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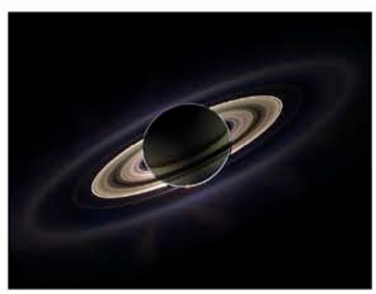
Cassini XXM Science: Introduction

- XXM Mission Overview
- XXM Goal and Objectives
  - ➢Seasonal-temporal change
  - ➢New Questions
- Discipline science XXM Priority 1 objectives
  - ➢Titan
  - ➢Icy Satellites
  - ➢MAPS
  - ➢Saturn
  - ➢Rings
- End-of-mission science
- Summary



Each discipline is like a mission in its own right!

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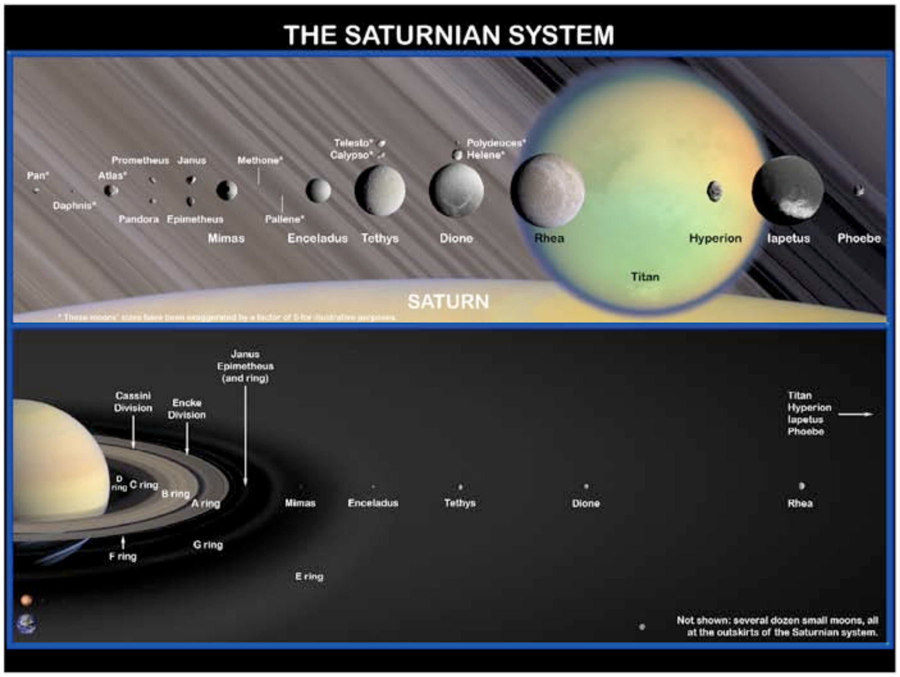
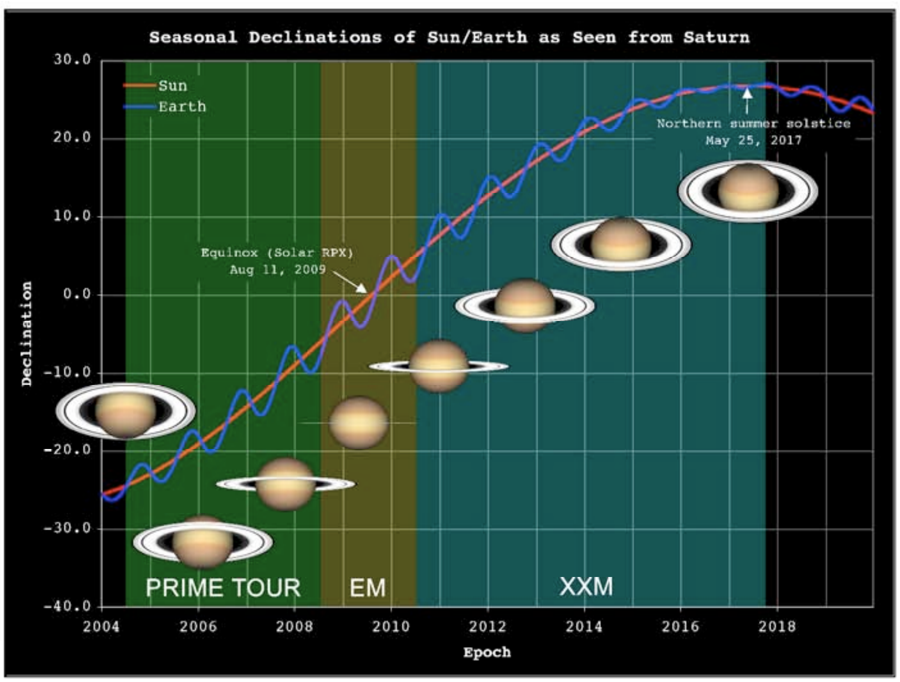
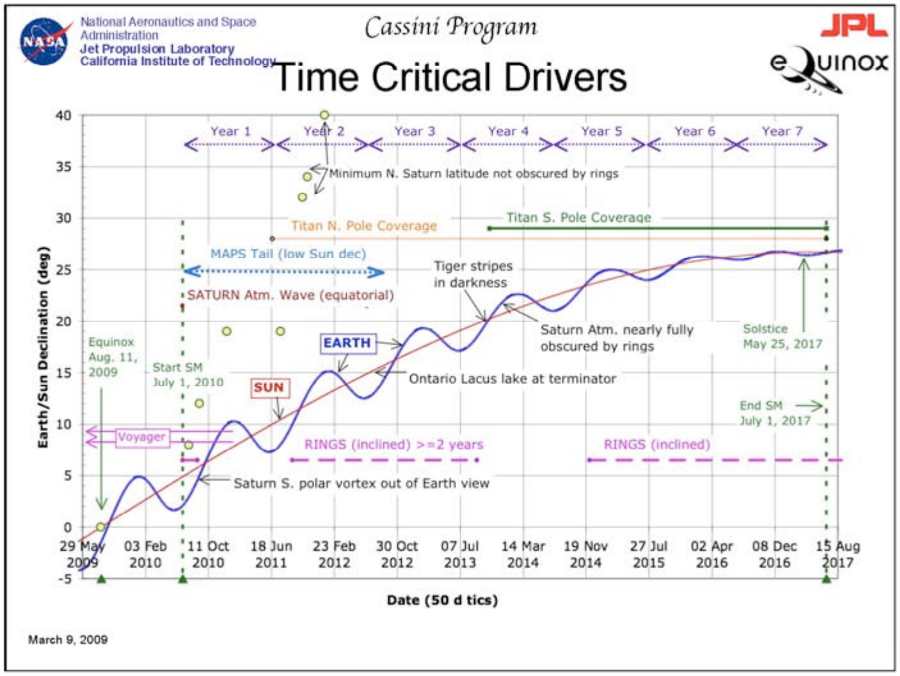

THE SATURNIAN SYSTEM
Pan*
Daphnis*
Atlas*
Prometheus
Pandora
Janus
Epimetheus
Mimas
Methone*
Pallene*
Enceladus
Telesto*
Calypso*
Tethys
Polydeuces*
Helene*
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
SATURN
Janus
Epimetheus
(and ring)
Cassini
Division
Encke
Division
D ring
C ring
B ring
A ring
F ring
G ring
E ring
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Not shown: several dozen small moons, all at the outskirts of the Saturnian system.


Seasonal Declinations of Sun/Earth as Seen from Saturn
Sun
Earth
Northern summer solstice
May 25, 2017
Equinox (Solar RPX)
Aug 11, 2009
Declination
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
PRIME TOUR
EM
XXM
2004
2006
2008
2010
2012
2014
2016
2018
Epoch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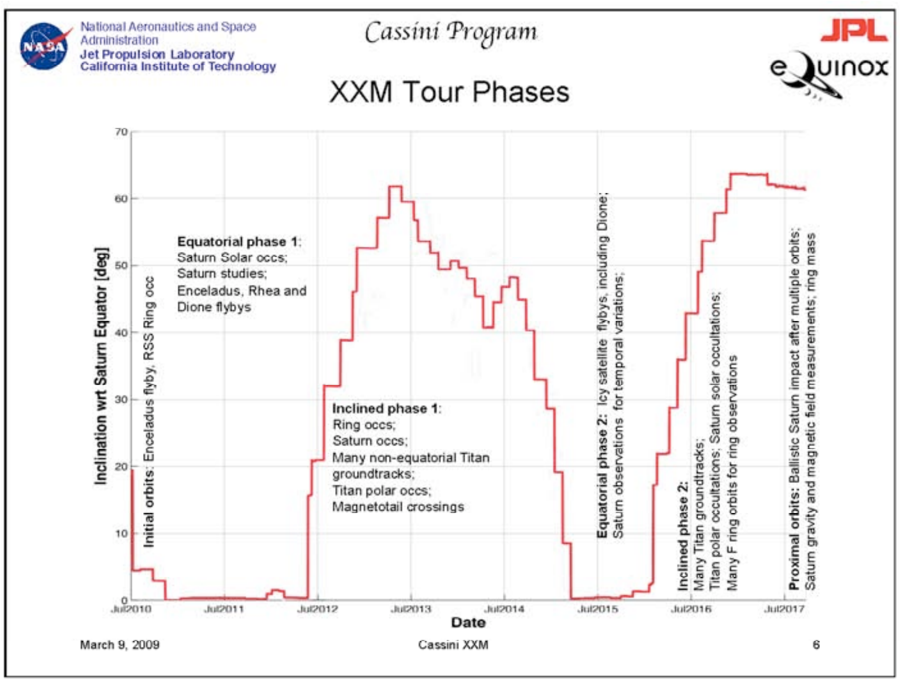
Time Critical Drivers
Year 1
Year 2
Year 3
Year 4
Year 5
Year 6
Year 7
Minimum N. Saturn latitude not obscured by rings
Titan N. Pole Coverage
Titan S. Pole Coverage
MAPS Tail (low Sun dec)
Tiger stripes in darkness
SATURN Atm. Wave (equatorial)
Saturn Atm. nearly fully obscured by rings
Solstice May 25, 2017
Equinox Aug. 11, 2009
EARTH
Start SM July 1, 2010
SUN
Ontario Lacus lake at terminator
End SM July 1, 2017
Voyager
RINGS (inclined) >=2 years
RINGS (inclined)
Saturn S. polar vortex out of Earth view
Earth/Sun Declination (deg)
29 May 2009
03 Feb 2010
11 Oct 2010
18 Jun 2011
23 Feb 2012
30 Oct 2012
07 Jul 2013
14 Mar 2014
19 Nov 2014
27 Jul 2015
02 Apr 2016
08 Dec 2016
15 Aug 2017
Date (50 d tics)
March 9, 2009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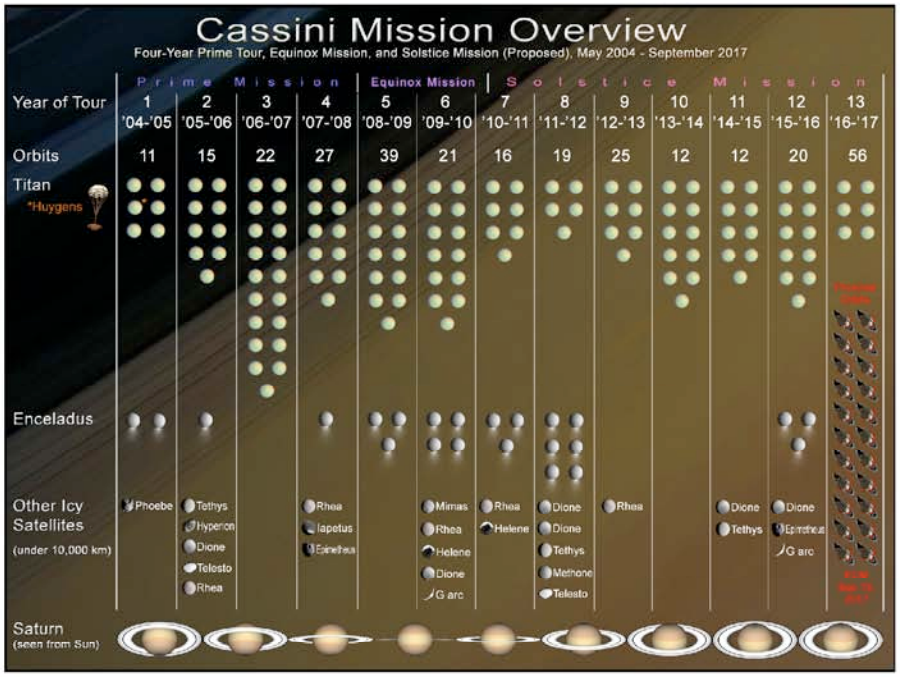
XXM Tour Phases
Inclination wrt Saturn Equator [deg]
Initial orbits: Enceladus flyby, RSS Ring occ
Equatorial phase 1: Saturn Solar occs; Saturn studies; Enceladus, Rhea and Dione flybys
Inclined phase 1: Ring occs; Saturn occs; Many non-equatorial Titan groundtracks; Titan polar occs; Magnetotail crossings
Equatorial phase 2: Icy satellite flybys, including Dione; Saturn observations for temporal variations;
Inclined phase 2: Many Titan groundtracks; Titan polar occultations; Saturn solar occultations; Many F ring orbits for ring observations
Proximal orbits: Ballistic Saturn impact after multiple orbits; Saturn gravity and magnetic field measurements; ring mass
Jul2010
Jul2011
Jul2012
Jul2013
Jul2014
Jul2015
Jul2016
Jul2017
Date
March 9, 2009
Cassini XXM
6



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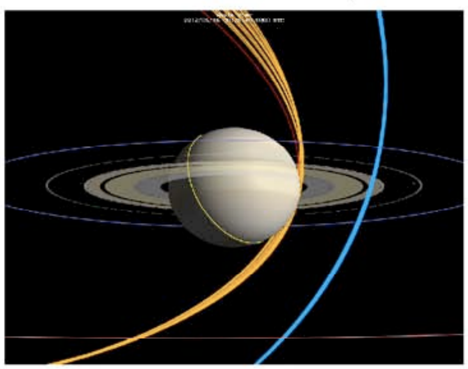
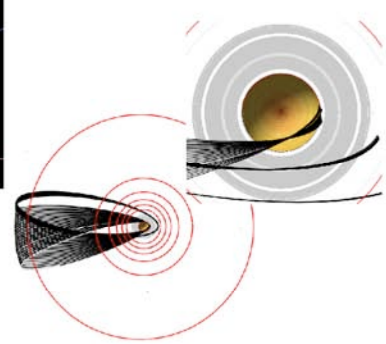
End of Mission Option with orbits inside D ring

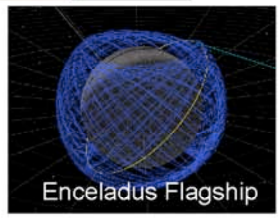


- Saturn impact from short period orbits
- Juno-like mission with Cassini instruments



Proposed Cassini XXM Goal and Objectives

- Proposed XXM Goal:
  - Observe seasonal and temporal change in the Saturn system to understand underlying processes and prepare for future missions.
- Objectives Categories:
  - Seasonal-temporal change
  - New Questions



Seasonal-Temporal Change in the Saturn System

- **Saturn:** Seasonal change.
- **Rings:** Opening angle and temporal variability.
- **MAPS:** Seasonal and solar cycle effects.
- **Icy Satellites:** Potential temporal variability of Enceladus activity.
- **Titan:** Seasonal change.

Cassini XXM offers an unparalleled opportunity to study seasonal and temporal change in a giant planet system.

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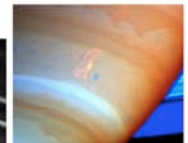
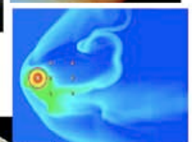
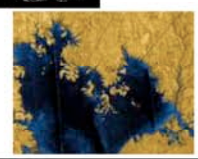
New Questions

- **Saturn:** Rotation rate; polar storms; trace gases; lightning.
- **Rings:** Age and mass; clearing gaps; compositional variations; microstructure; propellers.
- **MAPS:** magnetotail dynamics; inner radiation belts; magnetospheric periodicities; coupling to Saturn's ionosphere and rings.
- **Icy Satellites:** Enceladus ocean and interior structure; Iapetus' magnetic signature and heterogeneity; Dione activity; Rhea rings; Tethys MAPS interactions; Rhea differentiation; Hyperion's surface; Mimas.
- **Titan:** Surface lakes and other materials; internal structure; aerosols and heavy molecules; upper atmospheric density; surface topography; surface temperature and clouds; winds.







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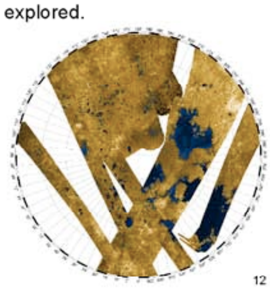
Titan: Need for follow-up

- **Seasonal changes: Spring equinox begins in the north this year**
  - Cassini S. Hemisphere observations → strong polar seasonality
  - North is different from south: large-scale coverage by lakes; weaker summer solstice flux in north vs south.
  - If lakes are not connected to an aquifer smaller ones should shrink.
  - Expect to observe convection/rainfall in north as in south. But more areas covered in liquids → different behavior?
  - Onset of spring in the north→ sunlight→ opportunity to map lake composition.
  - Seasonal asymmetry at high altitude → new chemistry to be explored.
- **Future Titan missions**
  - Completion of the map of Kraken mare is essential to its potential as a splashdown site for future probes.
- **Internal structure**
  - Detecting presence of an ocean requires many RSS flybys



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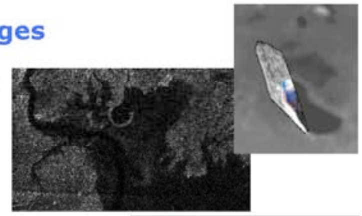
XXM Titan Priority 1 Objectives and Observations

Seasonal Changes



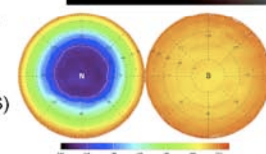
Methane/Hydrocarbon hydrological cycle:

- Lakes (RADAR, VIMS, ISS)
- Clouds (VIMS, ISS)
- Aerosols (INMS, CAPS, CIRS, ISS, VIMS, UVIS)

High latitude atmosphere

(temperature structure, formation and breakup of the winter polar vortex)

- Limb and nadir mapping of temperatures, aerosols, condensates, gas, with progression of the season (CIRS)
- Polar imaging (ISS, VIMS)
- Solar and stellar occultations for composition (UVIS)
- Radio occultation for temperature, moist convection (RSS)



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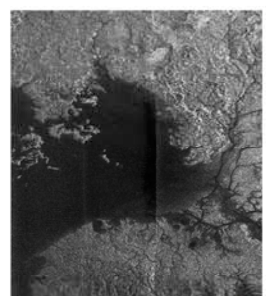
XXM Titan Priority 1 Objectives and Observations

New Questions



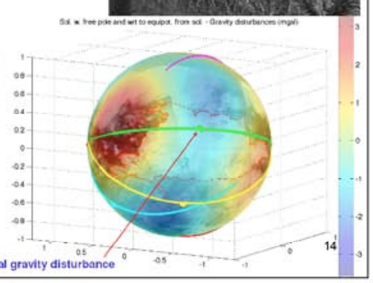
Types, composition, distribution, ages of surface units (most notably lakes)

- Composition of liquids and solids (VIMS)
- Depth of lakes (RADAR)
- Surface modification due to geologic activity (VIMS, RADAR)
  (Origin of depressions, Xanadu, fluvial features, crypto-circles, cryovolcanism)

Internal and Crustal Structure

(liquid mantle, crustal mass distribution, rotational state of surface with time, intrinsic and/or internal induced magnetic field)

- Gravity of Titan (RSS)
- Shape, topography (RADAR)
- Rotational state (RADAR, VIMS)
- Magnetic field (MAG)



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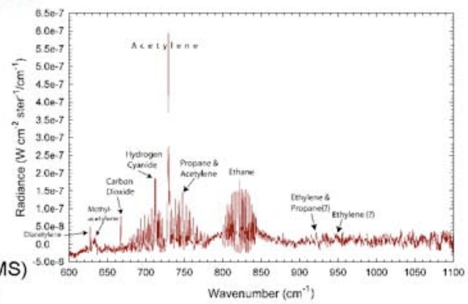
XXM Titan Priority 1 Objectives and Observations

New Questions

Aerosol and heavy molecule layers and properties



- Aerosol properties:
  - Limb, nadir mapping vs. time (ISS, VIMS, CIRS)
  - Stellar and solar occultations (UVIS)
- Properties of complex molecules
  - Direct sampling vs. latitude/time (INMS)
  - Stellar and solar occultations (UVIS)
  - Limb, nadir mapping (CIRS)
- Properties of complex ions
  - Direct sampling (INMS, CAPS)

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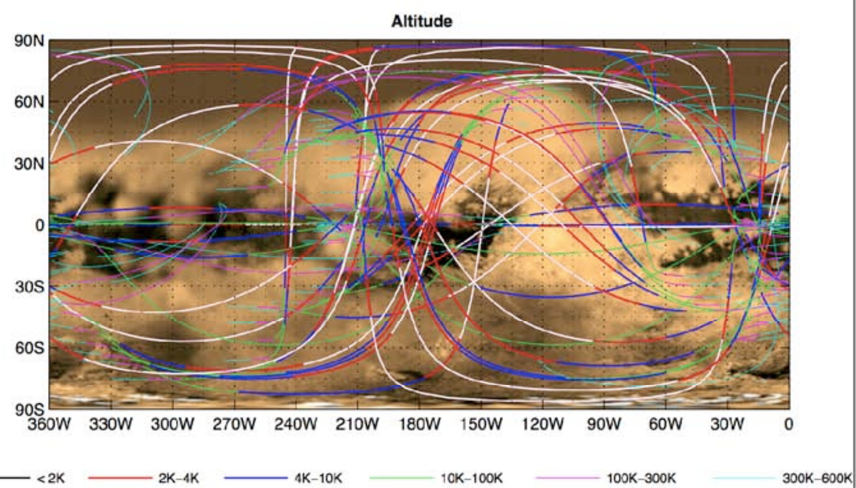
Titan Surface Coverage



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Saturn-Titan Year Scaled to an Earth Calendar Year

PM Titan flyby | EM Titan flyby | XXM Titan flyby

Season boundary | Voyager flyby

- Saturn year = 29.66 Earth years.
- Nearly 1/2 Saturn year will be sampled by Cassini Prime + Equinox + XXM.

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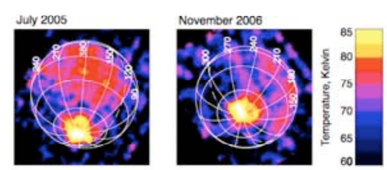
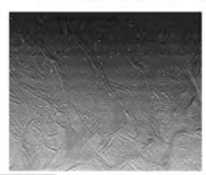
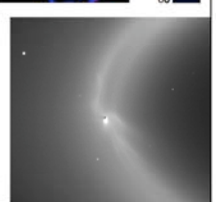
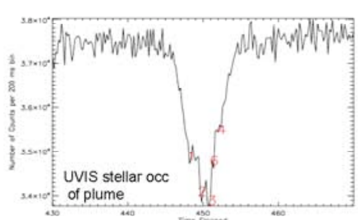
XXM Icy Satellite Priority 1 Objectives: Temporal Change at Enceladus

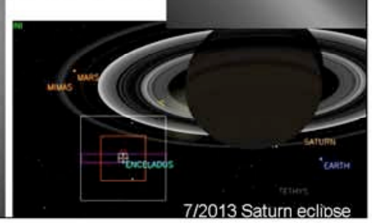
- Multiple plume penetrations, 2010 - 2015, to study changes in morphology and chemistry
- Multiple distant views of the south pole to study changes in heat output and distribution, 2010 - 2017
- Many distant high-phase views of the plumes to monitor dust output, including Saturn eclipses to study the "tendrils" seen in 2006
- UV stellar occultations in 2011 and 2016
- South polar imaging in Saturn-shine to look for morphological changes











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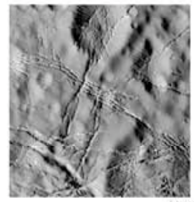
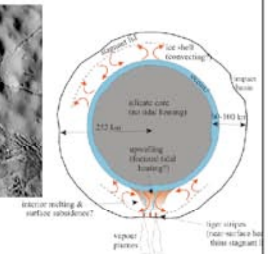
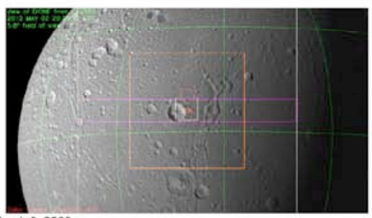
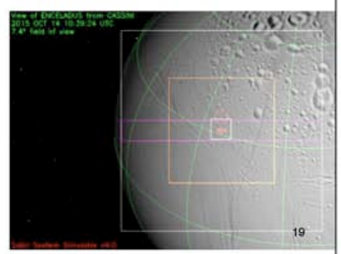
XXM Icy Satellite Priority 1 Objectives: Exploration of Enceladus and Dione

- Enceladus
  - High-resolution imaging of plume sources, 2010
  - Increase high-resolution imaging coverage of south pole in sunlight and Saturn-shine, 2010, 2015
  - High-resolution mapping of endogenic thermal emission, 2010, 2015
  - Gravity mapping to constrain interior structure (up to 3 passes total)
  - Search for magnetic induction signature
  - High-resolution imaging of the northern hemisphere, 2015
- Dione
  - High-resolution imaging and thermal mapping of fractures and other endogenic features to look for recent and ongoing activity
  - Close encounters to look for mass loading
  - Gravity passes to probe interior structure, degree of differentiation









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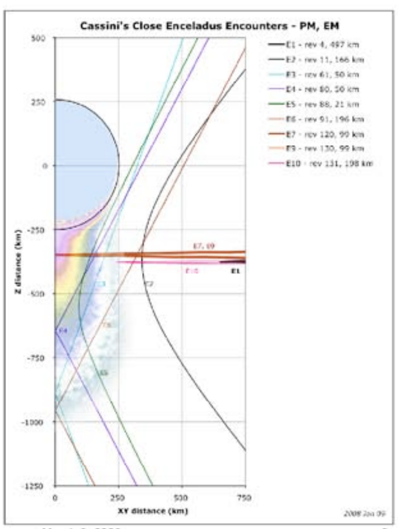
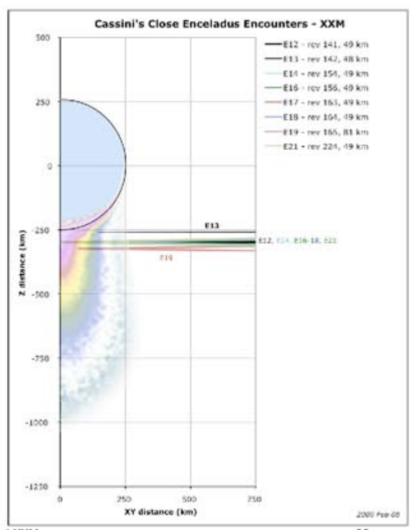
Enceladus Close Encounters





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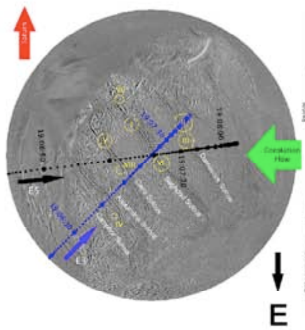
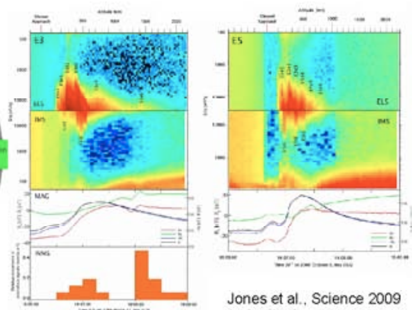
MAPS XXM Priority 1 Objectives

Enceladus

Determine the temporal variability of Enceladus' plumes.

- Tour offers 6 close plume flybys





Jones et al., Science 2009 (submitted)

CAPS-ELS and IMS detection of ~1nm size particles within the Enceladus plume and fine structure of plume observable in CAPS-ELS. Grains may be charged in the vent. Jets split into positive and negatively-charged components.

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MAPS XXM Priority 1 Objectives

Saturn's Magnetosphere

Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.

- Good LT coverage of the inner magnetosphere (<15 R_S)

Determine the dynamics of Saturn's magnetotail

- ~2 month in the tail

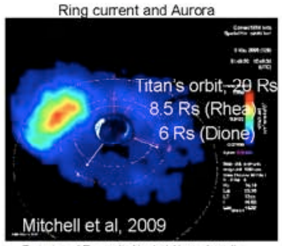
In situ studies of Saturn's ionosphere and inner radiation belt

- D ring/Juno-like EOM orbit

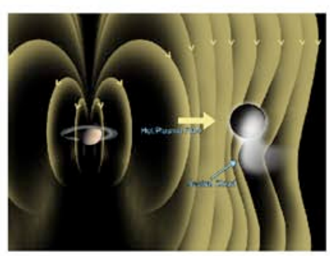
Investigate magnetospheric periodicities, their coupling to the ionosphere, and how the SKR period is imposed from close to the planet (3-5 R_S) out to the deep tail

- Low periapsis (3-5 R_S) with good local time coverage, tail excursion

Ring current and Aurora



Emission of Energetic Neutral Atoms from the Ring Current reveals presence of acceleration region rotating in lock-step with the bright UV auroral emission.



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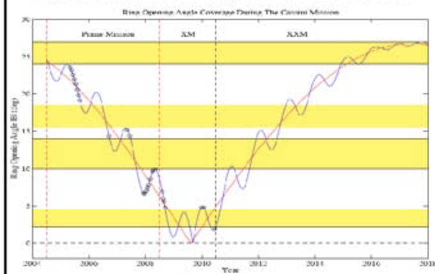
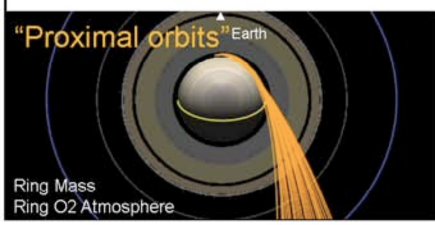
Rings: Objectives for the XXM

Opening angle affects insolation, ring temperature, RSS transmission, spoke frequency, diffuse ring structure; Long time baseline allows temporal variations to be tracked





Campaigns based on new discoveries

-***Ring Age:*** *measure meteoroid flux and ring mass to constrain formation age*

-***F Ring campaign:*** *closely monitor chaotic F ring region for interactions between ring and nearby (mostly unseen) moonlets*

-***Moonlet search:*** *Intensive searches of still-empty gaps to detect or rule out moonlets*

-***Ring composition:*** *zero in with VIMS on selected regions where known color differences have been seen*

-***Microstructure:*** *penetrate dense B ring to ascertain role of wakes and overstabilities*

- ***Propellers:*** *Track giant propellers to understand apparent radial drifts*

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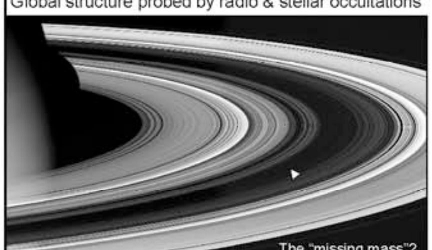
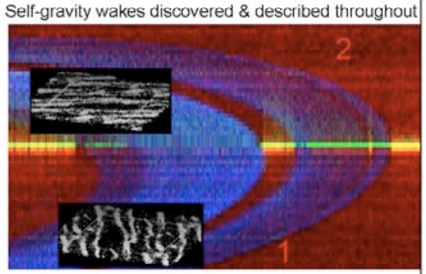
Ring XXM Objectives: Ring Structure - spatial and temporal variations

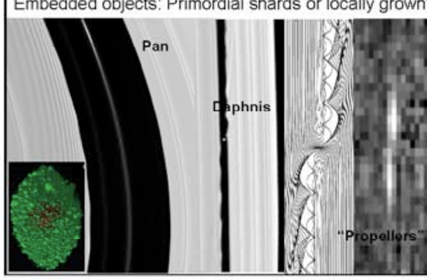
Global structure probed by radio & stellar occultations



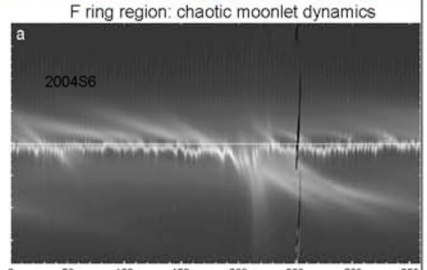
Self-gravity wakes discovered & described throughout



Embedded objects: Primordial shards or locally grown?



F ring region: chaotic moonlet dynamics



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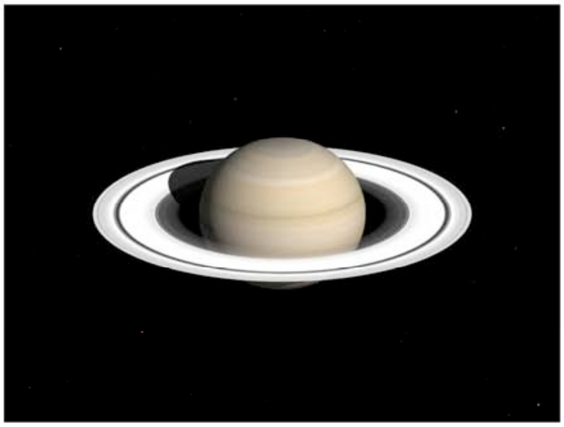
End of Mission Option with orbits inside D ring



- Saturn impact from short period orbits
- Planetary Protection approval pending
- EOM geometry reachable from any point in XXM tour
  - 2-10 months set up
  - Delta v: 5 - 30 m/s
- Unique Saturn science possible

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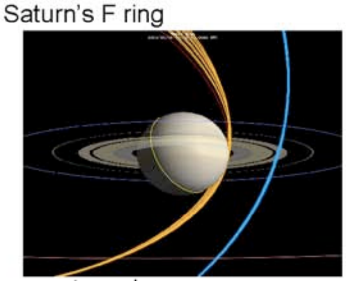
Key Orbital Characteristics of EOM phase

- 42 short period orbits from November 2016 to September 2017
- 20 F ring orbits with periapses just outside Saturn's F ring
  - Set up for final jump to orbits inside D ring
  - Rich scientifically
    - High resolution F and A ring observations
    - Ring occultations (Earth and Solar)
    - Auroral field line crossings at r = 3.4 - 4 R_S



- 22 Proximal orbits between D ring and Saturn atmosphere prior to ballistic impact
  - Periapses in 3,000 km "clear" region between inner edge of D ring and Saturn's upper atmosphere
- Critical inclination of 63.4° to prevent orbit rotation from J_2
- If delta v is available, could execute maneuver to delay spacecraft atmospheric entry a few more orbits
- Current impact date: 15 September 2017

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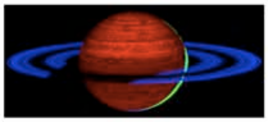
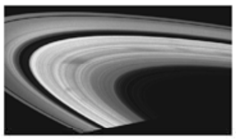
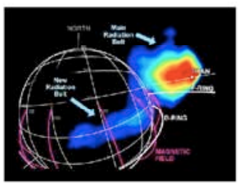
Key science objectives during End of Mission Phase







- High priority, **unique** science enabled by these orbits
- Saturn internal structure
  - Higher order moments for gravity field and magnetic field
  - Internal rotation rate for Saturn
- Ring mass
  - Ring mass currently uncertain by order of magnitude
  - Ring mass will be used to address age of main rings
- Saturn's ionosphere, innermost radiation belts & D ring
- Highest resolution main ring studies
- High resolution Saturn atmospheric studies

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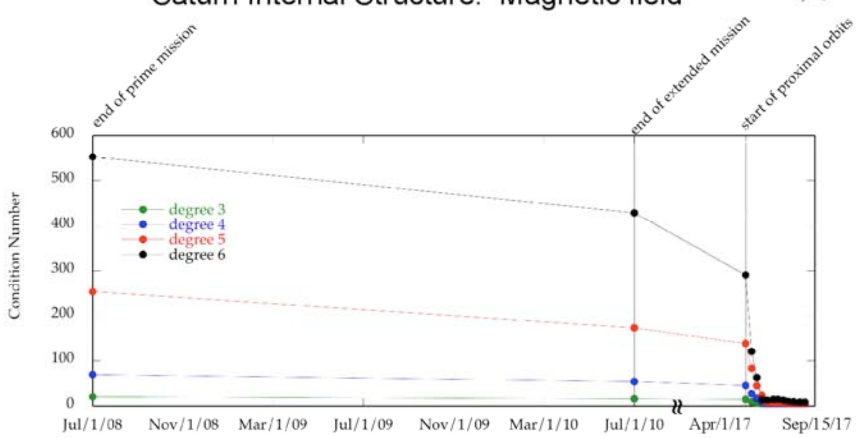
Saturn Internal Structure: Magnetic field



- Condition number is a measure of the accuracy with which a magnetic field model can be determined based on spacecraft trajectory.
- Significant improvement possible with periapse inside D ring.
- May be possible to determine depth of Saturn's conducting, metallic core.

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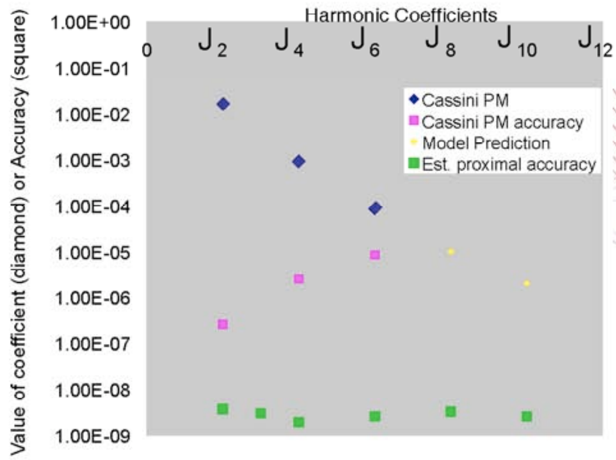
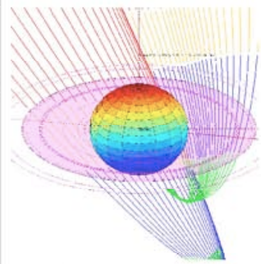
Saturn Internal Structure: Gravity Harmonics





- Saturn gravity harmonics (zonal) up to degree 10 can be estimated with an accuracy < 10^{-8} (with multiarc solution using 6 proximal orbits for gravity passes)

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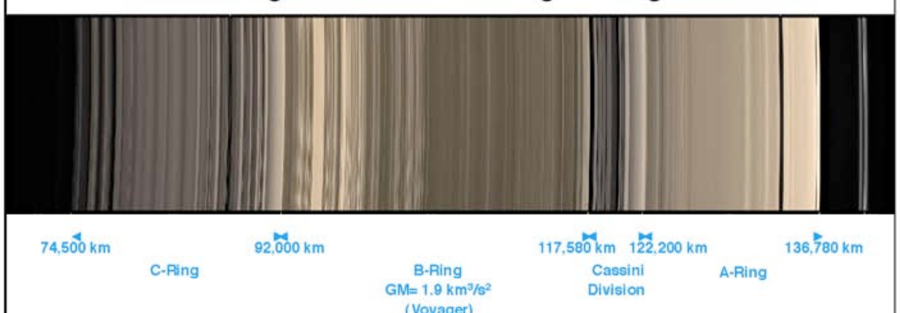
Ring Mass: Constrain age of rings



- Without proximal orbits, a-priori ring mass uncertainty is 100% of nominal values
- 6 orbital arcs for ring mass (and Saturn gravity) provide estimation accuracy for total ring δGM ~ 0.34 km^3/s^2 (~5%)

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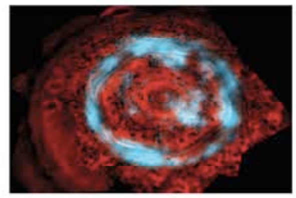
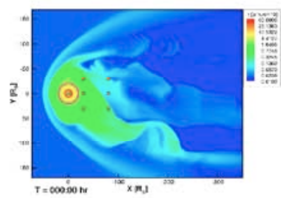
Proximal Orbit Hazard Studies

- Inner D ring opacity
  - Inside 65,000 km identified for "safe" passage

- Saturn upper atmosphere
  - Extrapolated tumble densities 1500 km above 1 bar (62,000 km) are acceptable



- Energetic particles
  - Low energy particles are not a risk to spacecraft
  - High energy particles still under study



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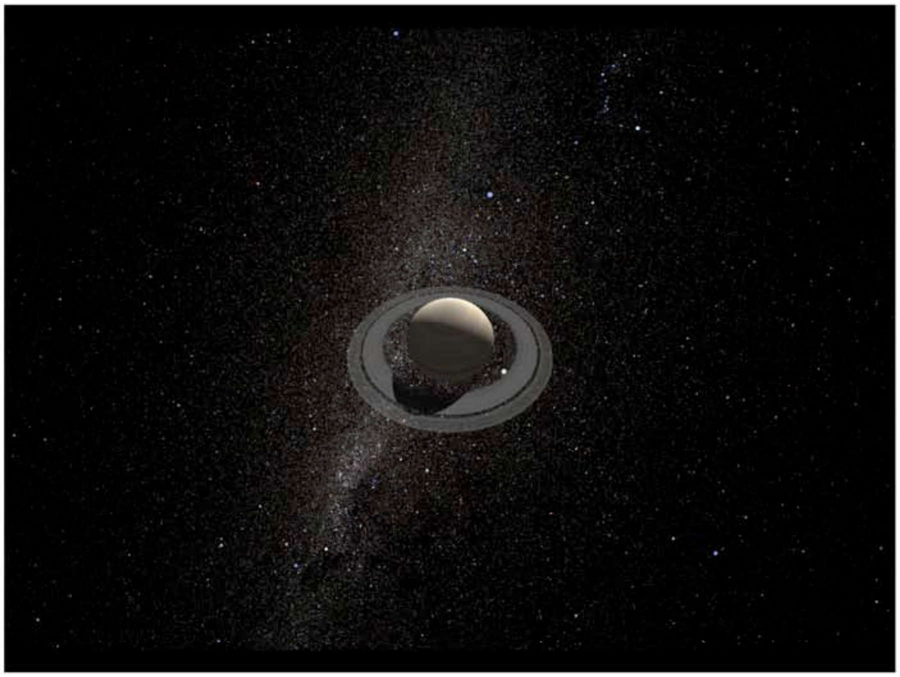
Compare F ring/Proximal orbits to Juno

- Comparable orbits and scientific goals
- Juno orbits Jupiter: Aug. 2016 to Oct. 2017
  - 33 science orbits
- Cassini's F ring/Proximal orbits: Nov. 2016 to Sept. 2017
  - 42 science orbits,
  - 22 orbits with Juno-like periapses
- Different inclinations (Cassini: 63.4^{o} vs. Juno: 90^{o})
- Common science goals:
  - Interior structure of giant planets: Gravity and magnetic field mapping
  - Dynamics of polar magnetosphere
  - High resolution measurements of giant planet atmospheres
- Differences in science goals:
  - Juno: Deep interior composition/water abundance
  - Cassini: Saturn rotation rate (well known for Jupiter)
  - Cassini: Saturn's ring mass and detailed ring structure



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Mapping of Cassini XXM Potential to Decadal Survey*

Fundamental Scientific Question	Saturn	Rings	MAPS	Icys	Titan
1. Planet and satellite formation processes	✓	✓	✓	✓	✓
2. Formation and timing of gas giants	✓	✓	✓	✓	✓
3. Timing of impactor flux decay				✓	✓
4. History of volatiles, especially water	✓	✓	✓	✓	✓
5. Nature of organic material	✓	✓	✓	✓	✓
6. Global mechanisms of volatile evolution				✓	✓
7. Habitable zones and processes for life			✓	✓	✓
8. Does (or did) life exist beyond Earth?				✓	✓
9. Differences among terrestrial planets					✓
10. Hazards to Earth's biosphere				✓	
11. Processes that shape planetary bodies	✓	✓	✓	✓	✓
12. Evolution of exoplanets	✓	✓	✓		

*Decadal Survey relevance is indicated; achieving such requires prudent funding of Cassini XXM science.

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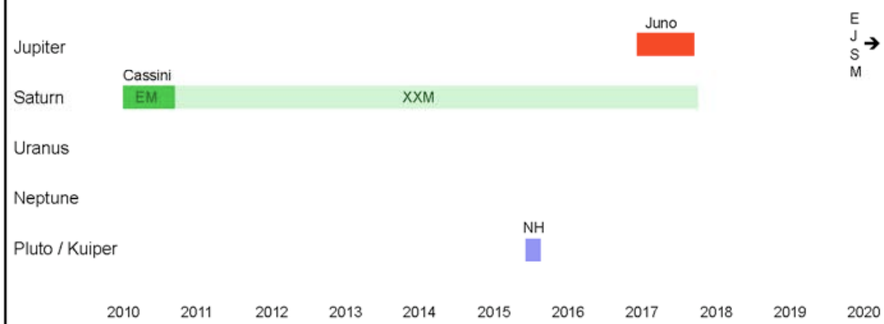
Outer Planets Missions, 2010–2020



Cassini XXM will fill a critical gap in NASA's outer solar system exploration.

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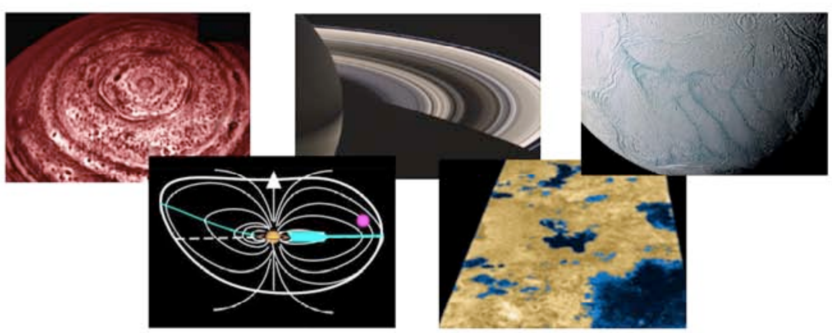
Cassini XXM Science

- Outstanding opportunities for unique, groundbreaking science.
- Direct relevance to the Planetary Decadal Survey and NASA's exploration program.



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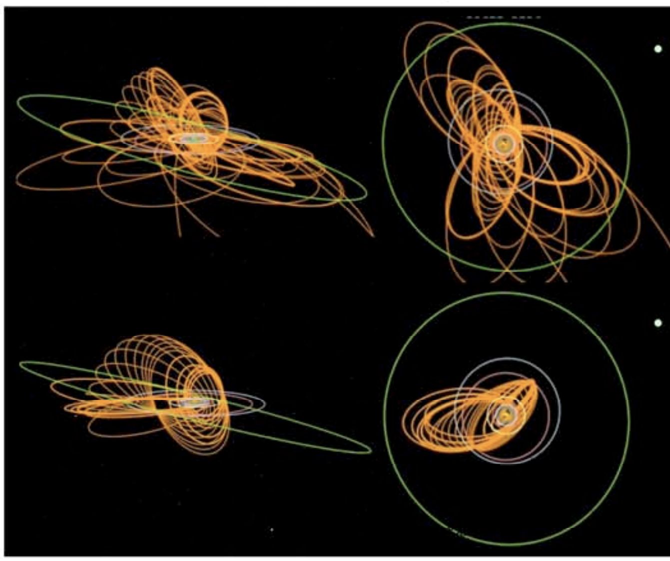
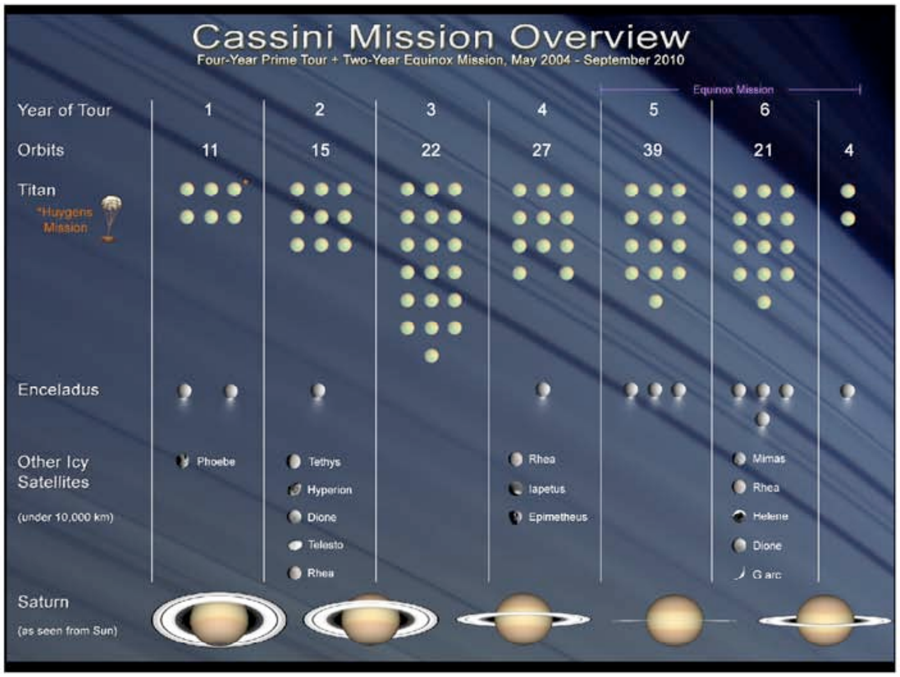
Backup Slides

Prime Mission and Equinox Mission Tours



- Prime:
  - SOI 7/1/04
  - 4 yr
  - 75 orbits
  - 45 Titan
  - 4 Enceladus
  - 9 other icys
- Equinox:
  - 7/1/08
  - 2-1/4 yr
  - 64 orbits
  - 28 Titan
  - 8 Enceladus
  - 4 other icys



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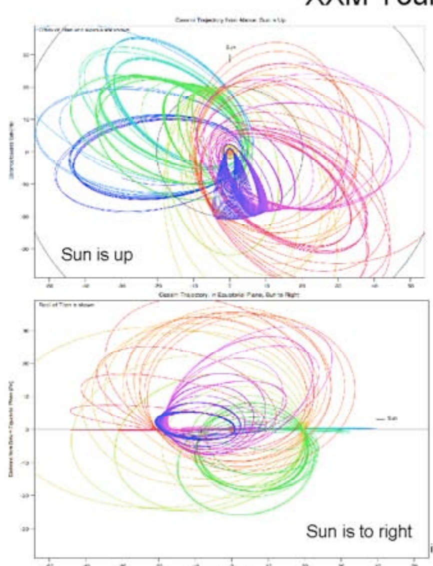
XXM Tour Overview



- 156 orbits (20 F ring, 22 proximal)
- 54 Titan flybys
- 11 Enceladus flybys (6 plume passages)
- 4 Dione flybys (1 in wake)
- 2 Rhea flybys
- 2 Tethys flybys
- 4 smaller moon flybys
  - Telesto, Methone, Helene, Epimetheus
- 1 G ring arc flyby
- Many dozens of radio, Solar, stellar occultations of Saturn, its rings, and Titan
- Maximum inclination: 62° (first inclined period) / 64° (second)
- Total cost: 160 m/s

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XXM Tour Drivers

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- Plume / ocean (mag field, plume passages, very low alt)
- Internal structure (RSS; low altitude, no occ, SEP>30)
- Thermal mapping of S.P. (CIRS/VIMS; S.P. viewing)
- Rhea ring detection (stellar occ, high phase obs); mass/gravity
- Iapetus internal ocean (low phase, sub-Saturn hemi)
- Dione plumes? (close flyby, wake passage); mass/gravity pass
- Tethys mass/gravity; wake passage
- Hyperion oddities, large grains (close flyby)
- Mimas (close flyby)

- Many Saturn occs spaced in latitude up to pole at high inclination
- Dedicated Saturn flybys inside 6Rs for multiple rotations
- Orbits with distant apoapses for compositional studies
- High inclined polar observations
- Saturn occultations within 2° of pole to study vortices

- Many Solar / radio / stellar occultations at high latitudes
- Matching Solar occ to INMS measurement close in time
- Mix of equatorial and mid-lat asymptotes
- Mix of flybys relative to Saturn's magnetic field
- Most flybys on day side at closest approach
- Another flyby as low as possible for MAG, at dawn
- Another mid-tail crossing

- Ring stellar and radio occultations at many geometries
- High resolution studies of F ring
- High resolution low phase moonlet searches
- High resolution propeller searches
- Long, high resolution ring gap / edge studies
- Lit ring face, low phase, close compositional ring studies
- Interplanetary meteoroid mass flux (close Rhea flyby)

- Many Titan flybys with mixture of geometries; most polar passes biased to north
- 2 Titan polar excursions of 20+ f/b
- Distant Titan flybys to round out north polar observations
- Close flybys (70%) for RADAR, VIMS, INMS; midrange flybys (10%) for RSS; long-range flybys (20%) for CIRS, ISS

≥ 15 Proximal orbits on sunlit side, periapsis below equator

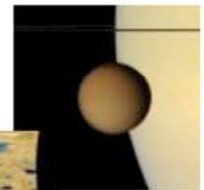
		SATURN	RINGS	MAPS	ICY SATS	TITAN
SEASONAL-TEMPORAL CHANGE	Priority 1	**SC1a** - Observe seasonal variations in temperature, clouds, and composition in three spatial dimensions.	**RC1a** - Determine the production mechanisms of spokes, and the microscale properties of ring structure, by observing at the seasonally maximum opening angle of the rings near Solstice.	**MC1a** - Determine the temporal variability of Enceladus' plumes.	**IC1a** - Identify long-term secular and seasonal changes at Enceladus, through observations of the south polar region, jets, and plumes.	**TC1a** - Determine seasonal changes in the methane-hydrocarbon hydrological cycle: of lakes, clouds, aerosols, and their seasonal transport.
		SC1b - Observe seasonal changes in the winds at all accessible altitudes coupled with simultaneous observations of clouds, temperatures, composition, and lightning.	**RC1b** - Understand the time-variability of ring phenomena on decadal timescales (Encke gap, D ring, ring edges, etc) by substantially increasing the time baseline of observations.	**MC1b** - Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.		**TC1b** - Determine seasonal changes in the high-latitude atmosphere, specifically the temperature structure and formation and breakup of the winter polar vortex.
	Priority 2	**SC2a** - Observe the magnetosphere, ionosphere, and aurora as they change on all time scales - minutes to years - and are affected by seasonal and solar cycle forcing.	**RC2a** - Focus on F Ring structure, and distribution of associated moonlets or clumps, as sparse observations show clumps, arcs, and possibly transient objects appearing and disappearing.	**MC2a** - Observe seasonal variation of Titan's ionosphere, from one Solstice to the next.		**TC2a** - Observe Titan's plasma interaction as it goes from south to north of Saturn's solar-wind-warped magnetodisk from one solstice to the next.
NEW QUESTIONS	Priority 1	**SN1a** - Determine Saturn's rotation rate and internal structure despite the planet's unexpected high degree of axisymmetry.	**RN1a** - Constrain the age of the rings by determining the meteoroid mass infall contamination rate, and by measuring the ring mass.	**MN1a** - Determine the dynamics of Saturn's magnetotail.	**IN1a** - Determine the presence of an ocean at Enceladus as inferred from induced magnetic field and plume composition, search for possible anomalies in the internal structure of Enceladus as associated with plume sources, and constrain the mechanisms driving the endogenic activity by *in situ* observations and remote sensing.	**TN1a** - Determine the types, composition, distribution, and ages, of surface units and materials, most notably lakes (i.e. filled vs. dry & depth; liquid vs. solid & composition; polar vs. other latitudes & lake basin origin).
		SN1b - Study the life cycles of Saturn's newly discovered atmospheric waves, south polar hurricane, and newly rediscovered north polar hexagon.	**RN1b** - Focus on still-unresolved puzzle of how narrow gaps are cleared, by performing deep searches for small embedded moonlets and studying gap edges.	**MN1b** - Conduct *in situ* studies of Saturn's ionosphere and inner radiation belt.	**IN1b** - Understand Iapetus' enigmatic magnetic signature.	**TN1b** - Determine internal and crustal structure: Liquid mantle, crustal mass distribution, rotational state of the surface with time, intrinsic and/or internal induced magnetic field.
		SN1c - Measure the spatial and temporal variability of trace gases and isotopes.	**RN1c** - Determine particle compositional variations at high resolution across selected ring features of greatest interest.	**MN1c** - Investigate magnetospheric periodicities, their coupling to the ionosphere, and how the SKR period is imposed from close to the planet (3-5 Rs) out to the deep tail.	**IN1c** - Determine whether Dione exhibits evidence for low-level activity, now or in recent geological time.	**TN1c** - Measure aerosol and heavy molecule layers and properties.
	Priority 2	**SN2a** - Observe Saturn's newly discovered lightning storms.	**RN2a** - Conduct in-depth studies of ring microstructure such as self-gravity wakes, which permeate the rings.	**MN2a** - Determine the coupling between Saturn's rings and ionosphere.	**IN2a** - Determine whether there is ring material orbiting Rhea, and if so, what its spatial and particle size distribution is.	**TN2a** - Resolve current inconsistencies in atmospheric density measurements (critical to a future Flagship mission).
			RN2b - Perform focused studies of the evolution of newly discovered "propeller" objects.		**IN2b** - Determine whether Tethys contributes to the E-ring and the magnetospheric ion and neutral population.	**TN2b** - Determine icy shell topography and viscosity.
					IN2c - Determine the extent of differentiation and internal inhomogeneity within the icy satellites, especially Rhea and Dione.	**TN2c** - Determine the surface temperature distribution and cloud distribution.
					IN2d - Understand the unusual appearance and environment of Hyperion with high-resolution remote sensing and in-situ observations.	**TN2d** - Determine surface and tropospheric winds.
					IN2e - Complete the comparative study of Saturn's mid-sized satellites and their geological and cratering histories with high-resolution remote sensing of Mimas.	
					IN2f - Use remote sensing of Iapetus to test models for the albedo heterogeneity of the satellite and the cratering history of the Saturn system.	

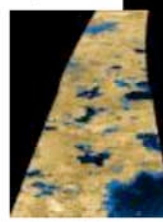
Cassini XXM Objectives

Some tour "tweaks" are under consideration, but no XXM tour can enable all objectives.

Discoveries of the Prime and Equinox Mission: Titan

- **Active methane cycle on Titan:**
  - Polar lakes
  - Clouds/precipitation
  - Erosional features (dendritic channels, rounded pebbles…)
  - Dunes
- **Evidence for an internal, presumably water, ocean**
- **Complex organic chemistry in upper atmosphere**
- **Strong connections to Saturn magnetosphere**
  - Imprint of Saturn magnetic field
  - Enceladus as a source of oxygen for Titan chem.





Key Questions

- What happens to methane on the surface and in the atmosphere over time? (methane hydrological cycle)
- What is the origin of Titan's atmospheric methane and nitrogen?
- How is methane supplied to the surface?

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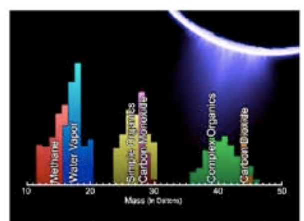
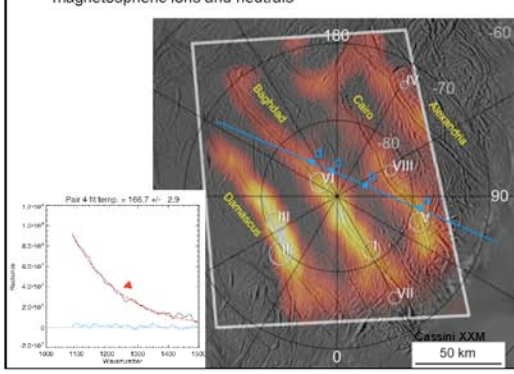
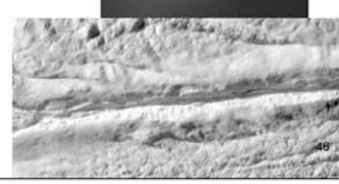
Prime Mission/XM Icy Highlights: Enceladus

Endogenic activity discovered and studied by multiple Cassini instruments

- Intense tectonism, active warm fractures with anomalous composition
- Total heat flow greatly exceeding steady-state predictions
- Multiple dust plumes supplying the E-ring, with several particle types including some that are salt-rich
- Gas plume with complex organic and inorganic chemistry, supplying magnetospheric ions and neutrals

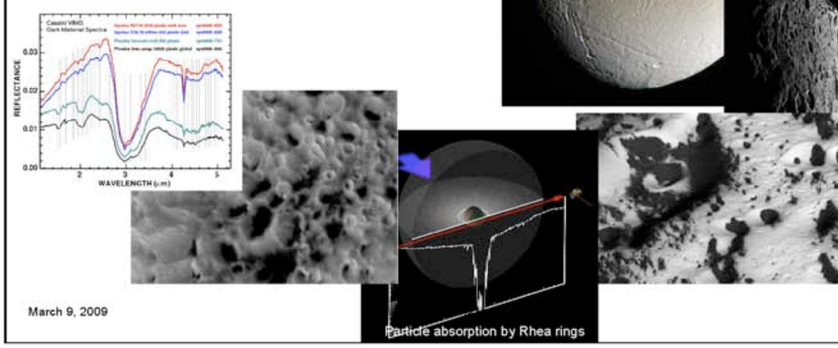






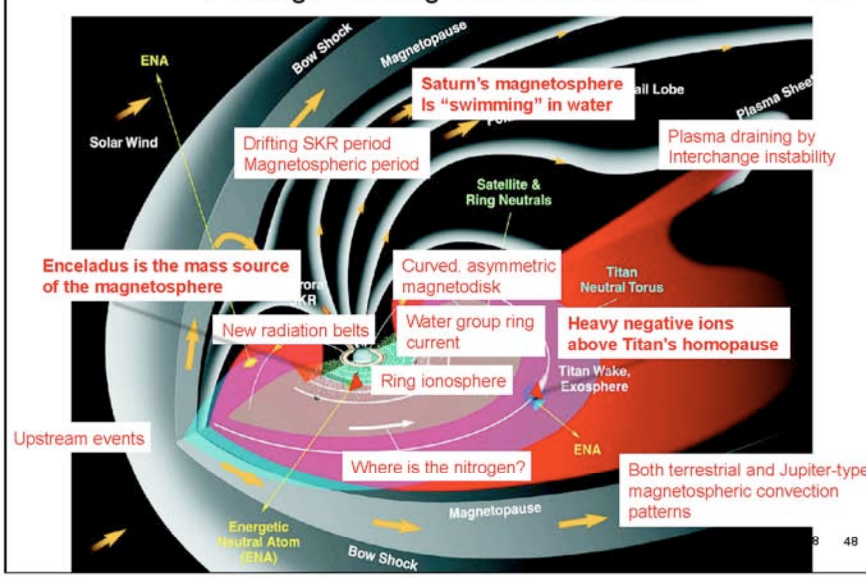
Prime Mission/XM Icy Highlights: Other Satellites

- Dione: complex geology and hints of mass loading
- Iapetus: Equatorial ridge and fossil bulge, thermal influence on albedo dichotomy, odd solar wind interaction
- Rhea: undifferentiated or non-hydrostatic, hints of a ring(!)
- Hyperion: Unusual "sponge-like" appearance
- Rich chemistry of dark material on all satellites



Particle absorption by Rhea rings

Paradigm-Shifting MAPS Discoveries



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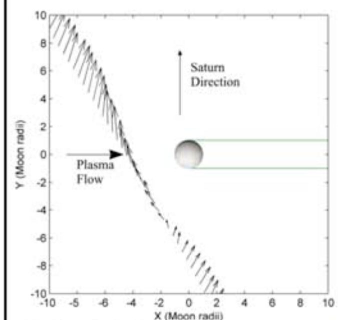
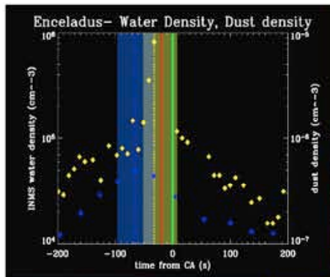
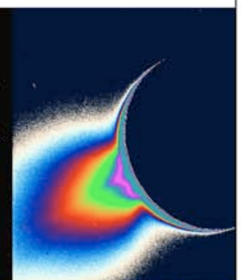
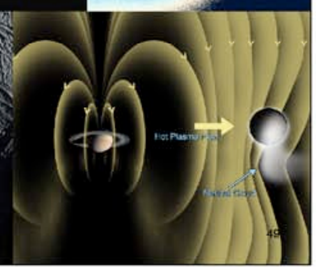
Major Discovery:
Enceladus is the Mass Source of Saturn's Magnetosphere







During the E1 flyby the magnetometer observed magnetic field draping that is characteristic of magnetospheric plasma interaction with a neutral gas cloud. This led to the discovery of the plumes of Enceladus.



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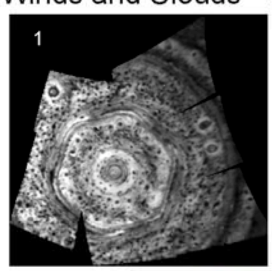
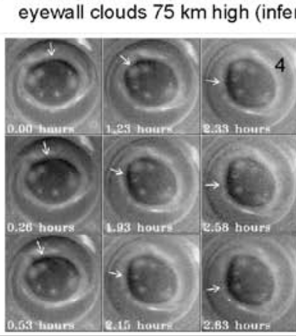
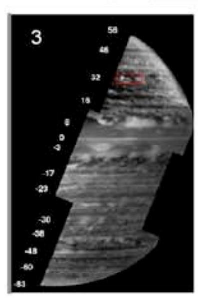
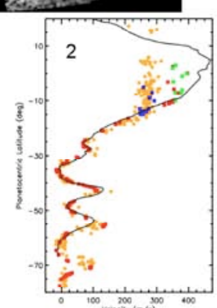
Prime Mission/XM Highlights: Saturn Winds and Clouds

1. North polar hexagon, a stationary pattern in an eastward jet, is still there after its discovery by Voyager in 1981 (size is two Earths)
2. Rotation rate of the interior is unknown – Saturn may not be the windiest planet after all
3. Deep atmosphere is active – near-IR and microwave imaging reveals detailed structures 100 km below the visible clouds
4. South polar hot spot is a warm core cyclone with eyewall clouds 75 km high (inferred from shadows)









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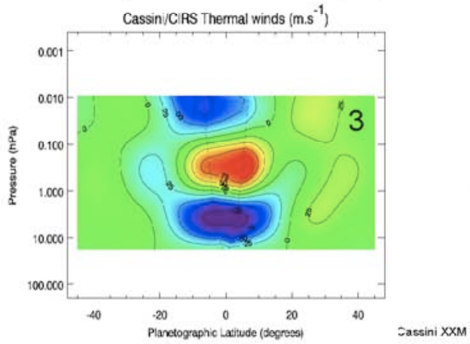
Prime Mission/XM Highlights: Saturn's Atmosphere

1. Dragon storms (rare - one every 1-2 years) are the source of Saturn electrostatic discharges (SED's), i.e., lightning
2. Aurora (shown in near-IR) is variable on all time scales. Blue = aurora; red = hexagon
3. Waves in the tropical stratosphere resemble Earth's quasi-biennial oscillation (QBO)



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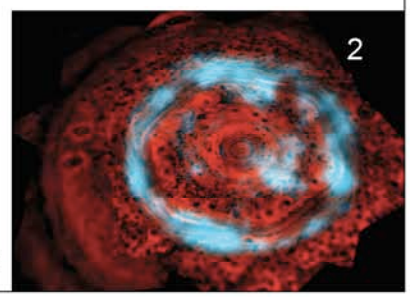

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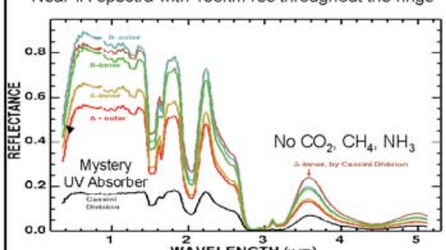
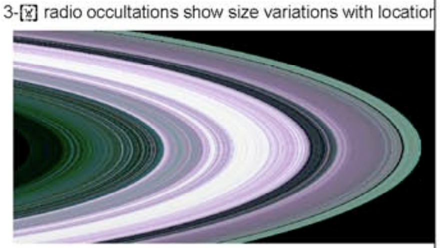
Prime Mission/XM highlights: Ring Composition and particle size

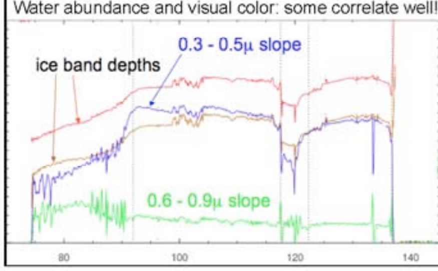
Near-IR spectra with 150km res throughout the rings



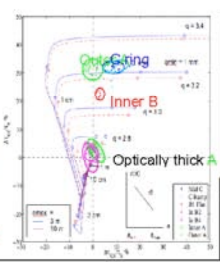
3-λ radio occultations show size variations with location

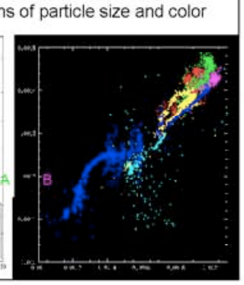


Water abundance and visual color: some correlate well!



Radial variations of particle size and color





National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Cassini Program

JPL

equinox

End of Mission Geometric Requirements for Science

- Periapsis orientation near noon (12:00 Local Solar Time) for continuous tracking of spacecraft
  - Radio Science (RSS) gravity mapping measurements
  - Low phase, high resolution imaging of main Rings
- Periapse below ring plane
  - Radio Science Earth occultations of planet and main rings
  - UVIS/VIMS Solar occultations of planet and main rings
- Approach to periapsis over northern hemisphere
  - Sunlit CIRS and VIMS observations (these instruments require pre-periapse observations during these orbits because of expected radiator heating)
- End of mission phase designed to address key science