift-and-add techniques using multiple short exposures to detect eruptions in the past (Rathbun and Spencer, 2010). We will report on the use of publically available deconvolution algorithms to further improve spatial resolution and hot spot detectability, using images of a standard star as our PSF, including experiments with performing the deconvolution both before and after shift and add. We will present results of observations from 2007 and 2013.

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429.25 – Measuring Io's Lava Eruption Temperatures with a Novel Infrared Detector and Digital Readout Circuit

One method of determining lava eruption temperature of Io's dominant silicate lavas is by measuring radiant flux at two or more wavelengths and fitting a black-body thermal emission function. Only certain styles of volcanic activity are suitable, those where thermal emission is from a restricted range of surface temperatures close to eruption temperature. Such processes include [1] large lava fountains; [2] fountaining in lava lakes; and [3] lava tube skylights. Problems that must be overcome are (1) the cooling of the lava between data acquisitions at different wavelengths; (2) the unknown magnitude of thermal emission, which often led to detector saturation; and (3) thermal emission changing on a shorter timescale than the observation integration time. We can overcome these problems by using the HOT-BIRD detector [4] and an advanced digital readout circuit [5]. We have created an instrument model that allows different instrument parameters (including mirror diameter, number of signal splits, exposure duration, filter band pass, and optics transmissivity) to be tested so as to determine eruption detectability. We find that a short-wavelength infrared instrument on an Io flyby mission can achieve simultaneity of observations by splitting the incoming signal for all relevant eruption processes and obtain data fast enough to remove uncertainties in accurate determination of the highest lava surface temperatures exposed. Observations at 1 and 1.5 µm are sufficient to do this. Lava temperature determinations are also possible with a visible wavelength detector [3] so long as data at different wavelengths are obtained simultaneously and integration time is very short. This is especially important for examining the thermal emission from lava tube skylights [3] due to rapidly-changing viewing geometry during close flybys. References: [1] Davies et al., 2001, JGR, 106, 33079-33104. [2] Davies et al., 2011, GRL, 38, L21308. [3] Davies et al., 2016, Icarus, in press. [4] Ting et al., 2012, Barrier infrared detector, U.S. Pat. No. 8217480. [5] Schultz et al., 2014, LL Journal, 20, 2, 36-51. This work was performed at the Jet Propulsion Laboratory–California Institute of Technology, under contract to NASA.

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500 – Martian Geology and Habitability

500.01 – Spectral characterization of volcanic rocks in the VIS-NIR for martian exploration

Igneous effusive rocks cover much of the surface of Mars [1,2,3]. Initially only two types of lithologies were thought to constitute the Martian crust, i.e. a basaltic one and a more andesitic one [1,2], while more evolved lithologies were ruled out.
Nevertheless a more complex situation is appearing in the last years. Recently several observations have highlighted the presence of evolved, acidic rocks. High-silica dacite units were identified in Syrtis Major caldera by thermal IR data [4]. Outcrops in Noachis Terra were interpreted as constituted of felsic (i.e. feldspar-rich) rocks essentially by the observation of a 1.3-μm spectral feature in CRISM data, attributed to Fe^{2+} in feldspars [5]. However different interpretations exist, invoking plagioclase-enriched basalts [6] rather than felsic products.
The increasing of high-resolution and in-situ rover-based observations datasets and the changing of the initial paradigm justify a new systematic spectral study of igneous effusive rocks. In this work we focus on the spectral characterization of volcanic effusive rocks in the 0.35-2.5-μm range. We are carrying out measurements and spectral analyses on a wide ensemble of effusive samples, from mafic to sialic, with variable alkali contents, following the classification in the Total-Alkali-Silica diagram, and discussing the influence on spectral characteristics of different mineral assemblages and/or texture ([7], [8]).

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500.02 – Properties of the Medussae Fossae Formation and its relation to the volcanic history of Mars

Medussae Fossae (MFF) is a well known formation, stretching west of Tharsis volanoes. It is characterized as a relatively young Amazonian units (Amm, Amu), due to widespread signs of erosion. Earth based imaging radar observations at 3.5 cm [1] and 12 cm [2] have discovered a dark radar feature (Stealth), which roughly correlates with the MFF outline.
Recent investigations [3], suggested that the unit emplacement is in fact during Hesperian period, but it is composed of material that can be easily eroded. It is not clear when the erosion happened and if it is a continuing process. Hypotheses on MFF formation range from volcanic material emplacement (ash flow tuffs or pyroclastic materials) to an ice-rich dusty mantle, deposited during high obliquity.
In this work, we will present the latest observations of the East Medussae Fossae formation by the long wavelength MARSIS radar, continuing the work reported in [4], as well as complementing data surveyed by SHARAD data in [5]. The MARSIS radar has detected strong subsurface interfaces in the areas of Gordi and Eumenides Dorsae at depths up to 1.5km. We will present our analysis of the data, inferring the dielectric properties of the material to constrain properties of the material constituting the Medusae Fossae formation. We will also demonstrate an efficient user interface to work with MARSIS data inside a Geographical Information System (GIS).

The research leading to these results has received funding from the European Unions Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement 607379.

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500.03 – Polygonal Ridge Networks on Mars

Polygonal ridge networks, also known as boxwork or reticulate ridges, are found in numerous locations and geological contexts across Mars. While networks formed from mineralized fractures hint at hot, possibly life-sustaining circulating ground waters, networks formed by impact-driven clasting diking, magmatic dikes, gas escape, or lava flows do not have the same astrobiological implications. Distinguishing the morphologies and geological context of the ridge networks sheds light on their potential as astrobiological and mineral resource sites of interest. The most widespread type of ridge morphology is characteristic of the Nili Fossae and Nilosyrtis region and consists of thin, criss-crossing ridges with a variety of heights, widths, and intersection angles. They are found in ancient Noachian terrains at a variety of altitudes and geographic locations and may be a mixture of clastic dikes, brecciated dikes, and mineral veins. They occur in the same general areas as valley networks and ancient lake basins, but they are not more numerous where these features are concentrated, and can appear in places where they morphologies are absent. Similarly, some of the ridge networks are associated with hydrated mineral detections, but some occur in locations without detections. Smaller, light-toned ridges of variable widths have been found in Gale Crater and other rover sites and are interpreted to be smaller version of the Nili-like ridges, in this case formed by the mineralization of fractures. This type of ridge is likely to be found in many other places on Mars as more high-resolution data becomes available. Hellas Basin is host to a third type of ridge morphology consisting of large, thick, light-toned ridges forming regular polygons at several superimposed scales. While still enigmatic, these are most likely to be the result of sediment-filled fractures. The Eastern Medusae Fossae Formation contains large swaths of a fourth, previously undocumented, ridge network type. The dark ridges, reaching up to 50 m in height, enclose regular polygons and erode into dark boulders. These ridge networks are interpreted to form as a result of lava flow embayment of deeply fractured Medusae Fossae Formation outcrops.

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500.04D – Insights into the stratigraphy of Mars' northern plains from impact crater mineralogy

The northern lowland of Mars has an ancient basement, buried underneath widespread Hesperian lavas and outflow channel sediments, and may have recorded geologic and aqueous activity related to global climate, e.g., the existence of a northern ocean. To better understand the geologic record of this depositional basin, we conducted a comprehensive survey of the mineralogy of northern plains impact craters, using 1905 images covering 689 impact craters, acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) onboard the Mars Reconnaissance Orbiter (MRO). Mafic minerals are detected in 33% of all the craters, and hydrated minerals in 10% of the craters. Thus, though the northern plains surface is relatively spectrally homogeneous, the subsurface is spectrally diverse and includes a set of mafic (olivine and pyroxene) and hydrated minerals (Fe/Mg phyllosilicate, chlorite/prehnite, hydrated silica etc.) similar to the southern highlands. The distribution of hydrated minerals, especially Fe/Mg phyllosilicates, is more concentrated in large craters, while mafic minerals are relatively insensitive to crater size. This is consistent with a deeper origin for hydrated minerals compared to mafic minerals, or alternatively the post-impact formation of hydrated minerals due to impact-induced hydrothermal alteration only in the largest craters. Under the assumption of excavation from depth, we calculate the possible origin of these hydrated minerals to be -5000 ~ -6000 m relative to the global Mars Orbital Laser Altimeter (MOLA) datum, possibly representing the ancient basement buried by 1-2 km layer with mafic minerals. In contrast, the mafic materials are derived from only ~200 m deep. We also delineate several distinct topographic and geographic provinces. The large number of mafic mineral detections in Chryse Planitia probably indicates the influence of a local volcanic source; and Arcadia and Amazonis Planitiae probably have been resurfaced more recently, leaving few detections of mafic or hydrated minerals. Detailed mapping using high-resolution imagery over regions of interest will continue to bring insights into the regional stratigraphy and possible geologic or aqueous processes involved.

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500.05 – Multispectral Imaging of Mars from the Mars Science Laboratory Mastcam Instruments: Spectral Properties and Mineralogic Implications Along the Gale Crater Traverse

The Mars Science Laboratory (MSL) Curiosity rover Mastcam is a pair of multispectral CCD cameras that have been imaging the surface and atmosphere in three broadband visible RGB color channels as well as nine additional narrowband color channels between 400 and 1000 nm since the rover's landing in August 2012. As of Curiosity sol 1159 (the most recent PDS data release as of this writing), approximately 140 multispectral imaging targets have been imaged using all twelve unique bandpasses. Near-simultaneous imaging of an onboard calibration target allows rapid relative reflectance calibration of these data to radiance factor and estimated Lambert albedo, for direct comparison to lab reflectance spectra of rocks, minerals, and mixtures. Surface targets among this data set include a variety of outcrop and float rocks (some containing light-toned veins), unconsolidated pebbles and clasts, and loose sand and soil. Some of these targets have been brushed, scuffed, or otherwise disturbed by the rover in order to reveal the (less dusty) interiors of these materials, and those targets and each of Curiosity's drill holes and tailings piles have been specifically targeted for multispectral imaging.
Analysis of the relative reflectance spectra of these materials, sometimes in concert with additional compositional and/or mineralogic information from Curiosity's ChemCam LIBS and passive-mode spectral data and CheMin XRD data, reveals the presence of relatively broad solid state crystal field and charge transfer absorption features characteristic of a variety of common iron-bearing phases, including hematite (both nanophase and crystalline), ferric sulfate, olivine, and pyroxene. In addition, Mastcam is sensitive to a weak hydration feature in the 900-1000 nm region that can provide insight on the hydration state of some of these phases, especially sulfates. Here we summarize the Mastcam multispectral data set and the major potential phase identifications made using that data set during the traverse so far in Gale crater, and describe the ways that Mastcam multispectral observations will continue to inform the ongoing ascent and exploration of Mt. Sharp, Gale crater's layered central mound of sedimentary rocks.

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500.06 – Cadence and cause of lake-forming climates on Mars

Paleolakes on Mars record a sustained hydrologic cycle, but soils upstream record a largely dry past, so lake-forming climates were intermittent. The cadence of lakes on Mars is constrained by relatively young (~3 Ga) deltas and alluvial fans. Deposit build-up required lakes to persist for >2 Kyr (assuming dilute flow), but the watersheds' little-weathered soils indicate a swift return to dry conditions. The lake-forming climates' duty cycle and trigger mechanism remain unknown. Here we show that these data are inconsistent with many previously-proposed triggers for lake-forming climates, but consistent with a novel CH_4-burst mechanism. Assuming runoff was sourced from snowmelt, SO_2- and impact-triggered warming are too brief, and H_2-enabled warming too persistent, to match data. However, chaotic transitions in mean obliquity are a potential trigger with suitable cadence. Mean-obliquity transitions drive latitudinal shifts in temperature and ice loading that destabilize CH_4 clathrate. For achievable hydrate stability zone occupancy fractions, CH_4 builds up to levels whose direct radiative forcing is comparable to a quadrupling of CO_2 (20 W/m^2), and sufficient to modulate lake-forming climates. Sub-lake CH_4destabilization provides positive feedback. Photolysis of CH_4 curtails individual lake-forming climates to 10^5-10^6 yr duration, and depletion of CH_4-clathrate limits lake-forming climates to 1-3 in number, consistent with intermittency data. We further propose that Mars' first atmospheric collapse could drive ice sheets from highlands to poles, destabilizing sub-ice clathrate and triggering the formation of the ~4 Ga-old valley networks. Our results show how a warmer early Mars can undergo intermittent orbitally-triggered excursions to a warm, wet climate state.

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500.07 – Acidic Conditions During Open System Weathering on Late Noachian/Early Hesperian Mars? Newly Identified Outcrops of Alunite and Jarosite from Orbital CRISM Data

Sequences of Al-phyllosilicates atop Fe,Mg-phylloslicates occur in multiple regions of Mars, including Mawrth Vallis/northern Arabia Terra, Nili Fossae/Northeast Syrtis Major, Terra Sirenum/Eridania basin, northern Hellas, and portions of Valles Marineris. The sequences are exposed beneath unaltered capping materials with Early Hesperian surface ages, thus implying phyllosilicate formation occurred earlier. Because of the presence of clay minerals, the sequences are certainly a product of water interactions with rocks and sediments, but key questions remain about the environmental conditions implied. Are Al-phyllosilicates simply a result of alteration of a silicic precursor? Or do they represent the end product of substantial open system leaching of a basaltic protolith? Was open system leaching substantial because of high water throughput, long cumulative duration, acidity, or some combination? Each scenario leads to Al-phyllosilicate formation but with different accompanying mineral phases in response to pH, Eh, and chemical species concentrations in the fluids. Key to further progress in constraining the environmental conditions of alteration is more sophisticated spectral analyses to identify intermixed phases and isolate rare spectral classes within the Al phyllosilicate units.

Here, we employ a newly developed, non-parametric Bayesian algorithm [1] for semi-automatic identification of rare spectral classes. We employ this algorithm on 139 CRISM images in areas with reported regional-scale occurrences of Al-phyllosilicates that were compiled from the literature [e.g. 2, 3]. Dozens of detections of the minerals alunite and jarosite were made with the algorithm and then verified by manual analysis. These sulfate hydroxides form only at low pHs, and thus their presence tightly constrains water chemistry. Crucial for understanding whether the alunite and jarosite deposits are contemporaneous with the Al phyllosilicates or later overprinting deposits is study of their stratigraphy at high resolution with the HiRISE and CTX cameras. This is presently ongoing and we will report final results.

[1] Dundar et al., 2016, IEEE WHISPERS procedings
[2] Ehlmann et al., 2011, Nature
[3] Carter et al., 2015, Icarus

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500.08 – Formation of oxidizing species via irradiation of perchlorates using high-energy electrons and D_2^+ ions

The perchlorate ion (ClO_4^-) has garnered particular interest in recent years following the discovery of perchlorate salts in the Martian regolith at levels of 0.4–0.6 wt% by the Phoenix lander in 2006 and Mars Science Laboratory's Curiosity rover in 2013. Due to their oxidizing properties, perchlorates are suspected to play a contributing role to the surprising lack of organics on the Martian surface. In this study, magnesium perchlorate hexahydrate ($Mg(ClO_4)_2 \bullet 6H_2O$) samples were irradiated with monoenergetic beams of 5 keV electrons and D_2^+ ions separately, sequentially, and simultaneously to simulate the effects of galactic cosmic ray exposure of perchlorates. The irradiation experiments were carried out under ultra-high vacuum conditions at 50 K, after which the samples were slowly heated to 300 K (0.5 K min^{-1}) while desorbing products were monitored by quadrupole mass spectrometry. In all cases, molecular oxygen (O_2) was detected upon the onset of irradiation and again during the warmup phase. In the case of simultaneous irradiation, deuterated water (D_2O) and deuterium peroxide (D_2O_2) were also detected as the sample was heated whereas in the D_2^+ experiment small amounts of D_2O_2 was found exclusively. When samples were irradiated sequentially, the production of D_2O_2 was dependent upon the sample being irradiated with D_2^+ ions prior to electrons. These experiments show that perchlorates are capable of producing multiple oxidizing agents (O_2, D_2O_2) which may also account for the lack of organics on the Martian surface.

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500.09 – Evolution of organic molecules under Mars-like UV radiation with EXPOSE-R2, a photochemistry experiment outside the International Space Station

The detection and identification of organic molecules on Mars are of prime importance, as some of these molecules are life precursors and components. While *in situ* planetary missions are searching for them, it is essential to understand how organic molecules evolve and are preserved at the surface of Mars. Indeed the harsh conditions of the environment of Mars such as ultraviolet (UV) radiation or oxidative processes could explain the low abundance and diversity of organic molecules detected by now.

The EXPOSE R2 facility has been placed in low Earth orbit (LEO) under solar radiation, outside the International Space Station (ISS) in 2014. One of the EXPOSE R2 experiment, called PSS (Photochemistry on the Space Station), is dedicated to astrobiology- and astrochemistry-related studies. Part of PSS samples have been dedicated to the study of the evolution of organic molecules under Mars-like surface radiation conditions. Indeed, UV radiation above 200 nm reaches the surface of Mars and could degrade organic matter. Organic samples have been exposed directly to the Sun under KBr filters (>200 nm) from November 2014 to February 2016, mimicking the UV radiation conditions of the surface of Mars. Four types of samples were exposed as thin layers of solid molecules: adenine, adenine with nontronite (a kind of clay mineral detected on Mars), chrysene and glycine with nontronite.

To characterize the evolution of our samples under irradiation, infrared (IR) transmission analyses were performed, before the launch of EXPOSE R2 to the ISS in 2014, and after the exposure in space and the return on Earth, this year. These analyses allowed determining whether each molecule is preserved or photodegraded, and if so, its photolysis rate. The effect of nontronite on organic molecules preservation has been investigated as well. We also compared these results from LEO with laboratory data, obtained by irradiating organic samples under a UV lamp.

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501 – Jovian Atmosphere III: Giant Planet Dynamics

501.01 – Dynamics of Giant Planet Polar Vortices

The polar atmospheres of the giant planets have come under increasing interest since a compact, warm-core, stable, cyclonic polar vortex was discovered at each of Saturn's poles. In addition, the south pole of Neptune appears to have a similar feature, and Uranus' north pole is exhibiting activity that could indicate the formation of a polar vortex. We investigate the formation and maintenance of these giant planet polar vortices by varying several key atmospheric dynamics parameters in a forced-dissipative, 1.5-layer shallow water model. Our simulations are run using the EPIC

(Explicit Planetary Isentropic Coordinate) global circulation model, to which we have added a gamma-plane rectangular grid option appropriate for simulating polar atmospheric dynamics.
In our numerical simulations, we vary the atmospheric deformation radius, planetary rotation rate, storm forcing intensity, and storm vorticity (cyclone-to-anticyclone) ratio to determine what combination of values favors the formation of a polar vortex. We find that forcing the atmosphere by injecting small-scale mass perturbations ("storms") to form either all cyclones, all anticyclones, or equal numbers of both, may all result in a cyclonic polar vortex. Additionally, we examine the role of eddy momentum convergence in the intensification and maintenance of a polar cyclone.
Our simulation results are applicable to understanding all four of the solar system giant planets. In the future, we plan to expand our modeling effort with a more realistic 3D primitive equations model, also with a gamma-plane rectangular grid using EPIC. With our 3D primitive equations model, we will study how various vertical atmospheric stratification structures influence the formation and maintenance of a polar cyclone. While our shallow-water model only involves storms of a single layer, a 3D primitive equations model allows us to study how storms of finite vertical extent and at differing levels in the atmosphere may further favor, or preclude the emergence of a polar cyclone.

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501.02 – Physical and Chemical Properties of Jupiter's Polar Vortices and Regions of Auroral Influence Revealed Through High-Resolution Infrared Imaging

We report characterization of the physical and chemical properties of Jupiter's polar regions derived from mid-infrared imaging of Jupiter covering all longitudes at unprecedented spatial resolution using the COMICS instrument at the Subaru Telescope on the nights of January 24 and 25, 2016 (UT). Because of Jupiter's slight axial tilt of 3°, the low angular resolution and incomplete longitudinal coverage of previous mid-infrared observations, the physical and chemical properties of Jupiter's polar regions have been poorly characterized. In advance of the Juno mission's exploration of the polar regions, this study focuses on mapping the 3-dimensional structure of Jupiter's polar regions, specifically to characterize the polar vortices and compact regions of auroral influence. Using mid-infrared images taken in the 7.8 - 24.2 µm range, we determined the 3-dimensional temperature field, mapped the para-H_2 fraction and aerosol opacity at 700 mbar and lower pressures, and constrained the distribution of gaseous NH_3 in Jupiter's northern and southern polar regions. Retrievals of these atmospheric parameters was performed using NEMESIS, a radiative transfer forward model and retrieval code. Preliminary results indicate that there are vortices at both poles, each with very distinct low-latitude boundaries approximately 60° (planetocentric) from the equator, which can be defined by sharp thermal gradients extending at least from the upper troposphere (500 mbar) and into the stratosphere (0.1 mbar). These polar regions are characterized by lower temperatures, lower aerosol number densities, and lower NH_3 volume mixing ratios, compared with the regions immediately outside the vortex boundaries. These images also provided the highest resolution of prominent auroral-related stratospheric heating to date, revealing a teardrop-shaped morphology in the north and a sharp-edged oval shape in the south. Both appear to be contained inside the locus of H_3^+ auroral emission detected at 3.417 µm two nights later at NASA's Infrared Telescope Facility using the SpeX guide camera.

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501.03 – Formation of a Bright Polar Hood over the Summer North Pole of Saturn in 2016

We report that a bright polar hood has formed over the north pole of Saturn, seen first in images captured by the Cassini ISS camera in 2016. When the north pole was observed during the previous period of Cassini spacecraft's high-inclination orbits in 2012-2013, the concentration of light-scattering aerosols within 2-degree latitude of the north pole appeared to be less than that of the surrounding region, and appeared as a dark hole in all ISS filters, in particular in the shorter wavelength filters BL1 (460 nm), and VIO (420 nm). The north pole's appearance in 2012 was in contrast to that of the south pole in 2007, when the south pole had a bright polar hood in those short wavelengths; the south pole appeared dark in all other ISS filters in 2007. The difference between the south pole in 2007 and the north pole in 2012 was interpreted to be seasonal; in 2007, Saturn was approaching the equinox of 2009 and the south pole had been continuously illuminated since the previous equinox in 1995. In 2012, the north pole had been illuminated for only ~3 years after the long winter polar night. The bright hood over the summer south pole in 2007 was hypothesized to consist of aerosols produced by ultraviolet photodissociation of hydrocarbon molecules. Fletcher et al (2015) predicted that a similar bright hood should form over the north pole as Saturn approaches the 2017 solstice. In 2016, the Cassini spacecraft raised its orbital inclination again in preparation for its Grande Finale phase of the mission, from where it has a good view of the north pole. New images captured in 2016 show that the north pole has developed a bright polar hood. We present new images of the north polar region captured in 2016 that show the north pole, and other seasonally evolving high-latitude features including the northern hexagon. Our research has been supported by the Cassini Project, NASA grants OPR NNX11AM45G, CDAPS NNX15AD33G PATM NNX14AK07G, and NSF grant AAG 1212216.

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501.04 – Zonal jets and QBO-like oscillations on Jupiter and Saturn

At the levels of their visible cloud decks, the giant planets Jupiter and Saturn exhibit numerous east-west (zonal) jet streams with speeds ranging up to 150 m/sec on Jupiter and 400 m/sec on Saturn. Moreover, both planets exhibit long-term stratospheric oscillations involving perturbations of zonal wind and temperature that propagate downward over time on timescales of ~4 years (Jupiter) and ~15 years (Saturn). These oscillations, dubbed the Quasi Quadrennial Oscillation (QQO) for Jupiter and the Semi-Annual Oscillation (SAO) on Saturn, are thought to be analogous to the Quasi-Biennial Oscillation (QBO) on Earth, which is driven by upward propagation of equatorial waves from the troposphere. Here, we test the hypothesis that the zonal jets on Jupiter and Saturn, as well as QBO-like oscillations, can result from interaction of the stably stratified atmosphere with an underlying convective interior. We performed global, three-dimensional, high-resolution numerical simulations of the flow in the stratosphere and upper troposphere of Jupiter-like planets. The effect of convection is parameterized by

introducing thermal perturbations that randomly perturb the radiative convective boundary with some characteristic timescale, horizontal wavenumber, and amplitude. Radiative damping is represented using a Newtonian cooling scheme with a characteristic radiative time constant. In the simulations, the convective perturbations generate atmospheric waves and turbulence that interact with the rotation to produce numerous zonal jets. Moreover, the equatorial stratosphere exhibits stacked eastward and westward jets that migrate downward over time, exactly as occurs in the terrestrial QBO, Jovian QQO, and Saturnian SAO. This is the first demonstration of a QBO-like phenomenon in 3D numerical simulations of a giant planet. We will describe how the properties of the zonal jets and equatorial oscillation depend on the details of the forcing and damping. These simulations have important implications for Jupiter and Saturn, which we will discuss.
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501.05 – Tracking Jupiter's Quasi-Quadrennial Oscillation and Mid-Latitude Zonal Waves with High Spectral Resolution Mid-Infrared Observations

We report on early results of a long term observational study to track the temporal and 3-dimensional evolution of the Quasi-Quadrennial Oscillation (QQO) and the propagation and evolution of mid-latitude zonal waves in Jupiter's stratosphere. These wave-driven phenomena affect variations in Jupiter's vertical and horizontal temperature field, which can be inferred by measuring methane emission in the thermal infrared near 1245 cm^{-1}. Using TEXES, the Texas Echelon cross-dispersed Echelle Spectrograph, mounted on the NASA Infrared Telescope Facility (IRTF) we observed high-spectral resolution (R=75,000) scan maps of Jupiter's equator to mid-latitudes from January 2012 through to the present. We will present the zonally averaged inferred thermal structure within ±30° latitude of the equator and between 10 and 0.01 mbar, showing the QQO's downward progression along with inferred 3-dimensional thermal maps (latitude, longitude, pressure) displaying a multitude of independent waves and eddies at various latitudes and pressures. These results reveal a vast array of wave activity on Jupiter and will serve to: 1) significantly improve the determination of the period and vertical descent velocity of Jupiter's QQO; 2) measure the zonal wavenumbers, vertical wavelengths, zonal group velocities and lifetimes of transient mid-latitude waves; and 3) record the thermal state of Jupiter's stratosphere in detail prior to, during, and after Juno's prime mission.
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501.06D – Modeling Jupiter's Quasi Quadrennial Oscillation (QQO) with Wave Drag Parameterizations

The QQO in Jupiter's atmosphere was first discovered after 7.8 micron infrared observations spanning the 1980's and 1990's detected a temperature oscillation near 10 hPa (Orton et al. 1991, Science 252, 537, Leovy et. al. 1991, Nature 354, 380, Friedson 1999, Icarus 137, 34). New observations using the Texas Echelon cross-dispersed Echelle Spectrograph (TEXES), mounted on the NASA Infrared Telescope facility (IRTF), have been used to characterize a complete cycle of the QQO between January 2012 and January 2016 (Greathouse et al. 2016, DPS) . These new observations not only show the thermal oscillation at 10 hPa, but they also show that the QQO extends upwards in Jupiter's atmosphere to pressures as high as 0.4 hPa. We incorporated three different wave-drag parameterizations into the EPIC General Circulation Model (Dowling et al. 1998, Icarus 132, 221) to simulate the observed Jovian QQO temperature signatures as a function of latitude, pressure and time using results from the TEXES datasets as new constraints. Each parameterization produces unique results and offers insight into the spectra of waves that likely exist in Jupiter's atmosphere to force the QQO. High-frequency gravity waves produced from convection are extremely difficult to directly observe but likely contribute a significant portion to the QQO momentum budget. We use different models to simulate the effects of waves such as these, to indirectly explore their spectrum in Jupiter's atmosphere by varying their properties. The model temperature outputs show strong correlations to equatorial and mid-latitude temperature fields retrieved from the TEXES datasets at different epochs. Our results suggest the QQO phenomenon could be more than one alternating zonal jet that descends over time in response to Jovian atmospheric forcing (e.g. gravity waves from convection).
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501.07 – Jupiter's Global Winds in Advance of the Juno Encounters

We use Hubble/WFC3 imaging observations in February 2016 to derive Jupiter's global wind field, the closest wind velocity measurement to Juno's focused atmospheric campaign (November 2016 through January 2017).
Using the methods of Asay-Davis et al. (2011, Icarus 211, 1215), we derive zonal wind profiles from Outer Planet Atmospheres Legacy (OPAL) program data in 2015 and 2016, and from 2009 and 2012 data, all taken at red optical wavelengths with the WFC3/UVIS instrument. Several jets show significant variability in peak speed over the 2000-2016 time period, while most jets are very stable.
We quantify uncertainties in order to determine which changes are significant, and we find a roughly 2x improvement in precision compared to the HST/WFPC2 and Cassini-derived zonal wind profiles in Asay-Davis et al. (2011). Some improvement in precision is likely to be instrumental. The WFC3/UVIS detector better samples the HST point-spread function by about 15% compared to WFPC2, and the larger WFC3/UVIS field of view reduces navigational uncertainty by capturing the entire planetary disk in every image. It is not yet clear whether instrumental effects can explain the entire reduction in uncertainty, which could potentially include time-variable noise due to coherent features (waves, vortices) as well as turbulence. Global variability of this magnitude would be a surprise, since Asay-Davis et al. (2011) found the same level of velocity uncertainty (~11 m/s) in both Cassini data from 2000 and HST/WFPC2 data from 2008.
We will generate spatial spectra of kinetic energy and cloud features (in multiple filters), using Fourier transforms of OPAL Jupier imaging data and 2D velocity fields. We will fit composite linear models (Barrado-Izagirre et al. 2009, Icarus 202, 181; Choi and Showman 2011, Icarus 216, 597) to the kinetic energy and cloud albedo spectra, comparing spectral indices to past observations and determining forcing scales.
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501.08 – Thermal Structure of Jupiter's Infrared Hotspots and Plumes in the Northern Equatorial Region

The most prominent features of Jupiter's northern equatorial region are the visibly dark, 5-µm-bright 'hotspots' that move rapidly eastward on the southern edge of the North Equatorial Belt (NEB, Allison 1990, doi:10.1016/0019-1035(90)90069-L). We combine high-resolution thermal-infrared (5-20 µm) imaging from VLT/VISIR and IRTF/SpeX with spatially resolved spectroscopy from IRTF/TEXES to examine the thermal and chemical conditions in the equatorial region during the 2015-2016 apparition. The high spatial resolution permits the first detailed cross-comparison of thermal and visible-albedo conditions within the hotspots. We find that: (i) cloud-clearing within the hotspots creates 8.6-µm bright patches that are broader and more diffuse than their 5-µm counterparts; (ii) cloudy, cool cells ("plumes") in the northern Equatorial Zone are ammonia-rich and dark in the 5- and 8-12 µm range; (iii) the hotspots sometimes demonstrate a westward tilt with altitude in the 0.1-0.8 bar region (Fletcher et al., 2016, doi:10.1016/j.icarus.2016.06.008); and (iv) blue-grey streaks on the southeastern edges of these ammonia-rich cells are also cloud free and bright at 5-12 µm. This regular longitudinal pattern of cloudy cells and cloud-free hotspots is consistent with condensation of NH3-rich air as it ascends in cells, and subsidence of dry, volatile-depleted air in the hotspots. The westward tilt of the NEB hotspots with height that was detected in 2014 (but not in 2016) supports the equatorial Rossby-wave hypothesis for the NEB pattern. This equatorial wave is distinct from those in the upper troposphere during the 2015-16 NEB expansion event (Orton et al., DPS/EPSC 2016). The cells and hotspots observed in the thermal-IR are the same type as those detected at near-IR wavelengths by Galileo/NIMS (Baines et al. 2002, doi:10.1006/icar.2002.6901) and in the radio, probing the deep atmosphere (de Pater et al., 2016, doi:10.1126/science.aaf2210), suggesting a coherent structure over tens of kilometres of altitude. Regular infrared tracking of the plume and hotspot locations will be used to aid interpretation of Juno observations.

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501.09 – Activity in Jupiter's Northern Hemisphere Before and During the Juno Mission: Waves Associated with the North Equatorial Belt and Relation to Expansion Phase

Visible and infrared observations of Jupiter in 2015-2016 reveal phenomena that may be active during the Juno mission. For the North Equatorial Belt (NEB), near-infrared observations of Jupiter's upper-tropospheric particulate field at wavelengths of strong gaseous absorption reveal a zonal wave structure that encompasses the longitudes of a northward expansion of dark-colored regions of the NEB. The longitudinal structure of the waves appears to be highly correlated with the structure of zonal waves in the upper-tropospheric temperature field. This wave pattern was also observed by Cassini and ground-based observers in late 2000 / early 2001 during its flyby of Jupiter, which Li et al. (2006, *Icarus* **185**, 416) argued was a planetary (Rossby) wave. The 2000-2001 wave was also observed during a period of NEB expansion. Using our historical infrared observations, as well as CCD images at 889 nm, the NEB expansion sequences in 2004 and 2009 also appear to be accompanied by zonal waves in the upper-tropospheric particulate field as well as by zonal waves in the upper-tropospheric temperature field. This correlation implies that the wave is a commonplace consequence of the dynamical reconfiguration at the northern edge of the NEB during its apparent expansion, created by a downwelling that causes sublimation of white aerosols at some longitudes. Properties of the 2015-2016 wave do not appear to be correlated with those of a nearby prominent stratospheric zonal temperature wave, although both began within months of each other. At cloud-top level, the NEB expansions lead to the generation of cyclonic circulations ('barges'), which are expected to be visible in 2016-2017. The current NEB-related phenomena, together with other types of waves and instabilities, mark a very interesting period for Juno observations and its coordinated campaign of Earth-based support.

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502 – Titan: Hydrocarbon Heaven

502.01 – Co-crystals on the Surface of Titan

Titan and Earth are the only bodies in the Solar System that have standing liquids on their surface. At Titan's low surface temperatures (90-95 K), this liquid is comprised of hydrocarbons, primarily methane and ethane. Photochemistry in the atmosphere, driven by solar radiation and energy from Saturn's magnetosphere, generates a wide range of organic products. Some of these products will dissolve in the hydrocarbon fluids and be concentrated in the lakes. Evaporation or other processes that reduce lake levels could potentially induce precipitation, forming evaporite deposits around the lakes. This might explain the deposits seen by the Cassini Visual and Infrared Mapping Spectrometer (VIMS) and Synthetic Aperture Radar (SAR) around some of the northern lakes. These evaporites would play an important role in Titan's surface chemistry.

While studying the potential identity of these evaporites, we discovered that solid benzene, when immersed in liquid ethane at Titan surface temperatures, forms a stable co-crystalline structure that can hold considerable amounts of ethane. Such material represents an exciting new class of compounds for Titan's surface, and implies that lake edges and evaporite basins could serve as hydrocarbon reservoirs on Titan. This finding has motivated our search for other co-crystals that may form under similar conditions. In this work, we report on the formation of a co-crystal between acetylene and ammonia (two other possible surface molecules) under Titan's conditions. A series of optical Raman experiments was performed in which solid acetylene was deposited onto solid ammonia at 100 K. Spectral features indicate that co-crystallization happens within minutes, with the structure being stabilized by a network of C-H···N interactions. Subsequent thermal stability studies show that this co-crystal can remain intact until a relatively warm temperature of 130 K. Thus, the ammonia-acetylene co-crystal can be expected to occur readily and remain fairly stable under Titan conditions. The combined results from both benzene-ethane and ammonia-acetylene systems suggest that organic co-crystals may be abundant on Titan's surface and may influence many aspects of Titan geology and atmospheric chemistry.

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502.02D – Acetylene on Titan

Saturn's moon Titan possesses a thick atmosphere that is mainly composed of N_2 (98%), CH_4 (2 % overall, but 4.9% close to the surface) and less than 1% of minor species, mostly hydrocarbons [1]. A dissociation of N_2 and CH_4 forms complex hydrocarbons in the atmsophere and acetylene (C_2H_2) and ethane (C_2H_6) are produced most abundently. Since years, C_2H_2 has been speculated to exist on the surface of Titan based on its high production rate in the stratosphere predicted by photochemical models [2,3] and from its detection as trace gas sublimated/evaporated from the surface after the landing of the Huygens probe by the Gas Chromatograph Mass Spectrometer (GCMS) [1]. Here we show evidence of acetylene (C_2H_2) on the surface of Titan by detecting absorption bands at 1.55 µm and 4.93 µm using Cassini Visual and Infrared Mapping Spectrometer (VIMS) [4] at equatorial areas of eastern Shangri-La, and Fensal-Aztlan/Quivira.
An anti-correlation of absorption band strength with albedo indicates greater concentrations of C_2H_2 in the dark terrains, such as sand dunes and near the Huygens landing site. The specific location of the C_2H_2 detections suggests that C_2H_2 is mobilized by surface processes, such as surface weathering by liquids through dissolution/evaporation processes.
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[4] Brown *et al., The Cassini-Huygens Mission* 111–168 (Springer, 2004).
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502.03 – Methane, Ethane, and Nitrogen Liquid Stability on Titan

Previous studies have shown that the lakes of Titan are composed of methane and/or ethane, but the relative proportions are mostly unclear. Understanding the past and current stability of these lakes requires characterizing the interactions of liquid methane and ethane, along with nitrogen. Previous studies have shown that the freezing point of methane is depressed when mixed with nitrogen. Our cryogenic laboratory setup allows us to explore ices down to 30 K through imaging and transmission spectroscopy. Recent work (see Thompson et al., this conference) discovered that although methane and ethane have similar freezing points, when mixed they can remain liquid down to 72 K. Concurrently with the freezing point measurements we acquire transmission spectra of these mixtures to understand how the spectral features change with concentration and temperature. Any mixing of these two species together will depress the freezing point of the lake below Titan's surface temperature, preventing them from freezing. Also, when ethane ice forms, it freezes on the bottom of the liquid, while methane ice freezes at the top of the liquid, implying ethane ice is denser than the solution, while methane ice is less dense; this holds for all concentrations. We will present new results exploring the ternary system of methane, ethane and nitrogen. In particular we will map out the N_2-C_2H_6 liquidus, as has been done for CH_4-N_2, as well as explore the effect of nitrogen on the eutectic of the methane-ethane system. This behavior has implications for not only the lakes on the surface of Titan, but also for the evaporation/condensation/cloud cycle in the atmosphere. These results will help interpretation of future observational data, and guide current theoretical models.

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502.04 – Evidence for frozen hydrocarbons on Titan

Cassini Visual and Infrared Mapping Spectrometer (VIMS) and Imaging Science Subsystem (ISS) have twice, now, observed widespread darkening of Titan's surface that has been interpreted as evidence of rainfall (Turtle et al., 2009, GRL 36; Turtle et al., 2011, Science 331) followed by an increase in albedo, well beyond the pre-darkened albedo (Barnes et al., 2013, Planet. Sci. 2; Soderblom et al., 2014, DPS). Based on the timescale and magnitude of the albedo changes, and the correlations between the timescale and temperature (inferred from latitude), we favor a thermodynamically controlled process to explain the brightening. Herein, we present a detailed comparison of the IR spectra of the bright materials of these two events. We also discuss the implications on the interpretation of these data from recent laboratory work investigating the freezing of ethane at Titan-like conditions (Farnsworth et al., 2016, LPSC 47).
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502.05D – Quantifying Precipitation Variability on Titan Using a GCM and Implications for Observed Geomorphology

Titan's zonal-mean precipitation behavior has been widely investigated using general circulation models (GCMs), but the spatial and temporal variability of rainfall in Titan's active hydrologic cycle is less well understood. We conduct statistical analyses of rainfall, diagnosed from GCM simulations of Titan's atmosphere, to determine storm intensity and frequency. Intense storms of methane have been proposed to be critical for enabling mechanical erosion of Titan's surface, as indicated by observations of dendritic valley networks. Using precipitation outputs from the Titan Atmospheric Model (TAM), a GCM shown to realistically simulate many features of Titan's atmosphere, we quantify the precipitation variability within eight separate latitude bins for a variety of initial surface liquid distributions. We find that while the overall wettest regions are indeed the poles, the most intense rainfall generally occurs in the high mid-latitudes, between 45-67.5 degrees, consistent with recent geomorphological observations of alluvial fans concentrated at those latitudes. We also find that precipitation rates necessary for surface erosion, as estimated by Perron et al. (2006) J. Geophys. Res. 111, E11001, frequently occur at all latitudes, with recurrence intervals of less than one Titan year. Such analysis is crucial towards understanding the complex interaction between Titan's atmosphere and surface and defining the influence of precipitation on observed geomorphology.
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502.06 – Titan's global geologic processes

We have mapped the Cassini SAR imaged areas of Saturn's moon Titan in order to determine the geological properties that modify the surface [1]. We used the SAR dataset for mapping, but incorporated data from radiometry, VIMS, ISS, and SARTopo for terrain unit determination. This work extends our analyses of the mid-latitude/equatorial Afekan Crater region [2] and in the southern and northern polar regions [3]. We placed Titan terrains into six broad terrain classes: craters, mountain/hummocky, labyrinth, plains, dunes, and lakes. We also extended the fluvial mapping done by Burr et al. [4], and defined areas as potential cryovolcanic features [5]. We found that hummocky/mountainous and labyrinth areas are the oldest units on Titan, and that lakes and dunes are among the youngest. Plains units are the largest unit in terms of surface area, followed by the dunes unit. Radiometry data suggest that most of Titan's surface is covered in high-emissivity materials, consistent with organic materials, with only minor exposures of low-emissivity materials that are consistent with water ice, primarily in the mountain and hummocky areas and crater rims and ejecta [6, 7]. From examination of terrain orientation, we find that landscape evolution in the mid-latitude and equatorial regions is driven by aeolian processes, while polar landscapes are shaped by fluvial, lacrustine, and possibly dissolution or volatilization processes involving cycling organic materials [3, 8]. Although important in deciphering Titan's terrain evolution, impact processes play a very minor role in the modification of Titan's landscape [9]. We find no evidence for large-scale aqueous cryovolcanic deposits.

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Contributing team(s): Cassini RADAR Team

503 – Titan: Upper Atmosphere

503.01 – Stellar background EUV as a source of Titan's nightside ionosphere

Stellar background EUV photons can ionize molecular species in planetary atmospheres, and in fact are the dominant source of the terrestrial E region at night. Recent modeling efforts based on in situ measurements of Titan's upper atmosphere by the Cassini spacecraft have proposed a range of possible sources of Titan's nightside ionosphere, including: persistence of ions created on the dayside, transport of dayside ions, and ionization due to precipitation of energetic particles from Saturn's magnetosphere. All of these sources are likely present, but the additional source of ionization due to stellar background EUV – which is also present – has thus far been neglected. Consequently, the currently modeled sources of nightside ionization have likely been overestimated in order to match observed densities. Moreover, there are uncertainties associated with each of the currently treated sources – such as complicated photochemistry, or precipitating energy fluxes and energies – that may be reduced by inclusion of this additional source of ionization.
We present calculated ion production rates at Titan based on an updated estimate of the stellar background EUV radiation field as well as preliminary 1D ionospheric modeling that includes a representative set of Titan photochemical reactions.

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503.02 – Neutral Chemistry in Titan's Ionospheric Simulated Conditions

Titan's atmospheric gas phase chemistry leading to the formation of organic aerosols can be simulated in laboratory experiments. Typically, plasma reactors can be used to achieve Titan-like conditions. Such a discharge induces dissociation and ionization processes to the N2-CH4 mixture by electron impact. This faithfully reproduces the electron energy range of magnetospheric electrons entering Titan's atmosphere and can also approximate the solar UV input at Titan's ionosphere. In this context, it is deemed necessary to apply and exploit such a technique in order to better understand the chemical reactivity occurring in Titan-like conditions.
In the present work, we use the PAMPRE cold dusty plasma experiment with an N2-CH4 gaseous mixture under controlled pressure and gas influx, hence, emphasizing on the gas phase which we know is key to the formation of aerosols on Titan. Besides, an internal cryogenic trap has been developed to accumulate the gas products during their formation and facilitate their detection. These products are identified and quantified by in situ mass spectroscopy and Fourier-Transform Infrared Spectroscopy. We present here results from this experiment in two experimental conditions: 90-10% and 99-1% N2-CH4 mixing ratios respectively. We use a quantitative approach on nitriles and polycyclic aromatic hydrocarbons.
Key organic compounds reacting with each other are thus detected and quantified in order to better follow the chemistry occuring in the gas phase of Titan-like conditions. Indeed, these species acting as precursors to the solid phase are assumed to be relevant in the formation of Titan's organic aerosols. These organic aerosols are what make up Titan's hazy atmosphere.

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503.03D – Simulating the VUV photochemistry of the upper atmosphere of Titan

The Cassini mission around Titan revealed that the interaction between the N2 and CH4 molecules and the solar VUV radiation leads to a complex chemistry above an altitude of 800km with the detection of heavy organic molecules like benzene (C6H6). This is consistent with an initiation of the aerosols in Titan's upper atmosphere. The presence of those molecules makes Titan a natural laboratory to witness and understand prebiotic-like chemistry but despite all the data collected, all the possible photochemical processes in such a hydrocarbon-nitrogen-rich environment are not precisely understood.
This is why Titan's atmospheric chemistry experiments are of high interest, especially those focusing on the photochemistry as most of the Titan-like experiments are based on N2-CH4 plasma techniques. In order to reproduce this VUV photochemistry of N2 and CH4, we designed a photochemical reactor named APSIS which is to be coupled window-less with a VUV photon source as N2 needs wavelengths shorter than 100 nm in order to be dissociated. Those wavelengths are available at synchrotron beamlines but are challenging to obtain with common laboratory discharge lamps. At LATMOS, we developed a table-top VUV window-less source using noble gases for the micro-wave discharge. We started with Neon, as it has two resonance lines at 73.6 and 74.3 nm which allow us to dissociate and/or ionize both CH4 and N2.
We will present here our first experimental results obtained with APSIS coupled with this VUV source. A range of different pressures below 1 mbar is tested, in parallel to different methane ratio.

Moreover, other wavelengths are injected by adding some other noble gases in the MO discharge (He, Kr, Xe, Ar). We will review the mass spectra obtained in those different conditions and then discuss them regarding the Cassini data and other previous laboratory photochemical studies.

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504 – Asteroid Spin States II: Notable Spinners

504.01 – Gemini and Keck Observations of Slowly Rotating, Bilobate Active Asteroid (300163)

One of the most puzzling questions regarding Active Asteroids is the mechanism of their activation. While some Active Asteroids show protracted and often recurrent mass loss, consistent with seasonal ice sublimation, some other eject dust impulsively as a result of a catastrophic disruption (e.g. Jewitt et al. 2015, Asteroids IV, 221). It has been suggested that ice can be excavated from the cold near-surface interior by an impact (Hsieh & Jewitt 2006, Science 312, 561) or, for small objects susceptible to YORP torques, by near-critical spin rate (Sheppard & Trujillo 2014, AJ 149, 44). But impact and rapid spin can also cause a catastrophic disruption (e.g. Jewitt et al. 2015, Asteroids IV, 221). It therefore becomes apparent that the different types of mass loss observed in Active Asteroids can be best classified and understood based on the nucleus spin rates (Drahus et al. 2015, ApJL 802, L8), but unfortunately the rotation periods have been measured for a very limited number of these objects. With this in mind we have initiated a survey of light curves of small Active Asteroids on the largest ground-based optical telescopes. Here we present the results for (300163), also known as 288P and 2006 VW139, which is a small 2.6-km sized asteroid that exhibited a comet-like activity over 100 days in the second half of 2011 (Hsieh et al. 2012, ApJL 748, L15; Licandro et al. 2013, A&A 550, A17; Agarwal et al. 2016, AJ 151, 12). Using Keck/DEIMOS and Gemini/GMOS-S working in tandem on UT 2015 May 21–22 we have detected an inactive nucleus and measured a complete, dense, high-S/N rotational light curve. The light curve has a double-peaked period of 16 hours, an amplitude of 0.4 mag, and moderately narrow minima suggesting a bilobate or contact-binary shape. The long rotation period clearly demonstrates a non-rotational origin of activity of this object, consistent with an impact. Furthermore, among the five small Active Asteroids with known rotation periods (300163) is only the second object with a confirmed slow spin rate, the other three rotating rapidly, near the limit of rotational stability. This suggests that rotation- and impact-driven origin of activity can be comparably common among small asteroids.

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504.02 – Detection of the YORP effect in asteroid (161989) Cacus

The rotation state of small asteroids is affected by the thermal Yarkovsky-O'Keefe-Radzievski-Paddack (YORP) torque. The directly observable consequence of YORP is the secular change of the asteroid's rotational period in time. We carried out new photometric observations of asteroid (161989) Cacus during its apparitions in 2014-2016. Using the new lightcurves together with archived data going back to 1978, we were able to detect a tiny deviation from the constant-period rotation. This deviation caused an observable shift between the observed lightcurves and those predicted by the best constant-period model. We used the lightcurve inversion method to derive a shape/spin solution that fitted the data at best. We assumed that the rotation rate evolved linearly in time and derived the acceleration of the rotation rate $d\omega/dt = (1.9 +/- 0.3) \times 10^{-8}$ rad/day^2. The accelerating model provides a significantly better fit than the constant-period model. By applying a thermophysical model on WISE thermal infrared data, we estimated the thermal inertia of the surface to $\Gamma = 250–2000$ J m^{-2} s$^{-0.5}$ K^{-1} and the volume-equivalent diameter to 0.8–1.2 km (1σ intervals). The value of dω/dt derived from observations is in agreement with the theoretical value computed numerically from the lightcurve inversion shape model and its spin axis orientation. Cacus has become the sixth asteroid with YORP detection. Surprisingly, for all six cases the rotation rate accelerates.

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504.03 – Secular obliquity variations for Ceres

We have constructed secular variation models for the orbit and spin poles of the asteroid (1) Ceres, and used them to examine how the obliquity, or angular separation between spin and orbit poles, varies over a time span of several million years. The current obliquity is 4.3 degrees, which means that there are some regions near the poles which do not receive any direct Sunlight. The Dawn mission has provided an improved estimate of the spin pole orientation, and of the low degree gravity field. That allows us to estimate the rate at which the spin pole precesses about the instantaneous orbit pole. The orbit of Ceres is secularly perturbed by the planets, with Jupiter's influence dominating. The current inclination of the orbit plane, relative to the ecliptic, is 10.6 degrees. However, it varies between 7.27 and 11.78 degrees, with dominant periods of 22.1 and 39.6 kyr. The spin pole precession rate parameter has a period of 205 kyr, with current uncertainty of 3%, dominated by uncertainty in the mean moment of inertia of Ceres.

The obliquity varies, with a dominant period of 24.5 kyr, with maximum values near 26 degrees, and minimum values somewhat less than the present value. Ceres is currently near to a minimum of its secular obliquity variations.

The near-surface thermal environment thus has at least 3 important time scales: diurnal (9.07 hours), annual (4.60 years), and obliquity cycle (24.5 kyr). The annual thermal wave likely only penetrates a few meters, but the much long thermal wave associated with the obliquity cycle has a skin depth larger by a factor of 70 or so, depending upon thermal properties in the subsurface.

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505 – Asteroid Physical Characteristics: Surfaces I

505.01 – What do Meteorite Falls Tell Us about the Strength of Asteroid Boulders

One possible source of data on the strength of a boulder on an asteroid's surface is the meteorite collection and the observations of meteorite falls. Since highly fractured boulders should breakup in the atmosphere and arrive as meteorite showers, the relative ratio of boulders to showers can provide insight into boulder strength. Since about 85-95% of the mass of a meteoroid is lost during atmospheric entry, we have chosen to investigate only those falls with a final recovered mass of at least 10 kg. This corresponds to a minimum pre-atmospheric mass of 100-200 kg and roughly 25 centimeter minimum diameter. Using the Catalogue of Meteorites and the Meteoritical Bulletins we compiled a list of observed

meteorite falls with a total recovered mass greater than or equal to 10 kg. We found a total of 269 meteorites that met these criteria, of which 263 entries reported or estimated the number of fragments associated with their falls. The overall percentage of observed showers was found to be around 34%. The ratio of “boulders” to showers was determined to be around 1.94:1. Comparing the percentage of showers within the meteorite types shows a trend in strength with irons (showers only 4.3%) very rarely exhibit reported showers, stony-irons (25%), ordinary chondrites (28.5%), achondrites (35.7%), and carbonaceous chondrites (70%) are dominantly showers.
The meteorite fall data primarily sample the “boulder” population of meteoroids roughly 0.25 meters to a few meters in their pre-atmospheric diameter because of the 85-95% atmospheric loss. The relative rarity of showers seems to indicate that most meteoroids that survive to produce meteorites in this size range are fairly strong and coherent. Not surprisingly, irons and stony-irons are the strongest class which is consistent with the overwhelmingly high production of Earth's smallest impact craters by iron meteorites. Carbonaceous chondrites are by far the weakest and most fracture-prone meteorite class with 70% of the falls being showers and single stone falls being very rare.
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505.02 – Studying low-velocity impacts in reduced gravity: an asteroid landing experiment

Several current and future small body missions include lander components e.g., MASCOT and the MINERVA rovers on-board JAXA’s Hayabusa-2 mission [1], MASCOT2 and possibly AGEX on board ESA’s AIM mission [2,3]. The understanding of surface-lander interactions is important for all such landers as these considerations influence the deployment strategy, the mission design and operations, and even the choice of payload. The dynamics of low-velocity interactions with granular material in reduced gravity are also important for other missions, such as OSIRIS-REx (NASA), that will interact directly with the asteroid’s surface in order to retrieve a regolith sample.
In our experiment, reduced gravity is simulated by releasing a free-falling projectile into a surface container with a downward acceleration less than that of Earth's gravity. The acceleration of the surface is controlled through the use of an Atwood machine, or a system of pulleys and counterweights. The experiment is built into an existing 5.5 m drop-tower frame and has required the custom design of all components, including the projectiles, surface sample container and release mechanism [4].
Previous experiments using similar methods have demonstrated the important role of gravity in the peak accelerations and collision timescales during low velocity granular impacts [5,6]. The design of our experiment accommodates collision velocities and effective accelerations that are lower than in previous experiments (<20 cm/s and ~0.1-1.0 m/s^2respectively), allowing us to come closer to the conditions that may be encountered by current and future small body missions.
Here we will present the results of our experimental trials and discuss the implications for small body missions. The unique experimental data obtained in these trials may also be valuable to benchmark different numerical simulation approaches. These simulations can then subsequently be used to extrapolate the results to even lower gravity regimes.
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505.03 – Space weathering of primitive bodies: From laboratory measurements to space missions

Space weathering (SpWe) is a combination of micrometeorite bombardment and irradiation by energetic particles leading to surface alterations of airless bodies and affecting their reflectance spectra. Numerous studies have been made on S-type asteroids, including laboratory experiments on silicate materials and a direct confirmation measured on Itokawa grains showing darkening and reddening trends. Few results have been obtained for C-types, no general trend has been found. In order to understand the influence of SpWe on primitive asteroids, we present an experimental study on ion irradiation of carbonaceous chondrites, simulating solar wind. The goal of our work is to better constrain the SpWe processes of low albedo objects and to develop a model that will also support sample return missions (OSIRIS-REx/NASA and Hayabusa-2/JAXA). The irradiations were performed on pressed pellets of several CC types, as well as on some silicate samples. We used 40 keV He^+ with fluences up to 6.10^{16} ions/cm^2. Reflectance spectra were acquired ex situ before and after irradiations in the visible to mid-infrared range (0.4 – 16 μm). In the MIR range, we observe a shift of the phyllosilicates (near 3 and 10 μm) and silicates (near 10 μm) bands toward longer wavelength. In the visible-NIR range, we confirm the red/dark trends on silicates, but CCs present a continuum of behaviors after ion irradiation correlated with the initial albedo/composition: from red to blue and from dark to bright.
We propose a model for SpWe effects on low albedo objects, showing that those with initial albedo between 5 and 9 % do not suffer SpWe effects in the visible range.
These new spectral alterations due to SpWe can be used by future and ongoing space missions to detect pristine/altered materials. To do so, we have started looking at VIR data on Ceres. Craters are ideal for this purpose as they expose both old and young surfaces in the same area. We have been looking at HAMO data on several craters, focusing on IR range and especially the 2.7 μm band seen on the whole surface of Ceres. No shift has been unveiled. The rich and complex composition (salts, ice) might explain this lack of SpWe effect of this dwarf planet.
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505.04 – A scaling analysis for thermal fragmentation on small airless bodies

The presence of regolith on airless bodies has typically been attributed to impact ejecta re-accumulation and gradual breakdown of boulders by micrometeoritic impacts. However, ejecta velocities for small kilometer-sized asteroids often exceed the gravitational escape velocity, limiting to a great extent the amount of retained debris following a high-velocity impact event. Close-surface images of small (sub-km) asteroid surfaces have shown the presence of a coarse-grained regolith layer on these bodies, suggesting that a different mechanism could be involved in the regolith generation process.
Recently, the existence of regolith on sufficiently small planetary bodies has also been attributed to cyclic stresses that develop within boulders due to the large diurnal temperature variation, which eventually lead to fracture by thermal fatigue. It was demonstrated

that thermal fatigue can be orders of magnitude faster than fragmentation by classical impact mechanisms, in terms of breaking down cm-sized rocks on small airless bodies. Larger (10 cm-size) rocks were shown to potentially break up faster than smaller (cm) rocks, an observation that is in contrast to the predictions of mechanical disruption models. This observation is justified by the existence of higher internal thermal stresses resulting from the larger temperature gradient in bigger rocks, but it is not clear that this conclusion can be extrapolated or scaled for meter-sized boulders.
In the current study, we present a computational and analytical approach that examines thermally driven crack growth within asteroidal rocks over a large range of lengthscales. We first examine the main length and timescales involved in the thermally-driven fatigue crack growth, and identify a critical lengthscale comparable to the thermal skin depth, after which thermal fatigue becomes slower, providing bounds on the thermal fragmentation mechanism. We also develop a simple scaling method to estimate the time required for thermal fatigue-induced rock breakdown while accounting for the composition and thermomechanical properties of the rocks, and the asteroid's heliocentric distance.
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505.05D – Linking CAI abundance to polarimetric response in a population of ancient asteroids

Polarimetry constitutes one of the fundamental tools for characterizing the surface texture and composition of airless Solar System bodies. In 2006, polarimetric observations led to the discovery of a new type of asteroids, which displays a peculiar polarimetric response. These asteroids are collectively known as “Barbarians”, from (234) Barbara the first discovered one.
The most commonly accepted explanation for this perculiar polarization response seems to be the presence of a high percentage of fluffy-type Calcium Aluminium-rich Inclusions (CAIs), whose optical properties could produce the observed polarization. Their reflectance spectra also exibit an absorption feature in the near-infrared around 2.1-2.2 microns, that is characteristic of this peculiar group.
Based on these results, we organized a systematic polarimetric and near-infrared observational campaign of known Barbarians or candidate asteroids. These campaigns include members of the family of 1040 Klumpkea, 2085 Henan and 729 Watsonia, which are known to contain Barbarian and/or L-type asteroids also suspected to have such a polarimetric behaviour. We have made use of the ToPo polarimeter at the 1m telescope of the Centre pédagogique Planète et Univers (C2PU, Observatoire de la Côte d’Azur, France). The spectroscopic observations in the near-infrared were obtained with the SpeX instrument at the NASA’s InfraRed Telescope Facility (IRTF).

By combining polarimetry and spectroscopy we find a correlation between the abundance of CAIs and the inversion angle of the phase-polarization curve of Barbarian asteroids. This is the first time that a direct link has been established between a specific polarimetric response and the surface composition of asteroids. In addition, we find a considerable variety of CAI abundance from one object to the other, consistent with a wide range of possible albedos. Since these asteroids constitute a reservoir of primitive Solar System material, understanding their origin can shed light on the processes driving the formation and transport of the refractory minerals that first condensed in the protoplanetary disk.
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505.06D – Constraining the wavelength dependence of polarization for various asteroid taxonomies

The polarization of sunlight reflected from asteroids is known to be inversely proportional to geometric albedo (Umov 1905). However, that was mainly derived from observations in the V-filter. Preliminary observations of the wavelength dependence were conducted by Belskaya et al. (2009) in the major asteroid taxonomic classes. The limited UBVRI data revealed trends of spectral slope vs. phase angle. To study the wavelength dependence of asteroid polarization more robustly, we have used the SPOL spectropolarimeter at the 2.3-m Bok and 1.6-m Kuiper telescopes. The finer spectral resolution of spectropolarimetry is needed to confirm the linearity of the wavelength dependence of polarization. We present polarization spectra from four asteroid taxonomic groups: B-, C-, S-, and X-types. Across the observed wavelength range (0.45 to 0.7 microns), the linear trend described by Belskaya et al. is confirmed and we determined the best-fit linear slope of each spectrum. For the S-type asteroids, the slope of the polarization spectra becomes more negative as the phase angle increases. The rate at which the polarization slope changes increases at phase angles greater than the inversion angle. C-type asteroids behave differently from the S-types in two ways. First, the polarization spectra for the C-types are positively sloped as opposed to negative (also noted in Belskaya et al.). Also, as you observe the C-types closer to the inversion angle (~20 degrees phase angle), the polarization slopes tend to flatten as opposed to steepen. The polarization spectra of B-type asteroids are positively sloped, but the tendency to flatten near the inversion angle like the C-type spectra is not evident. Our observations of low albedo X-types exhibit positive polarization slopes, while the high albedo observations exhibit negative slopes. Differences in the wavelength dependencies of polarization between various asteroid types appear to be driven by differences in their geometric albedos. Better understanding of how regolith structure affects light scattering is still needed.
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506 – Ceres Surface and Interior Processes

506.01 – Large-scale heterogeneity in Ceres’ subsurface: Clues to internal evolution

Dawn’s observations at Ceres indicate it is volatile-rich body that has undergone ice-rock differentiation and harbored a past subsurface ocean [1]. Gravity data indicate a volatile-rich shell (crust) overlying a denser core of hydrated silicates [2]. Ubiquitous ammoniated phyllosilicates [3] and carbonates [4] on the surface point towards pervasive hydrothermal alteration. The absence of an ice-dominated layer in the subsurface (from ocean freezing) may indicate partial loss of the ice shell by impact-induced sublimation [5], and mixing with the salts and silicate rich material present near the ancient seafloor. Although the surface shows compositional homogeneity, there are variations present, such as bluer material associated with several young craters, and a broad region of brighter material surrounding Dantu and Kerwan craters that is relatively ammonia-rich [6]. This compositionally-distinct region resides in a ~4 km deep basin – Vendemia Planitia – which has been proposed as a cryptic mega impact basin [7]. The smooth morphology and dearth of impact craters in this area, and the lack of large (>400 km) craters on Ceres in general points to an erasure process that could be the result of resurfacing, possibly in combination with viscous relaxation [7]. A similarly bright and smooth crater-free region surrounding the large impact craters Urvara and Yalode also appears spectrally-distinct, again with a relatively ammonia-rich composition. These areas contrast with the Hanami planum highland, which displays rougher topography and hosts localized regions of ammonia-poor composition associated with the brightest surface material. The surface morphology and composition likely reflect instrinsic subsurface heterogeneity due to convective processes, as well as modification by impact processes.

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Contributing team(s): Dawn Science Team

506.02 – Ceres' internal structure as inferred from its large craters

The Dawn spacecraft has gathered important data about the surface composition, internal structure, and geomorphology of Ceres, revealing a cratered landscape. Digital terrain models and global mosaics have been used to derive a global catalog of impact craters larger than 10 km in diameter. A surface dichotomy appears evident: a large fraction of the northern hemisphere is heavily cratered as the result of several billion of years of collisions, while portions of the equatorial region and southern hemisphere are much less cratered. The latter are associated with the presence of the two largest (~270-280 km) impact craters, Kerwan and Yalode. The global crater count shows a severe depletion for diameters larger than 100-150 km with respect to collisional models and other large asteroids, like Vesta. This is a strong indication that a significant population of large cerean craters has been obliterated over geological time-scales. This observation is supported by the overall topographic power spectrum of Ceres, which shows that long wavelengths in topography are suppressed (that is, flatter surface) compared to short wavelengths. Viscous relaxation of topography may be a natural culprit for the observed paucity of large craters. Relaxation accommodated by the creep of water ice is expected to result in much more rapid and complete decay of topography than inferred. In contrast, we favor a strong crust composed of a mixture of silicates and salt species (<30% vol water ice) with viscosity decreasing by two-three orders of magnitude in the top 45-70 km of Ceres' crust. This model can account for the observed topography power spectrum and explain the lack of craters in the size range ~100-600 km.

Interestingly, Ceres' surface exhibits an 800-km-wide, 4-km-deep depression, known as Vendimia Planitia. The overall topography of Vendimia Planitia is compatible with a partially relaxed mega impact structure. The presence of such a large scale depression bears implications for the rheology of the deeper interior, potentially implying a transition to higher viscosity/higher density materials at a depth of ~200 km. This is compatible with the presence of a central mass concentration, as inferred from gravity measurements.

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506.03 – Bright Spots on Ceres and Implications for Subsurface Composition and Structure

Images from the Dawn spacecraft show anomalously bright spots dotting Ceres' surface. Here we perform global mapping with FC data and find the spots can be classified into three geologic settings: 1) large crater floors, 2) rims/walls of craters of all sizes, or 3) the unique surface feature Ahuna Mons. There are at least 300 bright spots in total, over 200 of which are located on crater rims and walls. We examine controls on (1) and (2) as a function of crater diameter (D) and depth (d).

Floor bright spots occur only in D>15 km craters, and bright spots associated with the central pit and peak complex are restricted to D>30 km. 7 of 9 craters with d>4 km (D: 70-165 km) host floor bright spots, though 30 craters with D>75 km do not contain floor bright spots, thus indicating that diameter is a weaker control on bright spot occurrence than depth. Craters with bright spots have a high d/D for their size bin, and rim/wall bright spots in craters of all sizes occur preferentially in and around the largest craters. The chief control on crater depth is presumed to be age, with shallowing due to relaxation. Thus, data suggest that previously emplaced bright materials may be removed or obscured over time via relaxation-driven burial, impact-driven lateral mixing, sublimation, or space weathering. Analyses from Dawn's VIR instrument show that some large floor bright spots are comprised of materials enriched in carbonates and other salts [e.g., 1]. The presence of bright material in many deep craters is consistent with their formation via impact-induced subsurface processes, though formation via endogenous, heterogeneously distributed subsurface processes cannot be excluded [1, 2].

Here we use the Ceres production function [3] to construct a simple model in which only large (D>75 km) craters form central bright spots. These materials are then modified by later impacts. Initial results indicate that the excavation of previously emplaced bright material could explain the current distribution of craters with rim/wall bright spots if an average timescale of bright spot removal/obscuration is ~2.0-2.5 Gyr.

[1] De Sanctis et al., Nature, 2016.
[2] Bowling et al., LPSC 2016, #2268.
[3] Hiesinger and Schmedemann, pers. comm.

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Contributing team(s): Dawn Team

506.04 – Central Pit and Dome Formation as Seen in Occator Crater, Ceres

Dawn mapping of Ceres revealed that central depressions (or pits) are common in craters >75 km. The best preserved of these is Occator (D~92 km), where the pit is associated with a major bright deposit dominated by carbonates. The pit is ~9 km wide, 600-800 m deep and flanked by asymmetric massifs 0.7 to 1.3 km high. The pit is partially filled by a fractured central dome ~3 km wide and 700 m high. Fracturing could have been due to dome inflation by "magma" or by subsurface freezing of ice. Within the bright material, two color units are mapped, including a paler surface unit and a more yellowish to reddish unit exposed within the most fractured parts of the dome surface and at small bright spots, at least some of which could be post-Occator small craters. Some bright materials form as discrete small spots midslope along the pit wall and others avoid small hills, suggesting partial topographic control. Stratigraphic relations are ambiguous but suggest formation of a smooth carapace some meters thick that was subsequently disrupted by fractures crossing the floor of Occator, and by uplift of the dome surface. Pit and dome morphologies, including dome fracturing are potentially analogous to central pits and domes in many craters on Ganymede and Callisto, suggesting some commonality in formation processes. The absence of center pits or domes on Saturnian satellites could be related to much lower temperatures on those bodies. The prominence of central pits and domes on Ceres confirms the importance of volatile materials, mostly likely water ice, in the outer layers of Ceres, especially as compared to Vesta.

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Contributing team(s): Dawn Science Team

506.05 – Floor-fractured craters on Ceres and implications for interior processes

Several of the impact craters on Ceres have patterns of fractures on their floors. These fractures appear similar to those found within a class of lunar craters referred to as Floor-Fractured Craters (FFCs) [Schultz, 1976].
Lunar FFCs are characterized by anomalously shallow floors cut by radial, concentric, and/or polygonal fractures, and have been classified into crater classes, Types 1 through 6, based on their morphometric properties [Schultz, 1976; Jozwiak et al, 2012, 2015]. Models for their formation have included both floor uplift due to magmatic intrusion below the crater or floor shallowing due to viscous relaxation. However, the observation that the depth versus diameter (d/D) relationship of the FFCs is distinctly shallower than the same association for other lunar craters supports the hypotheses that the floor fractures form due to shallow magmatic intrusion under the crater [Jozwiak et al, 2012, 2015].
FFCs have also been identified on Mars [Bamberg et al., 2014]. Martian FFCs exhibit morphological characteristics similar to the lunar FFCs, and analyses suggest that the Martian FCCs also formed due to volcanic activity, although heavily influenced by interactions with groundwater and/or ice.
We have cataloged the Ceres FFCs according to the classification scheme designed for the Moon. Large (>50 km) Ceres FFCs are most consistent with Type 1 lunar FFCs, having deep floors, central peaks, wall terraces, and radial and/or concentric fractures. Smaller craters on Ceres are more consistent with Type 4 lunar FFCs, having less-pronounced floor fractures and a v-shaped moats separating the wall scarp from the crater interior.
An analysis of the d/D ratio for Ceres craters shows that, like lunar FFCs, the Ceres FFCs are anomalously shallow. This suggests that the fractures on the floor of Ceres FFCs may be due the intrusion of a low-density material below the craters that is uplifting their floors. While on the Moon and Mars the intrusive material is hypothesized to be silicate magma, this is unlikely for Ceres. However, a cryovolcanic extrusive edifice has been identified on Ceres [Ruesch et al., 2016], suggesting that cryomagmatic intrusions could be responsible for the formation of the Ceres FFCs.

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506.06 – Thermal stability of water ice in Ceres' crater Oxo

Dwarf planet Ceres, target of the NASA Dawn mission, exhibits evidences of ammoniated phyllosilicates on its surface [1], compatible with a likely outer Solar System origin. Considerable amounts of water ice have recently been detected in some craters by the Visible InfraRed mapping spectrometer (VIR) onboard Dawn in some small fresh crater, such as Oxo, located at about 40° N. The exposure mechanism of water ice is unknown: cryovolcanism, cometary type sublimation/recondensation [2]or impacts with other bodies are likely mechanisms. The evaluation of the time stability of the water ice is crucial to understand the plausible mechanism for its existence. For this purpose, we developed a 3D finite-elements model (FEM) by using the topography given by the shape model of Ceres derived on the basis of images acquired by the Framing Camera in the Survey mission phase. The illumination conditions are provided by the SPICE toolkit. We performed several simulations by analyzing the effect of thermal inertia and albedo on the temperature and rate of ice sublimation. The results of the simulations about the stability of water ice will be presented.

[1] De Sanctis et al. NATURE, doi:10.1038/nature16172
[2] Formisano et al. MNRAS, doi: 10.1093/mnras/stv2344

Author(s): Michelangelo Formisano[1], Costanzo Federico[1], Maria Cristina De Sanctis[1], Alessandro Frigeri[1], Gianfranco Magni[1], Federico Tosi[1]
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506.07 – Spectral modeling of water ice-rich areas on Ceres' surface from Dawn-VIR data analysis: abundance and grain size retrieval

Dawn spacecraft orbits around Ceres since early 2015 acquiring a huge amount of data at different spatial resolutions during the several phases of the mission. VIR, the visible and InfraRed spectrometer onboard Dawn [1] allowed to detect the principal mineralogical phases present on Ceres: a large abundance of dark component, NH_4-phillosilicates and carbonates.
Water has been detected in small areas on Ceres' surface by the Dawn-VIR instrument. The most obvious finding is located in Oxo crater [2]. Further detections of water have been made during the Survey observation phase (1.1 km/pixel) and High-Altitude Mapping Orbit (400 m/px) [3]. During the LAMO phase (Low Altitude Mapping Orbit), the data with increased spatial resolution (100 m/px) coming from both regions have improved the detection of water, highlighting clear diagnostic water ice absorption features. In this study, we focused on spectral modeling of VIR spectra of Oxo and another crater (lon = 227°, lat 57°), near Messor crater.

The Hapke radiative transfer model [4] has been applied in order to retrieve the water ice properties. We consider two types of mixtures: areal and intimate mixing. In areal mixing, the surface is modelled as patches of pure water ice, with each photon scattered within one patch. In intimate mixing, the particles of water ice are in contact with particles of the dark terrain, and both are involved in the scattering of a single photon. The best fit with the measured spectra has been derived with the areal mixture. The water ice abundance obtained is up to 15-20% within the field of view, and the grain size retrieved is of the order of 100-200 µm. Phyllosilicates and carbonates, which are ubiquitous on Ceres surface [5], have been also detected and modeled in correspondence with the icy regions. The water ice is typically located near and within the shadows projected by the crater rims. Further analysis is required to study the thermal state of the ice and its origin.

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Contributing team(s): Dawn/VIR Team

506.08 – Water-Rock Differentiation on Ceres as Derived From Numerical Studies: Late Water Separation and Thick Undifferentiated Crust

Water-rock separation is a major factor in discriminating between models of Ceres' present-day state. We calculate differentiation models of Ceres to investigate how water-rock separation and convection influence its evolution. We expand on the presence of liquids and the possibility of cryovolcanism in order to explain surface features observed by Dawn[1,2].
The model[3] includes accretion, reduction of the dust porosity, latent heat of ice melting, compaction driven water-rock separation, accretional heating, hydrothermal circulation, solid-state convection of ice, and convection in a water ocean.
Accretion times considered cover 1-10 Ma rel. to CAIs. Compaction of the dust pores starts with ice at T≈180-240 K and proceeds with rock minerals at temperatures of up to 730 K. Sub-surface remains too cold to close these pores. The water-rock separation proceeds by water percolation in a rock matrix. Differentiation timing depends on the matrix deformation and no differentiation occurs in layers with leftover dust porosity. Compaction takes several hundred million years due to a slow temperature increase. The differentiation is extended according to this time scale even though liquid water is produced early. While the radionuclides are concentrated in the core no heat is produced in the ocean. If convection is neglected, the ocean is heated by the core and cooled through the crust, and remains totally liquid until the present day. Convection keeps the ocean cold and results in a colder present-day crust. Only a thin basal part of the ocean remains liquid, while the upper part freezes. In our models, a water ocean starts forming within 10 Ma after CAIs, but its completion is retarded relative to the melting of ice by up to O(0.1 Ga). The differentiation is partial and a porous outer layer is retained. Present-day temperatures calculated indicate that hydrated salts can be mobile at a depth of ≥1.5-5 km implying buoyancy of ice and salt-enriched crustal reservoirs. The impacts Haulani, Ikapati and Occator may have cut into these reservoirs triggering the mobility that formed cryovolcanic features[1,2].
[1] Jaumann R et al. (2016) LPSC XLVII [2] Krohn K et al. (2016) LPSC XLVII. [3] Neumann W et al. (2015) A&A 584: A117.
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506.09 – Ceres' evolution before and after Dawn: Where are we now?

Observations of Ceres before Dawn indicated that it contains ~25 wt% water, and thermodynamic modeling indicated Ceres probably had experienced the same process of differentiation due to melting of the original ice after accretion as experienced by large icy moons. Consistent with that was a surface of altered mineralogy like clays suggesting aqueous alteration of the original chondritic silicates. Dawn has revealed some concentration of mass toward the center, specific aqueously altered mineralogies, a stiff surface with weaker material beneath, and extrusions and protrusions suggesting recent subsurface activity, including exposures of water ice that must be very recent. This wealth of new information from Dawn enables selection of more specific evolution models that best match the vastly improved Dawn observations. In this new study we propose one possibility is that Ceres accreted as an ice and silicate mixture after short-lived radionuclides in CAIs had significantly decayed, i.e. nearer 5 my after CAIs, and thus differentiated less completely than for hotter models. On the other hand, the presence of heavily aqueously altered mineralogies, including probably salts, suggests extensive mixing of water and silicates, which might normally be associated with more complete differentiation. Geologically recent activity, perhaps even to the present time, seems evident from several young landforms, including protrusions consistent with diapirism and recent exposures of water ice. This suggests recent flexing of the subsurface and rising of less dense interior material, including salts and ice. The presence of ammoniated minerals and what appear to be salt deposits suggest a major lowering of subsurface water ice melting temperature, enhancing the duration of water-silicate contact, and perhaps accelerating the mineralization processes and slowing or halting differentiation of water and silicates. Thus, Ceres is becoming known as the first body outward from the Sun that has had its evolution controlled by water-driven processes. Investigations of its interior and geology enable by Dawn's observations will in turn help to better understand other ice-rich bodies.
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507 – Mission Showcase: MSL Progress on Habitability

507.01 – Anatomy of an ancient aeolian sandstone on Mars: the Stimson formation, Gale crater, Mars

Since landing in 2012, the Mars Science Laboratory's (MSL) rover Curiosity has traversed the plains and foothills of Aeolis Mons (informally known as Mt. Sharp) investigating the environments preserved in the stratigraphic record of Gale crater. Recently, the Curiosity team has been investigating the Stimson formation, a sandstone exhibiting abundant crossbedding that drapes the underlying Murray formation mudstones. The contact between the Stimson and underlying Murray formation exhibits several meters relief over several 100 m hundred metres where encountered thus

far. The Stimson is observed to onlap onto this contact, indicating that accumulating Stimson sandstones unconformably onlapped or buried local palaeotopography.
Facies and architectural elements observed within the Stimson are interpreted to represent deposition within an ancient dune field. The Stimson formation is typically composed of decimeter-scale and meter-scale crossbedded sandstones, (exhibiting wind-ripple lamination and well rounded particles up to granule size). Architectural elements are visible in outcrops oriented perpendicular to the regional northwest dip. These consist of undulating surfaces parallel to the regional dip with observed lateral extents up to 30 m that truncate underlying cross-sets and commonly act as basal surfaces to overlying cross-sets. Undulating surfaces are interpreted possibly to be deflationary supersurfaces, which formed in response to deflation or dune-field stabilisation across a regional extent. Surfaces inclined relative to the regional dip ascend between supersurfaces towards the north east at an observed angle of 3-4°. These surfaces are interpreted to be dune bounding surfaces, which are preserved when dunes climb as a result of dune-field aggradation. Aggradation of the system during the duration of the dune field's existence possibly occurred as a response to episodic increases of sediment supply into the basin, allowing dunes to climb and preserving the basal parts of the dunes. The angle and orientation of bounding surfaces and trough crossbedding within the Stimson sandstone suggest that the dunes migrated to the northeast.
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507.02D – Testing a mechanical model of fracture formation by compaction-related burial in Gale crater, Mars: Implications for the origin of Aeolis Mons

Gale crater's 5-km-high central mound, Aeolis Mons (Mt. Sharp), has two leading hypotheses for its formation: buildup of windblown sediments, and exhumation of deeply buried strata. The deep burial hypothesis implies deformation by gravitational body forces and we evaluate that idea here. Ubiquitous fracture-related features have been regionally mapped from orbit and observed by the Curiosity rover in sedimentary strata including the Murray formation (dominantly mudstone) and the unconformably overlying Stimson formation (sandstone). Large fractures which exhibit complex banding structures with distinct chemical trends (e.g. halos) are primarily found in the Stimson fm, but do extend into the Murray fm in one location. Smaller, sulfate-filled fractures are most prevalent in the Murray but are also associated with haloed fractures in the Stimson. We test a compaction-related burial origin for these features based on a mechanical model for mode I fracture formation in order to constrain the regional stress history. According to the Mohr-Coulomb failure criterion, extension fracturing requires that the minimum principal stress (σ_3) exceed the elastic tensile strength in the plane perpendicular to the opening. Given that tectonic driving processes are inoperative within Gale, non-tectonic mechanisms including overburden (maximum compressive stress; $\sigma_1 = \rho g D$) and pore fluid pressure ($p_f \propto D$) must account for this tensile stress. Significant compaction as a result of increased depth of burial is required for p_f to exceed σ_3 and cause fracturing. When applied to Gale, we find that the estimated horizontal stress (σ_3), as influenced by crater geometry, requires a substantial burial depth to produce sufficient p_f to cause hydrofracture. Rheology contrasts likely caused fractures to develop and propagate more easily in the Stimson sandstone, which can support a smaller σ_3, than in the Murray mudstone. In these permeable rocks, the sudden local decrease of p_f at fractures likely caused flow of pore water into the fracture, creating the observed alteration. These results imply that formation of these fractures requires at least one significant burial event, providing key insight into the geologic history of Gale crater.
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507.03 – Chemical variations observed on Aeolis Mons in Gale Crater, Mars

The extraordinarily extensive exposure of hematite-, clay-, sulfate-bearing stratigraphic layers in the lower part of Aeolis Mons was the primary reason Gale Crater was selected as the landing site for the Mars Science Laboratory rover, Curiosity. 753 martian solar days (sols) after the Curiosity rover landed in Gale Crater in August 2012, and after driving more than 9 km, the Curiosity rover arrived at the first exposure of the Murray formation, the basal layer of Aeolis Mons. The Murray formation is a thinly laminated lacustrine mudstone showing stratification down to the millimeter scale. This supports the idea that the stratigraphic layers of Aeolis Mons are sedimentary, and likely deposited in a series of long-lived lakes extending into the early Hesperian time, as recently described by Grotzinger et al. (*Science, vol. 350,* 2015).
The chemical variations observed throughout the Murray formation by the ChemCam and APXS instruments in the 600+ sols since first arriving at Aeolis Mons will be presented. While Murray remains thinly laminated throughout the 30+ vertical meters of stratigraphy explored, large chemical variations are observed. The most extreme variations arise from likely co-located detrital and diagenetic silica enrichments in Murray. Remarkably, an associated diagenetic silica enrichment is also observed in the unconformably overlying eolian sandstone of the Stimson formation in that location. The detrital enrichment provides evidence of how the source region chemistry varied as the sedimentary layers of Aeolis Mons were deposited. Conversely, the diagenetic enrichment observed across both the Murray and Stimson formations provides compelling evidence for the presence of subsurface fluids in Gale Crater, thousands to millions of years after the crater lakes disappeared. This evidence of liquid water greatly extends the timescale in which Gale Crater might have been habitable.
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Contributing team(s): MSL Science Team

507.04 – Fluid migration through sandstone fractures in Gale Crater, Mars

The Curiosity Mars rover encountered numerous occurrences of light-toned fractures in lithified sediments along its traverse in Gale Crater. These alteration zones can be traced for tens of meters across the landscape and are generally less than a meter in width. Two of these features were investigated in detail by the rover instruments, including drilling to acquire samples both within and immediately outside the lighter-toned areas.
The chemical composition established by the Alpha Particle X-ray Spectrometer (APXS) on the arm of the rover shows that the alteration zones are significantly enhanced in silica (40% increase) and sulfur (factor of ~5) relative to the surrounding rocks.

Concentrations of Fe, Mg, Al, Mn, Ni and Zn are reduced by a factor of two or more. The correlation between Ca and SO3 indicates the presence of Ca-sulfates, but with up to 15% SO3 (and only 6% to 9% CaO) in the APXS data, the presence of Mg and Fe sulfates in the altered fractures is likely.
The Chemistry and Mineralogy (CheMin) X-ray diffraction instrument analyzed the drill fines and found mostly plagioclase feldspar, pyroxenes and magnetite in the unaltered sandstones. X-ray amorphous material and minor hematite and Ca-sulfates are also present. Samples from the alteration zones, however, show a factor of two decrease in the pyroxene to feldspar ratio, abundant Ca-sulfates in various hydration states, and a majority fraction of amorphous material rich in silica and mixed-cation sulfates.
The direct comparison of samples within and adjacent to the light toned fractures indicates an alteration process involving the dissolution of pyroxenes and removal of metal cations. The mobility of Al and the likely presence of Fe-sulfates suggest alteration in an acidic environment, but additional moderate pH episodes cannot be ruled out. These features post-date the sandstone lithification and are among the youngest fluid events studied thus far in Gale Crater.
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507.05 – In situ Investigations of Organics, Isotopes, and Inorganic Volatiles in Gale Crater

During its path toward and now onto the flanks of Mount Sharp in Gale crater the powerful set of instruments of the Curiosity rover have enabled a wide range of geological and geochemical studies. The focus of the Sample Analysis (SAM) at Mars Investigation is to conduct volatile and isotope measurements of both the atmosphere and drilled or scooped solids to help elucidate present and ancient environmental conditions and the global changes that have transformed Mars over time.
Discoveries, to date, include:
(1) definitive identification of an increasing number of S and Cl containing organic compounds in Gale crater samples,
(2) transient spikes and season-length variations in atmospheric methane abundance,
(3) the cosmic radiation exposure age of a mudstone using the spallogenic ^{3}He and ^{21}Ne and the neutron capture ^{36}Ar isotopes,
(4) the rock formation age in the same sample using the SAM ^{40}Ar and the K abundance from the Alpha Particle Backscatter instrument,
(5) constraints on atmospheric loss rates over geological time using the atmospheric ^{36}Ar/^{38}Ar ratio and isotopes of C and O in CO_2,
(6) D/H ratios locked into mudstone rocks more than 3 billion years ago,
(7) perchlorates and a variety of other minerals contained in the ubiquitous amorphous fraction of solid samples, and
(8) isotopic fractionation in the trace atmospheric Kr and Xe isotopes that allowed a first in situ comparison with martian gas trapped in meteorites.
In this overview of our exploration of volatiles in Gale crater we will focus on organic compounds discovered to date, variations in the chemistry and isotopic composition of solid samples taken on the traverse to Mount Sharp, and on seasonal variations in isotopes and mixing ratios in the atmosphere.
The results described have relied on significant contributions from many members of the MSL and SAM teams.
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Contributing team(s): The Mars Science Laboratory Team, The Sample Analysis at Mars Team

507.06 – ChemCam analysis of Martian fine dust

In this work, we examine the chemical composition of dust observed by the Chemistry Camera (ChemCam) instrument onboard the Mars Science Laboratory (MSL) rover at Gale Crater. The Laser Induced Breakdown Spectroscopy technique analyses samples without preparation, which allows detection of the elemental composition of surface deposits. Mars aeolian fine dust (<2-3 microns) composition is analyzed on the first shot of each Mars target. It is reproducible over time and present a composition characteristic of the global martian fine dust, which covers the entire planet and contributes to the local geology analyzed by MSL. Its composition can also be retrieved on the ChemCam Calibration Targets (CCCT) by subtraction of the well characterized CCCT spectra. The CCCT include eight glasses and ceramics that have been generated to simulate Martian rocks of interest and two targets of a single element (graphite for carbon and an alloy of titanium). ChemCam passive spectroscopy also indicates varying deposition of the dust cover on the CCCT. Major elements are quantified and shown to be very similar to the fine soils encountered at Gale crater. The composition is also similar to the soils and fine dust measured by APXS for the elements common to both instruments. The minor elements quantified by ChemCam (Ba, Sr, Rb, Li, Mn, Cr) are within the range of soil surveys, but we see a higher concentration of Li than in other types of remotely characterized targets. Sulfur is possibly detected at the ChemCam limit of detection. Hydrogen is clearly identified, indicating that this fine dust is a contributor to the H content of the martian soils, as also detected by the SAM and CheMin instruments, and provides constraints as to which fraction of the Martian surface is hydrated and altered. In conclusion, the finest fraction of dust particles on the surface of Mars contains hydrated components mixed intimately within the fine aeolian dust fraction, suggesting that this dust likely originates from mechanical weathering of altered grains.
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Contributing team(s): MSL Science Team

507.07 – Water cycle at Gale crater through MSL/REMS observations

The Mars Science laboratory (MSL) has been successfully operating at the Gale crater since early August 2012 and has provided a wealth of extremely valuable data. That includes atmospheric observations

by the REMS instrument performing atmospheric pressure, temperature of the air, ground temperature, wind speed and direction, relative humidity (REMS-H), and UV measurements. The REMS-H relative humidity device is based on polymeric capacitive humidity sensors developed by Vaisala Inc. and it makes use of three (3) humidity sensor heads. The humidity device is mounted on the REMS boom providing ventilation with the ambient atmosphere through a filter protecting the device from airborne dust.
The REMS-H humidity instrument has created an unprecedented data record of more than two full Martian. REMS-H measured the relative humidity and temperature at 1.6 m height for a period of 5 minutes every hour as part of the MSL/REMS instrument package. We focus on describing the annual in situ water cycle with the new REMS-H instrument calibration for the period of two Martian years. The results will be constrained through comparison with independent indirect observations and through modeling efforts. We inferred the hourly atmospheric VMR from the REMS-H observations and compared these VMR measurements with predictions of VMR from our 1D column Martian atmospheric model and regolith to investigate the local water cycle, exchange processes and the local climate in Gale Crater. The strong diurnal variation suggests there are surface-atmosphere exchange processes at Gale Crater during all seasons, which depletes moisture to the ground in the evening and nighttime and release the moisture back to the atmosphere during the daytime. On the other hand, these processes do not result in significant water deposition on the ground, because frost has not been detected in Gale Crater by any of the MSL observations. Hence, our modelling results presumably indicate that adsorption processes take place during the nighttime and desorption during the daytime. Other processes, e.g. convective turbulence play a significant role in the daytime in conveying the moisture into the atmosphere.
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508 – Jovian Atmospheres IV: Composition of Jupiter and Saturn

508.01 – Saturn's Helium Abundance from Cassini CIRS and RSS Data

The ratio of helium to hydrogen in Saturn's atmosphere provides an important constraint on models of Saturn's formation and evolution, but has been poorly constrained by available data. Measurements combining Voyager infrared and radio data [1] gave a He/H_2 mole ratio of 0.034 ± 0.024, far below the protosolar value and requiring either significant helium loss or sequestration in the interior. Prompted by discrepancies between the Voyager infrared/radio and Galileo probe measurements of helium on Jupiter, Conrath and Gautier [2] reevaluated the helium abundance on Saturn from Voyager infrared data only, obtaining a He/H2 mole ratio of 0.135 ± 0.025, inconsistent with the previous results. Because of this discrepancy, estimating Saturn's atmospheric helium abundance has been a major goal of the Cassini mission.
We are estimating the He/H_2 mole ratio in Saturn's atmosphere using a combination of data from the Cassini Radio Science Subsystem (RSS) and Composite InfraRed Spectrometer (CIRS). Radio occultations, in which a carrier signal is observed as Cassini passed behind Saturn as seen from antennas on Earth, give a vertical profile of atmospheric refractivity, which can be converted to temperature as a function of pressure assuming a mean molecular weight. The assumed molecular weight is adjusted until synthetic thermal infrared spectra match spectra observed by CIRS at the same latitude and time. Preliminary results from a set of eleven near-equatorial occultations taken in 2005 give He/H_2 mole ratios varying between ~0.060 and 0.085.
[1] Conrath, B. J., et al., 1984, Ap. J., 282:807-815
[2] Conrath, B. J. and D. Gautier, 2000, Icarus, 144:124-134
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508.02 – Slantwise convection on fluid planets: Interpreting convective adjustment from Juno observations

NASA's Juno mission provides unprecedented microwave measurements that pierce Jupiter's weather layer and image the transition to an adiabatic fluid below. This region is expected to be highly turbulent and complex, but to date most models use the moist-to-dry transition as a simple boundary. We present simple theoretical arguments and GCM results to argue that columnar convection is important even in the relatively thin boundary layer, particularly in the equatorial region. We first demonstrate how surface cooling can lead to very horizontal parcel paths, using a simple parcel model. Next we show the impact of this horizontal motion on angular momentum flux in a high-resolution Jovian model. The GCM is a state-of-the-art modification of the MITgcm, with deep geometry, compressibility and interactive two-stream radiation. We show that slantwise convection primarily mixes fluid along columnar surfaces of angular momentum, and discuss the impacts this should have on lapse rate interpretation of both the Galileo probe sounding and the Juno microwave observations.
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508.03 – Scavenging of ammonia by raindrops in Saturn's great storm clouds

Observations of the great Saturn storms of 2010-2011 by Cassini instruments showed a very large depletion in atmospheric ammonia. While dynamics will play a role, the very high solubility of ammonia in water may be another important contributor to ammonia depletion in storms. Ammonia exists in Earth's atmosphere and rainstorms dissolve ammonia to a great degree, leaving almost no NH_3 in the atmosphere. Studies by Elperin et al (2011, 2013) show that scavenging of ammonia is greatest as a rainstorm starts and lessens as raindrops fall, tapering off to almost zero by the time the rain reaches the ground (Elperin et al 2009). Ammonia is reaching saturation as it dissolves in the aqueous solution. As concentration increases, NH_3 is then converted to aqueous species $(NH_3)_x.(H_2O)_y$ (Max and Chapados 2013).
Ammonia has the highest solubility in water compared to all other gases in the Saturn atmosphere. The Henry's Law constant for NH_3 in water is 60 M/atm at 25 C. For H_2S, it is 0.001 M/atm. In Saturn storms, it is "raining UP": As water-laden storm clouds convectively rise, ammonia gas will be scavenged and go into solution to a great degree, whilst all the other gases remain mostly in the gas phase. Aqueous ammonia acts as an antifreeze: if ammonia is dissolved in water cloud droplets to the limit of its solubility, as water droplets rise, they can stay liquid (and continue to scavenge NH_3) to well below their normal freezing point of 0 Celsius (273 K). The freezing point for a 30 wt % water-ammonia solution is ~189 K. The pressure level where T = 189 K is at 2.8 bars. The normal freezing point of water occurs at the 9 bar pressure level in Saturn's atmosphere. 2.8

bars occurs at the -51 km altitude (below the 1 bar level). 9 bars is at the -130 km level: a difference of 79 km. A water droplet containing 30 wt% NH3 can move upwards from 9 bars to 2.8 bars (79 km) and still remain liquid, only freezing above that altitude. Calculations by the E-AIM model show that ammonia becomes the dominant species as the water droplets rise and cool. Ammonia will be effectively depleted as it is scavenged into water droplets in Saturn's storms.

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508.04 – Heating of Jupiter's upper atmosphere above the Great Red Spot

Measured upper-atmospheric, mid-to-low latitude temperatures of the giant planets are hundreds of degrees warmer than simulations based on solar heating alone can explain. Modelling studies, focused on additional sources of heating, have been so far unable to resolve this significant model-data discrepancy. Equatorward transport of energy from the hot auroral regions was expected to heat low latitude regions; instead, models have demonstrated that auroral energy is trapped at high latitudes, a consequence of the strong Coriolis forces on these rapidly rotating planets. Wave heating, driven from below, represents another potential source of upper-atmospheric heating. Using data taken in 2012 by the ground-based NASA IRTF, we found through observations of the H3+ ion that the upper atmosphere above Jupiter's Great Red Spot (GRS) - the largest storm in the solar system - is hundreds of degrees hotter than anywhere else on the planet. Specifically, the result shows that the northern region of the spot was over 1600 K, and that background temperatures away from the spot are ~850 K. The hotspot, by process of elimination, must be heated from below, and this detection is therefore strong evidence for coupling between Jupiter's lower and upper atmospheres, likely the result of upward propagating acoustic and/or gravity waves. Our results indicate that the lower atmosphere may yet play an important role in resolving the giant planet 'energy crisis'.

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508.05 – Volatile Abundances and the Deep Cloud Structure in Jupiter's Great Red Spot

Despite the presence of thick upper level clouds, Jupiter's Great Red Spot preserves the signature of physical conditions at much deeper levels in the troposphere. The Great Red Spot is dark at 5 microns due to thick clouds, but imaging alone does not reveal which cloud layers are responsible for attenuating this radiation. We used NIRSPEC on the Keck telescope and CSHELL on the Infrared Telescope Facility to spectrally resolve line profiles of CH_3D and other molecules on Jupiter in order to derive the pressure of the line formation region in the 5-micron window. Variations in CH_3D line shape with position on Jupiter are due to cloud structure rather than changes in gas mole fraction.

By aligning the slit east/west on Jupiter, we sampled the Great Red Spot and a Hot Spot at the same latitude. The profile of the CH_3D lines is very broad in the Hot Spot due to collisions with up to 8 bars of H_2, where unit optical depth due to collision induced H_2 opacity occurs. The extreme width of these CH_3D features implies that Hot Spots do not have significant cloud opacity where water is expected to condense. Within the Great Red Spot, the line profiles are substantially narrower than in the Hot Spot. The best fit to the line shape of CH_3D requires an opaque cloud at 5 bars, which we identify as being a water cloud. Thermal radiation from the 5-bar level is further attenuated by upper level clouds, but these colder clouds do not change the shape of the spectrum. Once we have established a cloud structure, gas mole fractions may then be retrieved. Gaseous H_2O is clearly evident in the Great Red Spot, which provides independent evidence that we are sounding deep in Jupiter's atmosphere. A combination of Keck and IRTF data allows us to retrieve NH_3, PH_3, and gaseous H_2O inside the Hot Spot and within the Great Red Spot. This technique can be applied to study the deep cloud structure anywhere on Jupiter whether or not upper level clouds are present. We will use this technique to observe Jupiter concurrent with observations from Juno in the next year.

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508.06 – Probing Below the Visible Cloud Layers in Jupiter's Atmosphere

Visible and near-infrared images of the giant planets reveal a multitude of clouds, ranging in size from tiny, hardly visible, features to giant storm systems, such as Jupiter's Great Red Spot and Oval BA. At radio wavelengths we can probe altitudes in Jupiter's atmosphere below these visible cloud layers. We used the upgraded Very Large Array to map this unexplored region down to ~10 bar. We will present full radio maps at frequencies between 4 and ~35 GHz, with typical spatial resolutions of order 1000-2000 km. We will also show spectra and radiative transfer calculations of individual features, such as the Great Red Spot, Oval BA, hot spots and ammonia-rich "plumes". Our maps are complementary to observations planned for Juno's microwave radiometer (MWR). MWR's field-of-view is tiny, ~1000 km at the highest frequencies at perijove, and is limited to extremely narrow swaths of longitude; as such, our VLA maps will provide regional and global context at wavelengths overlapping with Juno MWR. Several maps at 8-12 GHz, at a spatial resolution of ~1000 km, will be taken during Juno perijove passes.

Our analysis to date, based on 4-18 GHz maps, reveal a dynamically active planet at pressures < 2-3 bar. We identify a radio-hot belt on the interface between the NEB and EZ, consisting of relatively transparent regions (a low ammonia concentration, NH_3 being the dominant source of opacity) probing depths to over ~8 bar; these regions likely coincide with 5-mm hotspots. Just to the south we distinguish an equatorial wave, bringing up ammonia gas from Jupiter's deep atmosphere in "plumes", at concentrations similar to that measured by the Galileo Probe. At higher altitudes, the ammonia gas in these plumes will condense out, and as such could be responsible for the spectroscopically identified fresh ammonia ice clouds detected by the Galileo spacecraft at these latitudes.

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508.07D – Latitudinal variability of arsine, germane and phosphine in Jupiter's troposphere

High-resolution 5-μm observations of Jupiter from the CRIRES instrument at the Very Large Telescope are used to measure latitudinal variability in AsH_3, GeH_4 and PH_3. The 5-micron region is a spectral window allowing us to probe down to Jupiter's middle troposphere (4-8 bar). CRIRES observations in 2012 and 2013 provide high-resolution (R=96,000) latitudinally-resolved spectra in the 4.7-5.2 μm region. In the middle troposphere, AsH_3, $GeH_4$and PH_3 are disequilibrium species that are only present because of rapid upwelling from deeper regions of the planet. Their observed abundances depend on the chemical lifetimes, the strength of the vertical mixing and the rate of photolytic destruction, and are therefore likely to vary with latitude. We analyse the CRIRES observations using the NEMESIS radiative transfer code and retrieval algorithm in order to search for any latitudinal variability in the disequilibrium species. We find that there is a significant degeneracy between the retrieved gaseous abundances and the cloud structure – specifically, the scattering properties of the main tropospheric cloud deck, and the presence/absence of an additional deep cloud. Because of these degeneracies, there is no clear evidence for any variability in GeH_4. However, for AsH_3 and PH_3, there are significant latitudinal differences in the observed lineshape that cannot be accounted for by clouds. We conclude that both of these gases show an enhancement at high latitudes. In the case of AsH_3, the retrieved abundance varies from subsolar in the equatorial regions (as seen in previous studies) to supersolar in the polar regions. Our findings are in contrast with the theoretical simulations of Wang et al. (2016, doi:10.1016/j.icarus.2016.04.027), which predict that AsH_3 and PH_3 should not vary with latitude, and that GeH_4 should decrease in abundance at high latitudes.

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508.08 – Accurate Spectral Fits of Jupiter's Great Red Spot: VIMS Visual Spectra Modelled with Chromophores Created by Photolyzed Ammonia Reacting with Acetyleneχ±

We report results incorporating the red-tinted photochemically-generated aerosols of Carlson et al (2016, *Icarus* 274, 106-115) in spectral models of Jupiter's Great Red Spot (GRS). Spectral models of the 0.35-1.0-micron spectrum show good agreement with Cassini/VIMS near-center-meridian and near-limb GRS spectra for model morphologies incorporating an optically-thin layer of Carlson (2016) aerosols at high altitudes, either at the top of the tropospheric GRS cloud, or in a distinct stratospheric haze layer. Specifically, a two-layer "crème brûlée" structure of the Mie-scattering Carlson et al (2016) chromophore attached to the top of a conservatively scattering (hereafter, "white") optically-thick cloud fits the spectra well. Currently, best agreement (reduced χ^2 of 0.89 for the central-meridian spectrum) is found for a 0.195-0.217-bar, 0.19 ± 0.02 opacity layer of chromophores with mean particle radius of 0.14 ± 0.01 micron. As well, a structure with a detached stratospheric chromophore layer ~0.25 bar above a white tropospheric GRS cloud provides a good spectral match (reduced χ^2 of 1.16). Alternatively, a cloud morphology with the chromophore coating white particles in a single optically- and physically-thick cloud (the "coated-shell model", initially explored by Carlson et al 2016) was found to give significantly inferior fits (best reduced χ^2 of 2.9). Overall, we find that models accurately fit the GRS spectrum if (1) most of the optical depth of the chromophore is in a layer near the top of the main cloud or in a distinct separated layer above it, but is not uniformly distributed within the main cloud, (2) the chromophore consists of relatively small, 0.1-0.2-micron-radius particles, and (3) the chromophore layer optical depth is small, ~ 0.1-0.2. Thus, our analysis supports the exogenic origin of the red chromophore consistent with the Carlson et al (2016) photolytic production mechanism rather than an endogenic origin, such as upwelling of material from the depths of Jupiter.

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508.09 – A Possibly Universal Red Chromophore for Jupiter

A new laboratory-generated chemical compound made from photodissociated ammonia (NH_3) molecules reacting with acetylene (C_2H_2) was suggested as a possible coloring agent for Jupiter's Great Red Spot (GRS) by Carlson et al. (2016, Icarus 274, 106-115). Baines et al. (2016, AAS/DPS Meeting abstract) showed that the GRS spectrum measured by the visual channels of the Cassini VIMS instrument in 2000 could be accurately fit by a cloud model in which the chromophore appeared as small particles in a physically thin layer immediately above the main cloud layer of the GRS. Here we show that the same chromophore and similar layer structure can also provide close matches to the 0.4-1 micron spectra of many other cloud features on Jupiter, suggesting that this material may be a nearly universal chromophore responsible for the various degrees of red coloration on Jupiter. This is a robust conclusion, even for 12 percent changes in VIMS calibration and large uncertainties in the refractive index of the main cloud layer due to uncertain fractions of NH_4SH and NH_3 in its cloud particles. The chromophore layer can account for color variations among north and south equatorial belts, equatorial zone, and the Great Red Spot, by varying particle size from 0.12 to 0.29 micron and optical depth from 0.06 to 0.76. The total mass of the chromophore layer is much less variable than its optical depth, staying mainly within 6-10 micrograms/cm^2 range, but is only about half that amount in the equatorial zone. We also found a depression of the ammonia volume mixing ratio in the two belt regions, which averaged 0.4-0.5 × 10^{-4} immediately below the ammonia condensation level, while the other regions averaged twice that value.

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509 – Titan: The Stratosphere and Its Evolution

509.01 – Aerosol chemistry in Titan's ionosphere: simultaneous growth and etching processes

Since the Cassini-CAPS measurements, organic aerosols are known to be present and formed at high altitudes in the diluted and partially ionized medium that is Titan's ionosphere [1]. This unexpected chemistry can be further investigated in the laboratory with plasma experiments simulating the complex ion-neutral chemistry starting from N_2-CH_4 [2].

Two sorts of solid organic samples can be produced in laboratory experiments simulating Titan's atmospheric reactivity: grains in the volume and thin films on the reactor walls. We expect that grains are more representative of Titan's atmospheric aerosols, but films are used to provide optical indices for radiative models of Titan's atmosphere.

The aim of the present study is to address if these two sorts of analogues are chemically equivalent or not, when produced in the same N_2-CH_4 plasma discharge.

The chemical compositions of both these materials are measured by using elemental analysis, XPS analysis and Secondary Ion Mass Spectrometry. We find that films are homogeneous but significantly less rich in nitrogen and hydrogen than grains produced in the same experimental conditions. This surprising difference in their chemical compositions is explained by the efficient etching occurring on the films, which stay in the discharge during the whole plasma duration, whereas the grains are ejected after a few minutes [3].

The impact for our understanding of Titan's aerosols chemical composition is important. Our study shows that chemical growth and etching process are simultaneously at stake in Titan's ionosphere. The more the aerosols stay in the ionosphere, the more graphitized they get through etching process. In order to infer Titan's aerosols composition, our work highlights a need for constraints on the residence time of aerosols in Titan's ionosphere.

[1] Waite et al. (2009) Science , 316, p. 870
[2] Szopa et al. (2006) PSS, 54, p. 394
[3] Carrasco et al. (2016) PSS, 128, p. 52

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509.02 – Retrievals of the Abundances of Acetylene and other Hydrocarbons in Titan's Upper Atmosphere

Acetylene abundance in the Titan upper atmosphere has been extracted from Cassini Ultraviolet Imaging Spectrograph (UVIS) stellar occultations. The data reduction process is based on simulation of the discrete spectral absorption in the far ultraviolet (FUV) region between 110 and 190 nm. Pointing drift is corrected by instrument simulation of the stellar image location on the instrument detector. Latitude and seasonal dependence of the vertical profiles has been examined. The observed spectra have been compared to atmospheric chemical model calculations (KINETICS) by predicting the occultation spectra, allowing the imposition of constraints on the model, and directly establishing the level of uncertainty in the extraction process. Hydrocarbon and nitrile vertical profiles have been extracted, with limits set on the precursors to aerosols. Aerosol continuum spectral structure is recognized in the extinction spectra, but physical chemistry modeling of aerosol precursors to date indicate higher abundances than the upper limits set by observation.

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509.03 – ALMA observations of Titan : Vertical and spatial distribution of HNC and C2H5CN

We report submm observations of Titan performed with the ALMA interferometer centered at the rotational frequencies of HCN(4-3) and HNC(4-3), i.e. 354 and 362 GHz. These measurements yielded disk-resolved emission spectra of Titan with an angular resolution of ~0.47''. Titan's angular surface diameter was 0.77''. Data were acquired in summer 2012 near the greatest eastern and western elongations of Titan at a spectral resolution of 122 kHz (λ/d λ = 310^6).
We have obtained maps of several nitriles present in Titan' stratosphere: HCN, HC_3N, CH_3CN, HNC, C_2H_5CN and other weak lines (isotopes, vibrationnally excited lines).
We will present radiative transfer analysis of the spectra acquired focused on HNC and C2H5CN. With the combination of all these detected rotational lines, we will constrain the spatial and vertical distribution of these species.

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509.04 – Spatial Variations of Chemical Abundances in Titan's Atmosphere as Revealed by ALMA

Complex organic molecules in Titan's atmosphere - formed through the dissociation of N_2 and CH_4 - exhibit latitudinal variations in abundance as observed by Cassini. Chemical species including hydrocarbons - such as CH_3CCH - and nitriles - HCN, HC_3N, CH_3CN, and C_2H_5CN - may show spatial abundance variations as a result of atmospheric circulation, photochemical production and subsequent destruction throughout Titan's seasonal cycle. Recent calibration images of Titan taken by the Atacama Large Millimeter/Submillimeter Array (ALMA) with beam sizes of ~0.3'' allow for measurements of rotational transition lines of these species in spatially resolved regions of Titan's disk. We present abundance profiles obtained from public ALMA data taken in 2014, as Titan transitioned into northern summer. Abundance profiles in Titan's lower/middle atmosphere were retrieved by modeling high resolution ALMA spectra using the Non-linear Optimal Estimator for MultivariatE Spectral analySIS (NEMESIS) radiative transfer code. These retrievals were performed using spatial temperature profiles obtained by modeling strong CO lines from datasets taken in similar times with comparable resolution. We compare the abundance variations of chemical species to measurements made using Cassini data. Comparisons of chemical species with strong abundance enhancements over the poles will inform our knowledge of chemical lifetimes in Titan's atmosphere, and allow us to observe the important changes in production and circulation of numerous organic molecules which are attributed to Titan's seasons.

Author(s): Alexander E Thelen[3], Conor Nixon[1], Nancy J. Chanover[3], Edward Molter[1], Joseph Serigano[2], Martin Cordiner[1], Steven B. Charnley[1], Nicholas A. Teanby[4], Patrick Irwin[5]
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509.05 – Isotopic Ratios in Nitriles from Submillimeter Spectroscopy Using SMA and ALMA

We present submillimeter spectroscopic observations of Titan obtained using the Submillimeter Array (SMA) in 2011, and the Atacama Large Millimeter/Submillimeter Array (ALMA) in 2012, some of which have previously been presented but not fully analyzed (1, 2, 3). The SMA observations were obtained at low spatial resolution, providing disk average spectra, but the ALMA observations provide low resolution mapping of Titan (~0.4"-0.6" when Titan was 0.77" surface diameter). We will present detailed radiative transfer analysis of detected spectral lines to derive isotopic ratios in two nitriles: HCN (D/H, $^{13}C/^{12}C$, $^{15}N/^{14}N$) and HC_3N ($^{15}N/^{14}N$). The analysis makes use of nearly concurrent CIRS temperature profiles as important constraints for the vertical profiles of these species, allowing high precision measurements of the ratios. Finally, we will highlight current and future ALMA observations that will allow monitoring of non-symmetric molecular species in Titan's upper atmosphere from Earth, beyond the end of the Cassini mission.

(1) Gurwell et al (2011) EPSC-DPS Joint Meeting 2011, p270. (2) Moreno et al (2014) EPSC 2014 Abstracts, Vol. 9, id. EPSC2014-438. (3) Moreno etal (2014), DPS meeting #46, id.211.19

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509.06 – Seasonal radiative modeling of Titan's stratosphere

We have developed a seasonal radiative model of Titan's stratosphere to investigate the time variation of stratospheric temperatures in the 10^{-3} - 5 mbar range as observed by the Cassini/CIRS spectrometer. The model incorporates gas and aerosol vertical profiles derived from Cassini/CIRS spectra to calculate the heating and cooling rate profiles as a function of time and latitude. In the equatorial region, the radiative equilibrium profile is warmer than the observed one. Adding adiabatic cooling in the energy equation, with a vertical velocity profile decreasing with depth and having $w \approx 0.4$ mm sec^{-1} at 1 mbar, allows us to reproduce the observed profile. The model predicts a 5 K decrease at 1 mbar between 2008 and 2016 as a result of orbit eccentricity, in relatively good agreement with the observations. At other latitudes, as expected, the radiative model predicts seasonal variations of temperature larger than observed, pointing to latitudinal redistribution of heat by dynamics. Vertical velocities seasonally varying between -0.4 and 1.2 mm sec^{-1} at 1 mbar provide adiabatic cooling and heating adequate to reproduce the time variation of 1-mbar temperatures from 2005 to 2016 at 30°N and S. The model is also used to investigate the role of the strong compositional changes observed at high southern latitudes after equinox in the concomitant rapid cooling of the stratosphere.

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509.07 – Evolution and search for new molecules in Titan's stratosphere from Cassini CIRS observations

We observe the onset and enhancement at Titan's south pole in several trace species, such as complex hydrocarbons like C6H6 and nitriles like HC3N, observed only at high northern latitudes before equinox. We analyze Cassini/CIRS nadir spectra taken from 2012 to 2015 at high resolution at several latitudes from 70°S to 70°N after the Southern Autumnal Equinox [1-4]. In the more recent dates, most molecules show dramatic increases in the south. The 70°S and 50°S or mid-latitudes show different behavior demonstrating that they are subject to different dynamical processes in and out of the polar vortex region. For most species, we find higher abundances at 50°N compared to 50°S, with the exception of C3H8, CO2, C6H6 and HC3N, which arrive at similar mixing ratios after mid-2013 [3,4]. While the 70°N data show generally no change with a trend rather to a small decrease for most species within 2014, the 70°S results indicate a strong enhancement in trace stratospheric gases after 2012. In particular, HC3N, HCN and C6H6 have increased by 3 orders of magnitude over the past 3-4 years while other molecules, including C2H4, C3H4 and C4H2, have increased less sharply (by 1-2 orders of magnitude). This is a strong indication of the rapid and sudden buildup of the gaseous inventory in the southern stratosphere during 2013-2014, as expected as the pole moves deeper into winter shadow. Subsidence gases that accumulate in the absence of ultraviolet sunlight, evidently increased quickly since 2012 and some of them may be responsible also for the reported haze decrease in the north and its appearance in the south at the same time [5]. We also look for the appearance of new molecules (complex hydrocarbons and nitriles) in large averages of CIRS spectra, based on model predictions.

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Author(s): Athena Coustenis[2], Donald Jennings[3], Panayotis Lavvas[1], Richard Achterberg[3], Georgios Bampasidis[4], Conor Nixon[3], Gordon Bjoraker[3], F. Michael Flasar[3]
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509.08 – Titan's south polar stratospheric vortex evolution

Titan experienced northern spring equinox in August 2009 when the south polar region was plunged into perpetual darkness. Following equinox, the south pole experienced the most extreme changes in stratospheric behaviour ever observed: the global stratospheric circulation cell reversed direction (Teanby et al 2012), HCN ice clouds (de Kok et al 2014) and other exotic condensates appeared over the south pole (Jennings et al 2015, West et al 2016), and significant composition and temperature changes occurred (Vinatier et al 2015, Teanby et al 2015, Coustenis et al 2016). Here we use Cassini CIRS limb and nadir observations from 2004-2016 to investigate the evolution of south polar stratospheric temperature and composition in the post-equinox period. Reversal following equinox was extremely rapid, taking less than 6 months (1/60th of a Titan year), which resulted in an initial adiabatic polar hot spot and increased trace gas abundances (Teanby et al 2012). However, rather than develop this trend further as winter progressed, Titan's polar hot spot subsequently disappeared, with the formation of a polar cold spot. Recently in late 2015 / early 2016 a more subdued hotspot began to return with associated extreme trace gas abundances. This talk will reveal the rapid and significant changes observed so far and discuss implications for possible polar feedback mechanisms and Titan's atmospheric dynamics.

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de Kok et al (2014), Nature, 514, 65-67.
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Teanby et al (2015), DPS47, National Harbor, 205.02.
Vinatier et al (2015), Icarus, 250, 95-115.
West et al (2016), Icarus, 270, 399-408.

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509.09 – Seasonal variations in Titan's stratosphere observed with Cassini/CIRS after the northern spring equinox

Since 2004, Cassini has made more than 119 Titan flybys, observing its atmosphere with instruments including the Cassini Composite InfraRed Spectrometer (CIRS). We know from CIRS observations that the global dynamics drastically changed after the northern spring equinox that occurred in August 2009 ([1], [2], [3], [4]). The pole-to-pole middle atmosphere dynamics (above 100 km) experienced a global reversal in less than 2 years after the equinox [4], while the northern hemisphere was entering spring. This new pattern, with downwelling at the south pole, resulted in an enrichment of almost all molecules inside the southern polar vortex since 2011.

We will present an analysis of CIRS limb observations up to 2016. We will show that many species (C_2H_2, HCN, HC_3N, C_6H_6, C_4H_2, CH_3CCH, C_2H_4) experienced their highest enrichments near the south pole near 500 km in March 2015, with abundances similar to in situ results from INMS at 1000 km [5], suggesting that the air inside the confined polar vortex (observed at latitudes higher than 80°S) was very efficiently transported downward from very high altitudes. In September 2015, an extension of the polar vortex towards lower latitudes (~65°S) was observed, while the molecular abundances decreased by a factor of 10 at 500 km. In the same region, unexpectedly cold stratospheric temperatures were observed below 300 km from May 2013 to the end of 2015, allowing us to detect for the first time the C_6H_6 ice signature at 680 cm^{-1}. Simultaneously, after the disruption of the north polar vortex after the equinox, the enriched air that was previously confined at very high latitude gradually expended towards mid latitudes at altitudes higher than 300 km. At the beginning of 2016, a zone depleted in molecular gas and aerosol is observed in the entire northern hemisphere between 400 and 500 km, suggesting some complex unknown dynamical effect.

References:

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[2] Achterberg et al., DPS 46, abstract 102.07,Tucson, 2014.

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[5] Cui et al., 2009, , Icarus, 200, 581-615.
Author(s): Sandrine Vinatier[4], Bruno Bézard[4], Nicholas A. Teanby[2], Sebastien Lebonnois[3], Richard Achterberg[1], Nicolas Gorius[5], Andrei Mamoutkine[5], F. Michael Flasar[5]
Institution(s): *1. Department of Astronomy, University of Maryland, 2. Earth Sciences, University of Bristol, 3. Laboratoire de Météorologie Dynamique, Université Paris 6, 4. LESIA, Obs. de Paris-Meudon, 5. NASA/GSFC*
Contributing team(s): CIRS Team

510 – Asteroid Physical Characteristics: Surfaces II

510.01 – 3-µm Spectroscopy of Asteroid 16 Psyche

Asteroid 16 Psyche, an M-type asteroid, is thought to be one of the most massive exposed iron metal object in the asteroid belt. The high radar albedos of Psyche suggest that this differentiated asteroid is dominantly composed of metal. Psyche was previously found to be featureless in the 3-µm spectral region. However, in our study we found that this asteroid exhibits a 3-µm absorption feature, possibly indicating the presence of hydrated silicates.
We have observed Psyche in the 3-µm spectral region, using the long-wavelength cross-dispersed (LXD:1.9-4.2 µm) mode of the SpeX spectrograph/imager at the NASA Infrared Telescope Facility (IRTF). For data reduction, we used the IDL (Interactive Data Language)-based spectral reduction tool Spextool (v4.1). Psyche was observed over the course of three nights with an apparent visual magnitude of ~9.50: 8 December 2015 (3 sets), 9 December 2015 (1 set), and 10 March 2016 (1 set). These observations have revealed that Psyche may exhibit a 3-µm absorption feature, similar to the sharp group in the 2.9-3.3-µm spectral range. Psyche also exhibits an absorption feature similar to the one in Ceres and Ceres-like group in the spectral 3.3-4.0-µm range. These 3-µm observational results revealed that Psyche may not be as featureless as once thought in the 3-µm spectral region.
Evidence for the 3-µm band was found on the surfaces of many M-type asteroids and a number of plausible alternative interpretations for the presence of this 3-µm band were previously suggested. These interpretations include the presence of anhydrous silicates containing structural OH, the presence of fluid inclusions, the presence of xenolithic hydrous meteorite components on asteroid surfaces from impacts, solar wind-implanted H, or the presence of troilite. The detection of the Ceres-like feature in the 3.3-4.0-µm spectral range, however, would rule out some of these alternative interpretations, especially the solar wind-implanted H.
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510.02 – Asteroid 16 Psyche: Radar Observations and Shape Model

We observed 16 Psyche, the largest M-class asteroid in the main belt, using the S-band radar at Arecibo Observatory. We obtained 18 radar imaging and 6 continuous wave runs in November and December 2015, and combined these with 16 continuous wave runs from 2005 and 6 recent adaptive-optics (AO) images to generate a three-dimensional shape model of Psyche. Our model is consistent with a previously published AO image [Hanus et al. Icarus 226, 1045-1057, 2013] and three multi-chord occultations. Our shape model has dimensions 279 x 232 x 189 km (±10%), D_{eff} = 226 ± 23 km, and is 6% larger than, but within the uncertainties of, the most recently published size and shape model generated from the inversion of lightcurves [Hanus et al., 2013]. Psyche is roughly ellipsoidal but displays a mass-deficit over a region spanning 90° of longitude. There is also evidence for two ~50-70 km wide depressions near its south pole. Our size and published masses lead to an overall bulk density estimate of 4500 ± 1400 kg m^{-3}. Psyche's mean radar albedo of 0.37 ± 0.09 is consistent with a near-surface regolith composed largely of iron-nickel and ~40% porosity. Its radar reflectivity varies by a factor of 1.6 as the asteroid rotates, suggesting global variations in metal abundance or bulk density in the near surface. The variations in radar albedo appear to correlate with large and small-scale shape features. Our size and Psyche's published absolute magnitude lead to an optical albedo of p_v = 0.15 ± 0.03, and there is evidence for albedo variegations that correlate with shape features.
Author(s): Michael K. Shepard[2], James E. Richardson[5], Patrick A. Taylor[1], Linda A Rodriguez-Ford[1], Al Conrad[7], Imke de Pater[8], Mate Adamkovics[8], Katherine R. de Kleer[8],Jared Males[7], Kathleen M. Morzinski[7], Laird Miller Close[7], Mikko Kaasalainen[6], Matti Viikinkoski[6], Bradley Timerson[3], Vishnu Reddy[5], Christopher Magri[9], Michael C. Nolan[7],Ellen S. Howell[7], Brian D. Warner[4], Alan W Harris[4]
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510.03 – VLT/SPHERE observations and shape reconstruction of asteroid (6) Hebe

(6) Hebe is a large main-belt asteroid, accounting for about half a percent of the mass of the asteroid belt. Its spectral characteristics and close proximity to dynamical resonances within the main-belt (the 3:1 Kirkwood gap and the nu6 resonance) make it a probable parent body of the H-chondrites and IIE iron meteorites found on Earth.
We present new AO images of Hebe obtained with the high-contrast imager SPHERE (Beuzit et al. 2008) as part of the science verification of the instrument. Hebe was observed close to its opposition date and throughout its rotation in order to derive its 3-D shape, and to allow a study of its surface craters. Our observations reveal impact zones that witness a severe collisional disruption for this asteroid. When combined to previous AO images and available lightcurves (both from the literature and from recent optical observations by our team), these new observations allow us to derive a reliable shape model using our KOALA algorithm (Carry et al. 2010). We further derive an estimate of Hebe's density based on its known astrometric mass.
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510.04 – A search for differentiated fragments within asteroid families

The existence of iron meteorite samples suggest that a number of planetesimals differentiated fully and were subsequently disrupted. Within the current asteroid belt, there is little evidence of bodies that fully differentiated into core, mantle and crust layers (Moskovitz et al. 2008). However, because it has been suggested that differentiation can occur within the interior of a body while the primitive exterior remains intact (Elkins-Tanton et al. 2011), an understanding of the diversity of compositions from differentiated parent bodies is critical. Asteroid families, as constituents of a disrupted progenitor body, provide a glimpse into the interior of their progenitors. However, asteroid families, while spectrally unique from one another, are spectrally similar within each family (Parker et al., 2008, Masiero et al. 2011). Using the Sloan Digital Sky Survey (SDSS) to search for a "needle in a haystack" we identify candidate basaltic and olivine-rich asteroids that are dynamically associated with asteroid families to constrain the amount of differentiation that could have occurred within the parent asteroid. Using FIRE on the 6-meter Magellan Telescope and SpeX on the 3-meter IRTF Telescope we measure near-infrared spectra of more than thirty of these candidates, most of which are part of the Eunomia and Flora families. Results of these observations are presented in this talk.

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510.05 – SOFIA + FORCAST Observations of 10 Aqueously Altered Asteroids

Aqueous alteration, or the reaction of water and minerals to produce hydrated minerals, has affected certain groups of carbonaceous meteorites (e.g., the CM and CI meteorites) and asteroids. In the visible/near-infrared (VNIR), CM/CI meteorites and some dark C-complex asteroids are known to have 0.7-µm absorptions that indicate the presence of hydrated minerals [1, 2, 3]. However, this feature does not provide any information about the amount of hydrated minerals in asteroids or meteorites [1]. In contrast, at mid-infrared (MIR) wavelengths, strong spectral features change continuously with amount of hydrated minerals in a suite of well-characterized CM/CI meteorites [1].
Using these results, we analyze the spectra of 10 C-complex asteroids observed by SOFIA + FORCAST. These targets are large objects (>95 km diameter) situated in the mid to outer Main Asteroid Belt (2.4 – 3.4 AU). We present spectra of the following asteroids, spectral types in parentheses: 36 Atalante (C), 38 Leda (Cgh), 62 Erato (Ch), 121 Hermione (Ch), 165 Loreley (Cb), 194 Prokne (C), 203 Pompeja (C), 266 Aline (Ch), 52 Europa (Ch), and 19 Fortuna (Ch). Spectra were obtained in two wavelength regions: 8.5-13.6-µm and 17.6-27.7-µm. In these spectral regions, mineralogical features that are known to change continuously with amount of hydrated minerals appear. Most of these targets are known to have hydrated minerals on their surfaces by the presence of the 0.7-µm feature [e.g. 3, 4] or from observations in the 3-µm region [5]. We interpret the spectral features observed using SOFIA and estimate the abundances of hydrated minerals for each asteroid. Additionally, we compare these observations to Spitzer observations of similar objects. A subset of these asteroids have also been measured in VNIR, which allows us to directly compare the signatures of hydration in both the VNIR and the MIR.

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510.06 – C-complex asteroids: Two main compositional families?

An important goal of asteroid science is to link extraterrestrial materials (meteorites, IDPs) to their parent bodies in order to constrain their formation and evolution. To accomplish this task, we need to combine data from several different disciplines: ground based spectroscopic observations, laboratory studies (petrology, mineralogy), and thermal modeling. Here we report the result of a large observing campaign aimed at investigating the surface composition of the most massive C-complex Main Belt Asteroids (MBAs). We observed more than 100 of these C-types with SpeX/IRTF in the near-infrared thus complementing the existing visible part of the spectrum. We also analyzed their spectral properties in the mid-infrared, when available. We will show that by comparing the mineralogical composition of these C-type asteroids with the composition of CC meteorites and IDPs we are able to identify two main compositional families among C-types (CM-like and IDP-like). A further comparison with thermal evolution models supports the idea that these two populations likely formed in two different environments.

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510.07 – Spectrophotometric characterization of minor planets using VISTA-VHS survey - MOVIS catalog

Using the observations performed by VISTA-VHS survey we obtained the near-infrared colors of 35 000 minor planets. This survey uses Y, J, H, and Ks filters to image the entire sky of the southern hemisphere. A dedicated pipeline was developed to retrieve and process the measurements corresponding to Solar System objects, which are stored in three catalogues (available online): the detections catalogue - MOVIS-D, the magnitudes catalogue - MOVIS-M, and the colors catalogue – MOVIS-C.
The analysis of the near-infrared color-color plots derived from MOVIS-C data shows the large diversity of minor planets surfaces. The patterns identified in the distribution of NIR colors correspond to different taxonomic types. The color-color plots of the asteroids with known spectral properties reveal the color intervals corresponding to various compositional types. All the diagrams that use (Y-J) color separate the spectral classes much better than it has been done until now using the (J-H) vs (H-Ks) plots. Even for large color uncertainties (<0.1) the plots (Y-J) vs. (Y-Ks) and (Y-J) vs. (J-Ks) clearly separate the asteroids belonging to the main spectroscopic S- and C-complexes and allow to identify the end-members A, D, R, and V types.

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510.08D – Hungaria Asteroid Region Telescopic Spectral Survey (HARTSS): Stony Asteroids Abundant in the Background and Family Populations

The Hungaria region represents a "purgatory" for the closest, preserved samples of the material from which the terrestrial planets accreted. The Hungaria region harbors a collisional family of Xe-type asteroids, which are situated among a background of predominantly S-complex asteroids. Deciphering their surface composition may provide constraints on the nature of the primordial building blocks of the terrestrial planets. We hypothesize that planetesimals in the inner part of the primordial asteroid belt experienced partial- to full-melting and differentiation, the Hungaria region should retain any petrologically-evolved material that formed there.
We have undertaken an observational campaign entitled the Hungaria Asteroid Region Telescopic Spectral Survey (HARTSS) to record near-infrared (NIR) spectra to characterize taxonomy, surface

mineralogy, and potential meteorite analogs. We used NIR instruments at two ground-based facilities (NASA IRTF; TNG). Our data set includes spectra of 82 Hungaria asteroids (61 background; 21 family), 65 were observed during HARTSS. We compare S-complex background asteroids to calibrations developed via laboratory analyses of ordinary chondrites, and to our analyses (EPMA, XRD, VIS+NIR spectra) of 11 primitive achondrite (acapulcoite-lodranite clan) meteorites.
We find that stony S-complex asteroids dominate the Hungaria background population (~80%). Background objects exhibit considerable spectral diversity, when quantified by spectral band parameter measurements, translates to a variety of surface compositions. Two main meteorite groups are represented within the Hungaria background: unmelted, nebular *L* chondrites (and/or *L* chondrites), and partially-melted primitive achondrites. *H*-chondrite mineralogies appear to be absent from the Hungaria background. Xe-type Hungaria family members exhibit spectral homogeneity, consistent with the hypothesis that the family was derived from the disruption of a parent body analogous to an enstatite achondrite (i.e., aubrite) composition. Hungaria region asteroids exhibit a full range of petrologic evolution, from nebular, unmelted ordinary chondrites, through partially-melted primitive achondrites, to fully-melted igneous aubrite meteorites.
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510.09 – Size and Perihelion Distribution of S and Q-type Asteroid Spectral Slopes from the Near Earth Region Through the Main Belt
High resolution spectral observations of small S-type and Q-type Near Earth Asteroids (NEAs) have shown two important trends. The spectral slope of these asteroids, which is a good indication of the amount of space weathering the surface has received, has been shown to decrease with decreasing perihelion and size. Specifically, these trends show that there are less weathered surfaces at low perihelion and small sizes. With recent results from all-sky surveys such as the Sloan Digital Sky Survey's (SDSS) Moving Object Catalog, we have gained an additional data set to test the presence of these trends in the NEAs as well as the Mars Crossers (MCs) and the Main Belt. We use an analog to the spectral slope in the SDSS data which is the slope through the g', r' and i' filters, known as the gri-slope, to investigate the amount of weathering that is present among small asteroids throughout the inner solar system. We find that the trend of the gri-slope decreases with decreasing size at nearly the same rate in the Main Belt as in the MC and NEA regions. We propose that these results suggest a ubiquitous presence of Q-types and S-types with low spectral slopes at small sizes throughout the inner solar system, from the Main Belt to the NEA region. Additionally, we suggest that the trend of decreasing spectral slope with perihelion may only be valid at perihelia of approximately less than 1 AU. These results suggest a change in the interpretation for the formation of Q-type asteroids. Planetary encounters may help to explain the high fraction of Q-types at low perihelia, but another process which is present everywhere must also be refreshing the surfaces of these asteroids. We suggest the Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect as a possible mechanism.
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511 – Ceres Surface Properties and Composition

511.01 – Resolved Spectrophotometric Properties of the Ceres Surface from Dawn Framing Camera Images
We present a global spectrophotometric characterization of the Ceres surface using Dawn Framing Camera images. We identify the photometric model that yields the best results for photometrically correcting images. Corrected images acquired on approach to Ceres were assembled into global maps of albedo and color. The albedo map is dominated by a large, circular, bright basin-like feature, known from HST images, and dotted by smaller bright features mostly associated with fresh-looking craters. The dominant color variation over the surface is represented by the presence of "blue" material in and around such craters, which has a negative spectral slope when compared to average terrain. We also mapped variations of the phase curve by employing an exponential photometric model, a technique previously applied to asteroid Vesta. The surface of Ceres scatters light differently from Vesta in the sense that the ejecta of several fresh-looking craters appear to be physically smooth rather than rough. Albedo, blue color, and physical smoothness all appear to be indicators of youth. The physical smoothness of some blue terrains is consistent with an initially liquid condition, perhaps as a consequence of impact melting of subsurface water ice. We propose that the color of blue ejecta derives from an originally ice-rich condition, which implies the presence of sub-surface deposits of water ice. Space weathering may be responsible for the fading of the blue color over time. The large positive albedo feature of which the Dantu crater forms the northern part may be an ancient impact basin, or palimpsest, whose relief has mostly disappeared. Its visible color and phase curve are similar to those of Ceres average. Occator crater has several bright spots. The center spot is the brightest with a visual normal albedo of six times Ceres average and has a red color. Its scattering properties are consistent with those of a particulate surface deposit of high albedo. The less-bright secondary spots are neutral in color.
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511.02 – Compositional differences among Bright Spots on the Ceres surface
The Dawn mission detected areas of a relatively higher albedo defined as “bright spots” (BS) on the Ceres surface. The most important member of this family is represented by the Occator crater and more precisely by the two very high albedo areas located on the crater floor.
In this work we identified BS on Ceres by using the hyperspectral data produced by the VIR instrument [1]. We used an approach similar to the one used for Vesta [2], identifying 38 BS. More than 80% of BS’s are related to features generated by impacts. The remaining cases concern diffused material, spots, a scarp and the Ahuna Mons.
The absolute value of the albedo at 1.2 um of BS is approximately 40% larger than the average Ceres albedo, with the two Occator bright areas being by far the brightest on the entire surface.
The general spectral behavior with respect to surroundings includes increased band depths at 2.7, 3.4 and 4.0 um. This is clear especially for the Occator region [3], but is a common behavior also for other BS. This strongly supports that carbonates, producing the 3.4 and 4.0 um absorption band, are the main brightening agent in these regions [3]. Another common trend is the shallowing of the 3.05 um band [4], related to ammonia.

Increase of the two carbonate band depths is always evident in BS; this is not always true for the 2.7 um band. Six BS show a 2.7 um band depth decrease with respect to the surroundings. These six BS correspond to impact features; therefore, a possible interpretation is a dehydration due to the impact.
Four other BS show instead a 3.05 um band deepening, contrarily to the common BS behavior. The interpretation of this observation is in progress.

Acknowledgements
VIR was funded and coordinated by ASI, and built by SELEX ES, with the scientific leadership of IAPS-INAF, Rome, Italy, and is operated by IAPS-INAF, Rome, Italy. Support of the Dawn Teams is gratefully acknowledged.

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[4] Ammannito, E. et al., 2016, Science, in press

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511.03 – Space Weathering Effects on Sulfates and Carbonates: Laboratory Experiments

Introduction: The solar wind plasma continuously streams from the Sun, interacting with the surfaces of airless bodies throughout the solar system. Sulfates and carbonates, identified by the UV-Vis spectral slope [1] and 3.4 / 4.0 µm absorption features [2] on the surface of Ceres, will be exposed to solar H, He at ~1keV/amu. We investigate the stability of anhydrous salts under 4 keV He^+ irradiation as proxy for the solar wind.
Experiment: Anhydrous $MgSO_4$, Na_2SO_4, and Na_2CO_3 powders are pressed into pellets, with compositions confirmed by XRD. Pellet samples are placed in ultra-high vacuum (10^{-9} Torr) and the effects of 4keV He^+ irradiation on surface composition and chemistry are monitored by X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectroscopy, as a function of ion fluence. We measure *ex situ* diffuse optical reflectance prior and subsequent to irradiation through ranges 0.2-2.5µm (Lambda 1050) and 0.6-10µm (Thermo Nicolet 670).
Results: Ion irradiation of $MgSO_4$ damages the crystal structure, preferentially removing oxygen along with sulfur. XPS measurements imply the formation of MgO after $5x10^{17}He^+cm^{-2}$ (~15,000 years at 2.7AU). During irradiation, we observe secondary ion ejection (Mg, MgO, O, OH, H, S, and SO) and neutral SO_2. In addition, XPS sulfur spectra suggest the presence of a small amount of trapped SO_2, confirming this decomposition product observed in the optical UV spectra at ~240 and 280nm [3,4] with dehydration, as well as in the IR at ~7.8µm [5] with irradiation. Our observations are consistent with the potential decomposition pathway for $MgSO_4$ to SO_2 provided by McCord et al. (2001) [6]. Spectral darkening and reddening in the UV-Vis region after irradiation are observed by *ex situ* optical spectroscopy. We suggest that space weathering by solar ions limits the stability of salts on Ceres and other airless bodies, which influences the optical reflectance.
Acknowledgements: We thank the NASA SSW program for support.
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511.04 – Dehydration-Induced Optical Effects (0.20 – 2.50 µm) of Hydrated Salts: Laboratory Spectral Measurements with Application to Ceres

Introduction: Photometric measurements by the Dawn spacecraft find bright regions amidst the globally, low albedo (0.11) surface of Ceres, and possible constituents include Fe-poor clay minerals and salts, as suggested by the UV-Vis spectral shape at 0.4–1.0µm [1-2]. The albedo darkens with distance from the brightest spot at the center of Occator crater. Nathues et al [1] hypothesize that the darkening may result from the dehydration of $MgSO_4$ hexahydrate. We perform laboratory experiments with hydrated salts to determine the optical effects of dehydration [1-4].
Experiment: $MgSO_4.nH_2O$ (n=0, 1, 6, 7), $Na_2SO_4.10H_2O$ and $Na_2CO_3.10H_2O$ powders with composition confirmed by XRD were prepared in three grain size fractions (<45µm, 45-83µm, and 250-500µm). A Lambda-1050 UV/Vis/NIR spectrometer with a diffuse reflection accessory (Praying Mantis) was used to measure the reflectance of the hydrated salts, as a function of time, pressure, and temperature. Time-sequenced spectra (λ=0.2–2.5µm; $\Delta\lambda$=4nm; Δt=5min) were taken *in situ* as the samples were exposed to high vacuum (~10^{-4} Torr) at 297K and 147K. Teflon powder is used as the reference standard for UV-Vis measurements.
Results: 1) We measure the dehydration rate for $MgSO_4.6H_2O$ from the H_2O overtone absorptions (~1.5 & 1.9µm). We find with vacuum dehydration: **2)** UV/Vis reflectance (0.2–0.8µm) darkening, significantly enhanced at shorter wavelength (*reddening*) **3**) the appearance of new absorption features at ~0.24 and 0.28µm. Results of **1)**–**3)** were observed using different temperatures, grain sizes, and salts, with reduced rates at lower temperature and larger grain size.
Discussion: Our measurements support the hypothesis that dehydration of salts results in spectral darkening [1]. Derived dehydration rates and formation of new absorptions suggest that $MgSO_4.6H_2O$, if present, is not likely to be stable on Ceres' surface. The new absorption features may be decomposition or scattering due to particle size reduction.
Acknowledgements: We thank the NASA SSW and NSF-Astronomy programs.
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511.05 – Mineralogy of Ahuna Mons on Ceres surface

Ceres, the largest object in the main asteroid belt, and second target of the NASA Dawn mission, was mapped by VIR at different spatial resolutions. Visible and InfraRed (VIR) spectrometer onboard Dawn shed light on the overall surface composition of Ceres. The thermally-corrected average spectrum of Ceres as observed by VIR reveals the presence of several absorption bands in the 2.5 to 4 µm region (located at 2.7 µm, 3.1 µm, 3.3-3.4 µm, and 4 µm). The 2.7 µm band is diagnostic of hydrous minerals, the 3.1 µm band is associated with NH_4-phyllosilicates, while both the 3.3-3.4 and the 4 µm bands are typical of the carbonates signature (De Sanctis et al., 2015). The first spatial resolved map of Ceres obtained on the basis of Dawn optical imagery revealed an overall dark surface with widespread albedo variations (Nathues et al., 2015). Ahuna Mons is an isolated elliptical mountain (21x13 km) located at 10.48°S, 316.2°E, and it has peculiar morphological characteristics. It is surrounded by a smooth-textured unit, less cratered than nearby terrains, and it can divided in two units: a summit with sub-radial arcuate structures (ridges and troughs) and a steep flanks formed by talus material (Ruesch et al., 2016). Ahuna Mons was formed by a volcanic process involving ascent of cryomagma and extrusion onto the surface followed by dome development (ibid). Spectroscopic analysis carried out in the Ahuna Mons region on the basis of VIR data indicates that this geological unit stands out as being distinct from the surrounding regions with respect to a series of diagnostic spectral indicators. Although the overall composition is not dissimilar from what is found elsewhere on Ceres, at the local scale Ahuna Mons emerges to have a lower abundance of hydrous mineral phases and a greater abundance of Na-carbonates than the surrounding areas observed at the same spatial resolution. The presence of a large amount of Na-carbonates is also consistent with the composition of the Occator bright spot (De Sanctis et al., 2016). This evidence is ultimately consistent with a cryovolcanic origin of Ahuna Mons, which would locally raise a portion of terrain by exposing fresh subsurface material richer in carbonates.

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511.06 – Mineralogy of crater Haulani on dwarf planet Ceres

On dwarf planet Ceres, several high-albedo units are visible at the local scale. Haulani crater, located in the equatorial quadrangle having the same name, is one of the notable bright units highlighted by the Dawn spacecraft since its first approach to Ceres in early 2015. Due to the images obtained by the Dawn Framing Camera, it was possible to reveal that Haulani's bright material displays a very small or even negative ("blue") spectral slope in the range from the visible to the near infrared light, which is a peculiar occurrence compared to the average surface of Ceres.

Hyperspectral images returned by the Visible and InfraRed mapping spectrometer (VIR) onboard Dawn enabled a detailed mineralogical analysis of the Haulani crater area. Already at the spatial resolution of the Survey phase (~1.1 km/px), and even more so during HAMO (~0.38 km/px) and LAMO (~0.10 km/px) mission phases, Haulani crater shows considerable spectral variability. The spectral features centered at 2.7 and 3.06 µm, respectively indicative of the presence of hydrous minerals and ammoniated phyllosilicates, show a decrease of band depth in the floor and in the bright ejecta corresponding to the blue spectral slope. Spectral signatures at 3.4 and ~4 µm, indicative of carbonates, also show a moderate variability. Finally, Haulani shows the highest thermal contrast over the entire surface of Ceres, which may be linked to the albedo and texture of the material excavated by the impact, combined with its compactness in specific areas such as pitted terrain.

The application of a spectral unmixing model on VIR data acquired in Survey and HAMO suggests that the observed spectral variations might be due to substantial differences in grain size, rather than to significant variations in composition. However, a comprehensive analysis shall include LAMO data acquired at higher pixel resolution.

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512 – Galilean Satellites I: Chemistry and Particle Interactions

512.01 – Jovian magnetospheric weathering of Europa's nonice surface material

Jovian plasma and energetic charged particles bombard the Galilean satellites. These satellites vary from volcanically active (Io) to a nearly primordial surface (Callisto). These satellites are imbedded in a harsh and complex particle radiation environment that weathers their surfaces, and thus are virtual laboratories for understanding how particle bombardment alters the surfaces of airless bodies. Europa orbits deeply in the Jovian radiation belts and may have an active surface, where space weathering and geologic processes can interact in complex ways with a range of timescales. At Europa's surface temperature of 80K to 130K, the hydrated nonice material and to a lesser extent, water ice, will be thermally stable over geologic times and will exhibit the effects of weathering. The ice on the surface of Europa is amorphous and contains trace products such as H_2O_2 [1] due to weathering. The nonice material, which likely has an endogenic component [2] may also be partially amorphous and chemically altered as a result of being weathered by electrons, Iogenic sulfur, or other agents [3]. This hydrated salt or frozen brine likely compositionally 'matures' over time as the more weakly bound constituents are preferentially removed compared with Ca and Mg [4]. Electron bombardment induces chemical reactions through deposition of energy (e.g., ionizations) possibly explaining some of the nonice material's redness [5,6]. Concurrently, micrometeoroid gardening mixes the upper surface burying weathered and altered material while exposing both fresh material and previous altered material, potentially with astrobiological implications. Our investigation of the spectral alteration of nonice analog materials irradiated by 10s keV electrons demonstrates the prevalence of this alteration and we discuss relevance to potential measurements by the Europa MISE instrument.

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512.02 – What is Eating Ozone? Thermal Reactions between SO_2 and O_3 and Implications for the Icy Satellites

Here we present first results on a non-radiolytic, thermally-driven reaction sequence in solid $H_2O + SO_2 + O_3$ mixtures at 50 – 130 K, which produces bisulfate (HSO_4^-). The results show that at the temperatures of the Jovian satellites, SO_2 and O_3 will efficiently react making co-detection of these species unlikely. Our results also give a viable explanation for why O_3 has not been detected on Callisto and why the concentration of SO_2 appears to be highest in its leading hemisphere. Furthermore our results also predict that the SO_2 concentration on Ganymede will be lowest in the trailing hemisphere, where the concentration of O_3 is the highest. This work is supported by NASA's Outer Planets Research program.

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512.03 – The fate of solid particles in the Jovian circumplanetary disk : Implications for the formation of the Galilean satellites

The Galilean satellites are thought to have formed within an accretion disk surrounding Jupiter at the late stages of its formation. However, the structure of the gaseous disk, as well as the size and origin of the solids that eventually formed the satellites are yet to be constrained.

Here we model an evolving gaseous disk around Jupiter and investigate the fate of solid particles of different sizes submitted to aerodynamic drag, turbulent diffusion, and heated by the surrounding gas. The motion of the solid particles is integrated in the *(r-z)* plane, taking into account dust settling and radial drift. The evolution of their ice-to-rock ratio is tracked when they cross the snowline and start to sublimate. Sublimation is coupled to the equations of motion as it changes the radius of the particle and consequently acts on the drag force. The I/R ratio then serves as a comparison to the observed bulk compositions of Io and Europa.

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513 – Active Surface Process on Mars: Volatiles, Wind and Impacts

513.01 – New Observations Reveal How the Martian Residual South Polar Cap Develops Quasi-Circular Pits, Heart-Shaped Pits, Troughs, and Moats

The martian residual south polar cap (RSPC) is a ~1-10 m thick deposit of CO_2 ice perched on the much larger H_2O ice cap. Because it is the only known CO_2 reservoir annually exchanging with the predominantly-CO_2 martian atmosphere, understanding its evolution is important to understanding the modern martian climate. The 8 x 10^5 m^2 RSPC is perennial and characterized by mesas dissected by quasi-circular pits, heart-shaped pits, linear troughs and ridges, and moats (a low, CO_2-free boundary surrounding a mesa wholly contained within another mesa) that evolve at meter-scales each year [1,2]. However, the underlying processes leading to the development of these landforms have not yet been described. Using repeat-coverage HiRISE (25-50 cm/px) imagery, we observe previously undescribed features on the RSPC, which reveal the processes leading to the emergence of its meter-to-kilometer-scale morphology. We observe dark fans emanating from the sides of RSPC mesas and widespread fracturing and collapse of the upper surface of mesas, which we interpret as evidence for sublimation in the interiors of mesas. On relatively smooth areas of the RSPC, even small relief (~10 cm) collapses generate surface roughness, which concentrates sunlight and enhances sublimation, leading to the development of steep, eroding scarps. Typically, CO_2 deposition during the winter then smooths terrain and creates gently sloping scarps (although uneven CO_2 deposition can also create steep scarps). A collapse that drops down, such that it is entirely bounded by a steep scarp, develops into a quasi-circular pit. However, when a portion of the collapsing area remains attached to the upper surface, the perimeter is partially bounded by a steep scarp and partially bounded by a gently sloping ramp, which develops into either a heart-shaped pit, linear trough, or moat, depending on the local interplay between deposition and erosion. Finally, we use the spatial distribution of pits in order to determine the erosional history of the RSPC. [1] Malin et al., 2001, *Science* 294, 2146-2148 [2] Thomas et al., 2016,*Icarus* 268, 118-130

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513.02 – Translucent CO_2 ice on Mars ?

The Martian climate is driven by the condensation/sublimation of CO_2 representing 95% of the atmosphere. Many active surface features (such dark spot, dark flows), have been potentially linked to CO_2 exchange. Understanding the surface/atmosphere interactions is a major issue, for both atmospheric but also surface science. This study aims at estimating the physical properties of the seasonal CO_2 ice deposits. Are these deposits granular or compact? What is the thickness of the ice? How much impurities are included within the ice? These questions have been highly debated in the literature, in particular the presence of a translucent slab ice, the link with the H_2O cycle. In particular the cold jet geyser model requires translucent CO_2 ice. We use radiative transfer models to simulate spectroscopic data from the CRISM instrument and perform an inversion to estimate model's parameters though time. We then discuss the consistency of the results with other datasets.

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513.03 – Physical state and temporal evolution of icy surfaces in the Mars South Pole by retrieving their bidirectional reflectance from CRISM observations

On Mars H2O and CO2 ices can be found as seasonal or perennial deposits notably in the polar regions. At the moment little is known about their bidirectional reflectance factor (BRF) despite the significance of such information for characterizing the composition, physical state and energy balance of the icy surfaces from the bolometric albedo. The BRF is potentially accessible thanks to the near-simultaneous multi-angle, hyperspectral observations of the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) implying 11 viewing angles in visible and infrared ranges. However, its extraction from the CRISM measurements is especially challenging. Indeed, the atmospheric aerosols (mineral dust, sometimes H2O ice) have a strong contribution in the CRISM measurements that must be corrected. At high latitudes, their contribution is accentuated because the sun is low above the horizon. Besides, the BRF of ices is expected to be highly anisotropic especially under grazing illumination creating difficulties with the traditional Lambertian surface assumption commonly used for atmospheric correction. In previous research we put forward the Multi-angle Approach for Retrieval of Surface Reflectance from

CRISM Observations (MARS-ReCO), an algorithm that characterizes and corrects the aerosol scattering effects. The aerosol optical depth (AOD) and the BRF of surface materials are retrieved conjointly and coherently as a function of wavelength. In this work, we apply MARS-ReCO on time series of CRISM sequences over different regions of interest in the outskirts of the south permanent polar cap. The time series span from mid-spring to late summer during which the CO2 ice sublimates revealing H2O frost and defrosted terrains. No ground truth is available for the investigated regions but cross-validation with other datasets such as observations by OMEGA (mapping spectrometer on MEX) can be applied. Thanks to the atmospheric correction, we are able to identify various classes of spectro-photometric behavior suggesting diverse ice types in term of their composition, grain micro-texture, and surface roughness. We also note a regular increase of the directional-hemispherical surface albedo during the period of the time.

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513.04 – A complicated story of frost and wind: Present-day gully activity within the north polar erg, Mar

Analyses of high-resolution observations have shown that the dunes within the martian north polar erg (AKA Olympia Undae) are currently very active on seasonal and yearly timescales, with 20-60% of the dunes within five polar dune fields undergoing the formation of alcove-apron features each Mars year. Previous studies have hypothesized formation mechanisms, based on observations of when new alcove and alcove-apron features form within an individual field through one Mars year. However, results are ill-constrained (and thus different hypotheses have been proposed) as the polar hood and winter night mean very few images are taken during the actual period of activity. In this study, we mitigate this limitation by examining several fields over several Mars years -- thus bringing aggregated results as well as detailed correlation checks against environmental conditions and seasonal processes to bear on the problem. From this, we propose a new process that appears consistent with all observations: (1) small alcoves form along the dune brink in the autumn (under the polar hood) due to instabilities induced by the night-formation and morning-sublimation of frost. As autumn progresses, the seasonal frost layer builds over the altered dune slope. (2) In the early spring, sublimation activity is concentrated and/or enhanced over these alcoves, causing further erosion and the formation of larger alcove-apron features. From the planform dimensions of the newly formed alcoves, we can estimate the volume of sand moved down the dune slope during one period of activity and estimate the aeolian sediment flux by looking at how quickly the alcoves are erased. We find that, over a Mars year, the amount of material moved via alcove-apron activity and via the wind are both comparable to aeolian sand flux estimates over dunes within lower-latitude regions of Mars. Thus it appears that the formation of alcoves-aprons is a significant mechanism for dune advancement and evolution within the north polar erg, and understanding it better will add to our understanding of polar processes, aeolian sediment transport, and dune evolution on Mars.

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513.05 – How did the icy mantle of Mars contribute to the origins of gullies and FSVs?

Compared to the Martian valley networks, Fresh Shallow Valleys (FSVs) and gullies formed quite recently - in the Late Amazonian period. Recent studies propose that FSVs may be formed by meltwater flowing beneath ice, supported by evidence for the channels ignoring the constraints of drainage divides and often being found with ridges and mounds analogous to terrestrial esker environments. Our studies of gullies show that while multiple processes have contributed to their formation and modification over time, the key sources include groundwater flow, ground ice melt, or ice/snow surface melt, which includes the possibility of meltwater from ice-rich LDM. FSVs and gullies have been found to be spatially associated with viscous flow features (VFFs), mantle deposits, and various peri/paraglacial features such as arcuate ridges. It is important to note that the mid-latitude bands within which the FSVs and gullies concentrate are both near enough to the poles to experience frozen depositions during periods of high obliquity, and near enough to the equator to experience melt induced by peak temperatures, possible today where surface pressure is also favorable. While FSVs and gullies are often found dissecting into mantle deposits, it is possible that the easily-erodible ice-rich LDM simply provides insulation and protective blanketing to promote or enable water flow and ice melt from the near-subsurface. We are looking to identify any changes to channels and ice-rich LDM within FSVs and gullies to help determine whether the water's source is from the ice-rich mantling unit, the subsurface, or both.

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513.06 – Understanding Gully Formation and Seasonal Flows on Recent and Current Mars

The discoveries of gullies and seasonal slope flows (RSL) have re-ignited the debate over various channel, valley, and gully formation mechanisms on Mars. The controversy over whether liquid water was involved with gully formation, harkens back to the mid-1970s to early 2000s, where catastrophic flooding, surface runnoff and ground-water sapping processes were strongly debated along with other mechanisms as the primary processes responsible for channel and valley formation on Mars. However, over the past decade, the value of multiple working hypotheses has again become apparent, this time in understanding the formation of Martian gullies and Recurring Slope Lineae. Various mechanisms put forth to explain these landforms include liquid H_2O/ice erosion, CO_2 ice/frost sublimation, CO_2 ice block sliding, water and brine flows, salt deliquescence, and dry granular flows, among others.

We carried out detailed morphologic/morphometric studies of gullies in various environmental settings on Mars to evaluate the potential formation processes. Using HiRISE images and DTMs, we mapped and generated detailed longitudinal and cross-sectional profiles of gully systems and estimated volumes for both the gullies and their debris aprons. Several gullies form highly integrated patterns similar to fluvial systems. Additionally, RSL are often found either in the tributaries of these integrated systems or in adjacent regions, implying that RSL may play a role in initiating gully formation or mark the last vestiges of water activity in these locations. We also find that the more highly integrated gullies have volumes significantly larger than their aprons, suggesting that the missing volumes (~40-60% or more) were likely the volatiles involved in gully formation. Additionally, THEMIS and TES surface temperatures of these integrated gully sites, many of which also contain RSL, are at or above freezing seasonally suggesting that the volatile component may be consistent with H_2O although CO_2 cannot be ruled out. Other less integrated systems have apron volumes that equal or exceed the gully volumes suggesting that dry flows, avalanching, gully infill, or other dry processes may have been more important in these environments.

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513.07 – Grid-Mapping of Hellas Planitia, Mars - Geostatistical Analyses of Cold-Climate Landforms

Hellas Planitia is one of the largest impact basins on Mars, with a diameter of 2,300 km and located in the southern mid-latitudes. The basin also contains the topographically lowest parts of the planet, making it of special interest for water and ice-related geomorphological activities. We applied a Grid-Mapping method to analyze the geographical distribution of possibly ice-related landforms (e.g., latitude-dependent mantle [LDM] and scalloped terrain) in a visual and statistical manner. Thus, we are able to look for yet unrecognized correlations between the landforms themselves and external parameters such as elevation, slope inclination, slope aspect (azimuth), and thermal inertia.
By using this method, the study area is separated into 20,100 grids, each 20×20 km. Mapping is based on CTX images at a scale of 1:30,000 in a GIS environment. Because of the huge size of the study area, only every second grid has been mapped. For 21 different landforms, we attributed one of the five following classes to each grid: “dominant”, “present”, “possible”, “absent”, and “no data”. The non-mapped grids were interpolated later. Statistical calculations have only considered “dominant” and “present” values for reliable results. In normalized distribution diagrams only bins with more than 30 samples are shown.
Despite LDM covers Hellas almost entirely, our map shows an elliptical 800×200 km gap in NE Hellas. We suggest this lack of LDM may be the result of the dominant wind circulation pattern within the basin. According to global climate models, cold south-polar wind currents enter Hellas at a breach in its SW rim and rotate clockwise in Hellas. When they reach the northern parts of the Hellas floor around 30°S they warm up, and begin to move south again, subliming or preventing the evolution of LDM in the NE portions of Hellas because of the higher air temperature. In contrast to LDM, scalloped terrain occurs on higher inclined slopes between 6° to 9°. As they are apparently shaped by sublimation, we assume their location on steep slopes is caused by higher solar insolation, with the aspect maximum of these slopes towards north, and thus, to the sun.

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513.08 – Periglacial complexes in Utopia Planitia: rimless, tiered depressions, (clastically) sorted and unsorted polygonised terrain and an ice-rich mantle

We report the spatial and possible genetic-relationship at the mid-latitudes of Utopia Planitia (45-50^{0}N; 115-120^{0}E), Mars, of: (a) metre to decametre deep, rimless, tiered depressions; terrain that exhibits (b) (clastically) sorted and (c) unsorted (small-sized) polygons; and, (d) a very youthful, ice-rich mantle. We show that these individual landscape features are separated stratigraphically, this being presented to the Mars community for the first time, and suggest that the stratigraphical separation of these features could be the result of boundary conditions and formation processes that have varied much more widely than has been thought hitherto. In cold-climate and non-glacial regions such as the Yamal Peninsula of eastern Russia and the Tuktoyaktuk Coastlands of northern Canada, landscape assemblages comprised of similar features are referenced as “ice complexes” and are indicative of periglacialism on two fronts: first, the presence of “ice-rich” permafrost or permafrost comprised of “excess ice”, i.e. “permafrost” whose pore space is exceeded by the “water ice” within that body of sediment; and, second, antecedently or currently active freeze-thaw cycling, minimally, to the full depth of the “ice-complex” depressions. In the Dry Valleys of the Antarctic, where the atmospheric aridity and cold-temperatures approach those of Mars, ice-vapour diffusion and adsorption cycles are cited as the means by which the near-surface, permafrost, i.e. ≤1m deep, has become ice-cemented. However, the metre to decametre depths of the “ice-complex” depressions on Earth and the morphologically-similar ones on Mars lie beyond the vertical reach of the Antarctic diffusion and adsorption cycles, both empirically and theoretically. By deduction, this points to the freeze-thaw cycling of water to depth, fostered either by exogenic or endogenic means, perhaps playing a more important role in the formation of the possible Martian “ice complexes” than might be expected were expectations based solely on the current cold-climate “Antarctic-like” paradigm.

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513.09D – Super-resolution restoration applied to the characterisation of dynamic surface changes on the Martian surface

Higher spatial resolution imaging data is always desirable to the international community of planetary scientists interested in improving understanding of surface formation processes. We have previously developed a novel Super-resolution restoration (SRR) technique using Gotcha sub-pixel matching [*Shin & Muller, PR, 2012*], orthorectification, segmentation, and 4th order PDE-TV, called GPT SRR [*Tao & Muller, PSS, 2016*]. This technique is able to restore 5cm-12.5cm near rover scale images (Navcam at a range of ≥5m) from multi-angle repeat-pass 25cm resolution MRO HiRISE images [*Tao & Muller, ISPRS, 2016*].
We have successfully applied the GPT-SRR to the MER and MSL missions (http://www.progisweb.eu), as well as the alleged site of the Beagle-2 spacecraft (https://www.flickr.com/photos/uclnews/albums/72157667609698345). In this work, we further apply GPT-SRR on areas with known dynamic changes, including Recurring Slope Lineae (RSL), Gullies, and Polar Dune Flows. We restore static surface and meanwhile track the dynamic features to characterise the “change”, including directions and speed of the changes. We also demonstrate that such repeat images can be used to image the MER-A rover stuck in the sands.

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513.10 – The investigation of active Martian dune fields using very high resolution photogrammetric measurements

At the present time, arguments continue regarding the migration speeds of Martian dune fields and their correlation with atmospheric circulation. However, precisely measuring the spatial translation of Martian dunes has succeeded only a very few times—for example, in the Nili Patera study (Bridges et al. 2012) using change-detection algorithms and orbital imagery.
Therefore, in this study, we developed a generic procedure to

precisely measure the migration of dune fields with recently introduced 25-cm resolution orbital imagery specifically using a high-accuracy photogrammetric processor. The processor was designed to trace estimated dune migration, albeit slight, over the Martian surface by 1) the introduction of very high resolution ortho images and stereo analysis based on hierarchical geodetic control for better initial point settings; 2) positioning error removal throughout the sensor model refinement with a non-rigorous bundle block adjustment, which makes possible the co-alignment of all images in a time series; and 3) improved sub-pixel co-registration algorithms using optical flow with a refinement stage conducted on a pyramidal grid processor and a blunder classifier. Moreover, volumetric changes of Martian dunes were additionally traced by means of stereo analysis and photoclinometry.
The established algorithms have been tested using high-resolution HIRISE time-series images over several Martian dune fields. Dune migrations were iteratively processed both spatially and volumetrically, and the results were integrated to be compared to the Martian climate model. Migrations over well-known crater dune fields appeared to be almost static for the considerable temporal periods and were weakly correlated with wind directions estimated by the Mars Climate Database (Millour et al. 2015). As a result, a number of measurements over dune fields in the Mars Global Dune Database (Hayward et al. 2014) covering polar areas and mid-latitude will be demonstrated.

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The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement Nr. 607379.

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513.11 – Frequency of block displacements at the north pole of Mars based on HiRISE images

We identify active block displacements at the foot of the steep north polar scarps of Mars and estimate the frequency of these events. This will help us improve our knowledge of the erosion rate and evolution of the north polar cap. Thousands of single-block movements or events involving multiple blocks have been captured within 10 years of repeated high resolution imaging of the north polar cap's margins by High Resolution Imaging Experiment (HiRISE). These blocks, which are up to a couple of cubic meters in size, become detached either from the North Polar Layered Deposits (NPLD) or the Basal Unit (BU) [1] and come to rest intact or after breaking up into smaller fragments. We detect the new blocks automatically in co-registered images taken at different times. For the co-registration we use Ames Stereo Pipeline [2] to produce HiRISE Digital Terrain Models (DTMs) and ortho-rectify the images on these DTMs. We focus on retrieving the frequency of the events as well as the sizes and shapes of the moved blocks. Our results suggest that rock falls are presently an important, regular recurring seasonal process for certain areas of the north polar scarps. Estimates of the volume of the mass movements and hence the erosion rate are supported by analysis of corresponding DTMs.
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under iMars grant agreement nº 607379.
References:
[1] Russell et al., Landslide erosion rates of north polar layered deposit cliffs and the underlying basal unit, Eighth International Conference on Mars, 2014
[2] Moratto et al., Ames Stereo Pipeline, NASA's Open Source Automated Stereogrammetry Software, LPSC, 2010

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513.12 – Recent Impacts on Mars: Cluster Properties and Seismic Signal Predictions

Impacts are a key source of seismic waves that are a primary constraint on the formation, evolution, and dynamics of planetary objects. Geophysical missions such as InSight (Banerdt et al., 2013) will monitor seismic signals from internal and external sources. New martian craters have been identified in orbital images (Malin et al., 2006; Daubar et al., 2013). Seismically detecting such impacts and subsequently imaging the resulting craters will provide extremely accurate epicenters and source crater sizes, enabling calibration of seismic velocities, the efficiency of impact-seismic coupling, and retrieval of detailed regional and local internal structure.
To investigate recent impact-induced seismicity on Mars, we have assessed ~100 new, dated impact sites. In approximately half of new impacts, the bolide partially disintegrates in the atmosphere, forming multiple craters in a cluster. We incorporate the resulting, more complex, seismic effects in our model. To characterize the variation between sites, we focus on clustered impacts. We report statistics of craters within clusters: diameters, morphometry indicating subsurface layering, strewn-field azimuths indicating impact direction, and dispersion within clusters indicating combined effects of bolide strength and elevation of breakup.
Measured parameters are converted to seismic predictions for impact sources using a scaling law relating crater diameter to the momentum and source duration, calibrated for impacts recorded by Apollo (Lognonne et al., 2009). We use plausible ranges for target properties, bolide densities, and impact velocities to bound the seismic moment. The expected seismic sources are modeled in the near field using a 3-D wave propagation code (Petersson et al., 2010) and in the far field using a 1-D wave propagation code (Friederich et al., 1995), for a martian seismic model. Thus we calculate the amplitudes of seismic phases at varying distances, which can be used to evaluate the detectability of body and surface wave phases created by different sizes and types of impacts all over Mars.

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514 – Jovian Atmospheres V: Observations of Saturn, Uranus, Neptune, Exoplanets

514.01 – Going Out in a Blaze of Glory: Cassini's Grand Finale

The Cassini-Huygens mission, a joint collaboration between NASA, ESA and the Italian Space Agency, is approaching its final year of operations after more than 12 years in Saturn orbit. Cassini will send back its final bits of unique data on 15 September 2017 as it plunges into Saturn's atmosphere, vaporizing and satisfying planetary protection requirements.
Since early 2016 Cassini's orbital inclination has been slowly increasing. In November Cassini will transition to a series of 20 orbits with peripases just outside Saturn's F ring that include some of the closest flybys of the tiny ring moons and excellent views of the F ring and outer A ring. Cassini's final close flyby of Titan will propel it across Saturn's main rings and into its final orbits.

Cassini's Grand Finale begins in April 2017 and is comprised of 22 orbits at an inclination of 63 degrees. Cassini will repeatedly dive between the innermost ring and Saturn's upper atmosphere providing insights into fundamental questions unattainable during the rest of the mission. It will be the first spacecraft to explore this region.
These close orbits provide the highest resolution observations of both the rings and Saturn, and direct *in situ* sampling of the ring particles' composition, plasma, Saturn's exosphere and the innermost radiation belts. Saturn's gravitational field will be measured to unprecedented accuracy, providing information on Saturn's interior structure and mass distribution in the rings. Probing the magnetic field will give insight into the nature of the magnetic dynamo and the true rotation rate of Saturn's interior. The ion and neutral mass spectrometer will sniff the exosphere and upper atmosphere and examine water-based molecules originating from the rings. The cosmic dust analyzer will sample particle composition from different parts of the main rings.
New science highlights and science objectives from Cassini's final orbits will be discussed.
This work was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

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514.02 – Recent Variability Observations of Solar System Giant Planets: Fresh Context for Understanding Exoplanet and Brown Dwarf Weather

Over the past several years a number of of high cadence photometric observations of solar system giant planets have been acquired by various platforms. Such observations are of interest as they provide points of comparison to the already expansive set of brown dwarf variability observations and the small, but growing, set of exoplanet variability observations. By measuring how rapidly the integrated light from solar system giant planets can evolve, variability observations of substellar objects that are unlikely to ever be resolved can be placed in a fuller context. Examples of brown dwarf variability observations include extensive work from the ground (e.g., Radigan et al. 2014), Spitzer (e.g., Metchev et al. 2015), Kepler (Gizis et al. 2015), and HST (Yang et al. 2015). Variability has been measured on the planetary mass companion to the brown dwarf 2MASS 1207b (Zhou et al. 2016) and further searches are planned in thermal emission for the known directly imaged planets with ground based telescopes (Apai et al. 2016) and in reflected light with future space based telescopes. Recent solar system variability observations include Kepler monitoring of Neptune (Simon et al. 2016) and Uranus, Spitzer observations of Neptune (Stauffer et al. 2016), and Cassini observations of Jupiter (West et al. in prep). The Cassini observations are of particular interest as they measured the variability of Jupiter at a phase angle of $\sim 60^{\circ}$, comparable to the viewing geometry expected for space based direct imaging of cool extrasolar Jupiters in reflected light. These solar system analog observations capture many of the characteristics seen in brown dwarf variability, including large amplitudes and rapid light curve evolution on timescales as short as a few rotation periods. Simon et al. (2016) attribute such variations at Neptune to a combination of large scale, stable cloud structures along with smaller, more rapidly varying, cloud patches. The observed brown dwarf and exoplanet variability may well arise from comparable cloud structures. In my presentation I will compare and contrast the nature of the variability observed for the various solar system and other substellar objects and present a wish list for future observations.
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514.03 – HST Photometry of Uranus 1994-2015

Images of Uranus by the Hubble Space Telescope (HST) provide a useful tool in studying seasonal and other physical changes on Uranus. HST gives spatial resolution on the disk of Uranus, wide spectral coverage, temporal coverage over more than 20 years, and stable photometric properties. We selected 1368 images in 81 filters of four cameras between 240 and 1130 nm wavelength taken between August 1994 and October 2015.
We started with analyzing the photometry of the whole disk of Uranus. We divided the total light of Uranus into the light from "quiet" Uranus and the light from active storms, which can contribute as much as 2.3 % to the total light, although their median contribution is only 0.14 %. The statistical analysis of the light from storms as function of wavelength and time gives clues about their temporal distribution and altitude distribution since different filters probe different altitudes.
The photometry of quiet Uranus shows three main variations: a smooth seasonal variation, a small deviation from this on time scales of 1-2 years, and a small variation with phase angle. The latter variation is 0.15 % for each degree of phase angle between 0 and 3 degrees. This may be the first such measurement for Uranus. The deviations from the smooth curve are about 0.2 %, which is significant since most data otherwise fit to the 0.1 % level.
The seasonal variation has the same shape at all wavelengths, except that the amplitude differs. The shape is roughly a parabola with a minimum brightness in 2009, two years after the equinox of Uranus. The amplitude is negligible at wavelengths probing high altitudes but goes up to a factor of 2.1 in wavelengths probing the 1-2 bar level. The seasonal variation is a combined effect of physical change in the atmosphere and the geometric change due to variable sub-solar and sub-Earth latitudes. The physical change is further divided into darkening of high southern latitudes and brightening of high northern latitudes. The characteristics of the seasonal change in all filters give tight constraints on future global circulation models.
The research was supported by STScI through program AR12827 and by NASA through grant NNX12AI68G.
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514.04 – HST/WFC3 Observations of Uranus' 2014 Storm Clouds

In November 2014 Uranus was observed with the Wide Field Camera 3 (WFC3) instrument of the Hubble Space Telescope as part of the Hubble 2020: Outer Planet Atmospheres Legacy program, OPAL. OPAL annually maps Jupiter, Uranus and Neptune (and also Saturn from 2018) in several visible/near-IR wavelength filters. The Uranus 2014 OPAL observations were made on the 8 – 9th November at a time when a huge convective storm system, first observed by amateur astronomers, was present at 30 – 40°N. The entire visible atmosphere, including the storm system, was imaged in seven filters spanning 467 – 924 nm, capturing variations in the coloration of Uranus' clouds and also vertical distribution due to wavelength dependent changes in Rayleigh scattering and methane absorption. Here we analyse these new HST observations with the NEMESIS radiative-transfer and retrieval code, in multiple-scattering mode, to determine the vertical cloud structure in and around the convective storm cloud system.
The same storm system was also observed in the H-band (1.4 – 1.9 µm) with the SINFONI Integral Field Unit Spectrometer on the Very Large Telescope (VLT) on 31st October and 11th November (Irwin et al., 2016, 10.1016/j.icarus.2015.09.010). To constrain better the

cloud particle sizes and scattering properties over a wide wavelength range we also conducted a limb-darkening analysis of the background cloud structure in the 30 – 40°N latitude band by simultaneously fitting: a) these HST/OPAL observations at a range of zenith angles; b) the VLT/SINFONI observations at a range of zenith angles; and c) IRTF/SpeX observations of this latitude band made in 2009 at a single zenith angle of 23°, spanning the wavelength range 0.8 – 1.8 µm (Irwin et al., 2015, 10.1016/j.icarus.2014.12.020). We find that the HST observations and the combined HST/VLT/IRTF observations are well modeled with a three-component cloud comprised of: 1) a thin 'deep' cloud at a pressure of ~2 bars; 2) a methane-ice cloud at the methane-condensation level with variable vertical extent; and 3) a stratospheric haze. We present conclusions on the likely distribution of particle sizes in these clouds/hazes and the likely spectral dependence of their scattering properties.

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514.05 – New constraints on the deep oxygen abundance in Uranus and Neptune

One of the great mysteries in the Solar System is how Giant Planets formed. Two main formation scenarios coexist: disk gravitational instability and core accretion. These scenarios differ not only in the time required to form planets, but also in the final composition of the planets' interiors. In this sense, heavy element abundances are key constraints and they depend on how the ices of the planetesimal that formed the cores of these planets condensed (e.g., amorphous or crystalline).
Measuring the deep oxygen abundance can help differentiating the condensation processes of the planetesimal ices. Indeed, clathration needs a larger amount of water than the amorphous ice scenario. While Galileo probably failed to measure the Jovian deep oxygen abundance, Juno should shed light on this long lasting question. Measuring Saturn's deep oxygen is a goal of the entry probe that will be proposed to ESA (Mousis et al. 2016). Regarding the Ice Giants, there is no such mission planned in the near future to measure their deep oxygen abundance and it is very challenging to probe remotely below the water cloud in these planets with microwaves. Another way to constrain the deep oxygen abundance consists in using thermochemical modeling to link upper tropospheric disequilibrium species to the deep oxygen.
In this paper, we apply a thermochemical and diffusion model to the ice giant tropospheres to constrain their deep oxygen abundance from CO observations. Because the results depend on the thermal structure, on the strength of tropospheric mixing, and to a lesser extent on the deep carbon abundance, we have explored a 4D parameter space (temperature, tropospheric mixing, deep oxygen and carbon abundance) for each planet to fit their upper tropospheric composition. For instance, we have computed a series of classical thermal profiles based on dry/wet adiabats and new profiles that account for the mean molecular weight gradient at the water condensation layer (following the prescription of Leconte et al. 2016). We present the results of the 4D grids and the constraints we infer from the nominal models. These 4D grids can be used in the future once the deep temperature, tropospheric mixing and methane abundance are better known.

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514.06 – Seasonal Stratospheric Chemistry on Uranus and Neptune

We use a time-variable photochemical model to study the change in stratospheric constituent abundances as a function of altitude, latitude, and season on Uranus and Neptune. In the absence of meridional transport, the results for Neptune are similar to those predicted for Saturn: seasonal variations in the abundances of observable hydrocarbons such as C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_8, and C_4H_2 are large in the upper stratosphere but become increasingly damped with depth due to increased dynamical and chemical time scales. We also find that latitude gradients in hydrocarbon abundances would be maintained on Neptune in the absence of atmospheric circulation. On Uranus, however, the more stagnant, poorly mixed stratosphere leads to a lower-altitude homopause, with methane being photolyzed relatively deep in the stratosphere, at which point both diffusion and chemical time constants have become longer than a Uranian year. Seasonal variations in stratospheric constituents on Uranus are therefore muted, despite the planet's large obliquity. We compare our model results to global-average observations from Spitzer and to spatially-resolved infrared observations from the ground. The model-data comparisons have implications with respect to the importance and strength of meridional transport, the origin of stratospheric oxygen-bearing species, and the dust and cometary influx rates on Uranus and Neptune.

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514.07 – New observational constraints on hydrocarbon chemistry in Saturn's upper atmosphere

Until now there have been only a few observations of hydrocarbons and photochemical haze in the region where they are produced in Saturn's upper atmosphere. We present new results on hydrocarbon abundances and atmospheric structure based on more than 40 stellar occultations observed by the Cassini/UVIS instrument that we have combined with results from Cassini/CIRS to generate full atmosphere structure models. In addition to detecting CH_4, C_2H_2, C_2H_4 and C_2H_6, we detect benzene (C_6H_6) in UVIS occultations that probe different latitudes and present the first vertical abundance profiles for this species in its production region. Benzene is the simplest ring polyaromatic hydrocarbon (PAH) and a stepping stone to the formation of more complex molecules that are believed to form stratospheric haze. Our calculations show that the observed abundances of benzene can be explained by solar-driven ion chemistry that is enhanced by high-latitude auroral production at least in the northern spring hemisphere. Condensation of benzene and heavier hydrocarbons is possible in the cold polar night of the southern winter where we detect evidence for high altitude haze. We also report on substantial variability in the CH_4 profiles that arise from dynamics and affects the minor hydrocarbon abundances. Our results demonstrate the importance of hydrocarbon ion chemistry and coupled models of chemistry and dynamics for future studies of Saturn's upper atmosphere.

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514.08 – A change of seasons in Saturn's stratosphere from Cassini/CIRS: evolution of the equatorial oscillation and reversal of hemispheric transport.

Due to its axial tilt of 26.7°, Saturn's atmosphere undergoes significant seasonal variations in insolation that impact its thermal structure, chemistry and dynamics. The exceptional longevity of the Cassini mission enables us to uniquely investigate these changes over almost half a Saturn year. In this study, thermal infrared spectra acquired in 2015 by CIRS in limb viewing geometry are analyzed to map the temperature and the meridional distribution of five hydrocarbons from the lower to the upper stratosphere (10 mbar – 10 microbar). These new maps represent a snapshot of Saturn's atmosphere at the end of the northern spring and are compared to previous results obtained during northern winter (2005/2006) and early spring (2010/2011) (Guerlet et al., Icarus, 2009; Sylvestre et al., Icarus, 2015). Spectacular seasonal changes in temperature are observed, not only at high latitudes where the most extreme insolation variations take place, but also at 20N-20S where the mechanical forcing of the equatorial oscillation induces temperature anomalies of up to +/-20K. These results are compared with predictions from a radiative climate model (Guerlet et al., Icarus, 2014). Apart from the equatorial region, the seasonal warming and cooling trends observed by CIRS are, to first order, consistent with the predictions. One notable exception is that the region under the ring's shadow is found warmer than expected from the radiative model, both in 2005 and 2015. The spatial distribution of hydrocarbons, by-products of the methane photochemistry, also undergoes significant seasonal change in the upper stratosphere. In 2005, a local maximum of hydrocarbons was observed at 20-30N, at odds with the low photochemical production in this region (under the ring's shadow at that time). Together with the high temperature anomaly, we had interpreted this result as the signature of a downwelling branch of the meridional circulation. In 2015, not only has this local maximum vanished, but a new maximum is building in the opposite hemisphere, at 15-25S. We suggest that the hydrocarbon and temperature anomalies observed in 2015 in Saturn's upper stratosphere reflects the reversal of a seasonal circulation cell.

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Contributing team(s): Cassini/CIRS team

514.09 – Measurements of Seasonal Changes in Saturn's Zonal Wind and Vertical Wind Shear between 2004 and 2016 from Cassini ISS Images

We present updated zonal wind measurements of Saturn using Cassini ISS images between 2004 and 2016. In addition, we present measurements of the vertical wind shear between the cloud levels sensed in the near-infrared continuum band at 750 nm (CB2 filter) and the methane bands at 727 and 889 nm (MT2 and MT3 filters). We previously reported that there may be small seasonal changes in Saturn's zonal wind profile but it was inconclusive due to measurement uncertainties. In our previous reports, we used the zonal standard deviation of the wind vectors as a proxy for the measurement uncertainty. However, zonal standard deviation contains contributions from both real spatial variations in the wind speed as well as uncertainties in the measurements. This raised a difficulty in distinguishing small, real changes in the wind field from the uncertainties in the measurement. We have developed a technique which isolates real spatial variations from measurement uncertainties by analyzing the correlation fields produced in the two-dimensional Correlation Imaging Velocimetry (CIV) cloud-tracking wind measurement method. In our new method, for each single wind vector measurement, we fit an ellipse to the correlation threshold contour, and define it as the uncertainty ellipse of each wind vector. The advantage of our method is that it allows quantification of the anisotropic uncertainty components of each single wind vector, i.e., using the uncertainty ellipse, we deduce the northward, southward, eastward and westward uncertainties for each wind vector from the correlation peak. Comparing the uncertainty values of each wind vector to the zonal standard deviation of all wind vectors at each latitude allows us to decouple the real spatial variations in the wind from the measurement uncertainties. Using this technique, our measurements show small seasonal variations in Saturn's zonal wind profile as well as the vertical wind shear. As a next step, we plan to apply our uncertainty determination method to quantify the impact of anisotropic uncertainties to the eddy momentum flux measurements. Our work has been supported by NASA PATM NNX14AK07G, NSF AAG 1212216, and NASA NESSF NNX15AQ70H.

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514.10 – Monitoring Saturn's Upper Atmosphere Density Variations Using Helium 584 Å Airglow

The study of He 584 Å brightness of Saturn is interesting as the EUV planetary airglow have the potential to yield useful information about mixing and other important parameters in its thermosphere. Resonance scattering of sunlight by He atoms is the principal source of the planetary emission of He 585 Å. The helium is embedded in an absorbing atmosphere of H_2 and since it is heavier than the background atmosphere, it's concentration falls off rapidly above the homopause. The scattering region (i.e. where the absorption optical depth in H_2 is < ~1) generally lies well above the homopause. As the eddy diffusion coefficient, K_{zz}, increases in the middle atmosphere, relatively more helium is mixed into the scattering region and thus the reflected intensity increases. The principal parameter involved in determining the He 584 Å albedo are the He volume mixing ratio, f, well below the homopause, and K_{zz}, (which will generally be a function of altitude), the solar He 584 Å flux and line shape, and the atmospheric temperature profile.
The main science objective discussed is the estimation of the helium mixing ratio in the lower atmosphere. Specifically, He emissions come from above the homopause where τ =1 in H_2 and therefore the interpretation depends mainly on two parameters: He mixing ratio of the lower atmosphere and K_{zz}. The occultations of Koskinen et al (2015) give K_{zz} with an accuracy that has never been possible before and the combination of occultations and airglow therefore provide estimates of the mixing ratio in the lower atmosphere. We have made these estimates at several locations that can be reasonably studied with both occultations and airglow and then average the results. Our results point to a greatly improved estimate of the mixing ratio of He in the upper atmosphere and below. The second topic addressed is regarding constraining the dynamics in the atmosphere by using the estimate of the He mixing ratio from the main objective. Once we have an estimate of the He mixing ratio in the lower atmosphere that agrees with both occultations and airglow, helium becomes an effective tracer species as any variations in the Cassini UVIS helium data are direct indicator of changes in K_{zz} i.e., dynamics.

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514.11 – Saturn's Stratospheric Oxygen Compounds

There are three known oxygenated species present in Saturn's upper atmosphere: H_2O, CO and CO_2. The ultimate source of the water must be external to Saturn as Saturn's cold tropopause effectively prevents any internal water from reaching the upper atmosphere. The carbon monoxide and dioxide source(s) could be internal, external, produced by the photochemical interaction of water with Saturn's stratospheric hydrocarbons or some combination of all of these. At this point it is not clear what the external source(s) are. Cassini's Composite InfraRed Spectrometer (CIRS) has detected emission lines of H_2O and CO_2 (Hesman *et al*., DPS 2015, 311.16 & Abbas *et al*. 2013, *Ap. J*. doi:10.1088/0004-637X/776/2/73) on Saturn. CIRS also retrieves the temperature of the stratosphere using CH_4 lines at 7.7 microns. Using CIRS retrieved temperatures, the mole fraction of H_2O at the 0.5-5 mbar level can be retrieved and the CO_2 mole fraction at ~1-10 mbar. Coupled with ground based observations of CO (Cavalié *et al*., 2010, *A&A*, DOI: 10.1051/0004-6361/200912909) these observations provide a complete oxygen compound data set to test photochemical models.
Preliminary results will be presented with an emphasis on upper limit analysis to determine the percentage of stratospheric CO and CO_2 that can be produced photochemically from CIRS observational constraints on the H_2O profile.
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514.12 – Condensation in Saturn's Stratospheric Haze Layers
Haze particles in Saturn's stratosphere can be seen in the visible limb images of Cassini's Imaging Science Subsystem (ISS). These hazes are likely a mix of particles, including solid organics formed as a result of methane photolysis and electron deposition, as well as the condensation of water and hydrocarbon ices. We have examined data from both Cassini and Voyager to study the detailed vertical structure of absorbing/scattering particulates in Saturn's stratosphere and developed a Saturn version of the Community Aerosol and Radiation Model for Atmospheres (CARMA), adding a large database of hydrocarbons that are observed or expected to be present in Saturn's atmosphere.
Our modeling indicates that water ice condenses independently of the hydrocarbons to form a thin layer above the 0.1 mbar pressure level. Between about 5 and 50 mbar, the hydrocarbons reach their condensation levels (in order of increasing pressure level): C6H6, C5H12, C4H2, C4H10, and C2H2. Because of the proximity of their condensation levels and due to the gravitational settling of the particles, the hydrocarbons are likely condensing on one another and forming a thicker layer of mixed composition. Interestingly, butane (C4H10) has a triple point around 135 K which is much lower than most of the other condensing species we've explored. Given an approximate condensation level of 10 mbar and the observed temperature changes at this pressure level following the December 2010 northern-hemisphere storm (stratospheric temperatures were elevated by as much as 50-70 K in a region near 40° N latitude.), melting and further nucleation of droplets could be occurring.
A number of factors including temperature profile, vapor pressure equation, volatile abundance, nucleation critical saturation, and coagulation efficiency will affect the altitudes of the individual ice layers. We will present a summary of results following the nucleation and growth of compounds in order to quantify the likely size and altitude of these particles in Saturn's stratosphere.

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515 – Aerosols and Haze on Titan

515.01 – Titan's zonal winds in its lower stratosphere
Titan's atmosphere near 80 km (20 mbar) marks the transition between lower altitudes, where radiative damping times are large and seasonal variations are muted, and higher higher altitudes, where the damping times are much smaller and temperatures and winds vary significantly over the year. Cassini radio occultation soundings at high northern latitudes in winter have indicated a sharp transition from a highly stable temperature profile in the lower stratosphere to a layer between 80 and 100 km where temperatures decrease with altitude. The cause of this destabilization may be associated with the enhanced infrared opacity of a cloud of organic ices. It is curious that 20 mbar is also the level where the Doppler Wind Experiment on the Huygens Probe at 10° S observed a deep minimum in the zonal wind profile. Application of the gradient wind relation to the altitude-pressure profiles obtained from the Cassini radio occultation soundings have shown that this minimum is global. More recent soundings, obtained as Titan's southern hemisphere moves toward winter, indicate that this structure persists. The cause of this peculiar behavior is not really understood, but the the deceleration of the zonal winds observed in the lower stratosphere may be caused by radiative damping of vertically propagating atmospheric waves in a region where the damping time decreases rapidly with altitude.
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515.02 – Retrievals of boundary layer methane and isotope fractionation on Titan
The amount of methane in the boundary layer on Titan is an interesting diagnostic of whether or not it might be seeping out of the regolith. We know that kinetic fractionation of methane isotopes can be diagnostic of evaporation at the surface and condensation in the atmosphere. If a parcel is constrained to follow a moist adiabat while condensation occurs, we can predict the amount of fractionation that is expected (Ádámkovics & Mitchell, 2016). We will present our most recent efforts to measure boundary layer methane abundance and isotopic composition, which include our recently published Keck NIRSPAO observations from 17 July 2014 (Ádámkovics et al., 2016), as well as preliminary results from follow-up measurements made on 15 May 2016. Our measurements are tantalizingly close to being able to distinguish between different hydrological parameterizations of the polar regions in the Titan Atmospheric Model (Lora & Ádámkovics, 2016). We will discuss the systematic uncertainties that can be evaluated with the combination of these two datasets and the prospects for exceptionally high S/N observations via particularly deep integrations over multiple nights.
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515.03 – Presence of PAH or HAC below 900 km in the Titan's stratosphere?
In 2006, during Cassini's 10th flyby of Titan (T10), Bellucci et al. (2009) observed a solar occultation by Titan's atmosphere through the solar port of the Cassini/VIMS instrument. These authors noticed the existence of an unexplained additional absorption superimposed to the CH4 3.3 microns band. Because they were unable to model this absorption with gases, they attributed this intriguing feature to the signature of solid state organic components. Kim et al. (2011)

revisited the data collected by Bellucci et al. (2009) and they considered the possible contribution of aerosols formed by hydrocarbon ices. They specifically took into account C2H6, CH4, CH3CN, C5H12 and C6H12 ices. More recently, Maltagliati et al. (2015) analyzed a set of four VIMS solar occultations, corresponding to flybys performed between January 2006 and September 2011 at different latitudes. They confirmed the presence of the 3.3 µm absorption in all occultations and underlined the possible importance of gaseous ethane, which has a strong plateau of absorption lines in that wavelength range. In this work, we show that neither hydrocarbon ices nor molecular C2H6 cannot satisfactorily explain the observed absorption. Our simulations speak in favor of an absorption due to the presence of PAH molecules or HAC in the stratosphere of Titan. PAH have been already considered by Lopes-Puertas et al. (2013) at altitudes larger than ~900 km and tentatively identified in the stratosphere by Maltagliati et al. (2015); PAH and HAC are good candidates for Titan's aerosols precursors.

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515.04 – Seasonal evolution of C_2N_2, C_3H_4, and C_4H_2 in Titan's lower stratosphere, inferred from Cassini/CIRS far-IR observations

Due to its obliquity (26.7°), Titan's atmosphere undergoes significant seasonal variations of insolation, which are expected to affect significantly its photochemistry and large-scale dynamics. The duration of the Cassini mission enables us to monitor these changes and to better understand the atmospheric processes at play.
Here, we study the seasonal evolution of the composition of Titan's lower stratosphere (10 mbar). We analyse nadir and limb high resolution (0.5 cm^{-1}) spectra from Cassini/CIRS (Composite InfraRed Spectrometer) in the far infrared (200-400 cm^{-1}), in order to retrieve the abundances of three photochemical species: C_2N_2 (cyanogen), C_4H_2 (diacetylene), and C_3H_4 (methylacetylene). These data span all the latitudes and were acquired from 2004 to 2015. Consequently, they provide a good overview of the seasonal evolution of the meridional distributions of C_2N_2, C_4H_2, and C_3H_4, from northern winter to mid-spring. For instance, these measurements show a strong enrichment in these three species at the South pole in the lower stratosphere, consistent with previous observations (Coustenis et al., 2016 ; Vinatier et al., 2015 ; Teanby et al., 2012). In contrast, other latitudes present much less variations in the mixing ratios of these gases, especially at the North Pole. These vertical and meridional abundances profiles and their comparison with previous studies provide constraints on the photochemical processes in Titan's atmosphere. We also use these measurements to monitor the seasonal evolution of atmospheric circulation in the lower stratosphere.

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515.05 – Solid-State Chemistry as a Formation Mechanism for C_4N_2 Ice and Possibly the Haystack (220 cm^{-1} ice emission feature) in Titan's Stratosphere as Observed by Cassini CIRS

A profusion of organic ices containing hydrocarbons, nitriles, and combinations of their mixtures comprise Titan's complex stratospheric cloud systems, and are typically formed via vapor condensation. These ice particles are then distributed throughout the mid-to-lower stratosphere, with an increased abundance near the winter poles (see Anderson *et al.,*2016). The cold temperatures and the associated strong circumpolar winds that isolate polar air act in much the same way as on Earth, giving rise to compositional anomalies and stratospheric clouds that provide heterogeneous chemistry sites.
Titan's C_4N_2 ice emission feature at 478 cm^{-1} and "the Haystack," a strong unidentified stratospheric ice emission feature centered at 220 cm^{-1}, share a common characteristic. Even though both are distinctive ice emission features evident in Cassini Composite InfraRed (CIRS) far-IR spectra, no associated vapor emission features can be found in Titan's atmosphere. Without a vapor phase, solid-state chemistry provides an alternate mechanism beside vapor condensation for producing these observed stratospheric ices. Anderson *et al*., (2016) postulated that C_4N_2 ice formed in Titan's stratosphere via the solid-state photochemical reaction HCN + HC_3N → C_4N_2 + H_2 can occur within extant HCN-HC_3N composite ice particles. Such a reaction, and potentially similar reactions that may produce the Haystack ice, are specific examples of solid-state chemistry in solar system atmospheres. This is in addition to the reaction HCl + $ClONO_2$ → HNO_3 + Cl_2, which is known to produce HNO_3 coatings on terrestrial water ice particles, a byproduct of the catalytic chlorine chemistry that produces ozone holes in Earth's polar stratosphere (see for example, Molina *et al.,* 1987; Soloman, 1999).
A combination of radiative transfer modeling of CIRS far-IR spectra, coupled with optical constants derived from thin film transmittance spectra of organic ice mixtures obtained in our Spectroscopy for Planetary ICes Environments (SPICE) laboratory, will be used to: 1) derive the vertical column abundance of C_4N_2 ice in Titan's early spring polar stratosphere, and 2) narrow the range of possible chemical compositions for the material comprising the Haystack.

Author(s): Carrie Anderson[1], Robert E. Samuelson[1], Jason L McLain[1], Delphine Nna Mvondo[1], Paul Romani[1], F. Michael Flasar[1]
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515.06 – The disappearance and reappearance of Titan's detached haze layer

Titan's extended haze is a prominent and long-lived feature of the atmosphere that encompasses a rich variety of chemical, dynamical and microphysical processes operating over a wide range of temporal and spatial scales. The so-called 'detached' haze layer is easily seen in high-resolution short-wave (near-UV and blue wavelengths) images and is a consequence of a nearly global (outside of the winter polar hood region) layer depleted in aerosol content. It was first seen near 350 Km altitude in Voyager images (Rages and Pollack, 1983) and later observed by the Cassini ISS cameras (Porco et al., 2005; West et al., 2010) and UV stellar occultation profiles (Koskinen et al. 2011). A series of Cassini images from 2009 to 2010 revealed what appears to be a seasonally related altitude variation with remarkable regularity (comparing the Voyager and Cassini images). The drop in altitude is most rapid at equinox. Here we report on images of the upper haze layer over the period 2012 to early 2016. In the early part of this period the detached haze continued to drop in altitude and disappeared. There was no evidence for it beginning late in 2012 and extending to early 2016 when it was again detected with very low contrast at an altitude near 500 Km. We document this behavior and examine the evolution of the haze as functions of both latitude and time. These new details put additional constraints on models that attempt to account for the existence of the detached layer. Part of this work was done by the Jet Propulsion Laboratory, California Institute of Technology. References: Rages, K., and J. B. Pollack (1983), Vertical distribution of scattering hazes in Titan's upper atmosphere, *Icarus*, **55**, 50–62, doi:10.1016/0019-1035 (83)90049-0; Porco, C. C. et al., Imaging Titan from the Cassini Spacecraft, *Nature* **434**, 159-168 (2005); West, R. A. et al., The evolution of Titans detached haze layer near equinox in 2009", *Geophys. Res. Lett.* **38**, L06204, doi:10.1029/2011GL046843, 2011; Koskinen T.T., et al., The mesosphere and lower thermosphere of Titan revealed by Cassini/UVIS stellar occultations, *Icarus* **216**507534, 2011.

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515.07D – Aerosols optical properties in Titan's Detached Haze Layer

Titan's Detached Haze Layer (DHL) was first observed in 1983 by Rages and Pollack during the Voyager 2 is a consistent spherical haze feature surrounding Titan's upper atmosphere and detached from the main haze. Since 2005, the Imaging Science Subsystem (ISS) instrument on board the Cassini mission performs a continuous survey of the Titan's atmosphere and confirmed its persistence at 500 km up to the equinox (2009) before its drop and disappearance in 2012 (West et al. 2011). Previous analyses showed, that this layer corresponds to the transition area between small spherical aerosols and large fractal aggregates and play a key role in the aerosols formation in Titan's atmosphere (Rannou et al. 2000, Lavvas et al. 2009, Cours et al. 2011).
In this talk we will present the UV photometric analyses based on radiative transfer inversion to retrieve aerosols particles properties in the DHL (bulk and monomer radius and local density) performed on ISS observations taken from 2005 to 2007.
References:

- Rages and Pollach, Icarus **55** (1983)
- West, et al., Icarus **38** (2011)
- Rannou, et al., Icarus **147** (2000)
- Lavvas, et al., Icarus **201** (2009)
- Cours, et al., ApJ Lett. **741** (2015)

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515.08 – Characteristics of Titan's haze derived from solar occultation observations in the infrared

The Visual and Infrared Mapping Spectrometer (VIMS) has acquired 14 solar occultation observations between January 2006 and April 2016. The observations span a large range of latitude and seasons, allowing us to witness atmospheric variability. We use only the infrared channel of the VIMS instrument between 884- and 5108-nm. The observations are first processed to provide light curves which are the transmission through Titan's atmosphere as a function of the impact parameter. The transmission is calculated by dividing the signal by the solar spectrum obtained when the value of the impact parameter is much larger than the thickness of Titan's atmosphere, which makes it independent of the choice of the solar spectrum. The data set is composed of 14 3D arrays (transmission, wavelength, impact parameter). Errors are calculated using the SNR derived from the acquisition of the solar spectra and the value of transmission. The observations use a solar port which is aligned with the UVIS boresight in order to simultaneously record the atmospheric transmission in both UV and IR. For this purpose, VIMS has a solar port. However, one difficulty is to remove the additional light that often comes from the boresight. The technic will be described. In the seven infrared wavelengths where Titan's surface can be observed, the transmission is a direct measurement of the scattering by the aerosols. An inversion process has been set up to provide the density distribution of the aerosols as a function of altitude for each of these observations. The model is simple model with only one population of aerosols with a cross section that is wavelength-dependent. The model allows us to provide extinction curves at those wavelengths. The three observations obtained at the equator, close to where the Huygens probe landed, are compared with the DISR observations which have been recently revised (Doose et al., Icarus, 2016).
This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

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515.09 – Titan's Oxygen Chemistry and its Impact on Haze Formation

Though Titan's atmosphere is reducing with its 98% N_2, 2% CH_4 and 0.1% H_2, CO is the fourth most abundant molecule with a uniform mixing ratio of ~50 ppm. Two other oxygen bearing molecules have also been observed in Titan's atmosphere: CO_2 and H_2O, with a mixing ratio of ~15 and ~1 ppb, respectively. The physical and chemical processes that determine the abundances of these species on Titan have been at the centre of a long-standing debate as they place constraints on the origin and evolution of its atmosphere [1]. Moreover, laboratory experiments have shown that oxygen can be incorporated into complex molecules, some of which are building blocks of life [2]. Finally, the presence of CO modifies the production rate and size of tholins [3, 4], which transposed to Titan's haze may have some strong repercussions on the temperature structure and dynamics of the atmosphere.
We present here our current understanding of Titan's oxygen chemistry and of its impact on the chemical composition of the haze. We base our discussion on a photochemical model that describes the first steps of the chemistry and on state-of-the-art laboratory experiments for the synthesis and chemical analysis of aerosol analogues. We used a very-high resolution mass spectrometer (LTQ-Orbitrap XL instrument) to characterize the soluble part of tholin samples generated from $N_2/CH_4/CO$ mixtures at different mixing ratios and with two different laboratory set-ups. These composition measurements provide some understanding of the chemical mechanisms by which CO affects particle formation and growth. Our final objective is to obtain a global picture of the fate and impact of oxygen on Titan, from its origin to prebiotic molecules to haze particles to material deposited on the surface.

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[4] S.M. Hörst and M.A. Tolbert, The effect of carbon monoxide on planetary haze formation, *Astrophys. J.*, 781, 53 (2014).

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515.10 – Orographic Condensation at the South Pole of Titan

Although many clouds have been observed on Titan over the past two decades (Griffith et al. 1998, Rodriquez et al 2009, Brown et al. 2010), only a handful of clouds have been analyzed in detail (Griffith et al 2005, Brown et al 2009, Adamkovics et al 2010). In light of new data and better radiative transfer (RT) modelling, we present here a reexamination of one of these cloud systems observed in March 2007, formerly identified as ground fog (Brown et al 2009), using the Cassini VIMS instrument. Combining our analysis with RADAR observations we attempt to understand the connection and correlation between this low altitude atmospheric phenomenon and the local topography, suggesting instead, a topographically driven (orographic) cloud formation mechanism. This analysis would present the first links between cloud formation and topography on Titan, and has valuable implications in understanding additional cloud formation mechanisms, allowing for a better understanding of Titan's atmospheric dynamics.

We will also present an update on an ongoing ground based observation campaign looking for clouds on Titan. This campaign, begun back in April 2014, has been (nearly) continuously monitoring Titan for ongoing cloud activity. Although a variety of telescope and instruments have been used in an effort to best capture the onset of cloud activity expected at Titan's North Pole, no cloud outbursts have yet been observed from the ground (though frequent observations have been made with Cassini ISS/VIMS). This is interesting because it further suggests a developing dichotomy between Titan's seasons, since clouds were observable from the ground during southern summer. Thus, monitoring the onset of large scale cloud activity at Titan's North Pole will be crucial to understanding Titan's hydrologic cycle on seasonal timescales.

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515.11 – Chapman Solar Zenith Angle variations at Titan

Solar XUV photons and magnetospheric particles are the two main sources contributing to the airglow in the Titan's upper atmosphere. We are focusing here on the solar XUV photons and how they influence the airglow intensity. The Cassini-UVIS observations analyzed in this study consist each in a partial scan of Titan, while the center of the detector stays approximately at the same location on Titan's disk. We used observations from 2008 to 2012, which allow for a wide range of Solar Zenith Angle (SZA). Spectra from 800 km to 1200 km of altitude have been corrected from the solar spectrum using TIMED/SEE data. We observe that the airglow intensity varies as a function of the SZA and follows a Chapman curve. Three SZA regions are identified: the sunlit region ranging from 0 to 50 degrees. In this region, the intensity of the airglow increases, while the SZA decreases. Between SZA 50 and 100 degrees, the airglow intensity decreases from it maximum to its minimum. In this transition region the upper atmosphere of Titan changes from being totally sunlit to being in the shadow of the moon. For SZA 100 to 180 degrees, we observe a constant airglow intensity close to zero. The behavior of the airglow is also similar to the behavior of the electron density as a function of the SZA as observed by Ågren at al (2009). Both variables exhibit a decrease intensity with increasing SZA. The goal of this study is to understand such correlation. We demonstrate the importance of the solar XUV photons contribution to the Titan airglow and prove that the strongest contribution to the Titan dayglow occurs by solar fluorescence rather than the particle impact that predominates at night.

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515.12 – Air-Sea Interactions over Lakes on Titan

The exchange of methane between the atmosphere and surface liquid reservoirs dominates the short time-scale methanological cycle. In this study, previous two-dimensional simulations of the exchange of methane vapor, sensible heat and momentum between the atmosphere and lakes are updated with the inclusion of radiative forcing, three dimensions, and realistic coastlines. Titan's air-sea exchange in two dimensions indicated that the exchange process was self-limiting. Evaporation from lakes produced a shallow but extremely stable marine layer that suppressed turbulent exchange. Furthermore, the circulation associated with the higher buoyancy of methane-rich atmosphere over the lake was offset by the oppositely directed thermal sea breeze circulation, which muted the mean wind. Two major weaknesses of this previous work were the lack of radiative forcing and the imposition of two dimensionality, which limited the full range of dynamical solutions. Based on early theoretical studies, it was thought that magnitude of turbulent energy flux exchanges would be much larger than radiative fluxes, thereby justifying the neglect of radiation, but the two-dimensional simulations indicated that this was not a valid assumption. The dynamical limitations of two-dimensional simulations are well known. Vorticity stretching (i.e., circulation intensification through vertical motion) is not possible and it is also not possible to produce dynamically balanced gradient wind-type circulations. As well, the irregular shape of a realistic coastline cannot be expressed in two dimensions, and these realistic structures will generally induce complex convergence and divergence circulations in the atmosphere. The impact of radiative forcing and the addition of the third dimension on the air-sea exchange are presented.

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516 – Asteroid Physical Characteristics: Surfaces III

516.01 – Thermal inertia as an indicator of rockiness variegation on near-Earth asteroid surfaces

Determining key physical properties of asteroids such as sizes and albedos or reflectance spectra is crucial to understand their origins and the processes that they have undergone during their evolution. In particular, one of the aims of NEOShield-2 project, funded by the European Union's Horizon 2020 Research and Innovation programme, is to physically characterize small near Earth asteroids (NEA) in an effort to determine effective mitigation strategies in case of impact with our planet [Harris et al. 2013 2013AcAau,90,80H]. We performed thermophysical modelling of NEAs, such as (1685) Toro, and potentially hazardous asteroids (PHAs), such as (33342) 1998 WT24. In addition to size, thermophysical models (TPM) of asteroids can constrain the surface thermal inertia, which is related to the material composition and physical nature, namely its "rockiness" or typical size of the particles on its surface. These have observable effects on the surface temperature distribution as a function of time and thus on the thermal infrared fluxes we observe, to which we can fit our model.

In the case of WT24, its thermal inertia has been previously constrained to be in the range 100-300 SI units [Harris et al. 2007, Icarus 188, 414H]. But this was based on a spherical shape model approximation since no shape model was available by the time. Such a low thermal inertia value seems in disagreement with a relatively high metal content of the enstatite chondrites, the meteorite type to which WT24, classified as an E-type [Lazzarin et al. 2004 A&A 425L, 25L], has been spectrally associated. Using a three-dimensional model and spin vector based on radar observations

[Busch et al. 2008 Icarus 197, 375B], our TPM produces a higher best-fitting value of the thermal inertia. We also find the intriguing possibility that the hemisphere of WT24 dominated by concave terrains, possibly be the result of an impact crater, has a higher thermal inertia. This would be similar to the case of our Moon, where young impact craters are rockier than older craters covered by fully developed (i.e., fine-grained) regolith resulting from the erosion of the rocks exposed to the space environment for longer time scales.
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516.02 – NEOs in the mid-infrared: from *Spitzer* to *JWST*
Near-Earth Objects (NEOs) account for a surprisingly large fraction of the Spitzer observing time devoted to Solar System science. As a community, we should think of ways to repeat that success with JWST. JWST is planning an open Early Release Science Program, with the expected deadline for letters of intent in early 2017. We can't wait for next year's DPS to develop ideas. The time is now!
In order to stir up the discussion, we will present ideas for NEO observing programs that are well adapted to JWST's capabilities and limitations, based on our recent PASP paper (Thomas et al., 2016). Obvious measurement objectives would include
* size and albedo from thermal continuum (MIRI photometry);
* thermal inertia for objects with well-known shape and spin state (MIRI);
* taxonomy through reflection spectroscopy and emission spectroscopy in the NIR and MIR; NIR colors for faint objects.
In all cases, JWST's sensitivity will allow us to go deeper than currently possible by at least an order of magnitude. Meter-sized NEOs similar to 2009 BD or 2011 MD are *easy*targets for MIRI spectrophotometry!
The following limitations must be kept in mind, however: JWST's large size makes it slow to move. Most problematic for NEOs is probably the resulting 'speed limit': non-sidereal tracking is supported up to a rate of 30 mas/s, NEOs can easily move faster than that (ways to relax this constraint are under discussion). The average slew to a new target is budgeted to take 30 min, effectively ruling out programs many-target programs like ExploreNEOs or NEOSurvey (see D. Trilling's paper). Additionally, JWST will only observe close to quadrature, translating to large solar phase angles for NEO observations; this is familiar from other space-based IR facilities.
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516.03 – Observed asteroid surface in the infrared: more than meets the eye
Most thermal IR observations of asteroids are unresolved. We consider what fraction of an asteroid's surface area contributes the bulk of the emitted thermal flux by computing the temperature of two model asteroids of different shapes over a range of thermal parameters. The resulting observed surface in the infrared is often different than the area observed in visible wavelengths. In some cases, only 12% of the surface contributes the majority of thermally emitted flux, when the object is observed at opposition. Calculating observed surface area in the infrared ensures that results from thermophysical modeling are interpreted accurately.
Author(s): Carolyn Nugent[1], Amy K. Mainzer[2], Joseph R. Masiero[2], Edward L. Wright[4], James M. Bauer[2], Tommy Grav[3], Emily A. Kramer[2], Sarah M. Sonnett[2]
Institution(s): *1. IPAC/Caltech, 2. JPL, 3. PSI, 4. UCLA*

516.04 – A Novel and Simple Means to Estimate Asteroid Thermal Inertia
Calculating accurate values of thermal inertia for asteroids is a difficult process requiring a shape model, thermal-infrared observations of the object obtained over broad ranges of rotation period and aspect angle, and detailed thermophysical modeling. Consequently, reliable thermal inertia values are currently available for relatively few asteroids. On the basis of simple asteroid thermal modeling we have developed an empirical relationship enabling the thermal inertia of an asteroid to be estimated given adequate measurements of its thermal-infrared continuum and knowledge of its spin vector. In particular, our thermal-inertia estimator can be applied to hundreds of objects in the WISE cryogenic archive (limited by the availability of spin vectors). To test the accuracy of our thermal-inertia estimator we have used it to estimate thermal inertia for near-Earth asteroids, main-belt asteroids, Centaurs, and trans-Neptunian objects with known thermal inertia values derived from detailed thermophysical modeling. In nearly all cases the estimates agree within the error bars with the values derived from thermophysical modeling.
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516.05 – Discovery of Spin-Rate-Dependent Asteroid Thermal Inertia
Knowledge of the surface thermal inertia of an asteroid can provide insight into surface structure: porous material has a lower thermal inertia than rock. Using WISE/NEOWISE data and our new asteroid thermal-inertia estimator we show that the thermal inertia of main-belt asteroids (MBAs) appears to increase with spin period. Similar behavior is found in the case of thermophysically-modeled thermal inertia values of near-Earth objects (NEOs). We interpret our results in terms of rapidly increasing material density and thermal conductivity with depth, and provide evidence that thermal inertia increases by factors of 10 (MBAs) to 20 (NEOs) within a depth of just 10 cm. On the basis of a picture of depth-dependent thermal inertia our results suggest that, in general, thermal inertia values representative of solid rock are reached some tens of centimeters to meters below the surface in the case of MBAs (the median diameter in our dataset = 24 km). In the case of the much smaller (km-sized) NEOs a thinner porous surface layer is indicated, with large pieces of solid rock possibly existing just a meter or less below the surface. These conclusions are consistent with our understanding from in-situ measurements of the surfaces of the Moon, and a few asteroids, and suggest a very general picture of rapidly changing material properties in the topmost regolith layers of asteroids. Our results have important implications for calculations of the Yarkovsky effect, including its perturbation of the orbits of potentially hazardous objects and those of asteroid family members after the break-up event. Evidence of a rapid increase of thermal inertia with depth is also an important result for studies of the ejecta-enhanced momentum transfer of impacting vehicles ("kinetic impactors") in planetary defense.
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516.06 – Thermal Properties and a Revised Shape Model for Near-Earth Asteroid (162421) 2000 ET70
We present thermal properties and an improved shape model for potentially hazardous asteroid (162421) 2000 ET70. In addition to the radar data from 2000 ET70's apparition in 2012, our revised model incorporates optical lightcurves and infrared spectra that were not used for the shape model of Naidu et al. (2013). We confirm the general "clenched fist" shape of their model but find the

asteroid's dimensions to be somewhat different. In particular, the lightcurves favor a model that is significantly shorter along its z-axis (rotation axis) than the model of Naidu et al. With the available data, 2000 ET70's rotation period and pole position are degenerate with each other. The radar and lightcurve data together constrain the pole direction to fall along an arc that is about twenty-five degrees long and ten degrees wide. Infrared spectra from the NASA InfraRed Telescope Facility (IRTF) provide an additional constraint on the pole. Thermophysical modeling, using our SHERMAN software, shows that only a subset of the pole directions along that arc are compatible with the infrared data. This study demonstrates the power of multiple data sets in the investigation of near-Earth asteroids.

Author(s): Sean E. Marshall[2], Ellen S. Howell[5], Christopher Magri[7], Donald B. Campbell[2], Michael C. Nolan[5], Yanga R. Fernandez[6], Ronald J. Vervack, Jr.[4], Jenna L Crowell[6], Michael D. Hicks[3], Kenneth J. Lawrence[3], Patrick A. Taylor[1]

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516.07D – Radar imaging, shape modeling, and Yarkovsky drift of near-Earth asteroid 1566 Icarus

Near-Earth asteroid (NEA) 1566 Icarus (a=1.08 au, e=0.83, i=22.8 degrees) made a rare close approach to Earth in June 2015 at 22 lunar distances (LD). Its detection during the 1968 approach (16 LD) was the first in the history of asteroid radar astronomy. The next approach in 1996 (40 LD) did not yield radar images. We provide the results of analyses of the first radar images obtained of 1566 Icarus during the 2015 close approach. These data suggest that this object is 1.77+-0.3 km in diameter, which is larger than previously thought, and has strongly specular surface scattering behavior. We also provide constraints on 1566 Icarus' spin pole orientation. Finally, we present the first use of our Integration and Determination of Orbits System (IDOS) for the generation of radar predictions, and we demonstrate its ability to measure subtle perturbations on NEA orbits by measuring 1566 Icarus' orbit-averaged drift in semi-major axis (-5.8+-0.5 x 10^-4 AU/Myr).

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516.08 – Shape, size, physical properties and nature of low-perihelion near-Earth asteroid (3200) Phaethon

We apply the convex inversion method to the new optical data obtained by six instruments together with the already existing observations and derive convex shape model of low-perihelion near-Earth asteroid (3200) Phaethon. This shape model is then used as an input for the thermophysical modeling. We present new convex shape model and rotational state of Phaethon – sidereal rotation period of 3.603958(2) h and ecliptic coordinates of the preferred pole orientation of (319, −39) with a 5 degree uncertainty. Moreover, we derive its size (D=5.1±0.2 km), thermal inertia (Γ=600±200 J m-2s-1/2K-1), geometric visible albedo (pV=0.122±0.008), and estimate the macroscopic surface roughness by the thermophysical model. We also estimate the average size of the surface regolith to few centimeters. The Spitzer emission spectrum of Phaethon is similar to those of CV/CK carbonaceous chondrite meteorites, match with CI/CM carbonaceous chondrites is ruled out. We also study the long-term stability of Phaethon's orbit and spin axis by a numerical orbital and rotation-state integrator. We find that the Sun illumination at the perihelion passage during past thousands of years is not connected to a specific area on the surface implying non-preferential heating. Considering the most important meteor stream of the Geminids is associated with Phaethon, we predict that the meteorites dropped by Geminids are CVs or CKs. We also discuss the possible dynamical link between Phaethon and Pallas and its collisional family.

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516.09 – Shapes of binary asteroid primaries from photometric observations

I will present results from a method which combine lightcurve inversion for single bodies and the method for inversion of lightcurves of occulting/eclipsing binary systems. A code developed by M. Kaasalainen and J. Durech for inversion of lightcurves of single bodies is adapted to fit our purposes. The original code uses a slightly elongated ellipsoid as an initial shape for optimization. We substituted this ellipsoid with a variety of shapes using Gaussian random spheres. This allowed the optimization algorithm to iterate to a range of final shapes.

For each binary system, the short-period (rotational) component of its lightcurve is inverted using this code and a set of possible shapes of the primary are obtained. In the next step these shape models of the primary are, one by one, incorporated into the full model of the binary system and complete photometric data including the mutual events are fitted. Comparing synthetic lightcurves of the best-fit solutions with the observed data enables another narrowing of the selection of the possible shapes of the primary. This process is based on the times of phases of mutual events occurring on different geometries (i.e. the secondary passing in front of/behind the primary not only equator-on).

We will also test a hypothesis that most of the primaries of the binary systems are similar in shape to each other. A figure resembling the shape of the primary of 1999 KW4, i.e., the top-shaped object with an equatorial ridge, will be used for the primary's shape. Its main characteristics – a polar flattening and width and height of the equatorial ridge, will be used as independent parameters. A variety of the shapes generated by a combination of these parameters will be used as an initial shapes for the optimization using the code described above.

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516.10 – Evaluation of Topographic Error and Quality with Stereophotoclinometry

One of the primary means to evaluate the accuracy of a shape model is to measure the deviation between a truth model (if available) and the shape model. Typically, this is done by calculating

the square root of the average error squared of all the points, i.e the root mean squared error (RMS).
This technique provides valuable insight into the error distribution of a shape model, as well as providing an objective measurement of deviations. However, it does not fully explain the error and especially the quality of a digital terrain model. Systematic errors can obscure poorly performing regions and may over-report errors. We have begun an extensive analysis of using normalized cross-correlation to evaluate the quality of shape models compared to truth topography, as well as the agreement between images rendered from the model with the original images. This technique provides a tool to differentiate between local accuracy and global accuracy. It also provides an effective way to decompose the error vector into horizontal and vertical displacements. It is especially useful for stereophotoclinometry (SPC) because it allows a clear determination of the quality of the model at the resolution of the source images (i.e. if the source images have a 5cm pixel size, it shows how well the SPC solution is at 5cm). Additionally, it demonstrates how essential a good imaging plan is to the quality of the shape model.
We are using these techniques in support of the OSIRIS-REx mission to the asteroid Bennu.
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516.11 – Thermal History of Near-Earth Asteroids: Implications for OSIRIS-REx Asteroid Sample Return

The connection between orbital and temperature history of small Solar System bodies has only been studied through modeling. The upcoming OSIRIS-REx asteroid sample return mission provides an opportunity to connect thermal modeling predictions with laboratory studies of meteorites to predict past heating and thus dynamical histories of bodies such as OSIRIS-REx mission target asteroid (101955) Bennu. Bennu is a desirable target for asteroid sample return due to its inferred primitive nature, likely 4.5 Gyr old, with chemistry and mineralogy established in the first 10 Myr of solar system history (Lauretta et al. 2015). Delbo & Michel (2011) studied connections between the temperature and orbital history of Bennu. Their results suggest that the surface of Bennu (assuming no regolith turnover) has a 50% probability of being heated to 500 K in the past. Further, the Delbo & Michel simulations show that the temperature within the asteroid below the top layer of regolith could remain at temperatures ~100 K below that of the surface. The Touch-And-Go Sample Acquisition Mechanism on OSIRIS-REx could access both the surface and near surface regolith, collecting primitive asteroid material for study in Earth-based laboratories in 2023. To quantify the effects of thermal metamorphism on the Bennu regolith, laboratory heating experiments on carbonaceous chondrite meteorites with compositions likely similar to that of Bennu were conducted from 300–1200 K. These experiments show mobilization and volatilization of a suite of labile elements (sulfur, mercury, arsenic, tellurium, selenium, antimony, and cadmium) at temperatures that could be reached by asteroids that cross Mercury's orbit. We are able to quantify element loss with temperature for several carbonaceous chondrites and use these results to constrain past orbital histories of Bennu. When OSIRIS-REx samples arrive for analysis we will be able to measure labile element loss in the material, determine maximum past temperature of the samples, and predict the past orbital and thermal history of Bennu.
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516.12 – The Global Surface Roughness of 433 Eros from the NEAR-Shoemaker Laser Altimeter (NLR)

Surface roughness is the quantitative measure of the change in topography at a given scale. Previous studies have used surface roughness to map geologic units, choose landing sites, and understand the relative contribution of different geologic processes to topography. In this study we focus on understanding how surface roughness is linked to the geologic processes acting on asteroids, with a case study of 433 Eros through the generation of global surface roughness maps. The scale that surface roughness is measured at will dictate the geologic processes studied; the majority of studies of the surface roughness of asteroids have focused on centimeter scale roughness (derived from radar measurements). Spacecraft that rendezvous with asteroids and carry laser altimeters on board provide topographic data that allows surface roughness to be measured at the scale of meters to hundreds of meters.
To calculate surface roughness on 433 Eros from 1 m to 300 m, we use the Near Earth Asteroid Rendezvous (NEAR)-Shoemaker's laser altimeter (NLR). We measure surface roughness as Root-Mean Square (RMS) deviation, which is simply the RMS difference in height over a given scale. RMS deviation is then used to calculate the Hurst exponent, which quantifies the fractal behavior of the surface and is indicative of the type of geologic processes controlling topography at that scale. The surface roughness on 433 Eros varies regionally, with smaller roughness values where regolith has accumulated, and more elevated roughness values along the walls of large craters or near linear grooves. The roughness seen in crater walls may be evidence for subsurface structures (visible as aligned blocks protruding from the crater walls). The surface roughness of 433 Eros is also remarkably fractal relative to other asteroids and planets. To understand in greater detail the geological origin of the surface roughness and fractal nature of Eros, this study presents the first global maps of surface roughness on 433 Eros.
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517 – Galilean Satellites II: Europa and Io

517.01 – A new spectral feature on the trailing hemisphere of Europa at 3.78 microns

We present hemispherically resolved spectra of the surface of Europa from 3.4 – 4.15 microns, which we obtained using Keck NIRSPEC. These include the first high-quality L-band spectra of the surface to extend beyond 4 microns. In our data, we identify a previously unseen spectral feature at 3.78 microns on the trailing hemisphere. This feature is coincident with an SO_2 frost absorption. However the corresponding, typically stronger 4.07-micron feature of SO_2 frost is absent from our data. This result is contrary to the suggested detection of SO_2 at 4.05 microns in Galileo NIMS data [1] of the trailing hemisphere, which was severely affected by radiation noise. Thus, we use simple spectral modeling to argue that the 3.78-micron feature is not easily explained by the presence of SO_2 frost on the surface. However, the longitudinal distribution of the feature is consistent with that of a radiolytic product. We explore alternative explanations and discuss other potential candidate species. [1] Hansen and McCord (2008) GRL, 35: L01202.
Author(s): Samantha K. Trumbo[1], Patrick D Fischer[1], Michael E. Brown[1]
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517.03 – "Sniffing" Jupiter's moon Europa through ground-based IR observations

The ability to sample possible plumes from the subsurface ocean in Europa represents a major step in our search for extraterrestrial life. If plumes exist, sampling the effluent material would provide insights into their chemistry and relevant information about the prospect that life could exist, or now exists, within the ocean. Most of the difficulties in detecting plumes come from the less frequent observational coverage of Europa, which contrasts strongly with the frequent Cassini flybys of Enceladus (Spencer & Nimmo 2013). Recent observations have been taken with HST/STIS in 2014/2015, but results have shown no evident confirmation of the 2012 plume detection (Roth et al. 2014, 2015). Future in situ observations (Europa Mission) will provide definitive insights, but not before the spacecraft's arrival in ~2025, thus an interim approach is needed to inform such space mission planning and to complement existing observations at other wavelengths.

In 2015, we initiated a strong campaign to build a comprehensive survey of possible plumes on Europa through high-resolution IR spectroscopy with Keck/NIRSPEC. We were awarded 10 nights out of 15 total nights available for Key Strategic Mission Support projects for the 2016A, 2016B, 2017A, and 2017B semesters under NASA time with the Keck Observatory. In 2016A, we observed Europa during 10 half-nights and will continue to do so for another 10 half-nights in 2017A. We target a serendipitous search of gaseous activity from Europa to confirm and constrain the chemical composition of possible Europan plumes that can aid the investigation of physical processes underlying (or on) its surface. Ultimately, we seek to: (1) provide information that can inform planning for NASA's Europa mission, (2) further our current understanding of Europa's gas environment, and (3) complement studies that are currently underway with other facilities (like the Hubble Space Telescope). In this presentation, we will discuss preliminary results, challenges, and future plans of our observing campaign.

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517.04D – On the origin of alkali metals in Europa exosphere

At a time when Europa is considered as a plausible habitat for the development of an early form of life, of particular concern is the origin of neutral sodium and potassium atoms already detected in its exosphere (together with magnesium though in smaller abundance), since these atoms are known to be crucial for building the necessary bricks of prebiotic species. However their origin and history are still poorly understood. The most likely sources could be exogenous and result from the contamination produced by Io's intense volcanism and/or by meteoritic bombardment. These sources could also be endogenous if these volatile elements originate directly from Europa's icy mantle. Here we explore the possibility that neutral sodium and potassium atoms were delivered to the satellite's surface via the upwelling of ices formed in contact with the hidden ocean. These metallic elements would have been transferred as ions to the ocean at early epochs after Europa's formation, by direct contact of water with the rocky core. During Europa's subsequent cooling, the icy layers formed at the top of the ocean would have kept trapped the sodium and potassium, allowing their future progression to the surface and final identification in the exosphere of the satellite. To support this scenario, we have used chemistry numerical models based on first principle periodic density functional theory (DFT). These models are shown to be well adapted to the description of compact ice and are capable to describe the trapping and neutralization of the initial ions in the ice matrix. The process is found relevant for all the elements considered, alkali metals like Na and K, as well as for Mg and probably for Ca, their respective abundances depending essentially of their solubility and chemical capabilities to blend with water ices.

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Contributing team(s): LCT, LAM

517.05D – Origin and Evolution of Europa's Oxygen Exosphere

Europa's icy surface is constantly bombarded by sulfur and oxygen ions originating from the Io plasma torus. The momentum transferred to molecules in Europa's surface results in the sputtering of water ice, populating a water product exosphere. We simulate Europa's neutral exosphere using a ballistic 3D Monte Carlo routine and find that the O_2exosphere, while global, is not uniformly symmetric in Europa local time. The O_2 exosphere, sourced at a rate of ~ 5 kg/s with a disk-averaged column density of N_{O2} ~ 2.5 x $10^{14} O_2/cm^2$, preferentially accumulates towards Europa's dusk. These dawn-dusk atmospheric inhomogeneities escalate as the surface-bounded O_2 dissociates into an atomic O corona via electron impact. The inhomogeneities persist and evolve throughout the satellite's orbit, implying a diurnal cycle of the exosphere, recently evidenced by a detailed HST oxygen aurorae campaign (Roth et al. 2016). We conclude that the consistently observed 50% increase in FUV auroral emission from dusk to dawn is principally driven by the day-to-night thermal diffusion of O_2 coupled with the Coriolis acceleration. This leads to a dawn-to-dusk gradient, peaking at Europa's leading hemisphere. This exospheric oxygen cycle, dependent on both orbital longitude and magnetic latitude, is fundamentally due to the bulk-sputtering vector changing with respect to the subsolar and subjovian points throughout the orbit. In principle, a similar mechanism should be present at other tidally-locked, rapidly orbiting satellite exospheres.

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517.06 – Sublimation as a Continuous and Transient Source of Water in Europa's Exosphere

Europa's crust is composed primarily of water ice, which may be vaporized by sputtering and sublimation when exposed to the jovian radiation environment. Models of H_2O in Europa's exosphere have focused primarily on the contribution of sputtering by energetic particles, with globally averaged production rates estimated to be $\sim 10^{15}$ H_2O m^{-2} s^{-1}. Although sublimation rates at Europa's average dayside temperature of ~106 K are much lower at $\sim 10^{10}$ H_2O m^{-2} s^{-1}, surfaces at low- to mid-latitude experiences temperatures in excess of 130 K, with expected sublimation rates of $>10^{15}$ H_2O m^{-2} s^{-1} possible. These production rates would be reduced where the surface ice is mixed with impurities, or through development of a non-ice lag deposit. In addition to the continuous flux due to sublimation, transient outgassing may be caused by exposure of fresh ice to direct sunlight, for example by mass wasting on steep slopes. Here, we revisit the process of sublimation on Europa's surface to quantify possible H_2O vapor production on a range of spatial and temporal scales.

The model includes solar heating, conduction, and vapor diffusion. Temperatures and sublimation rates are calculated by the instantaneous energy budget within each model layer, and outgassing to the exosphere depends on the surface vapor pressure and molecular thermal velocities. Vapor densities and line-of-sight

column abundances can be directly compared to observations. Our results show that for surfaces composed of pure ice, sublimation contributes significant quantities to the dayside exosphere. The production rate declines as a sublimation lag develops, with a characteristic timescale of ~1 – 10 kyr at the equator. Freshly exposed ice may produce localized sources. For example, a fresh exposure of ice at 60° latitude with dimension ~2 km would be expected to produce a line-of-sight column abundance of $\sim 10^{20}$ H_2O m^{-2} near the limb. However, expansion of the plume would lead to lower column abundance at higher altitudes.
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517.07 – On the formation of the atmosphere of Europa

Europa was observed to possess spatiotemporal variability in water above the surface. In addition, there were reports of a tenuous atmosphere that interacts with the magnetospheric plasma. To explain the presence of an ionosphere in a thin atmosphere, we developed a photochemistry-transport model that includes ion-neutral chemistry and diffusive transport. We examine sources of neutrals from Europa's surface geophysical activity and from ion sputtering at the surface by particles from the Jovian magnetosphere. Sensitivity of the results to the surface and magnetospheric activities is presented and discussed.
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517.08 – Cassini ENA Observations of an Asymmetric Europa Torus and Implications for JUICE

From about December 2000 to January 2001 the Ion Neutral Camera (INCA) on board the Cassini spacecraft imaged Jupiter in Energetic Neutral Atoms (ENA) that are created when singly charged ions charge exchange with neutral gas atoms or molecules. The INCA observations were obtained from a distance of about 137-250 Jovian planetary radii (RJ) over an energy range from about 10 to 300 keV. Here, we present an analysis of the ENA images implying an asymmetric Europa neutral gas torus with indications of magnetospheric dynamics. The analysis uses images with a minimum integration time and background. A forward model using a parametric energetic ion model and a neutral gas model simulates ENA images through the instrument response function of INCA in order to determine the spatial distribution of the neutral gas. Implications for the ENA observations from the ESA JUICE Mission obtained by the Jovian Energetic Neutrals and Ions (JENI) Camera on the Particle Environment Package (PEP) suite will be discussed.
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517.09 – Io's SO_2 Atmosphere Viewed in Silhouette by Jupiter Lyman-α

We report a new technique for mapping Io's SO_2 vapor distribution. Hubble's Space Telescope Imaging Spectrograph (STIS) instrument observed Io during four Jupiter transit events to obtain medium resolution far-UV spectral images near the Lyman-α wavelength of 121.6 nm. Jupiter's bright Lyman-α dayglow provides a background light source for opacity measurements, much like during a stellar occultation or transiting exoplanet event. Peaks in the photoabsorption cross-sections for sulfur dioxide occur near 122 nm, with resulting absorptions raising the altitude where a tangential line of sight opacity of tau=1 is detected up to resolvable distances above the disk. This method of measuring column densities along lines of sight above the limb complements Lyman-α reflectance imaging and other methods for measuring Io's SO_2 gas. For example, interpretation of Io's surface reflected components at far-UV wavelengths is complicated by SO_2 frost features being correlated with regions of known volcanic outgassing activity, while Jupiter's Lyman-α dayglow provides a more spatially uniform background light source. Initial examination of these near-terminator limb observations with STIS confirms the findings from previous Lyman-α disk reflectance imaging using STIS's G140L mode (e.g., Feldman et al., *GRL*, 2000; Feaga et al. 2009) that Io's polar SO_2 density is roughly an order of magnitude lower than found at the equator. As Strobel & Wolven (2001) described it, Io appears to wear its dayside atmosphere as "a belt" around the equator. We describe detailed simulations, now underway, that incorporate the STIS point spread function and consideration of additional attenuation by atmospheric hydrogen atoms, which are produced by charge exchange reactions between magnetospheric protons and Io's atmosphere.
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Institution(s): *1. KTH Royal Institute of Technology, 2. Southwest Research Inst., 3. University of Maryland*

517.10 – The Nature of Io's Primary Atmosphere: Collapse in Jupiter Eclipse

Io's SO_2 atmosphere on the dayside is collisionally thick and inhomogeneous. This atmosphere is thought to be sustained by the combination of direct volcanic injection and SO_2frost sublimation off the surface. The degree to which frost sublimation contributes to the overall atmosphere has been a long-standing problem in studying Io's atmosphere and its interactions with the surface and plasma environment. A key observation is determining the behavior of Io's atmosphere going into and during eclipses by Jupiter, which helps separate the sublimation component of the atmosphere in vapor pressure equilibrium with the surface from the volcanic component.
We present high-time (10 mins) and high spectral resolution (R~67,000) spectra of Io's primary molecular SO_2 atmosphere from the Gemini telescope with the TEXES spectrometer, as Io enters eclipses by Jupiter. The mid-IR spectra, which are the first ever observation of Io's bulk atmosphere going into and in eclipse, show significant change in the absorption bands of SO_2. With further modeling, we show the atmosphere collapses onto the surface as frost. This study presents a strong case for atmospheric support by vapor pressure from surface frost. This daily atmospheric collapse has implications on the supply of material to the plasma environment around Io and Jupiter, and should also be viewed in the context of the larger scale seasonal changes of the atmosphere that occur on Io.
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517.11 – Tvashtar's Plume during the New Horizons Flyby of the Jovian System

During the gravity-assist flyby of the Jovian system from 26 Feb 2007 to 3 Mar 2007, the New Horizons spacecraft obtained multiple images of Io's Pele-class plume "Tvashtar" using the panchromatic

LORRI camera, including a unique "movie" sequence of 5 images taken 2 minutes apart that provide the only record of dynamical activity for an extra-terrestrial volcanic plume. Prominent plume activity included a single traveling wave traveling down the west side of the canopy and a semi-regular particulate pattern that evolved down the canopy. The spout was detected in an average of the 5 movie images and its intensity may constrain the refractory complement of the plume. Comparison with the observed plume irradiance may then constrain the condensate complement. Other features, more apparent after subtracting the mean movie image, include semi-periodic azimuthal density variation in the canopy at plausibly common flight times from the vent, implying an azimuthal component to the dust density distribution at the vent. There are features that show a few large tendrils distributed in azimuth around the canopy that extend all the way to the surface, like the canopy projection, while the rest of the canopy appears to have a large discontinuity in density at the rim, as if the canopy were suspended. Successive waves having contrasting mean wavefront density suggest a fundamental-mode temporal pulsing at the vent. The scattering phase function for the plume particulates was found to be strongly forward scattering, increasing nearly monotonically during the flyby by an order of magnitude over the solar phase angle range 57 – 150 deg. Rathbun et al. (2014; Icarus 231, 261) reported that neither the Girru nor Tvashtar surface eruptions varied dramatically over 1-2 Mar 2007; however, most of the growth we found in Tvashtar's brightness during the flyby occurred by these dates. Therefore, increasing eruption activity, rising refractory dust density, or condensation may have contributed to the brightness increase with phase angle, along with forward scattering. Any transition in the mode of eruption (e.g., lava lake to fire fountain) was continuous and gradual. [NASA grant NNX14A039G]
Author(s): Laurence M. Trafton[1], William Andrew Hoey[1], Peter Ackley[1], David B. Goldstein[1], Philip L Varghese[1]
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517.12 – Time-Evolution and Thermal Mapping of Io's Loki Patera at High Resolution

Observations of Loki Patera with Keck, Gemini N, and the Large Binocular Telescope have yielded a wealth of information in the past several years. Observations with adaptive optics at the Keck and Gemini N telescopes have captured multiple brightening events since 2009. High-cadence observations of the three most recent events place constraints on the thermal properties of the magma and indicate a dependency of the observed intensity on either viewing geometry or mean anomaly. Large Binocular Telescope Interferometer (LBTI) observations during a Europa mutual event have yielded the first-ever temperature map of the entire patera floor at high spatial resolution. M-band (4.7-micron) images were recorded during the event at a cadence of 123 milliseconds, corresponding to a spatial resolution of 10 km across the entire ~200-km patera. This represents a factor of 40 improvement over the spatial resolution achieved by standard adaptive optics imaging with a 10-m telescope at this wavelength. A map of the lava age distribution within the patera is derived from the temperature map using models for cooling basaltic lavas, and the resurfacing rate is calculated. This age distribution, as well as the locations of emission derived from the Keck and Gemini N observations, suggests that resurfacing proceeds in a clockwise direction, contrary to previous findings. All data are consistent with resurfacing by an overturn front on a magma sea, but other resurfacing mechanisms are not ruled out.
Author(s): Katherine R. de Kleer[3], Michael F. Skrutskie[5], Jarron Leisenring[2], Imke de Pater[3], Ashley Davies[1], Al Conrad[2], Aaron Caleb Resnick[5], Philip Hinz[4], Denis Defrère[2], Christian Veillet[2]
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518 – Formation and Evolution of Planets and Satellites

518.01 – Planetesimal Growth through the Accretion of Small Solids: Hydrodynamics Simulations with Gas-Particle Coupling

The growth and migration of planetesimals in young protoplanetary disks are fundamental to the planet formation process. A number of mechanisms seemingly inhibit small grains from growing to sizes much larger than a centimeter, limiting planetesimal growth. In spite of this, the meteoritic record, abundance of exoplanets, and the lifetimes of disks considered altogether indicate that growth must be rapid and common. If a small number of 100-km sized planetesimals do form by some method such as the streaming instability, then gas drag effects could enable those objects to accrete small solids efficiently. In particular, accretion rates for such planetesimals could be higher or lower than rates based on the geometric cross-section and gravitational focusing alone. The local gas conditions and properties of accreting bodies select a locally optimal accretion size for the pebbles. As planetesimals accrete pebbles, they feel an additional angular momentum exchange - causing the planetesimal to slowly drift inward, which becomes significant at short orbital periods. We present self-consistent hydrodynamic simulations with direct particle integration and gas-drag coupling to evaluate the rate of planetesimal growth due to pebble accretion. We explore a range of particle sizes, planetesimal properties, and disk conditions using wind tunnel simulations. These results are followed by numerical analysis of planetesimal drift rates at a variety of stellar distances.
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518.02 – Implications of pebble accretion on the composition of hot and cold Jupiters

The formation of the planetary cores of gas giants via the accretion of planetesimals takes very long and is not compatible with the lifetime of protoplanetary discs (Levison et al. 2010). This time-scale problem can be solved through the accretion of pebbles onto a planetary seed. Contrary to planetesimals, pebbles feel the headwind from the gas which robs them of angular momentum allowing an efficient growth from the entire Hill sphere, which reduces the growth time-scale by several orders of magnitude (Lambrechts & Johansen, 2012; 2014). However, pebble accretion self-terminates when the planets start to open a partial gap in the disc, which accelerates the gas outside of the planets orbit to super-Keplerian speeds and thus stops the flow of pebbles onto the planetary core (Lambrechts et al. 2014). Typically this mass is of the order of 10-20 Earth masses, depending on the local disc properties. The planet can then start to accrete a gaseous envelope without a pollution of pebbles. During its growth, the planet migrates through the disc, which evolves in time (Bitsch et al. 2015a,b).

Different volatile species like CO_2 or H_2O have different condensation temperatures and are thus present in either solid or gaseous form at different locations in the disc. A pebble accreting planet can thus only accrete volatiles that are in solid form, while a gas accreting planet will only accrete volatiles which are in gaseous form. Therefore the final chemical composition of the planetary atmosphere of a giant planet is strongly influenced by the formation location of the initial planetary seed and its subsequent migration path through the disc. Additionally, the envelope can be enriched through the erosion of the planetary core.

I will discuss the implications of the formation of planets via pebble accretion and their subsequent migration through the disc on the composition of gas giants. In particular I will focus on the carbon to oxygen ratio of hot Jupiters around other stars and on the carbon to oxygen ratio of Jupiter in our own solar system.

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518.03 – Exploring How Giant Planet Formation Affected the Asteroid Belt

The asteroid belt is observed to be a mixture of objects with different compositions, with volatile-poor asteroids (mostly S-complex) dominant in the inner asteroid belt while volatile-rich (mostly C-complex) asteroids dominate the outer asteroid belt. While this general compositional stratification was originally thought to be an indicator of the primordial temperature gradient in the protoplanetary disk, the very distinct properties of these populations suggest that they must represent two completely decoupled reservoirs, not a simple gradient (e.g., Warren 2011). It is possible to create this general stratification (as well as the observed mixing) as the implantation of outer Solar System material into the asteroid belt by the early migration of the giant planets (e.g. the Grand Tack, Walsh et al. 2011). However, this presupposes that the inner and outer Solar System materials were still sorted in their primordial locations prior to any migration of the planets. The lack of a fully dynamically self-consistent model of giant planet core formation has prevented the study of how the core formation process itself may result in dynamical mixing in the early Solar System's history. Recently, pebble accretion, the process by which planetesimals can grow to giant planet cores via the accretion of small, rapidly drifting sub-meter-sized bodies known as ``pebbles,'' (Lambrechts & Johansen 2012, Levison, Kretke & Duncan 2015) finally offers such a model. Here we show how the process of giant planet formation will impact the surrounding planetesimal population, possibly resulting in the observed compositional mixture of the asteroid belt, without requiring a dramatic migration of the giant planets. For example, preliminary runs suggest planetesimals from the Jupiter-formation zone can be implanted in the outer main belt via interactions with scattered Jupiter-zone protoplanets. This could potentially provide an alternative non-Grand Tack solution to the origin of many C-complex bodies, including Ceres.

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518.04 – Mantle Debris in Giant Impacts: Parameter-Space Study and Scaling Laws

Collisions between similar-sized planetesimals are prevalent throughout the early stages of the formation of the Solar System. N-body dynamics simulations commonly employed to understand planetary evolution depend on parameterized disruption/accretion criteria in order to consider the diversity of outcomes of these collisions. Additionally, understanding the debris from collisions is essential in tracing the source regions of volatiles, placing constraints on collisional grinding, and explaining the formation of small solar system bodies. We describe the transport of mantle material through debris production in giant impacts using a large database of SPH hydrocode simulations. We then develop new scaling laws that accurately capture the production of diverse debris products found in giant impacts with a range of relative velocities up to a few times the mutual escape velocity and a complete range of impact geometries. At typical impact angles it is found that giant impacts are significantly less erosive than suggested by existing scaling laws. This discrepancy grows with impact velocity and the impactor-to-target mass ratio, and thus it grows with the kinetic energy of the system. Our database spans a wide parameter space of pre-impact initial conditions, and includes chondritic and icy, chondritic material representative of the bulk abundances in the inner and outer solar system respectively. Implications for this new understanding in debris production through giant impacts are discussed.

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518.05 – Low-velocity impacts into cryogenic icy regolith

The first stages of planet formation take place in the protoplanetary disk (PPD), where µm-sized dust grains accrete into km-sized planetesimals. In the current discussion on the processes involved in accretion beyond the cm scale, the size distribution of the particles colliding at low speeds (a few m/s) inside the PPD is thought to play an important role. A few larger bodies that survived bouncing and fragmentation collisions accumulate the fine dust residue of the erosion and fragmentation of other particles that were destroyed in more energetic collisions. A significant component of this dust on bodies farther out in the PPD will be composed of ices.
We have carried out a series of experiments to study the ejecta mass-velocity distribution from impacts of cm-scale particles into granular media at speeds below 3 m/s in both microgravity and 1-g conditions in vacuo and room temperature. Aggregate-aggregate collision experiments have shown bouncing and fragmentation at speeds above ~ 1 m/s. However, most planetesimal formation occurred beyond the frost line and at much lower temperatures than our earlier experiments. We have performed impact experiments at 1-g into JSC-1 lunar regolith simulant at low temperatures (<150 K) with water ice particles mixed into the JSC-1 sample. We varied the impact energy and the water ice content of the sample and measured the ejecta mass-velocity distribution as well as the final crater size. Our goal is to determine if the cryogenic temperature and the presence of water ice in the regolith affects the dynamic response to low-velocity impacts and the production of regolith. We will present the results of the cryogenic impacts and compare them to the study performed at room temperature without water ice. The inclusion of water ice into the target sample is a first step towards better understanding the influence of the presence of water ice in the production of ejecta in response to low-velocity impacts. We will discuss the implications of our results for planetary ring particle collisions as well as planetesimal formation.

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518.06 – Isotopic mixing by magnetorotational instability in the protolunar disk

One explanation for the striking similarity in isotopic ratios between the Earth and Moon is that isotopes were efficiently mixed in the protolunar disk and between the disk and the Earth. We examine the ability of the magnetorotational instability to act in the protolunar disk, calculating the ionization fraction of the vapor component and the resultant Elsasser numbers. We perform shearing box magnetohydrodynamic simulations to calculate the rate of turbulent mixing. We conclude that mixing of isotopes in the disk is effective on ~ 10^2yr timescales, faster than the time for the disk to evolve and the Moon to form. We also consider the effectiveness of isotopic mixing between the disk and the Earth.

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518.07 – Could the Craters on the Mid-Sized Moons of Saturn Have Been Made by Satellite Debris?

Saturn's mid-sized moons have usually been assumed to be primordial. However, Charnoz et al. (2011) and Crida and Charnoz (2012) showed that the steep trend of mass vs. distance of the moons out to Rhea is consistent with the spreading of an early massive ring (e.g., Canup 2010) beyond Saturn's Roche limit. In this model, these moons would be billions of years old, but with Mimas forming perhaps 1 Gyr after Rhea.
Cuk et al. (2016) investigated the dynamical evolution of the, mid-sized saturnian moons due to tides. They infer that the moons have migrated little. Tethys and Dione probably did not cross their 3:2 resonance, but the system likely did cross a Dione-Rhea 5:3 resonance and a Tethys-Dione secular resonance. These crossings would have happened recently; for Q = 1500 (Lainey et al. 2012), within the past 100 Myr. Cuk et al. suggested that a previous generation of moons underwent an orbital instability, perhaps due to a solar evection resonance, leading to catastrophic collisions between them (Movshovitz et al. 2016). Today's moons would have reaccreted from the debris. This model implies that most craters on the moons were formed by this debris, with impacts taking place at much lower speeds than applies for impacts by comets.
Many crater properties, such as the depth-to-diameter ratio (Bray and Schenk 2015) and the amount of melting and vaporization (Kraus et al. 2011), depend on the impact velocity. We will discuss how measurements of craters in Cassini images of saturnian moons can be used to distinguish between the Cuk et al. scenario and the view in which the largest craters are made by comets and planetocentric debris makes only smaller craters (Alvarellos et al. 2005).
We thank the Cassini Data Analysis Program for support and Amy Barr Mlinar for discussions.
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518.08 – Formation of Janus and Epimetheus from Saturn's rings as coorbitals, thanks to Mimas' 2:3 inner Mean Motion Resonances

Janus and Epimetheus orbit Saturn at 151461 km on average, on mutual horseshoe orbits with orbital separation 50 km, exchanging position every 4 years. This configuration is unique and intriguing : Lissauer et al. (1985) have shown that their orbital separation should converge to zero in about 20 Myrs only, and no satisfactory model for the origin of this co-orbital resonance exists yet.
Charnoz et al. (2010) have shown that Janus and Epimetheus probably formed from the spreading of the rings beyond the Roche radius. Here, we show that this happened when Mimas' 2:3 Lindblad Resonance, which used to confine the rings, receded past the Roche radius. This first explains the gap in mass and distance between Janus and Mimas, which is unexpected in the pyramidal regime of the ring spreading model (Crida & Charnoz 2012). Furthermore, at this time, the two capture sites of Mimas's 2:3 Corotation Resonance were full of ring material. We suggest that as the two capture sites were brought beyond the Roche radius, the captured material agglomerated into two bodies of ~10^{15} kg on the exact same orbit. These bodies then migrated outwards together due to their interaction with the rings, in mutual horseshoe orbits. The rings then spawn new small satellites, eventually accreted by the proto-Janus and the proto-Epimetheus. This excites their orbital separation, leading to today's configuration.
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518.09 – Cuckoo in the Nest: The Fate of the Original Moons of Neptune

Neptune's moon Triton is the largest captured satellite in the solar system, as indicated by its inclined retrograde orbit. The most likely mechanism for its capture is binary disruption, which ejected its former binary companion and placed Triton on a large, eccentric orbit around Neptune (Agnor and Hamilton 2006). While the tides would in principle circularize Triton's orbit (Goldreich et al. 1989), Triton's early orbit would have evolved much faster through interactions with preexisting moons of Neptune (Cuk and Gladman 2005). Assuming that the pre-existing moons of Neptune were similar to those of Uranus, analytical estimates are unclear on which outcome is most likely during moon-moon scattering. Cuk and Gladman (2005) suggested that collisions among the regular moons happen first, while Nogueira et al. (2011) find that collisions between Triton and an old moon, or an ejection should happen first. Here we use the general purpose (T+U) symplectic integrator to explore this short-lived epoch of orbit crossing in the Neptunian system. Our preliminary results indicate that Triton might have collided with one of the preexisting moons of Neptune before the regular satellites could have been destroyed in mutual collisions. Goldreich et al. (1989) claimed that a collision with a moon larger than Miranda would destroy Triton and therefore could be ruled out. However, using modern collisional disruption estimated from Stewart and Leinhardt (2012), we find that Triton could have accreted a 1000-km moon at relevant velocities without being disrupted. The product of this merger would have a much tighter orbit as the accreted moon would not have been retrograde like Triton. At the meeting we will present a more detailed exploration of possible post-capture configurations, and report quantitative probabilities for different outcomes of this exciting and violent episode of Triton's history.
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519 – Outer Icy and Irregular Satellites II: Environment, Processes, and Composition

519.01D – Constraining the processes modifying the surfaces of the classical Uranian satellites

Near-infrared (NIR) observations of the classical Uranian moons have detected relatively weak H_2O ice bands, mixed with a spectrally red, low albedo constituent on the surfaces of their *southern* hemispheres (sub-observer lat. ~10 – 75°S). The H_2O bands and the degree of spectral reddening are greatest on the leading hemispheres of these moons. CO_2ice bands have been detected in spectra collected over their trailing hemispheres, with stronger CO_2 bands on the moons closest to Uranus. Our preferred

hypotheses to explain the distribution of CO_2, H_2O, and dark material are: bombardment by magnetospherically-embedded charged particles, primarily on the trailing hemispheres of these moons, and bombardment by micrometeorites, primarily on their leading hemispheres.
To test these complementary hypotheses, we are constraining the distribution and spectral characteristics of surface constituents on the currently observable *northern* hemispheres (sub-observer lat. ~20 – 35°N) to compare with existing southern hemisphere data. Analysis of northern hemisphere data shows that CO_2 is present on their trailing hemispheres, and H_2O bands and the degree of spectral reddening are strongest on their leading hemispheres, in agreement with the southern hemisphere data. This longitudinal distribution of constituents supports our preferred hypotheses.
However, tantalizing mysteries regarding the distribution of constituents remain. There has been no detection of CO_2 on Miranda, and H_2O bands are stronger on its trailing hemisphere. NIR slope measurements indicate that the northern hemisphere of Titania is redder than Oberon, unlike the spectral colors of their southern hemispheres. There are latitudinal variations in H_2O band strengths on these moons, with stronger H_2O bands at northern latitudes compared to southern latitudes on Umbriel and Titania. Several Miranda and Ariel spectra potentially include weak and unconfirmed NH_3-hydrate bands, which could be tracers of cryovolcanic emplacement. We will present work related to our goals of constraining the processes modifying the surfaces of the classical Uranian moons.

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519.02 – Theoretical predictions of source rates for exospheric CO_2 on icy satellites of the outer planets due to sublimation of deep subsurface CO_2 ice

The abundances of CO2 observed in the exospheres of Callisto and, more recently, Rhea and Dione are difficult to explain. The previously proposed sources for the CO2 either have production rates well below the expected rates of escape/destruction or should produce other species (e.g. CO) that are not observed.
We consider a potential source that has not been previously investigated – CO2 vapor originating from crustal CO2 ice and driven upward by the endogenic heat flux – and have developed a model to make quantitative estimates of the corresponding global subsurface vapor flux.
Our model is based on previous theoretical work by Clifford (1993) and Mellon et al. (1997) for equatorial ground ice on Mars, who showed that in times or places where subsurface pore ice is undergoing long-term sublimation and diffusive loss, the ice table (the shallowest depth where any pore ice exists) will not continue to recede indefinitely. Beyond a certain, predictable depth, the linear diffusive profile of vapor density between the ice table and the surface will become supersaturated with respect to the local temperature and recondense as pore ice. This is true for any planetary body with a non-negligible interior heat source (e.g. radiogenic, tidal, etc) and is due to the fact that, while the ice temperature increases ~linearly with depth, the corresponding equilibrium vapor density increases exponentially.
Once this occurs, a steady-state profile of ice volume fraction, f_ice(z), develops, with net mass loss only occurring from the retreating pore-filling ice layer. The rate of vapor flux to the surface is then determined only by the vapor density and temperature gradient at the ice table depth. We use a 1-D thermal model coupled with an analytic physical model for regolith thermal conductivity (including its depth- and T-dependence), to calculate the zonally-integrated global CO2 vapor flux corresponding to the range of expected heat flow values. Our preliminary results show agreement with previous estimates of the source flux required to maintain the observed exospheric abundances of CO2 on Callisto, Rhea, and Dione.

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519.03D – Electron irradiation effects in icy regoliths: The PacMan anomalies at Saturn

The anomalous regions identified on the leading hemispheres of the icy Saturnian moons, colloquially known as the 'PacMan' features, were found to have larger thermal inertia than the surrounding regions. The locations of the anomalies were shown to closely match the expected deposition profile of high energy (~ MeV) electrons moving counter rotational to the moons, suggesting an energetic source to drive their formation. Here we consider the mechanisms by which electron radiation can produce changes in the thermal conductivity of an icy regolith and compare estimates obtained from theoretical and experimental results with the measured thermal inertia and grain impact resurfacing rates on the icy moons.
Electron interactions with the grains can both create and anneal defects in the crystalline lattice, and deposited energy drives molecular diffusion. Mobilized molecules accumulate in the contact region between grains due to the surface energy minimum, thus increasing the contact volume or 'sintering' the grains. Previously developed sintering rate equations and measured electron energy distributions near the icy moons were used to estimate the timescale for the energetic electrons to increase the contact volume sufficiently to produce the enhanced thermal conductivity of the anomalous regions. In order to properly constrain the sintering calculations, molecular dynamics (MD) simulations of electron interactions in water ice were carried out to determine the number and diffusion length of excited molecules. Water molecules were artificially excited both in a water ice bulk and near a grain surface, and several ice polymorphs relevant to ice grain formation in outer solar system conditions were considered. Comparing the estimated sintering timescales to micrometeorite resurfacing rates indicates that grains must be small (~5um) and/or irregularly shaped with a high defect density in the contact regions. Since there is some disagreement in these grains sizes and published estimates based on reflectance measurements, and we will consider statistical grain size distributions on both the sintering rates and the thermal conductivity.

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519.04 – ICE-HEART Study of Survival of Organics in Ice Analogs under simulated Europa's Surface MeV-Electron Radiation on the Trailing Hemisphere

Europa's surface receives high-energy radiation from Jovian magnetosphere that consists of MeV electrons, protons, and ions. This radiation environment is on one hand a source for energetic oxidants that can support life's energy/oxidant needs, but on the other hand, could be harmful for the potential life or tracers of life such as organic biomolecules. With a planned Europa orbiter and lander mission concept on the horizon, it is critical to understand and quantify the role of Europa's radiation environment on potential life, if existed close to the surface.
Electrons penetrate through ice by far the deepest at any given energy compared to protons and ions, making the role of electrons very important to understand. In addition, secondary radiation – Bremsstrahlung in X-ray wavelengths – is generated during high-energy particle penetration through solids. Secondary X-rays are equally lethal to life and penetrate even deeper than electrons, making the cumulative effect of radiation on damaging organic

matter on the near surface of Europa a complex process that could have effects several meters below Europa's surface.
In order to quantify this effect under realistic Europa trailing hemisphere conditions, we devised, built, tested, and obtained preliminary results using our ICE-HEART instrument prototype totally funded by JPL's internal competition funding for Research and Technology Development. Our Ice Chamber for Europa High-Energy Electron And Radiation-Environment Testing (ICE-HEART) operates at ~100 K. The telescopic chamber can accommodate ice cores up to 110 cm in length and diameters of ~ 6 cm.
We have also devised a magnet that is used to remove primary electrons subsequent to passing through an ice column, in order to determine the flux of secondary X-radiation and its penetration through ice. Preliminary results from these studies will be presented and the relevance to the Europa lander mission concept will be discussed.
This work has been carried out at Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration, and funded by JPL's R&TD Program and NASA Planetary Atmospheres Program.
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519.05 – Mid-infrared spectroscopy to better characterize icy moon surface compositions

Previous spectroscopy work on icy moons has focused primarily on the visible and near-IR portion of the spectrum due to challenges presented by a low signal to noise ratio at the longer wavelengths. However, the mid-IR is the region of the strongest fundamental vibrations of many important types of molecules (e.g., organics) and has the potential to reveal unique compositional information [1]. We use the wealth of data that is now available from Cassini's Composite Infrared Spectrometer (CIRS) to average spectra over similar regions to improve the signal to noise, helping to reveal spectral features never before observed.

Our initial work has already led to the detection and tentative laboratory identification of the first spectral features observed for any icy moon in the mid-IR [2]. On Iapetus' dark terrain, we found an emissivity feature at ~855 cm^{-1} and a possible doublet at 660 and 690 cm^{-1} that does not correspond to any known instrument artifacts. We attributed the 855 cm^{-1} feature to fine-grained silicates, similar to those found in dust on Mars and in meteorites, which are nearly featureless at shorter wavelengths [e.g., 3, 4]. Silicates on the dark terrains of Saturn's icy moons have been suspected for decades, but there have been no definitive detections until this work.
We measured the vacuum, low temperature mid-IR spectra of various fine-grained powdered silicates, including Mg-rich serpentines, often present in meteorites. Some of these materials do have emissivity features near 855 cm^{-1} and exhibit a doublet. Presently, we are continuing to comb the CIRS icy moon database for spectral features (particularly focusing on the warmer surfaces in the Saturn system) and are performing further vacuum chamber measurements to experiment with more sample types and ice/sample mixtures to determine the impacts of changing conditions in the chamber on features. We are also working to understand how surface porosity and mixing with various darkening agents may impact our spectra.
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Author(s): Cindy L Young[1], James J. Wray[1], Kevin P. Hand[2], Michael Poston[2], Robert W. Carlson[2], Roger Nelson Clark[4], John R. Spencer[5], Donald Jennings[3]
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519.06 – Composition of Phoebe and Iapetus: Bound Water and Possible Deuterated Water

Cassini VIMS has obtained spatially resolved 0.35 to 5.1 micron reflectance spectra of Saturn's satellites beginning with the Phoebe fly-by in 2004. We report new discoveries of bound water absorptions on Iapetus and Phoebe, and a new narrow absorption at 3.61 microns that
is strong in Phoebe spectra and trace in Iapetus spectra. The bound water absorption is at 1.96 microns and is consistent with bound water in nano-hematite at cryogenic temperatures that Clark et al (Icarus 2012, v218 p831) used to match the 3-micron absorption in Iapetus dark material spectra. The bound water absorption in nano-hematite has a unique position and shape at least among the materials whose spectra have been measured so far. The new 3.61 micron absorption is not matched by organics, salts or other materials whose spectra have been measured that we can find. The best match so far is a D-O stretch. If so, this enrichment in deuterium may be due to stripping the water and dark material from Phoebe, preferentially leaving a deuterium-enriched surface. Alternatively, if Pheobe is indeed a captured outer solar system object, the source material from which Phoebe was formed may be enriched in deuterium.
Some confusing interpretations of VIMS spectra have been due a shift in VIMS wavelengths with time with subsequent degradation of the calibration to radiance and I/F with time. A new calibration has been developed that tracks the time-varying calibration that resulted in patterns in the VIMS I/F calibration. Those patterns masked some spectral features and produced others that were not real. The new calibration fixes these problems, reducing pattern problems by a couple of orders of magnitude. With new tools for querying the growing massive VIMS data, we have averaged many pixels to obtain the highest precision spectra of objects in the Saturn system. Clark et al (JGR 2012) found a triplet at 1.9 microns in Phoebe and Iapetus dark material and attributed the triplet to bound water but could not find specific matches to any known materials. The new calibration shows that the triplet was an artifact of calibration and the new calibration correctly shows the position shape of the single bound-water absorption.
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519.07 – Geologic constraints on Rhea's bombardment mass

The mid-sized moons (MSMs) of Saturn display a peculiar set of properties that indicate the system may have been altered early in its history. The MSMs have a large spread in silicate content and diverse inferred thermal and physical histories that, unlike the Galilean satellites, do not demonstrate a trend with semi-major axis or size, which would indicate orbital evolution was a significant driver of their thermal histories. Rather, these features may indicate a significant role for impact-induced thermal and physical evolution. Geophysical properties along with measured crater counts can be used to constrain the bombardment history of the MSMs. Here we apply a fully three-dimensional Monte Carlo cratering model along with Rhea's measured cratering to provide constraints on the cumulative bombardment mass (Mb) experienced by the moon. The classic Nice model estimates Rhea's cumulative bombardment mass

(MNice) to be 8.4x10^19 kg; our preliminary results suggest Rhea experienced a bombardment of 0.05 MNice < Mb < 0.06 MNice. Results agree well with similar constraints from Iapetus and provide further support to the Nice II model, which suggests a reduced bombardment for the outer solar system due to the planetesimals having higher kinetic energies. The inferred Mb and typical impact characteristics suggests Rhea may avoid runaway differentiation.

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519.08 – Periods, poles, and shapes of Saturn's irregular moons

We report rotational-lightcurve observations of irregular moons of Saturn based on disk-integrated observations with the Narrow-Angle Camera of the Cassini spacecraft. From 24 measured rotation periods, 20 are now known with an accuracy of ~2% or better. The numbers are as follows (in hours; an '*' marks the less reliable periods): Hati 5.42; Mundilfari 6.74; Loge 6.94*; Skoll 7.26; Kari 7.70; Suttungr 7.82*, Bergelmir 8.13; Phoebe 9.274; Siarnaq 10.188; Narvi 10.21; Tarvos 10.69; Skathi 11.30; Ymir 11.922; Hyrrokkin 12.76; Greip 12.79*; Ijiraq 13.03; Albiorix 13.32; Bestla 14.624; Bebhionn 16.40; Paaliaq 18.75; Kiviuq 21.96; Erriapus 28.15; Thrymr 35 or >45*; Tarqeq 76.8.

More recent data strengthen the notion that objects in orbits with an inclination supplemental angle $i' > 27°$ have significantly slower spin rates than those at $i' < 27°$ ($i' = 180° - i$ for retrograde objects, and $i' = i$ for prograde moons, with i being the orbit inclination). Actually, the fastest rotator with $i' > 27°$, Siarnaq, stands opposed to at least eight objects with faster spins and $i' < 27°$. A null hypothesis claiming that objects of the two inclination bins come from the same population is rejected at the 99% confidence level. The $i' > 27°$ bin contains all nine known prograde moons and four retrograde objects.

A total of 25 out of 38 known outer moons has been observed with Cassini, and there is no chance to observe the 13 missing objects until end-of-mission. However, all unobserved objects are part of the $i' < 27°$ bin. This means that the periods of all known moons with $i' > 27°$ are known, and none of them is a fast rotator, with no exception.

Several objects were observed repeatedly to determine pole directions, sidereal periods, and convex shapes. A few lightcurves have been observed to show three maxima and three minima even at low phase angles, suggesting objects with a triangular equatorial cross-section. Some objects with 2 maxima/ 2 minima are probably quite elongated. One moon even shows lightcurves with 4 maxima/ 4 minima.

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519.09 – K2 and Herschel/PACS photometry of irregular satellites

The combination of optical and far-infrared photometric measurements yields an unambiguous method for characterizing the basic physical and surface properties of minor bodies in the Solar System. In principle, an object with a certain visible brightness can either be an object with a small but bright or a large but dim surface. To resolve this issue, conducting thermal emission measurements can also be acquired since both larger and dimmer objects have higher infrared radiations. In addition, the precise modelling of thermal emission should certainly take into account the rotation period of these bodies - otherwise the presence of surface thermal inertia can result in inaccurate conclusions regarding to the physical size and albedo.

Since early 2014, Kepler Space Telescope surveys fields close to the Ecliptic in a framework of quarterly campaigns of the K2 initiative. This program makes possible to continuously observe Solar System bodies during this period of 80-90 days and hence provide an uninterrupted photometric series of moving Solar System objects down to the magnitude range of R = 23.5. This instrument hence an ideal observatory now for Solar System studies. Due to the fact that the expected rotational periods of these objects are commensurable to the diurnal characteristics of ground-based observations, such uninterrupted light curves are rather valuable for the accurate determination of rotational characteristics - including the physical rotation period, the amplitude and the confirmation of the presence of double- or multiple peaked features.

In this presentation we summarize our results of current K2 and legacy Herschel/PACS observations regarding to some of the irregular satellites of Uranus and Neptune, namely Caliban, Sycorax, Prospero, Setebos and Nereid. By comparing these results with similar kind of observations for trans-Neptunian objects (see Kiss et al., this DPS meeting), one can conclude how the formation and evolution of the outer Solar System were eventuated.

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520 – Titan: Lower Atmosphere

520.01 – Constraining the distribution of methane on the surface and in the troposphere of Titan

Titan's surface supports large lakes of stable hydrocarbon liquids, while active weather and a seasonal cycle operate in the troposphere, transporting methane between the atmosphere, the surface, and, potentially, the sub-surface on various timescales. Yet the detailed distribution of methane both in the lower atmosphere and in the surface is relatively unknown, though efforts to measure the boundary layer methane abundance are maturing. Using a combination of general circulation modeling and both ground-based and Cassini observations of Titan, we are working toward measuring and interpreting the variability of lower-atmosphere humidity, and clarifying the distribution of surface liquids and their connection to the atmosphere. We present recent results that provide initial estimates of the latitudinal variation of low-level atmospheric methane, and their implications for the presence of surface liquids. Determining whether or not the observed seas represent the entire reservoir of surface methane on Titan will affect our understanding of the atmospheric circulation and surface-atmosphere interactions that affect the hydrologic cycle, and lead to a better insight into Titan's climate system and its evolution.

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520.02 – Transparency of the 2 µm (5000 cm^{-1}) methane window in Titan's atmosphere and impact on retrieved surface reflectivity

The study of Titan properties with remote sensing relies on a good knowledge of the atmosphere properties. The in-situ observations made by Huygens combined with recent advances in the definition of methane properties enable to model and interpret observations with a very good accuracy. Thanks to these progresses, we can analyze in this work the observations made at the limb of Titan in order to retrieve information on the haze properties as its vertical profiles and its spectral behaviour along the VIMS/Cassini range (from 0.88 to 5.1 µm). However, for applications to real atmospheres, one need to account for the widening of the spectroscopic lines (e.g., Voigt profile) and apply an empirical cut-off of the far wings. In general, this is a multiplying function of the

wavenumber, **f(ν)**, applied to the Voigt profile that allows a faster decay of the wing profile beyond a given distance from the center of the line ν_0 : **f(ν)=1** if $|\nu-\nu_0| \leq \Delta\nu$, and $f(\nu)=\exp(-|\nu-\nu_0|/\sigma)$ if $|\nu-\nu_0| > \Delta\nu$.
Although the 2-µm window is apparently straitforward to model, it appears that the standard cut-off parameters (that is $\Delta\nu \sim 26\ cm^{-1}$ and $\sigma \sim 120\ cm^{-1}$) which is used for other windows in Titan's atmosphere is not adequat for this window. Other sets of parameter must be used to reproduce Titan spectrum at 2 µm. However, there is no convergence of the results between these works and a large variety of cut-off parameters are used. Alternatively, it was found that some gas absorptions (ethane and another unknown gas) leave a signature around 2-µm and also affect the transparency in this window. In our study we make an exhaustive investigation on the cut-off parameters to determine which are the best couples of parameters to fit the 2-µm window. We also evaluated how gaseous absorptions can allow to reach a satisfactory agreement and, especially, if it allows to match observations with the standard cut-off. Finally, we investigate the impact of the different solutions (different cut-off, with or without supplementary absorptions) on the retrieved surface albedo.
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520.03 – Three-Carbon Planetary Chemistry - Propylene and Propylene Oxide

We recently have published new studies of solid CO_2, CH_4, C_2H_2, C_2H_4, and C_2H_6, recording new, and in some cases the first, infrared (IR) spectra of the amorphous phases of these compounds and correcting multiple problems and contradictions in the literature that have persisted for several decades and influenced both planetary and interstellar studies (e.g., Hudson et al. 2014, 2015). We now extend this work by examining two three-carbon molecules, the acyclic propylene (C_3H_6) and the cyclic molecule propylene oxide (OC_3H_6). Both molecules have been detected in low-temperature astronomical environments (Titan, interstellar medium (ISM)) and are suspected in others. However, in contrast to the astronomical relevance of these compounds, there are almost no laboratory measurements of spectra and other properties for either of them at low temperatures. Here we report new results on ices containing propylene and propylene oxide including IR spectra of multiple solid phases and measurements of phase transition temperatures, IR band strengths, refractive indices, vapor pressures, and sublimation energies. Radiation-chemical reactions connecting propylene and propylene oxide have been investigated for possible applications to the moon, Europa, TNOs, comets, and the ISM, and first results will be presented. Propylene oxide is of particular interest as it recently was announced (McGuire et al. 2016) as the first chiral molecule identified in the ISM. [Our work was supported by NASA Goddard's DREAM2 center, funded by NASA's SSERVI program, and by the NASA Astrobiology Institute's Goddard Center for Astrobiology.]
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521 – Dust and Solar Wind

521.01 – Stable motions of charged dust grains subject to solar wind, Poynting-Robertson drag, and the mean interplanetary magnetic field

We investigate the combined effect of solar wind, Poynting-Robertson drag, and the frozen-in interplanetary magnetic field on the motion of charged dust grains in our solar system. It is generally accepted that the combined effects of solar wind and photon absorption and re-emmision (Poynting-Robertson drag) lead to a decrease in semi-major axis on secular time scales. On the contrary, we demonstrate that the interplanetary magnetic field may counteract these drag forces under certain circumstances. We derive a simple relation between the parameters of the magnetic field, the physical properties of the dust grain as well as the shape and orientation of the orbital ellipse of the particle, which is a necessary conditions for the stabilization in semi-major axis.
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521.02 – Dynamical evolution of interplanetary dust particles trapped in Earth's horseshoe and quasi-satellite co-orbital resonance regions

We use numerical integrations to model the orbital evolution of IDPs decaying from the asteroid belt into the inner solar system under the influence of radiation pressure, Poynting-Roberston light drag, and solar wind drag. In our models the ratio of radiation pressure to solar gravity ranges from 0.0025 up to 0.02, corresponding to IDP diameters ranging from about 200 microns down to about 25 microns, respectively. In this size range nearly 100% of IDPs become temporarily trapped in mean-motion resonances just outside Earth's orbit. While trapped in these outer resonances the orbital eccentricities of IDPs significantly increases. This causes most IDPs to eventually escape the resonances, allowing their orbits to continue decaying inwards past 1 AU. We've shown previously (Kortenkamp, Icarus 226, 1550-1558, 2013) that significant fractions of IDPs in this size range can subsequently become trapped in Earth's co-orbital horseshoe and quasi-satellite resonance regions, with semi-major axes just inside of 1 AU. Here, we present new results on the long-term effects of Earth's varying orbital eccentricity and inclination on the trapping and evolution of these co-orbital IDPs.
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521.03 – The Toroidal Sporadic Sources: Looking for parent bodies of meteor streams

The origin and characteristics of the North toroidal (NT) and South toroidal (ST) sporadic meteoroid sources remain poorly known. The NT was first noted in radar measurements in the late 1950s, however, its origin has puzzled astronomers for more than 50 years. The ST started being more thoroughly observed in recent years. The NT and ST meteoroid population shows orbital elements unlike any known contemporary parent population in the Solar System, dominated by particles with very high inclinations, modest semi-major axis values and low eccentricities. Recently, several dynamical models have suggested that the parent bodies of the NT source may be linked to the population of Halley-type comets. However, no model to date has been able to reproduce in detail the significant temporal variations in activity seen throughout the year.
In this work we present observations of the NT meteoroid source made by the Canadian Meteor Orbit Radar (CMOR) between 2011 - 2015 and of the ST source obtained with the South Argentina Agile Meteor Radar (SAAMER) between 2011 - 2015. We use these results to define in detail the temporal and orbital element variations in the activity of both sources. We also present preliminary results from a model, in which we have identified 169 near-Earth objects that are potential contributors to the NT/ST meteoroid population at the current time. Furthermore, we integrate their orbits backward in time 25,000 years. For each potential parent body, we simulate 5 clones to span the range of possible parent body orbits as a function of time. From our initial epoch 25 ka, we eject 2000 test meteoroids

per 100 years of sizes 30 µm to 1 mm per potential parent clone and examine the resulting dust trail intersecting the Earth to match the various temporally distinct portions of the NT/ST meteoroid complex. We find that while some of the observed features of both sources can be modeled as distinct past contributions from individual parent bodies, many major features shown no correspondence with known parent bodies or their potential clones. We discuss a best estimate for the age of observed NT and ST features and candidate parent bodies that are able to reproduce some sub-structure in the NT and ST source.

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521.04 – Calibration of impact ionization cosmic dust detectors: first tests to investigate how the dust density influences the signal

Impact ionization experiments have been performed since more than 40 years for calibrating cosmic dust detectors. A linear Van de Graaff dust accelerator was used to accelerate the cosmic dust analogues of submicron to micron-size to speeds up to 80 km s^-1. Different materials have been used for calibration: iron, carbon, metal-coated minerals and most recently, minerals coated with conductive polymers. While different materials with different densities have been used for instrument calibration, a comparative analysis of dust impacts of equal material but different density is necessary: porous or aggregate-like particles are increasingly found to be present in the solar system: e.g. dust from comet 67P Churyumov-Gerasimenko [Fulle et al 2015], aggregate particles from the plumes of Enceladus [Gao et al 2016], and low-density interstellar dust [Westphal 2014 et al, Sterken et al 2015]. These recalibrations are relevant for measuring the size distributions of interplanetary and interstellar dust and thus mass budgets like the gas-to-dust mass ratio in the local interstellar cloud.

We report about the calibrations that have been performed at the Heidelberg dust accelerator facility for investigating the influence of particle density on the impact ionization charge. We used the Cassini Cosmic Dust Analyzer for the target, and compared hollow versus compact silica particles in our study as a first attempt to investigate experimentally the influence of dust density on the signals obtained. Also, preliminary tests with carbon aerogel were performed, and (unsuccessful) attempts to accelerate silica aerogel. In this talk we explain the motivation of the study, the experiment set-up, the preparation of — and the materials used, the results and plans and recommendations for future tests.

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521.05D – Automated Detection of coronal mass ejections in three-dimensions using multi-viewpoint observations

A new, automated method of detecting Solar Wind transients such as Coronal Mass Ejections (CMEs) in three dimensions for the LASCO C2 and STEREO COR2 coronagraphs is presented. By triangulating isolated CME signal from the three coronagraphs over a sliding window of five hours, the most likely region through which CMEs pass at 5 solar radii is identified. The centre and size of the region gives the most likely direction of propagation and angular extent. The Automated CME Triangulation (ACT) method is tested extensively using a series of synthetic CME images created using a flux rope density model, and on a sample of real coronagraph data; including Halo CMEs. The accuracy of the detection remains acceptable regardless of CME position relative to the observer, the relative separation of the three observers, and even through the loss of one coronagraph. By comparing the detection results with the input parameters of the synthetic CMEs, and the low coronal sources of the real CMEs, it is found that the detection is on average accurate to within 7.14 degrees. All current CME catalogues (CDAW, CACTus, SEEDS, ARTEMIS and CORIMP) rely on plane-of-sky measurements for key parameters such as height and velocity. Estimating the true geometry using the new method gains considerable accuracy for kinematics and mass/density. The results of the new method will be incorporated into the CORIMP database in the near future, enabling improved space weather diagnostics and forecasting.

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521.06 – Dust occultation at Titan measured by CDA onboard Cassini

The Cosmic Dust Analyzer (CDA) onboard Cassini characterized successfully the dust environment at Saturn since 2004. The instrument measures the primary charge, speed, mass and composition of individual submicron and micron sized dust grains. The detection threshold scales with speed^3.5 such that the detection of fast nanograins (~100 km/s) is possible. Saturn's nanodust environment (streams) is studied many years. However, a special geometric condition of Saturn, Cassini and Titan during a Titan flyby in 2014 (DOY 65) provided a special dust occultation opportunity. Titan and its atmosphere blocked the stream of fast nanoparticles such that CDA registered a clear drop in impact rate around closest approach. An analysis of the data allows to constrain the source region of the nanograins, which is compatible with a source region in the ring plane at distances from Saturn between 4 and 8 Saturn radii. Backward and forward modeling was performed leading to dust grain sizes between 3 and 9 nm and speeds between 80 and 150 km/s. The new modeling results also show that Enceladus acts a direct source for nanodust streams leading to the observation of periodic impact rates in the outer Saturn system. Such periodicities were observed recently by CDA and showed a clear signature of the Enceladus orbital period. A second dust occultation opportunity using Titan is planned august 2016.

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Contributing team(s): CDA science team

522 – Origin and Evolution of Asteroids

522.01 – Forming Chondrites in a Solar Nebula with Magnetically Induced Turbulence

Chondritic meteorites provide valuable opportunities to investigate origins of the solar system. We explore impact jetting as a mechanism to form chondrules and subsequent pebble accretion as a mechanism to accrete them onto parent bodies of chondrites, and investigate how these two processes can account for the currently available meteoritic data. We find that when the solar nebula is < 5 times more massive than the minimum-mass solar nebula at a = 2-3 AU and parent bodies of chondrites are < 10^{24} g (< 500 km in radius) there, impact jetting and subsequent pebble accretion can reproduce a number of properties of the meteoritic data. The properties include the present asteroid belt mass, formation timescale of chondrules, and the magnetic field strength of the nebula derived from chondrules in Semarkona. Since this scenario requires a first generation of planetesimals that trigger impact jetting and serve as parent bodies to accrete chondrules, the upper limit of parent bodies' mass leads to the following implications: primordial asteroids that were originally >10^{24} g in mass were unlikely to contain chondrules, while less massive primordial asteroids likely had a chondrule-rich surface layer. The scenario developed from impact jetting and pebble accretion can therefore provide new insights into origins of the solar system.

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Institution(s): *1. JPL/Caltech*

522.02 – Origins and Asteroid Main-Belt Stratigraphy for H-, L-, LL-Chondrite Meteorites

We trace the origins of ordinary chondrite meteorites to their main-belt sources using their (presumably) larger counterparts observable as near-Earth asteroids (NEAs). We find the ordinary chondrite stratigraphy in the main belt to be LL, H, L (increasing distance from the Sun). We derive this result using spectral information from more than 1000 near-Earth asteroids [1]. Our methodology is to correlate each NEA's main-belt source region [2] with its modeled mineralogy [3]. We find LL chondrites predominantly originate from the inner edge of the asteroid belt (nu6 region at 2.1 AU), H chondrites from the 3:1 resonance region (2.5 AU), and the L chondrites from the outer belt 5:2 resonance region (2.8 AU). Each of these source regions has been cited by previous researchers [e.g. 4, 5, 6], but this work uses an independent methodology that simultaneously solves for the LL, H, L stratigraphy. We seek feedback from the planetary origins and meteoritical communities on the viability or implications of this stratrigraphy.

Methodology: Spectroscopic and taxonomic data are from the NASA IRTF MIT-Hawaii Near-Earth Object Spectroscopic Survey (MITHNEOS) [1]. For each near-Earth asteroid, we use the Bottke source model [2] to assign a probability that the object is derived from five different main-belt source regions. For each spectrum, we apply the Shkuratov model [3] for radiative transfer within compositional mixing to derive estimates for the ol / (ol+px) ratio (and its uncertainty). The Bottke source region model [2] and the Shkuratov mineralogic model [3] each deliver a probability distribution. For each NEA, we convolve its source region probability distribution with its meteorite class distribution to yield a likelihood for where that class originates. *Acknowledgements: This work supported by the National Science Foundation Grant 0907766 and NASA Grant NNX10AG27G.*

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522.03 – A Newborn Asteroid Family of Likely Rotational Origin Harboring a Doubly-Synchronous Binary

From the total number of about twenty active asteroids identified to date, one of the most intriguing is P/2012 F5. The 2-km sized object has a short rotation period of 3.24 hr – the shortest known among main-belt active asteroids and comets – and is trailed by several fragments recently separated from the main nucleus (Drahus et al. 2015, ApJL 802, L8). Our extensive observations with Hubble in late 2015 and early 2016 have revealed that the fragments are real and stable "baby asteroids", still cocooned in their birth dust trail. Consequently, P/2012 F5 is the first known asteroid family forming in the present-day epoch. Given the rapid spin of the main nucleus, the system is also the best candidate for the first "rotational" asteroid family originating from rotational fission (as opposed to the long-known "collisional" families), extending the recently identified class of asteroid pairs (Pravec et al. 2010, Nature 466, 1085). Furthermore, the HST data allowed us to measure a light curve of the brightest fragment of P/2012 F5, several magnitudes fainter than the main nucleus. The light curve has all the characteristics of a close binary with significantly elongated, roughly equal sized components, having equal rotation and orbital periods of about 9 hr. The existence of a doubly-synchronous binary in an ultra-young asteroid family is seemingly inconsistent with the established "slow" binary formation path, in which YORP torques first lead to rotational fission and then tides lead to synchronization (Jacobson & Scheeres 2011, Icarus 214, 161). Instead, we believe that the object fissioned while orbiting the main nucleus and drawing its angular momentum, and was subsequently ejected from the system as a finished doubly-synchronous binary. This scenario is consistent with computer simulations in that the timescales for secondary fission and ejection from the system are indeed very short (Jacobson & Scheeres 2011, Icarus 214, 161). But the empirical evidence that fissioned secondaries can escape as doubly-synchronous binaries came as a surprise, so we seem to have accidentally identified a new, "rapid" formation path of such systems, not yet accounted for by the prevailing theory.

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522.04 – New insights into main belt asteroid collisional lifetimes

We are developing a new Monte Carlo code to study the collisional and spin evolution of main belt asteroids. A byproduct is information on asteroid lifetimes. We find new interpretations and values of those lifetimes.

In the conventional approach, the "collisional lifetime" is measured by the time when an asteroid is struck by an impactor large enough to remove one-half of the target's mass. That event is called a catastrophic disruption (CD). From an assumed population of impactors and Poisson statistics, one can estimate the largest expected impactor to impact in a given time interval to get its expected collisional lifetime. However, our Monte Carlo simulations give lifetimes that are distinctly shorter. That raises questions about the basic definition of catastrophic disruption.

During its presence in the main belt, many other asteroids of all sizes continually strike a target asteroid. Before the CD one happens, there are many small impacts, and a few less than but not equal to the CD one. Each impact erodes the target asteroid. Very commonly, it is eroded to a much smaller mass before some CD event. We will present examples.

So what shall we define as its collisional lifetime? Should it be the time for which its mass is reduced to one-half of its original mass, irrespective of how that happened, perhaps from many impacts? Or when any single impact reduces its mass to one-half of its original mass? Or when a single impact reduces it to one-half of its current

mass?
We propose that collisional lifetime is defined as the time at which it reaches 50% of its original mass, from any combination of small and/or large events. We use cratering and ejecta scaling formulas (e.g. Holsapple, 1993, Housen and Holsapple, 2011) to calculate the eroded mass history of the target for a history of impactors and calculate the outcome of any impact using the current size. In the gravity regime, the eroded body is easier to disrupt. We will present our lifetime estimates and those of several others to illustrate our view.
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522.05 – The partial fission of fast spinning asteroids
The spin rates of asteroids systematically change over time due the Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect. Above a certain spin rate that depends on the body's density, regions of an asteroid can enter in tension, with components held to the body by cohesive forces. When the body fails, deformation or fission can occur. Catastrophic fission leading to complete disruption has been directly observed in active asteroid P/2013 R3. Partial fission, the loss of only part of the body, has been proposed as a mechanism for the formation of binaries and is explored here.
The equatorial cavities of (341843) 2008 EV5 and of (185851) 2000 DP107 (a binary system) are consistent with a localized partial fission of the body (LPSC 2016 #1036). The examination of the gravity field of these bodies reveals that a mass placed within these cavities could be shed. In this mechanism, the outward pull of inertial forces creates an average stress at the cavity interface of ≈1 Pa for 2008 EV5 and ≈3 Pa for 2000 DP107 at spin periods of ≈3.15 h for the assumed densities of 1.3 g/cm^3.

This work continues the study of this partial, localized fission. Specifically, it addresses the issue of the low cohesion necessary to the mechanism. These cohesion values are typically lower than global strength values inferred on other asteroids (10 - 200 Pa), meaning that partial fission may occur prior to larger-scale deformations. Yet, several processes can explain the discrepancy, as they can naturally segregate particles by size. For instance, landslides or granular convection (Brazil nut effect) could bring larger boulders to the equator of the body, while finer particles are left at higher latitudes or sink to the center. Conversely, failure of the interior could bring boulders to the surface. The peculiar profile shape of these asteroids, shared by many binaries (e.g. 1999 KW4, 1996 FG3) may also be a clue of this heterogeneity, as this "spin top" shape is obtained in simulations with a weak shell and a strong core. Using observations and simulations, we consider these processes and the role that this partial fission mechanism could play in the formation of binary asteroids and the creation of equatorial divots on asteroids.
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522.06 – Triggering Comet-Like Activity of Main Belt Comets
Main-belt comets (MBCs) have attracted a great deal of interest since their identification as activated asteroids by Hsieh and Jewitt in 2006. It has been suggested that the comet-like activity of these objects are due to the sublimation of sub-surface water-ice that has been exposed as a result of their surfaces being impacted by small (e.g, m-sized) bodies. We have examined the viability of this scenario by simulating impacts between m-sized impactors and km-sized targets using a smooth particle hydrodynamics (SPH) approach. We have carried out simulations for a range of impact velocities and angles, material type and strength, and water content of the target allowing m-sized impactors to erode enough of an MBC's surface to trigger its activation. Results indicate that for the range of impact velocities corresponding to those in the asteroid belt, the depth of an impact crater is slightly larger than 10 m suggesting that if the activation of MBCs is due to the sublimation of sub-surface water-ice, this ice has to exist no deeper than a few meters from the surface. Our simulations point to a clearly notable spread in the aggregated crater depths due to different impact energy, impact angles, and MBC's water contents showing deeper craters due to less overall material strength. Results also show that ice-exposure occurs in the bottom and on the interior surface of impact craters as well as the surface of the target where some of the ejected icy inclusions are re-accreted. Our results, in addition to demonstrating that the impact scenario is indeed a viable mechanism to expose ice and trigger the activity of MBCs, indicate that the activity of the current MBCs is likely due to ice sublimation from multiple impact sites and/or the water contents of these objects (and other asteroids in the outer asteroid belt) is larger than the 5% that is traditionally considered in models of terrestrial planet formation. We present details of our simulations and discuss their results and implications.
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522.07 – A Proposed Unified Theory of Hydrated Asteroids
The last decade has seen tremendous growth in the study of hydrated and hydroxylated minerals (hereafter simply called "hydrated minerals") on asteroids. Several workers have used absorptions in the 3-µm region and a correlated absorption near 0.7 µm to determine not only the presence or absence of these minerals but gain insight into the compositions of asteroid surfaces. Spectra of hundreds of asteroids have been measured and published or presented at meetings, and we are in a position to use these newer datasets to globally assess the patterns and relationships we see, as previously done by Jones et al. (1990) and Takir et al. (2012).
There are several points to be addressed by any such assessment. Several different band shapes are seen in the 3-µm region, only one of which is seen in the hydrated meteorites in our collections. However, each of the main 3-µm band shapes is represented among parent bodies of collisional families. There seems to be little correlation in general between asteroid spectral class and 3-µm band shape, save for the Ch meteorites which are overwhelmingly likely to share the same band shape as the CM meteorites. Ceres has an unusual but not unique band shape, which has thus far only been found on the largest asteroids.
I will present an outline scenario for the formation and evolution of hydrated asteroids, where aqueous alteration serves to lithify some objects while other objects remain unlithified and still others differentiate and suffer collisional modification. While some details will no doubt be altered to account for better or new information, this scenario is offered as a starting point for discussion.
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522.08 – Quantifying the lack of differentiated material amongst asteroid families
Asteroid families are created during catastrophic and cratering events on parent bodies. Family identification and parent body reconstruction has been a focus of a number of prior works (e.g. Tanga et al. 1999, Durda et al. 2007, Broz et al. 2003). These works used identified family members from dynamical hierarchical clustering methods to estimate family size distributions. From these

size distributions parent body masses can be estimated. The asteroid family parent body mass is a lower limit on the accreted planetesimal mass, since it could have been a fragment of some larger body. Different models of planetesimal accretion make different predictions for the size at which significant melting and differentiation should occur. Here, we test these models by comparing the lower limit on the accreted planetesimal mass to the amount of expected exposed crust, mantle and core material. The fraction of mass in the largest remnant compared to the parent body mass can differentiate between catastrophic and cratering events as well as provide an assessment for the minimum exposed depth of the parent body. We make upper limit estimates on the amount of differentiated mass contained in each family using spectroscopic and color surveys have become complete for V-type and A-type asteroids at relevant sizes. We compare these masses with those expected from totally and partially differentiated bodies.
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522.09 – Shared origin for seven of Mars Trojans - impact ejecta from Mars?

Seven out of nine Mars Trojans belong to an orbital grouping that started to spread about 10^9 years ago (Cuk et al. 2015). We spectrally observed two of them (311999 and 385250) using the IRTF telescope and found that both present an identical olivine-rich reflectance spectrum, that is similar to the reflectance spectrum of (5261) Eureka, the largest of these seven Trojans (Rivkin et al. 2007). These measurements confirm the shared origin of the seven. Moreover, olivine-rich reflectance spectra is rare within asteroids, but is visible in numerous locations on Mars and is found within SNC meteorites that are argued to originate from Mars (Chassigny, ALHA77005; McSween 1985). This spectral resemblance encourages us to suggest that the seven Trojans are impact ejecta from Mars' plutonic rock. We will present dynamical calculations showing how the impact ejecta could have been caught in L5 and that there are enough size-relevant craters on Mars surface to produce these seven Trojans.
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523 – Mars Satellites: Phobos and Deimos

523.01 – The Cyclic Nature of Martian Satellites

The inward tidal decay of Phobos will cause the satellite to rapidly disrupt into a ring as it reaches the Rigid Roche Limit at ~ 1.6 Mars radii in less than 70 My. This ring will viscously spread to eventually form a new generation of satellites at the Fluid Roche Limit at ~ 3.2 Mars radii. We have constructed a ring-satellite model to show that this is only the latest in a series of satellite-ring cycles that have occurred repeatedly throughout Martian history, beginning with a ring created by a giant impact. During each cycle, ring material is deposited onto Mars, decreasing the mass of the ring-satellite system, such that each cycle produces progressively less massive satellites. We find that at least ~ 5 ring/satellite cycles are needed to produce a Phobos mass satellite in its current orbit. Furthermore, the decay of each ring system would have deposited a significant volume of ring material onto Mars throughout the early Noachian and into the late Amazonian. Some anomalous sedimentary deposits on Mars may be linked to these periodic episodes of ring deposition.
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523.02 – SPH modeling of the Stickney impact at Phobos

Stickney crater stretches across nearly half the diameter of ~22-km Phobos, the larger of the two martian moons. The Stickney-forming impact would have had global consequences for Phobos, causing extensive damage to the satellite's interior and initiating large-scale resurfacing through ejecta blanket emplacement. Further, much of the ejected material that initially escaped the moon's tiny gravity (escape velocity of ~11 m/s) would have likely reimpacted on subsequent orbits. Modeling of the impact event is necessary to understand the conditions that allowed this "megacrater" to form without disrupting the entire satellite. Impact simulation results also provide a means to test several different hypotheses for how the mysterious families of parallel grooves may have formed at Phobos. We report on adaptive SPH simulations that successfully generate Stickney while avoiding catastrophic fragmentation of Phobos. Inclusion of target porosity and using sufficient numerical resolution in fully 3-D simulations are key for avoiding over-estimation of target damage. Cratering efficiency follows gravity-dominated scaling laws over a wide range of velocities (6-20 km/s) for the appropriate material constants. While the adaptive SPH results are used to constrain crater volume and fracture patterns within the target, additional questions about the fate of ejecta and final crater morphology within an unusual gravity environment can be addressed with complementary numerical methods. Results from the end of the hydrodynamics-controlled phase (tens of seconds after impact) are linked to a Discrete Element Method code, which can explore these processes over longer time scales (see Schwartz et al., this meeting).
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-695442.
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523.03 – Numerical modeling of Stickney crater and its aftermath

Phobos is characterized by a large crater called Stickney. Its collisional formation and its aftermath have important implications on the final structure, morphology, and surface properties of Phobos that still need further clarification. This is particularly important in the current environment, with space mission concepts to Phobos under active study by several space agencies. SPH hydrocode simulations of the impact that formed Stickney crater [1] have been performed. Using the Soft-Sphere Discrete Element Method (SSDEM) collisional routine of the N-body code pkdgrav [2], we take the outcome of SPH simulations as inputs and model the ensuing phase of the crater formation process and its ejecta evolution under the gravitational influence of Phobos and Mars. In our simulations, about 9 million particles comprise Phobos' shape [3], and the evolution of particles that are expected to form or leave the crater is followed using multiple plausible orbits for Phobos around Mars. We track the immediate fate of low-speed ejecta (~3–8 m/s), allowing us to test an hypothesis [4] that they may scour certain groove marks that have been observed on Phobos' surface and to quantify the amounts and locations of re-impacting ejecta. We also compute the orbital fate of ejecta whose speed is below the system escape speed (about 3 km/s). This allows us to estimate the thickness and distribution of the final ejecta blanket and to check whether crater chains may form. Finally, particles forming the crater walls are followed until achieving stability, allowing us to estimate the final crater depth and diameter. We will show examples of these simulations from a set of SPH initial conditions and over a range of parameters (e.g., material friction coefficients). Work ongoing to cover a larger range of plausible impact conditions, allowing us to explore different scenarios to explain Phobos' observed properties and to infer more, giving useful constraints to space mission studies.

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524 – Inner Planets: Magnetospheres

524.01 – Effects of Crustal Fields on the Ionosphere of Mars as seen by MAVEN

Mars lacks a global intrinsic magnetic field but possesses regions of strong crustal magnetic field that are concentrated in the southern hemisphere. Previous studies have used Mars Global Surveyor or Mars Express data to show that these crustal fields influence the electron densities in the Martian ionosphere. However, many of these studies relied on remote radio occultation or radar sounding measurements and therefore relied on models to infer the crustal magnetic field strength and direction. In fall 2015 the MAVEN spacecraft passed through these crustal field regions at low altitudes, on the day side, and collected comprehensive measurements of the local plasma and magnetic field properties. The MAVEN observations therefore provide an excellent dataset with which to examine the effects of crustal fields on the ionosphere. We report on the MAVEN electron density measurements in the southern crustal field regions and discuss the influence of the magnetic field direction and topology on the dayside Martian ionosphere.

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524.02D – Martian low-altitude magnetic topology deduced from MAVEN/SWEA observations

The Mars Atmosphere and Volatile Evolution (MAVEN) mission for the first time make regular particle and field measurements down to ~150 km altitude. The Solar Wind Electron Analyzer (SWEA) instrument provides 3-D measurements of the electron energy and angular distributions. This study presents the pitch angle-resolved shape parameters that can separate photoelectrons from solar wind electrons, therefore used to deduce the Martian magnetic topology. The three-dimensional view of the magnetic topology is manifested for the first time. The northern hemisphere is found to be dominated by the crustal closed field lines, instead of draped interplanetary magnetic fields (IMF), on the dayside and more day-night connections through cross-terminator closed field lines than in the south. This study can also single out open field lines attached to the dayside ionosphere, which provide possible passage for ion outflow. Magnetic topology governs energetic electrons' movement, thus necessary to understand nightside ionosphere, and aurora.

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Institution(s): *1. Goddard Space Flight Center, 2. IRAP, CNRS and University Paul Sabatier, 3. University of California, Berkeley, 4. University of California, Los Angeles, 5. University of Colorado, Boulder, 6. University of Michigan Ann Arbor*

524.03D – Mercury's Plasma Mantle – a survey of MESSENGER observations

The plasma mantle is a region of solar wind plasma entry into the nightside high-latitude magnetosphere. We present a survey of plasma mantles identified in particle and magnetic field measurements from four years of MESSENGER spacecraft observations of Mercury's magnetosphere. The two common observational signatures of this region are ion energy latitude dispersions as well as diamagnetic depressions. From these observations we estimate the contribution of plasma from the solar wind via the mantle and infer magnitude and variability in the cross-magnetospheric electric fields present at Mercury's dynamic magnetosphere.

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525 – Meteorites

525.01D – A combined FE-SEM/EDS and µ-IR analysis of Carbonaceous Chondrites, analogue of the next returned asteroid samples

A combined method for the analysis of extraterrestrial samples returned by spacecrafts foresees two different analytical techniques: Field Emission-Scanning Electron Microscope with Energy Dispersive Spectroscopy (FE-SEM/EDS) and Infrared µ-spectroscopy (µ-IR). These are non-destructive analytical techniques that allow obtaining mineral and organic information of the samples: µ-IR spectroscopy is able to provide thermal maps of selected area, whereas FE-SEM/EDS microscopy provides information on sample morphology and chemical composition. The combined results provide a complete overview of the sample mineralogy.

In the past, different types of analysis were performed in order to characterise returned asteroid and cometary samples, and meteorites [e.g. 1,2,3]. Waiting for the analyses of the samples to be returned from primitive asteroids targets by Hayabusa 2 and Osiris Rex missions [4,5], we applied the combined FE-SEM/EDS and µ-IR techniques to Carbonaceous Chondrites (CC) meteorites as possible analogues. In particular, we selected 3 samples: Murchinson (CM2 group), characterised by small chondrules and refractory inclusions [6]; Orgueil (CI1 group) characterised by the absence of chondrules and refractory inclusion and with a high degree of hydration [7]; NWA2086 (CV3 group) with considerable amount of large mm-size chondrules, many surrounded by igneous rims [8]. A preliminary analysis was performed on the samples using a Stereo Microscope (Leica M205c) equipped with a digital camera in order to select regions of the samples showing a significant mineralogical heterogeneity.

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525.02 – Micrometer-Scale Spectral Properties of Howardite, Eucrite, and Diogenite Meteorites

We used visible-short wavelength infrared (VSWIR) imaging spectroscopy to survey the spectral diversity of the howardite, eucrite, and diogenite (HED) meteorite suite at 80-µm/pixel spatial scale. This group of meteorites is widely believed to originate from the asteroid Vesta. Our goal in this work is to contribute to understanding the petrologic diversity of the HED suite and the evolution of Vesta by (1) resolving spectral end members – i.e., spectra of the mineral constituents of Vesta— for use in interpretation of infrared remote sensing data from the Dawn spacecraft, (2) locating rare phases that can be examined using detailed analytical techniques, and (3) non-destructively and rapidly classifying large numbers of meteorites, including estimating their modal mineralogy within a petrographic context. We analyzed 11 howardite, 8 eucrite, and 9 diogenite fragments using JPL's Ultra-Compact Imaging Spectrometer (UCIS). We identified four major classes of materials based on VSWIR absorptions that include pyroxenes, olivines, Fe-bearing feldspars, and glass-bearing/featureless materials. There is significant HED spectral diversity within the pyroxene class at the microscale. On the whole, band centers are consistent with previous measurements of bulk HED spectra, although there are some intriguing trends that become apparent at this spatial resolution. In the howardite and eucrite samples, the positions of BI and BII centers of single pixel pyroxene spectra, which are controlled primarily by Fe- and Ca-content, plot mostly within established fields of bulk howardite and eucrite spectra. The positions differ from established centers for diogenites, however, and there appear to be two spectral classes within this field. Future work with spatially coregistered SEM/EDS will determine whether these differences are due to compositional differences, the effects of impact shock, or sub-pixel mixtures of multiple phases. Olivine is a rare phase in howardites and diogenites, but is identifiable in several of our samples. The small-scale spectral observations will be used to aid in interpretations of large-scale spectral data of Vesta.

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525.03 – Meteorite Fractures and Scaling for Atmospheric Entry

We are attempting to understand the behavior of asteroids entering the atmosphere in order to help quantify the impact hazard. The strength of meteorites plays a critical role in determining the outcome of their impact events. Our objective is to scale fracture parameters in meteorites to their parent body.

In this study over a thousand meteorite fragments in the Natural History Museums of Vienna and London (mostly hand-sized, some 40 or 50 cm across) were examined and fracture patterns in selected fragments were imaged. We identified six kinds of fracturing behavior. The density and length of the observed fractures were measured in hand specimens and thin sections. We assume that fracturing follows the Weibull distribution, where fractures are assumed to be randomly distributed through the target and the likelihood of encountering a fracture increases with distance. The images collected of the six fracture behaviors provide a two-dimensional view of the fractures. A relationship exists between the distributions of measured trace length and actual fracture size, where the slope of a log-log plot of trace length vs fracture density is proportional to α, the shape parameter. The value for α is unclear and a large range in α has been determined from light curve data. α can be used to scale strengths from the meteorite to the larger parent body.

The majority of the meteorite fractures imaged displayed no particular sensitivity to meteorite texture. A value of α of 0.185 has been determined for a chondrite with a fracture pattern that shows no sensitivity to meteorite texture and has no point of origin. This study will continue to examine additional meteorites with similar fracture patterns along with the other 5 patterns to see if there is a correlation between fracture pattern and α. This may explain the variations in α determined from fireball data. Values of α will be used in models created by the Asteroid Threat Assessment Project to try to determine the behavior of asteroids entering the atmosphere and quantify their impact hazard.

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Authors Index