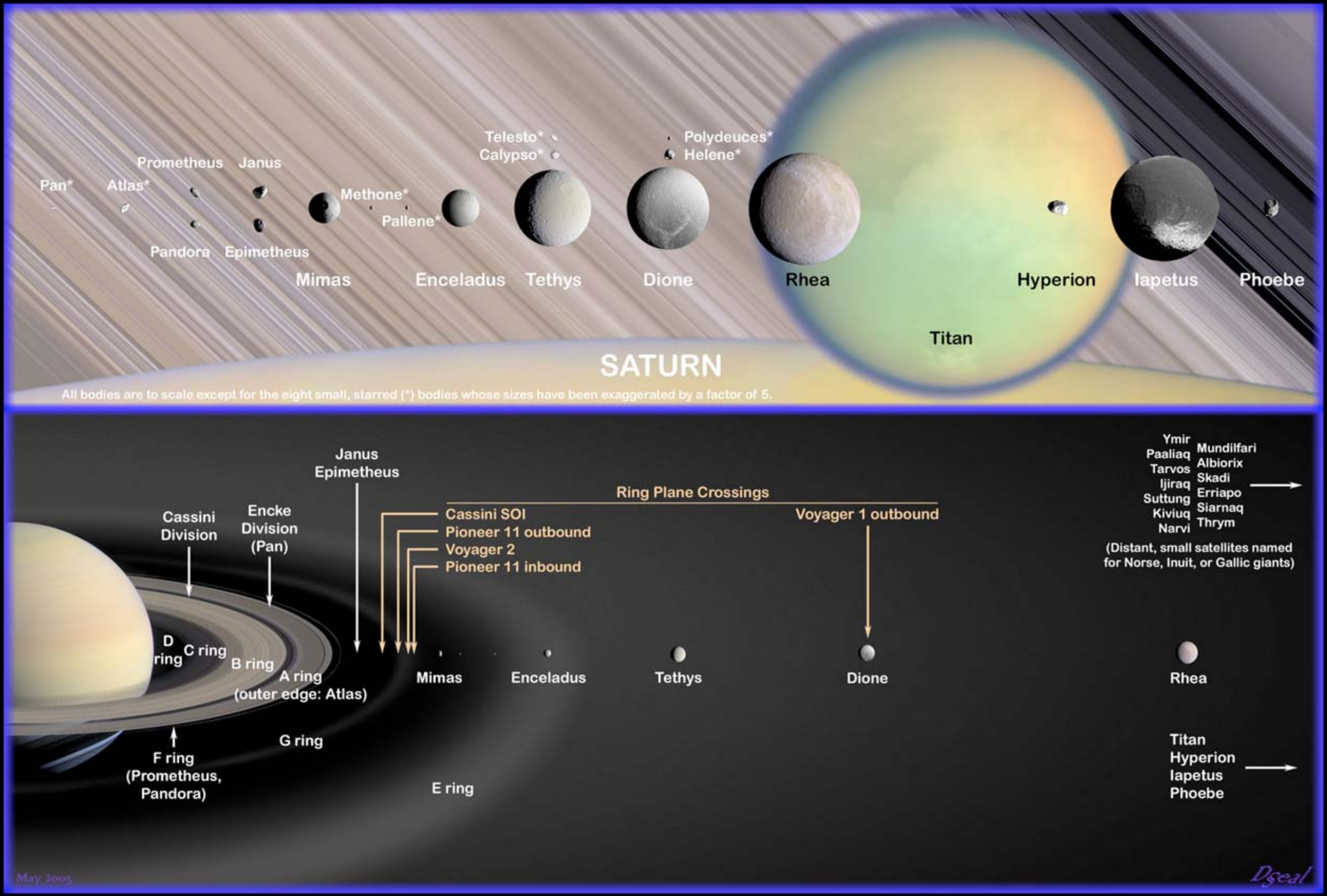
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Cassini
Extended Missions

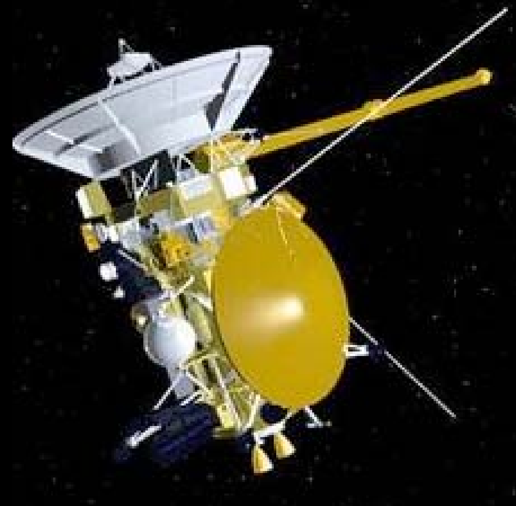
Linda Spilker
Cassini Deputy Project Scientist

April 1, 2008

The Saturnian System



Numbers



- 1 Cassini-Huygens
- 5 Scientific disciplines
- 18 Instruments (12 Orbiter)
- 27 Investigations
- 30 Project Science Group (PSG) Executive
- ~80-100 Scientists at PSG Plenary session
- ~270 Scientists on Investigation Teams (more than half are in Europe)
  - Does not include science associates and postdocs

Extended Mission (XM) Tour

- 2-year duration (1 July 2008 - 1 July 2010)
  - Informally termed Cassini Equinox Mission
    - Saturn Equinox in August 2009
- Driven by scientific requirements
- XM tour produces the maximum scientific return possible with the Cassini-Huygens spacecraft

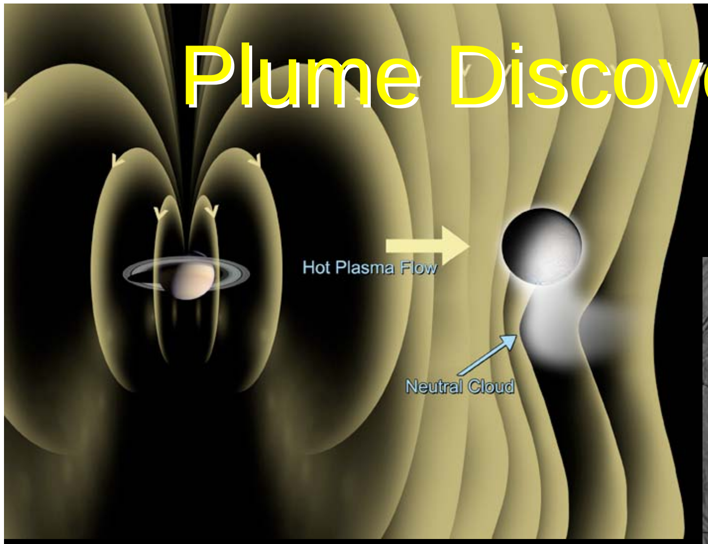
Identification of XM Scientific Objectives

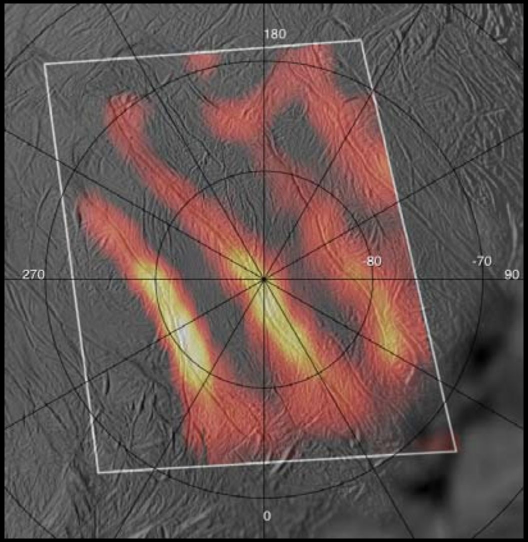
- New discoveries
  - Enceladus' plumes, Titan's complex surface
- Theoretical advances
  - Importance of Titan and Enceladus for organic chemistry
  - Dynamics of satellites imbedded in the rings
  - Satellite geophysics (e.g. Iapetus ridge)
- New opportunities, temporal and spatial

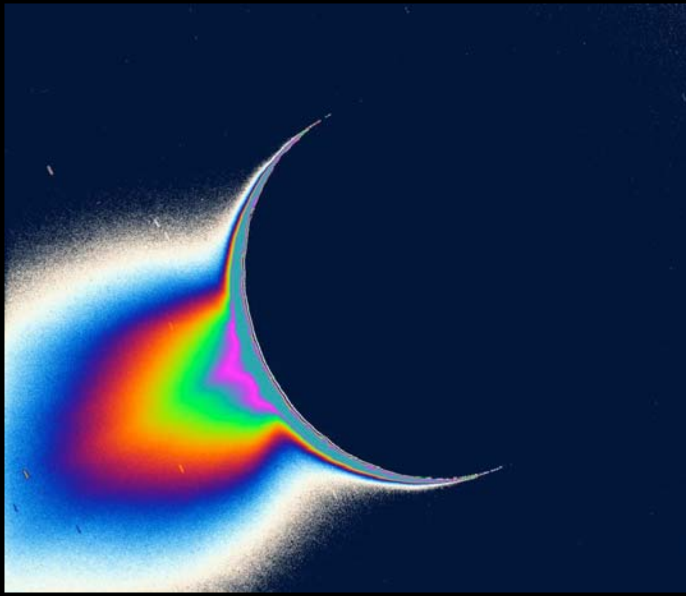
  - New seasons for Saturn and Titan
  - New ring event: Equinox (August 2009) is prime opportunity for ring discoveries
  - New places to explore in Saturn's huge magnetosphere
- Address incomplete AO objectives
  - Titan Radar coverage increases from 22% to 30%

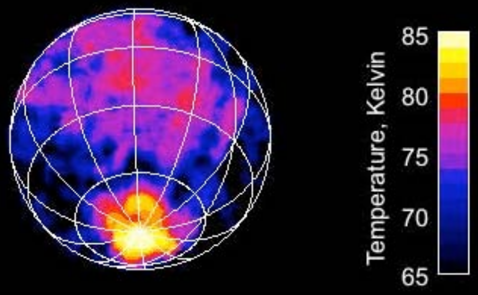
- Gather information needed for future missions
  - Spatial and temporal coverage for Titan and Enceladus

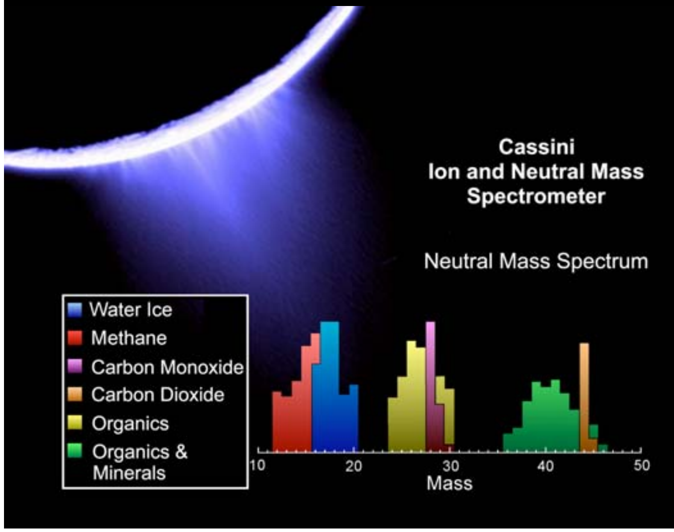
Plume Discovery through Interdisciplinary Science

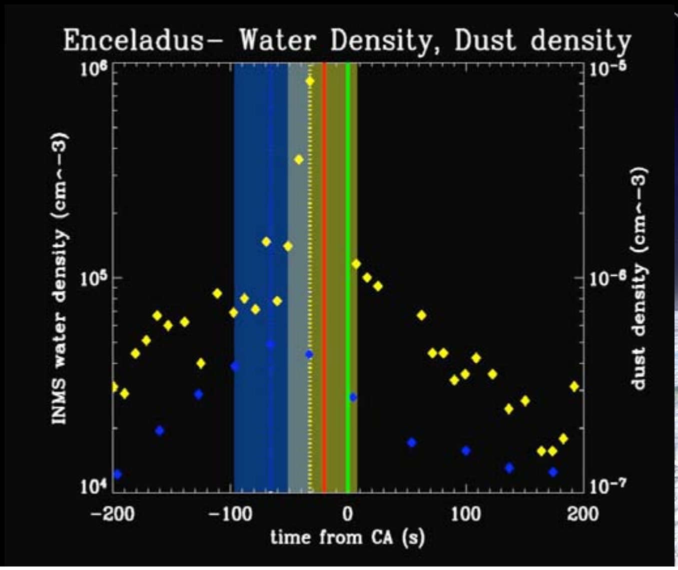


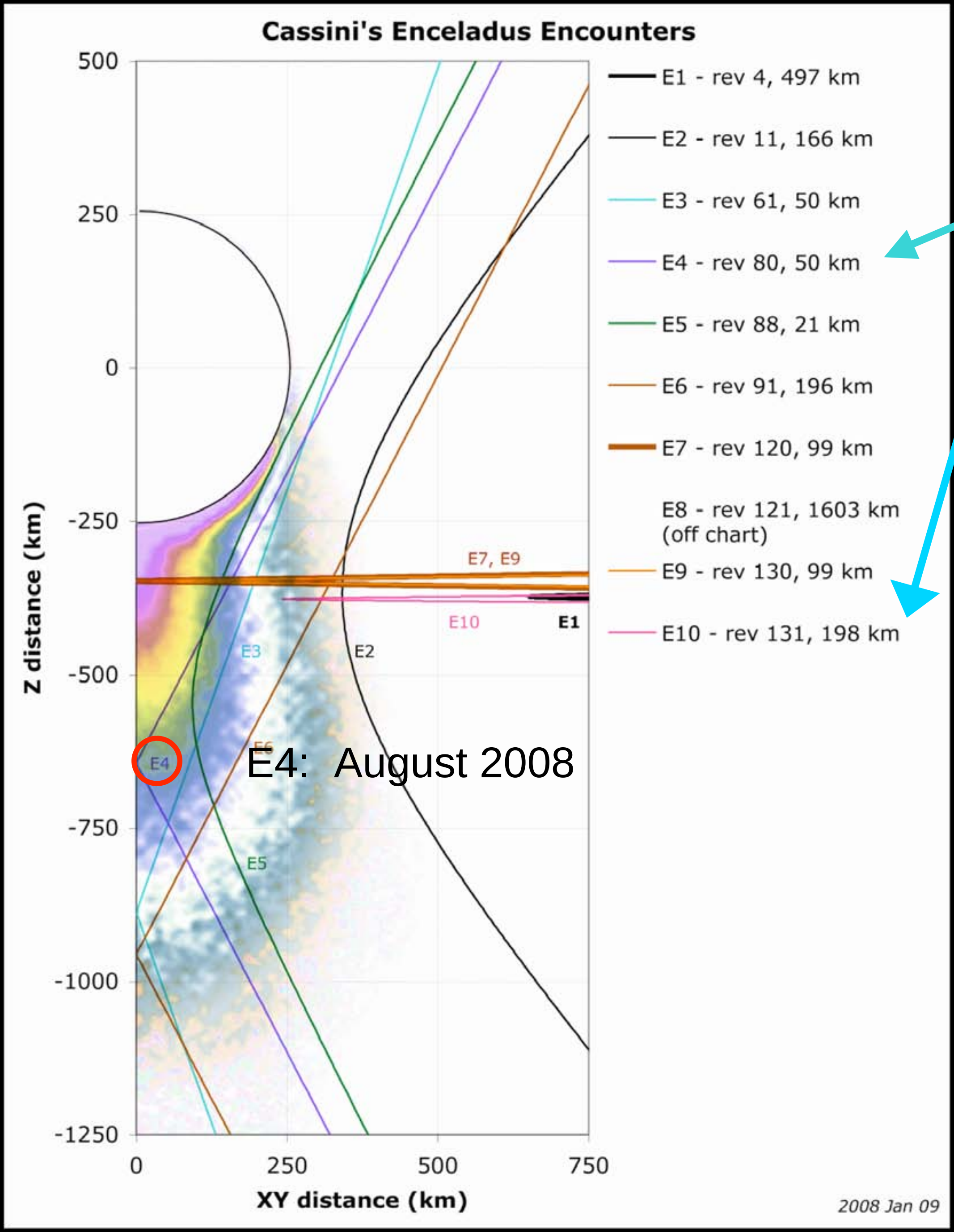






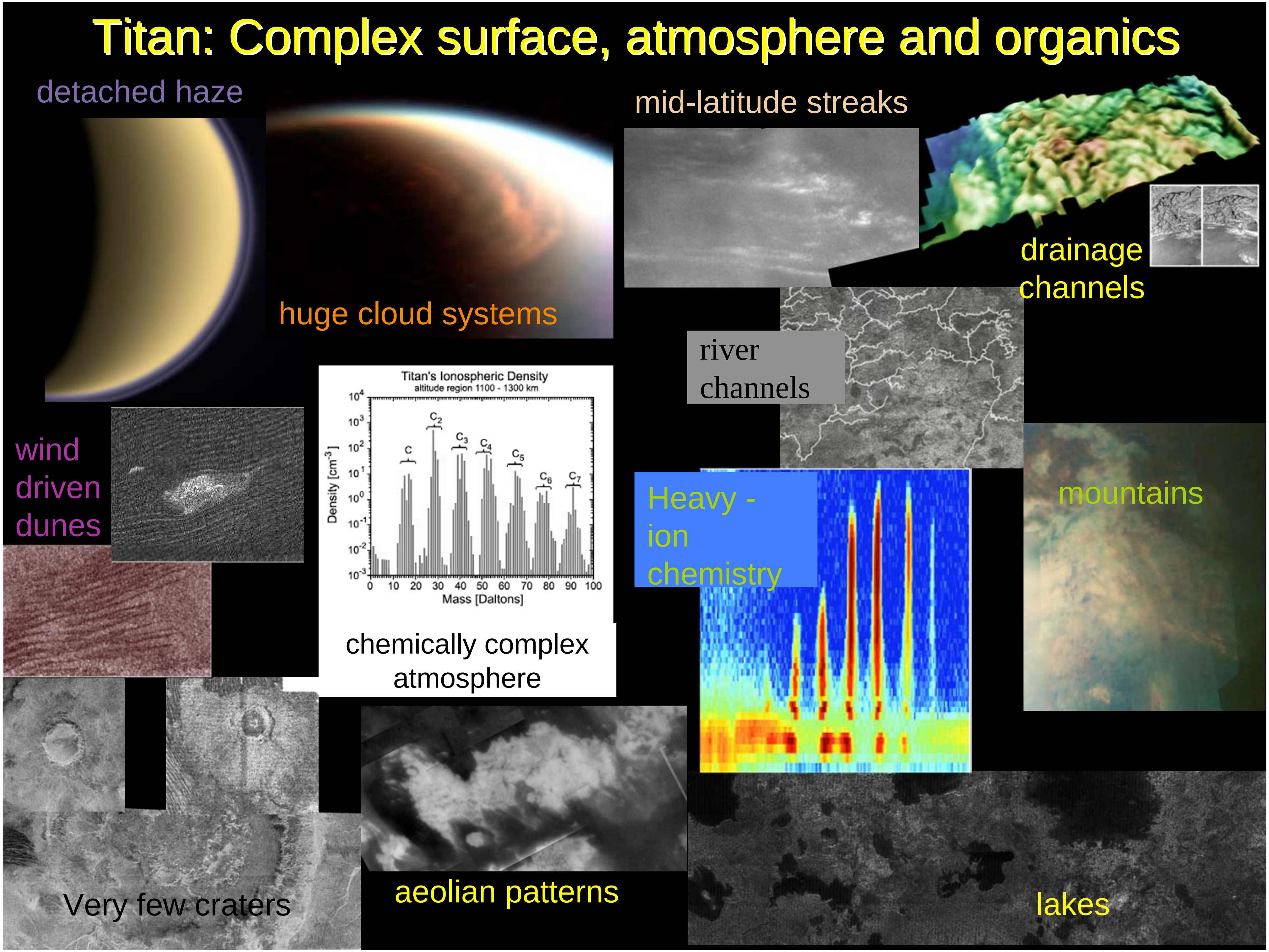






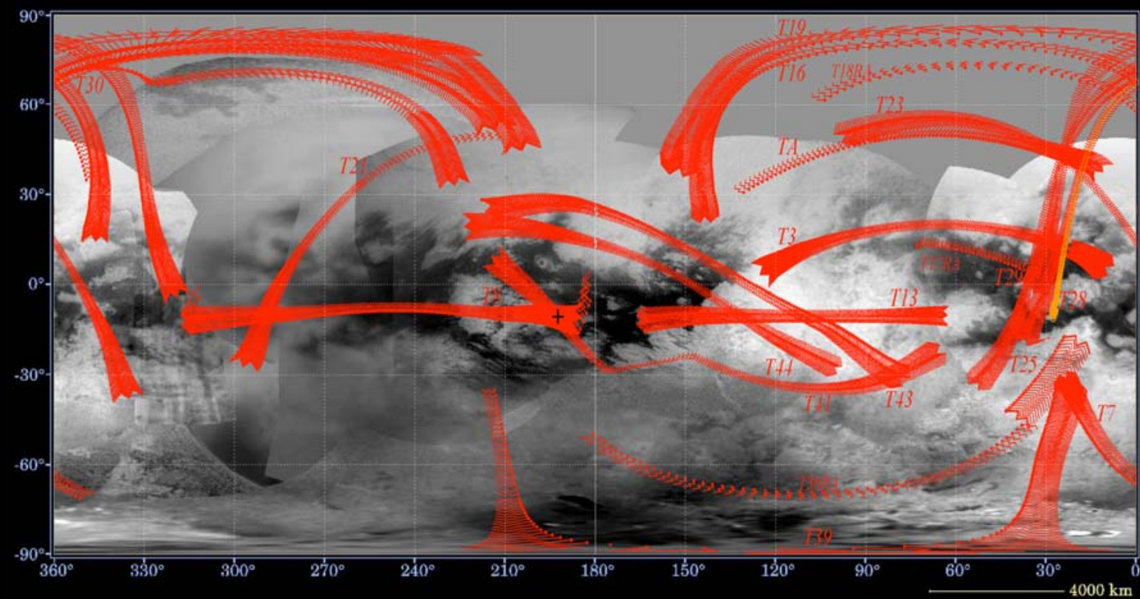
7 Enceladus flybys

E4 - E10


Titan: Complex surface, atmosphere and organics
detached haze
huge cloud systems
mid-latitude streaks
drainage
channels
river
channels
wind
driven
dunes
Titan's Ionospheric Density
altitude region 1100 - 1300 km
Density [cm-3]
Mass [Daltons]
chemically complex
atmosphere
Heavy -
ion
chemistry
mountains
Very few craters
aeolian patterns
lakes

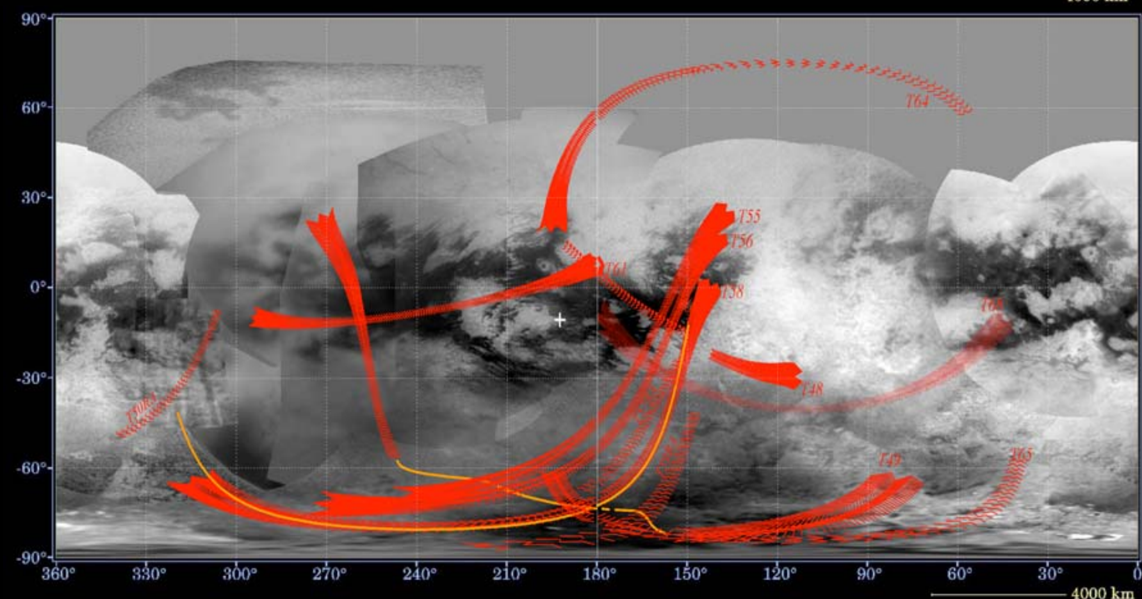
Radar coverage of Titan surface

Prime 22%



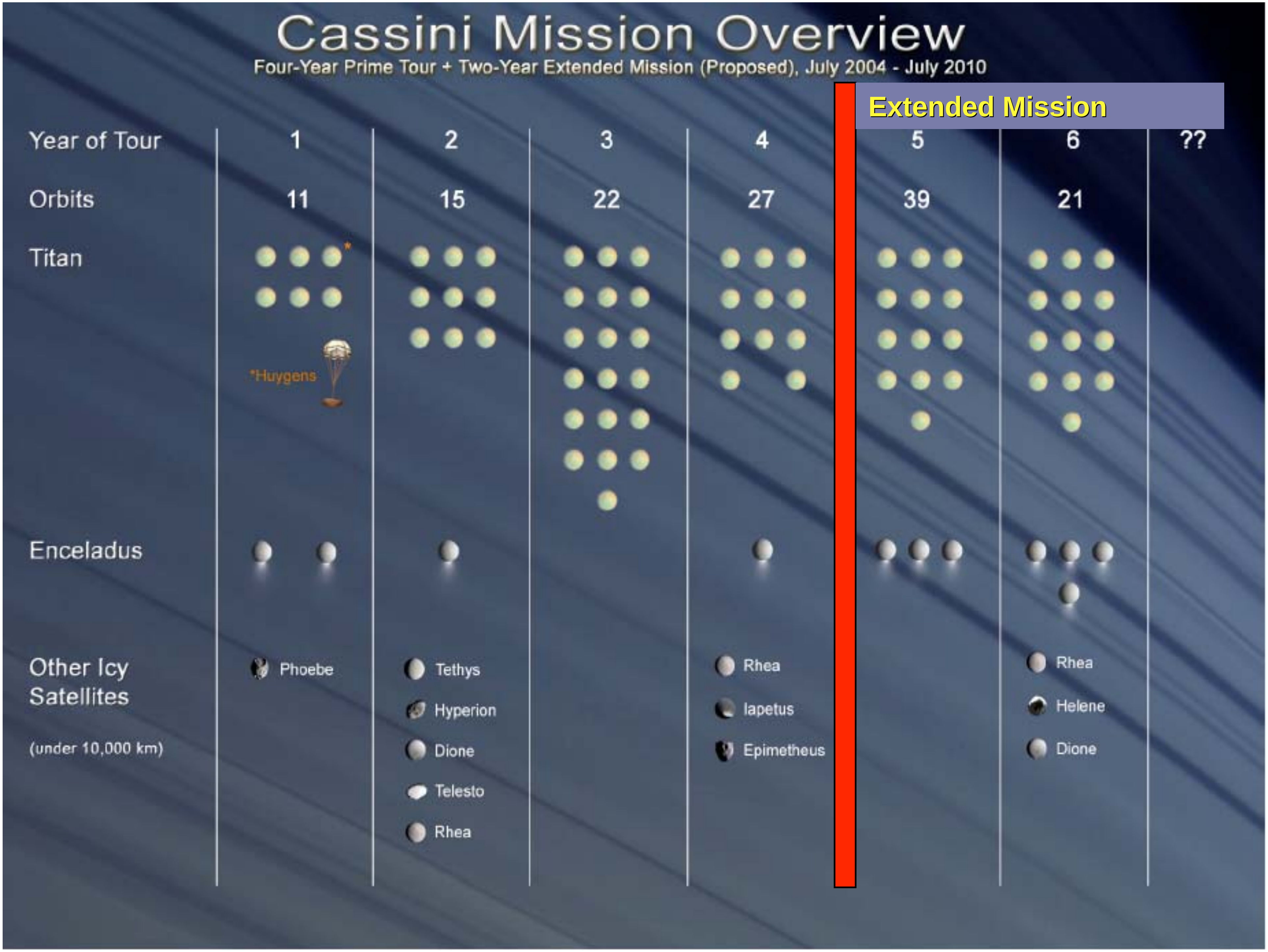
XM 8%

(30% total)



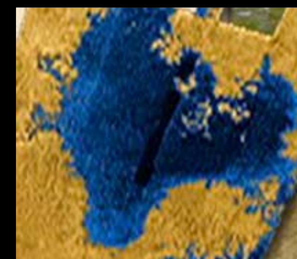
New types of terrain still being uncovered

Gather information to support future missions

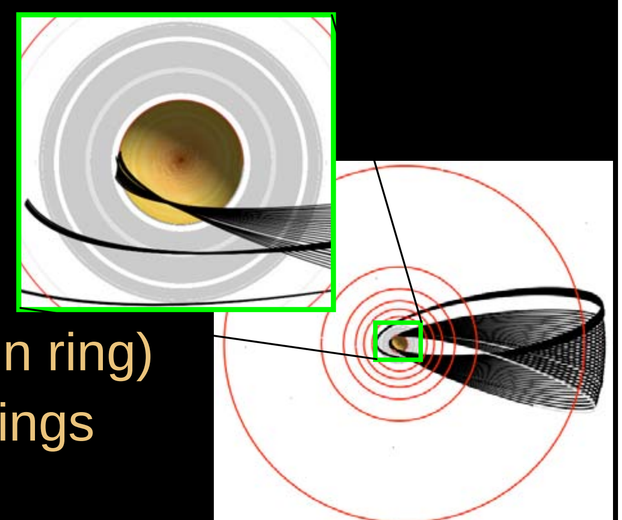


Cassini Mission Overview
Four-Year Prime Tour + Two-Year Extended Mission (Proposed), July 2004 - July 2010
Extended Mission
Year of Tour
1
2
3
4
5
6
??
Orbits
11
15
22
27
39
21
Titan
*Huygens
Enceladus
Other Icy Satellites
(under 10,000 km)
Phoebe
Tethys
Hyperion
Dione
Telesto
Rhea
Rhea
Iapetus
Epimetheus
Rhea
Helene
Dione

Extended-Extended (XXM) Mission Possibilities

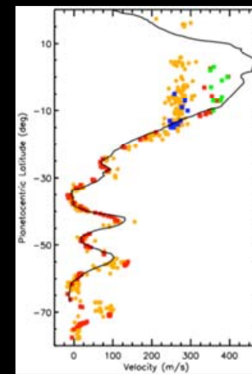


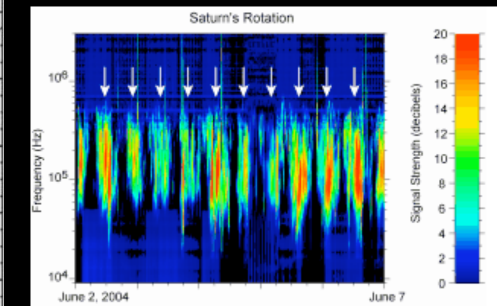
- Key XXM goals
  - Seasonal-Temporal Change
  - New Questions
- Cassini scientists are advocating
  - ~7-year XXM, lasting until Saturn solstice
    - Informally termed Cassini Solstice Mission
  - Juno-like end of mission option
    - Orbit Saturn between D ring and top of atmosphere at “critical inclination”
    - Map magnetic field and gravity field
    - Determine B ring mass (most massive main ring)
    - High resolution optical remote sensing of rings and planet, in situ F&P measurements

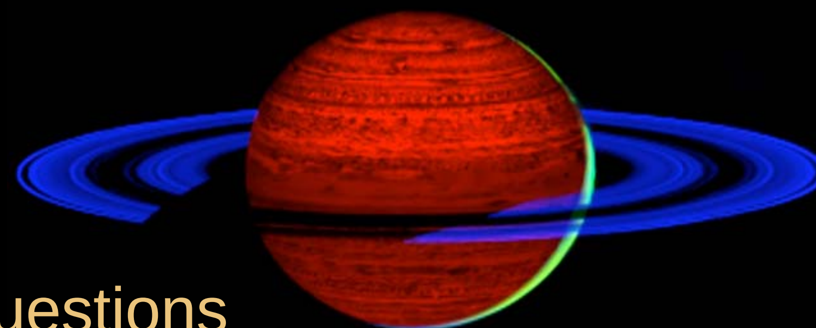


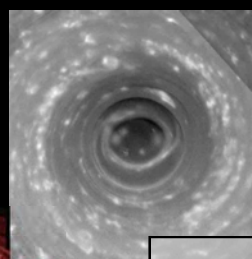
XXM Science Objectives - SATURN

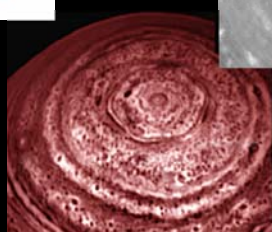
- Seasonal-Temporal Change
  - Observe seasonal variations in temperature, clouds, and composition
  - Observe seasonal changes in the winds at all accessible altitudes

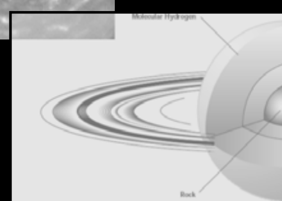


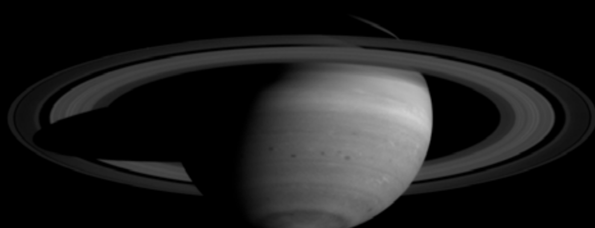








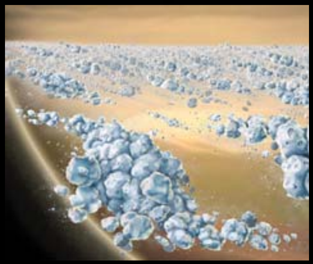


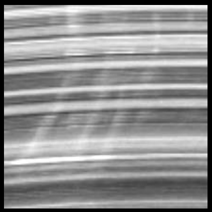


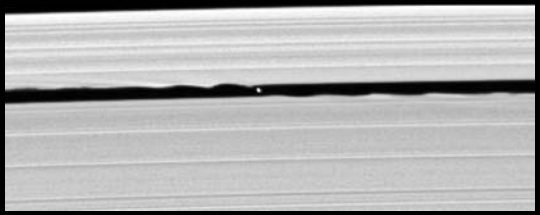
- New Questions
  - Determine Saturn's rotation rate and internal structure
  - Study the life cycles of newly discovered atmospheric waves
  - Measure the spatial and temporal variability of trace gases and isotopes

XXM Science Objectives - RINGS

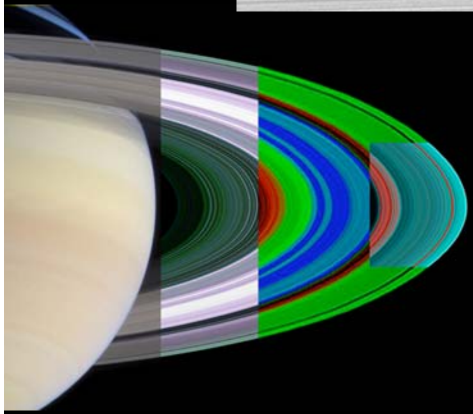
- Seasonal-Temporal Change
  - Determine spoke formation mechanisms, and microscale properties of ring structure
  - Understand time-variability of ring phenomena on decadal timescales

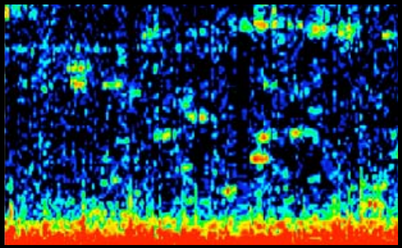






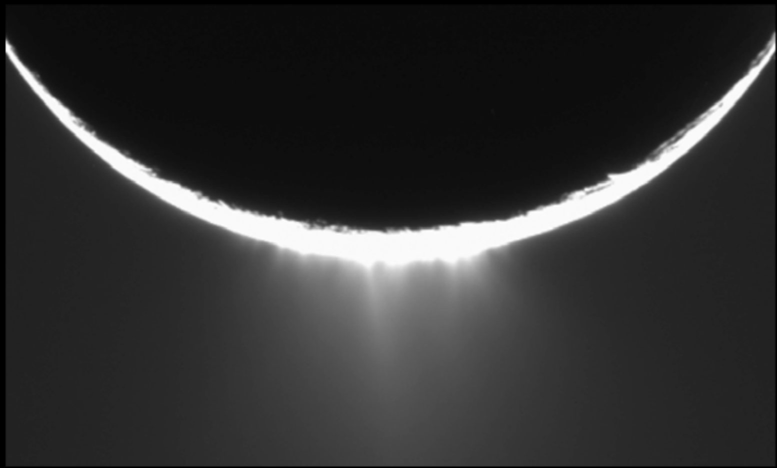
- New Questions
  - Constrain the age of the rings
  - Understand how narrow gaps are cleared
  - Determine particle compositional variations at high resolution

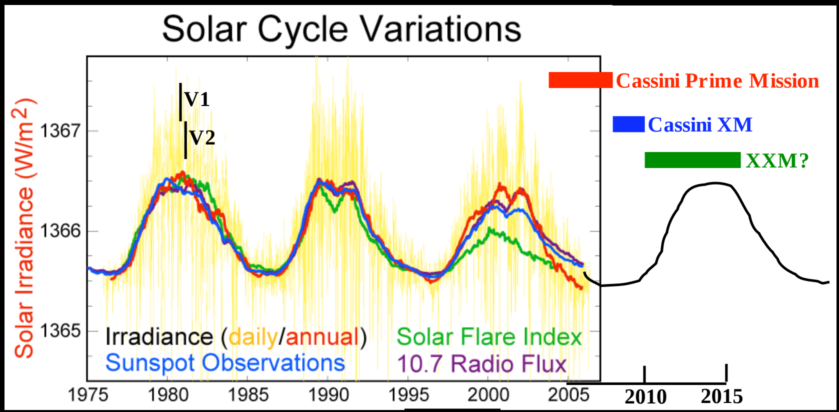


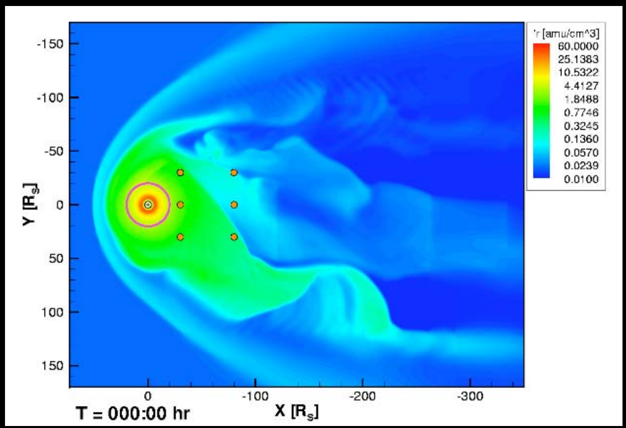


XXM Science Objectives - MAPS

- Seasonal-Temporal Change
  - Determine the variability of Enceladus' plumes
  - Observe Saturn's magnetosphere over a solar cycle

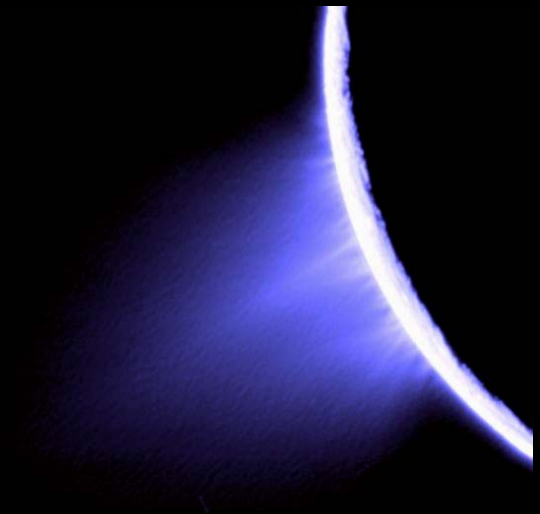




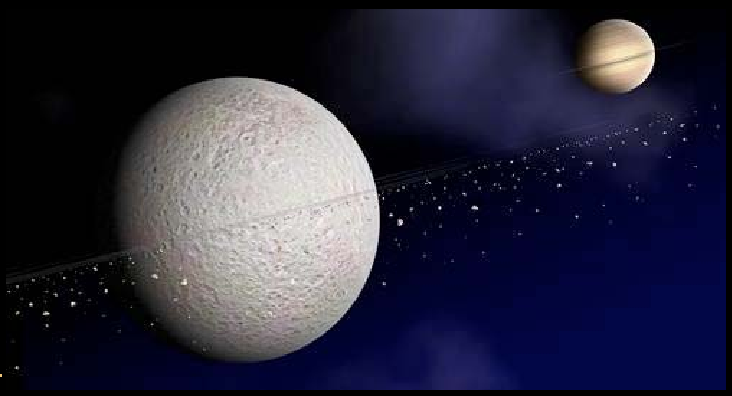


- New Questions
  - Determine the dynamics of Saturn's magnetotail
  - Conduct in situ studies of Saturn's ionosphere
  - Investigate magnetospheric periodicities

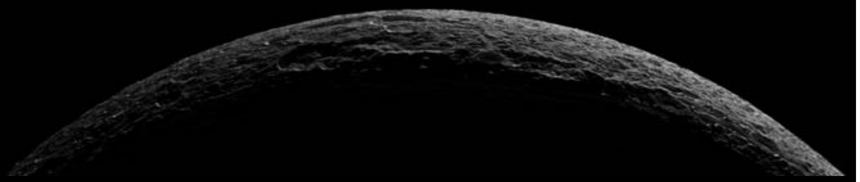
XXM Science Objectives - ICY SATS



- Seasonal-Temporal Change
  - Identify long-term secular and seasonal changes at Enceladus

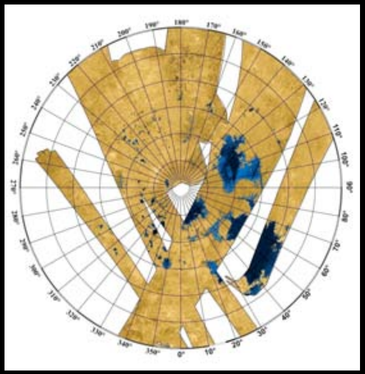


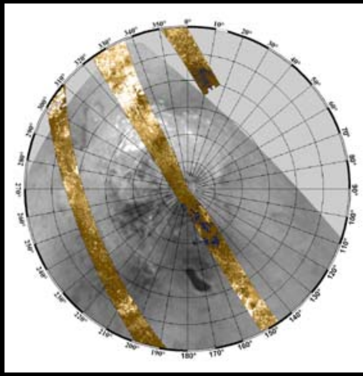
- New Questions
  - Determine the presence of an ocean at Enceladus, and search for possible anomalies in the internal structure
  - Determine whether there is ring material orbiting Rhea
  - Search for low level activity on Dione

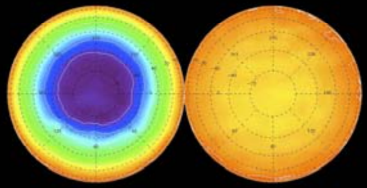


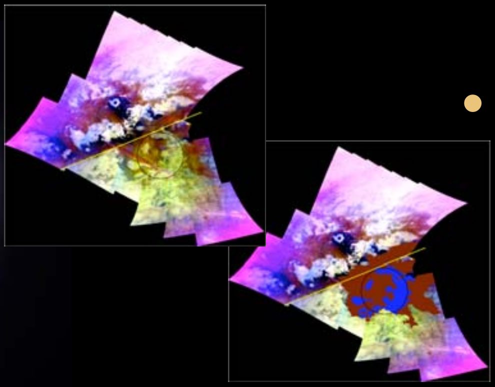
XXM Science Objectives - TITAN

- Seasonal-Temporal Change
  - Determine seasonal changes in the methane/hydrocarbon hydrological cycle
  - Determine seasonal changes in the high latitude atmosphere

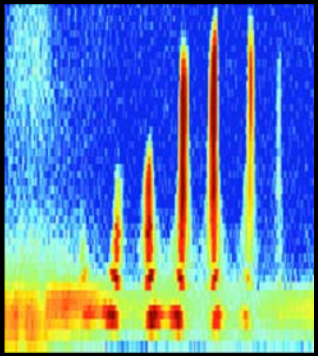








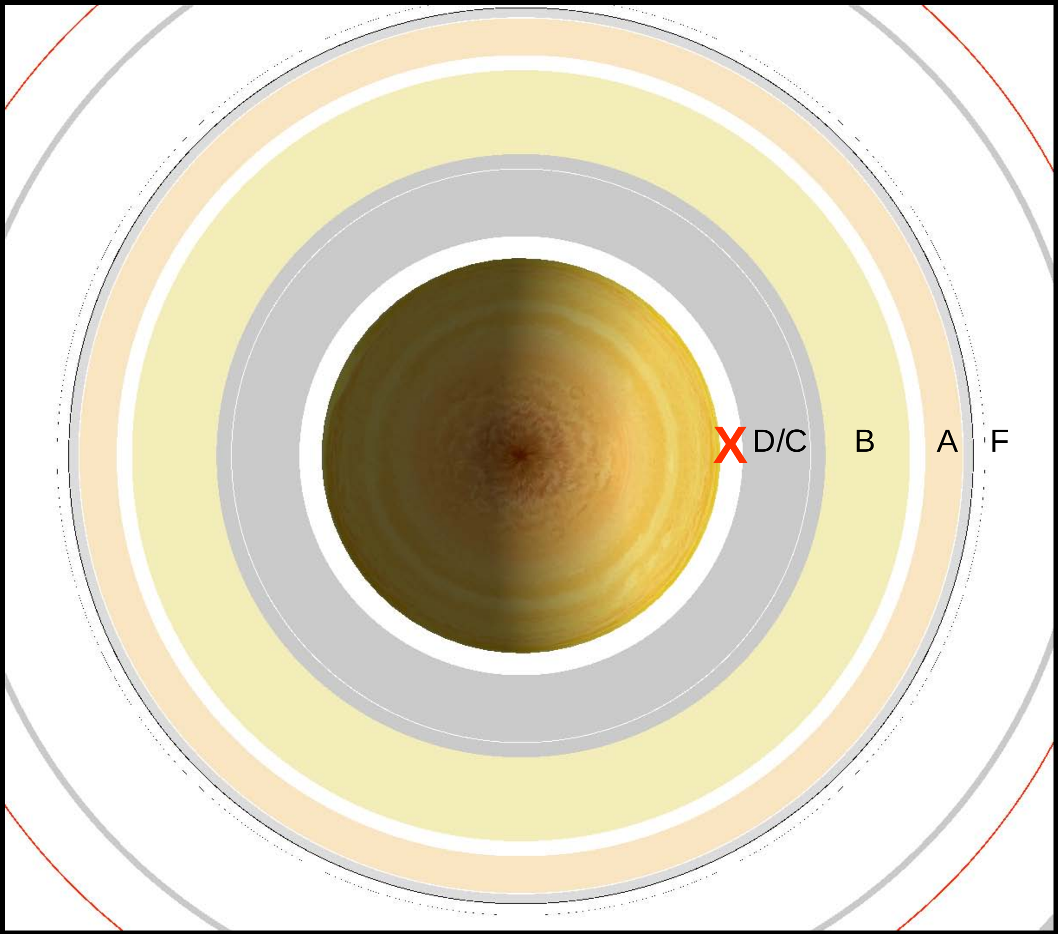
- New Questions
  - Determine the types, composition, distribution, and ages, of surface units
  - Determine internal and crustal structure
  - Measure aerosol and heavy molecule layers and properties



EOM Options with Science Evaluation

Criteria color coded by appeal; dark green = excellent; green = good; yellow = fair; red = poor

Option	Set Up Requirements	Execution Time	Operability + Assurance of EOL	Delta-vee required	Science Evaluation
Saturn Impact – Short Period Orbits	High inclination achievable via any XXM design	2-10 months total	Short time between last encounter and impact	5-30 m/s	D-ring option satisfies unachieved AO goals; cheap and easily achievable



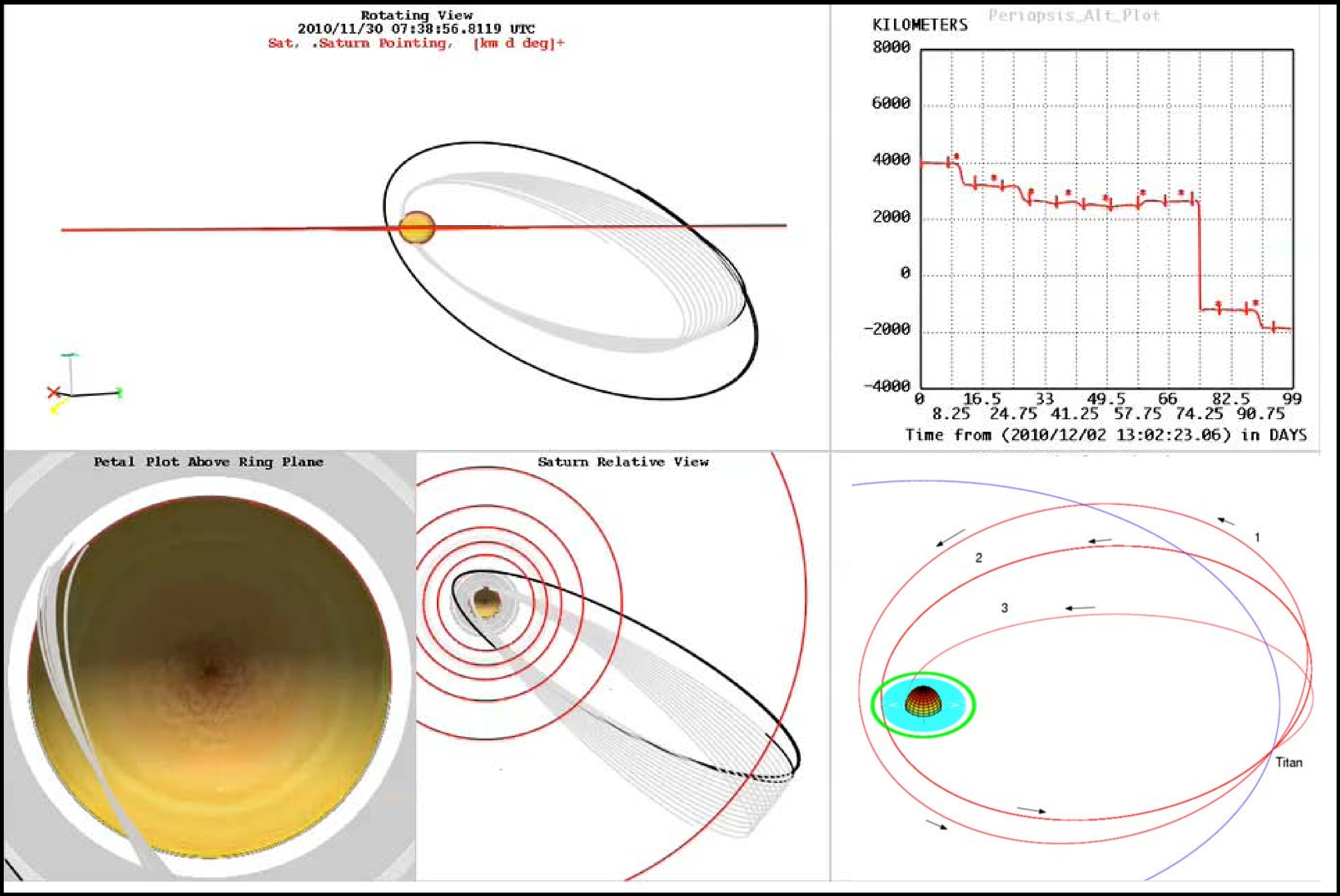
- Inner D-ring radius:
  - ~ 65,000 km
- Upper Extent of Saturn atmosphere:
  - ~ 61800 km (at equator)
- Gap: ~ 3200 km

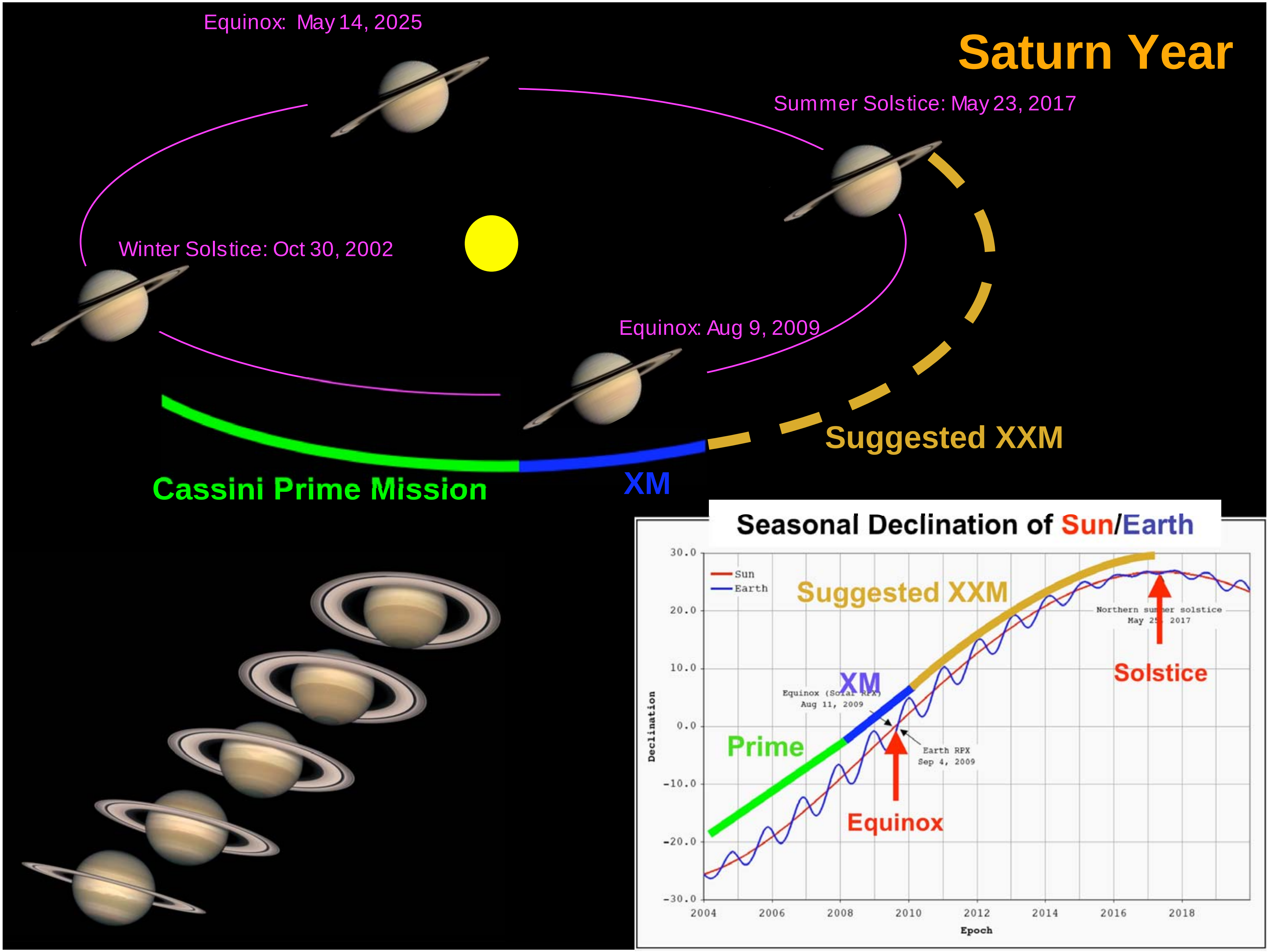
EOM Options with Science Evaluation

Criteria color coded by appeal; dark green = excellent; green = good; yellow = fair; red = poor

Option	Set Up Requirements	Execution Time	Operability + Assurance of EOL	Delta-vee required	Science Evaluation
Saturn Impact – Short Period Orbits	High inclination achievable via any XXM design	2-10 months total	Short time between last encounter and impact	5-30 m/s	D-ring option satisfies unachieved AO goals; cheap and easily achievable
Saturn Impact – Long Period Orbits	Specific orientation and inclination required	4-22 months to set up long period orbit + 3 years for final orbit	Three years between last encounter and impact	5-35 m/s	Operations costs required for 3 years with no science could be applied elsewhere
Impact Icy Satellite	Can be implemented from any geometry	0.5-3 months total	Short time between last encounter and impact	5-15 m/s	Cheap and achievable anywhere/time
Impact Main Rings	Can be implemented from any geometry	0.5-3 months total	Short time between last encounter and impact but difficult to prove spacecraft destruction	5-15 m/s	Cheap and achievable anywhere/time; close-in science before impact
Escape to Gas Giant	Specific orbit period, orientation and inclination required + specific departure dates	1.4-2.4 years to escape + long transfer time (Jup 12y, Ura 20y, Nep 40y)	Planetary impact can only be guaranteed shortly after escape for Jupiter	5-35 m/s	Gas giant science unlikely
Escape to Heliocentric Orbit	Can be implemented from any geometry	9-18 months to escape, open-ended Solar orbit	Last encounter goes to escape	5-30 m/s	Solar wind data only
Escape to Centaur	Large target set offers wide range of departures	1-2 years to escape + 3+ year transfer	Last encounter goes to escape; must maintain teams for 3+ years for Centaur science	5-30 m/s	Multi-year lifetime and funding seems better spent in target-rich Saturnian environment
Stable Orbit Outside Titan	Specific orientation and orbit period required	13-24 months + open-ended time in stable orbit	200 days between last encounter and final orbit	50 m/s	Limited Saturn / magnetospheric science, but for long period of time
Stable Orbit Outside Phoebe	Specific orientation and orbit period required	8+ years + open-ended time in stable orbit	Many months between last encounter and final orbit	120 m/s	Solar wind data; very rare passages through magnetotail

Scientifically interesting end of life option

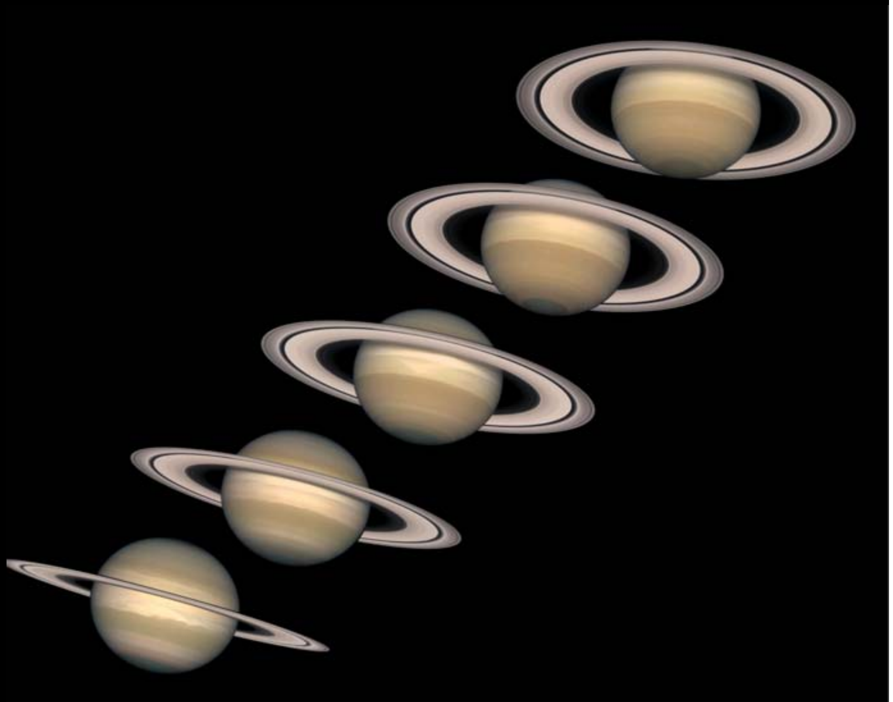




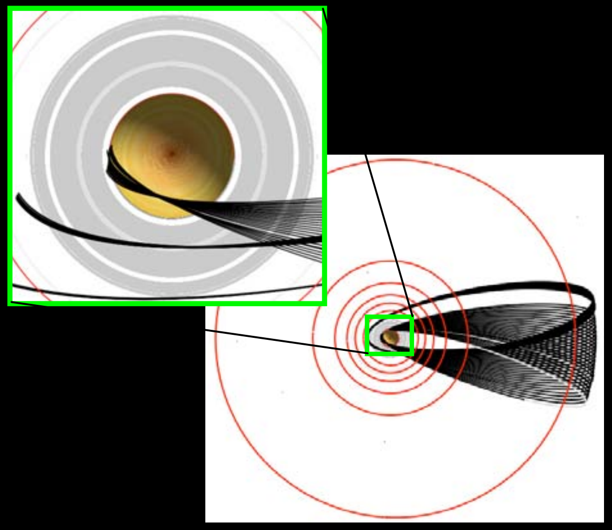
Saturn Year
Equinox: May 14, 2025
Summer Solstice: May 23, 2017
Winter Solstice: Oct 30, 2002
Equinox: Aug 9, 2009
Suggested XXM
Cassini Prime Mission
XM
Seasonal Declination of Sun/Earth
Sun
Earth
Suggested XXM
XM
Prime
Aug 11, 2009
Earth RPX
Sep 4, 2009
Equinox
Solstice
Declination
Epoch
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
2004
2006
2008
2010
2012
2014
2016
2018

Conclusions

- Cassini spacecraft is working well
- Plenty of propellant for XM and XXM
- Important scientific opportunities



We welcome your input!



END

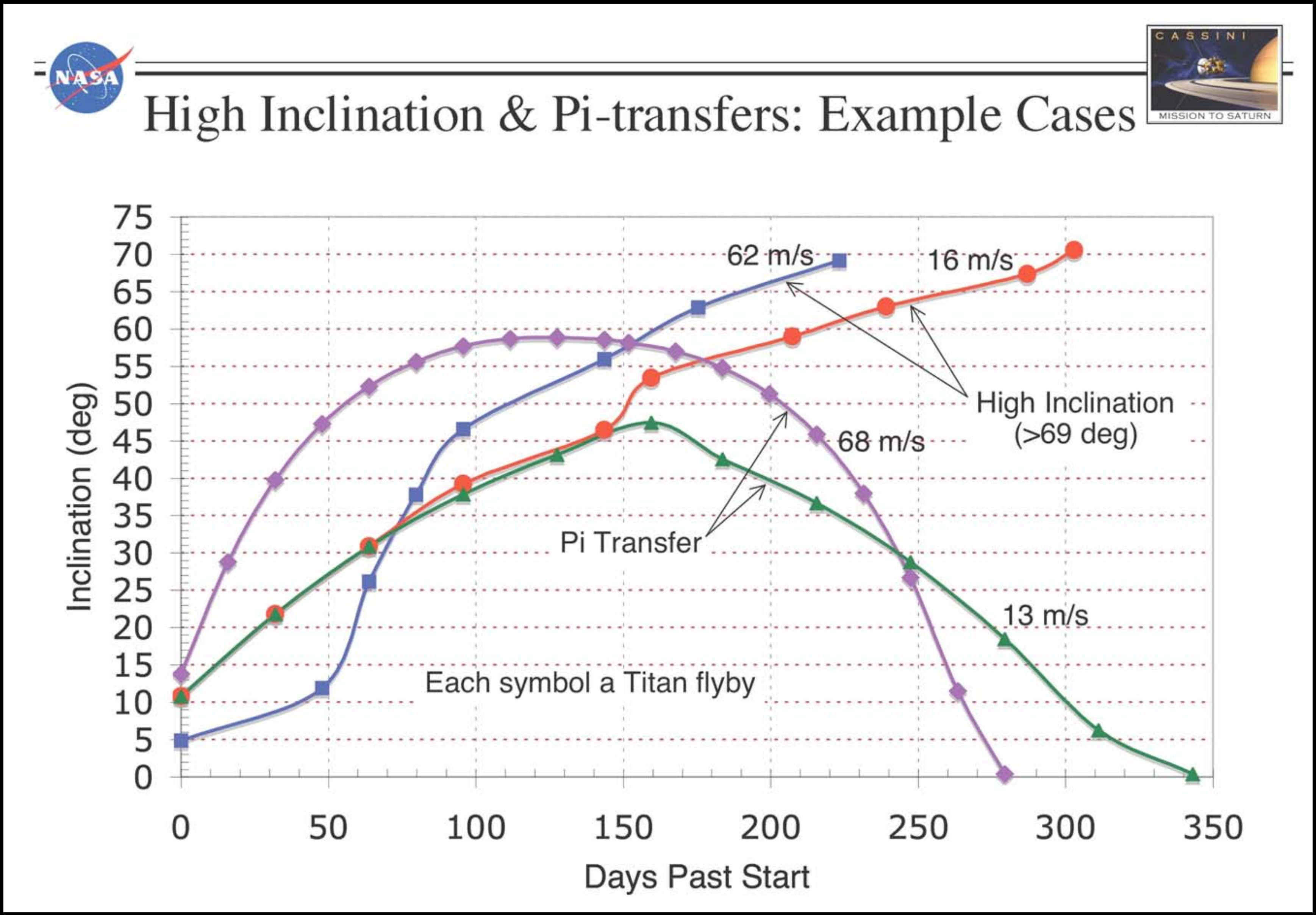
Backup material

Detailed XXM Scientific Objectives

GOAL: Observe seasonal change in the Saturn system, to understand the underlying process and prepare for future missions.

		SATURN	RINGS	MAPS	ICY SATS	TITAN
SEASONAL-TEMPORAL CHANGE	Priority 1	Observe seasonal variations in temperature, clouds, and composition in three spatial dimensions.	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.	Determine the variability of Enceladus' plumes.	Identify long-term secular and seasonal changes at Enceladus, through thermal and visible observations of the polar region.	Determine seasonal changes in the methane/hydrocarbon hydrological cycle: of lakes, clouds, aerosols, and their seasonal transport.
		Observe seasonal changes in the winds at all accessible altitudes coupled with simultaneous observations of clouds, temperatures, composition, and lightning.	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.	Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.		Determine seasonal changes in the high-latitude atmosphere, specifically the temperature structure and formation and breakup of the winter polar vortex.
	Priority 2	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.	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.	Observe seasonal variation of Titan's ionosphere, from one Solstice to the next.		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	Determine Saturn's rotation rate and internal structure despite the planet's unexpected high degree of axisymmetry.	Constrain the age of the rings by determining the meteoroid mass infall contamination rate, and by measuring the ring mass.	Determine the dynamics of Saturn's magnetotail.	Determine the presence of an ocean at Enceladus as inferred from induced magnetic field and plume composition, and search for possible anomalies in the internal structure of Enceladus as associated with plume sources.	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).
		Study the life cycles of Saturn's newly discovered atmospheric waves, south polar hurricane, and newly rediscovered north polar hexagon.	Focus on still-unresolved puzzle of how narrow gaps are cleared, by performing deep searches for small embedded moonlets and studying gap edges.	Conduct *in situ* studies of Saturn's ionosphere	Determine whether there is ring material orbiting Rhea, and if so, what its spatial and particle size distribution is.	Determine internal and crustal structure: Liquid mantle, crustal mass distribution, rotational state of the surface with time, intrinsic and/or internal induced magnetic field.
		Measure the spatial and temporal variability of trace gases and isotopes.	Determine particle compositional variations at high resolution across selected ring features of greatest interest.	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.	Determine whether Dione exhibits low-level activity.	Measure aerosol and heavy molecule layers and properties.
	Priority 2	Observe Saturn's newly discovered lightning storms	Conduct In-depth studies of ring microstructure such as self-gravity wakes, which permeate the rings.	Determine the coupling between Saturn's rings and ionosphere.	Complete the imaging coverage of Iapetus.	Resolve current inconsistencies in atmospheric density measurements (critical to a future Flagship mission).
			Perform focused studies of the evolution of newly discovered "propeller" objects.		Determine whether Tethys contributes to the E-ring.	Determine icy shell topography and viscosity.
					Determine the mass and gravity fields of the icy satellites.	Determine the surface temperature distribution and cloud distribution.
					Observe Hyperion at high resolution.	Determine surface and tropospheric winds.
					Observe Mimas at high resolution.	

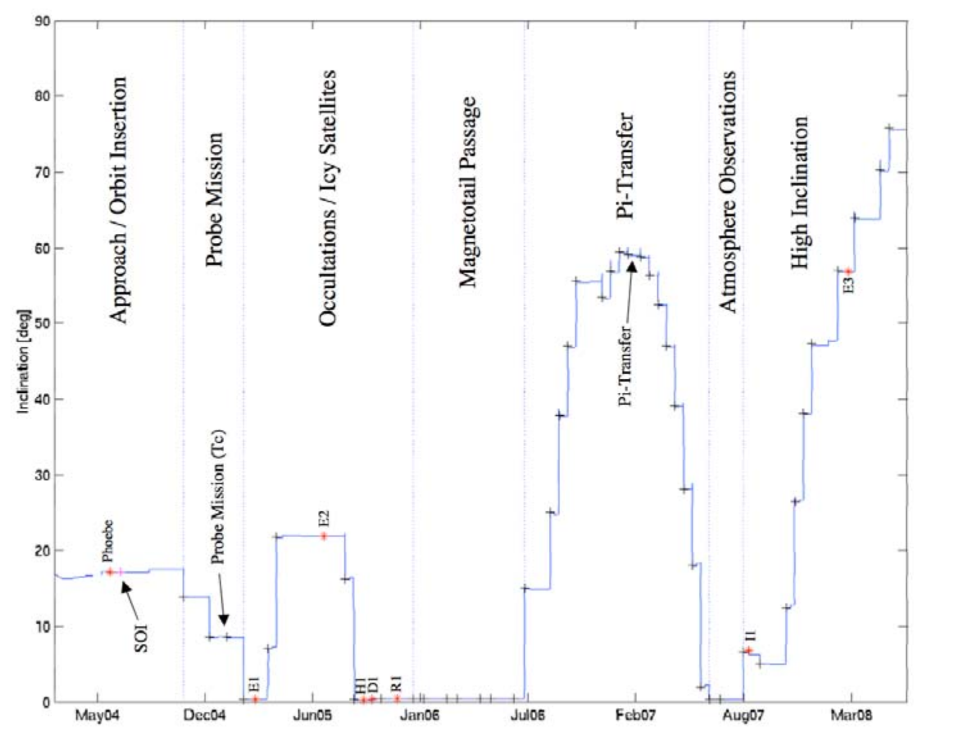
Fuel Efficiency!



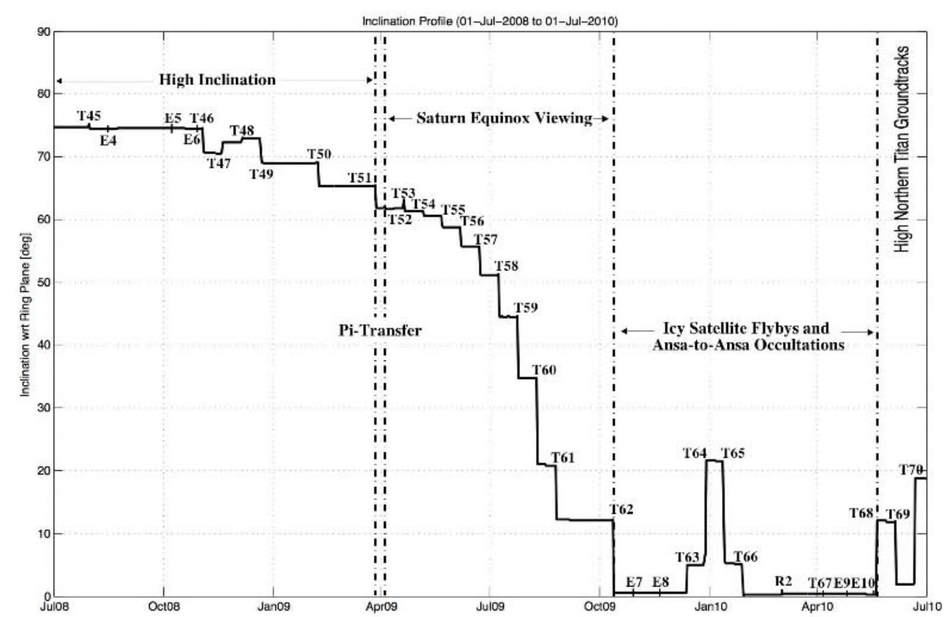
Extended Mission Overview

- 26 Titan flybys
  - 7 dusk encounters, 3 high northern groundtracks, a mid-tail wake crossing, numerous “quality” RSS occultations, separate solar and earth equatorial occultations
- 7 Enceladus flybys less than 2050 km
  - 2 at 25 km, 2 at 100 km, and the others at 250, 1810, and 2030 km
- Additional Icy/Rocky satellite flybys
  - 1 Dione at 500 km (downstream wake flyby), 1 Rhea at 100 km, and 1 Helene at 1500 km
- Inclined two months post-equinox campaign
  - 21.8 degrees at equinox, and 13.2 deg., 25-Aug - 12-Oct
- Three ansa-to-ansa ring/Saturn RSS occultations
- High number of mid-latitude northern hemisphere Saturn occultations, although a lack of high northern occultations.
- 5 equatorial targeted Saturn periapsis passages (i.e. no targeted/pseudo-targeted icy satellite flybys)
- 28 spacecraft orbits with inclination > 64.3 degrees (not including T44-to-T45 4:9 transfer)

Prime and Extended Mission Inclination Profiles



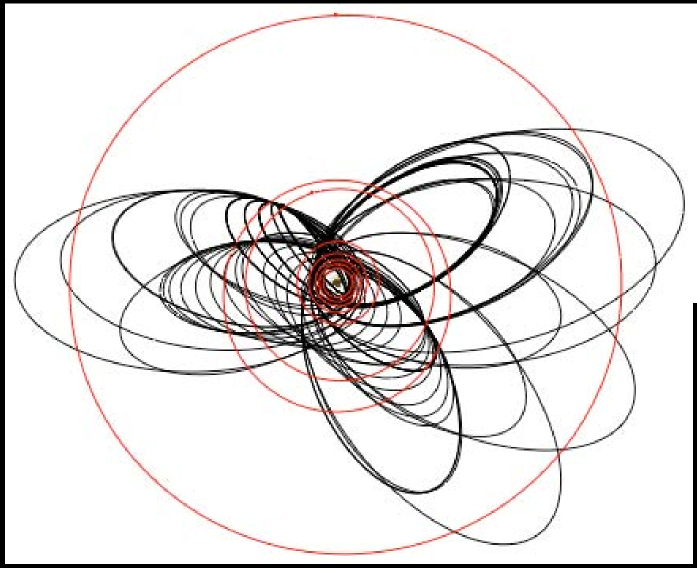
Prime

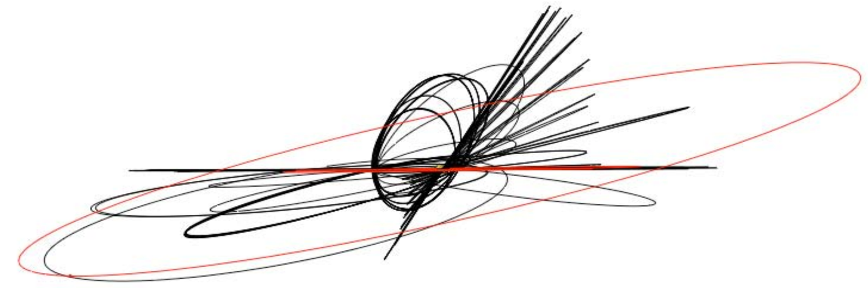


XM

Petal plot comparison

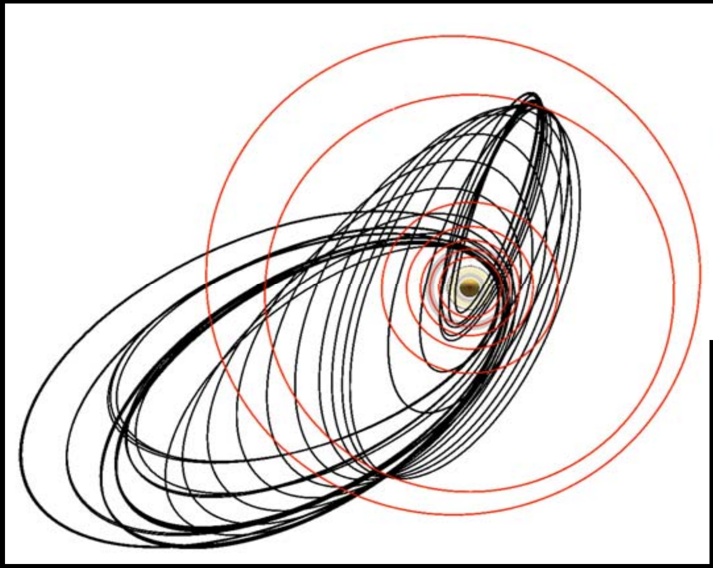
- Prime

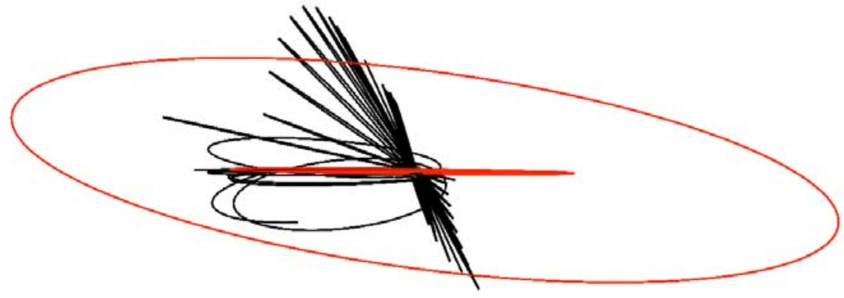




- **Prime**
- **Left: Saturn north-pole view (sun towards top of page)**
- **Top: Saturn equatorial-plane view.**
- **Black – Cassini, Red – Eight inner icy satellites]**

- XM





- **XM**
- **Left: Saturn north-pole view (sun towards top of page)**
- **Top: Saturn equatorial-plane view.**
- **Black – Cassini, Red – Eight inner icy satellites]**