Cassini Equinox and Solstice Missions: Saturn, Rings, Magnetosphere

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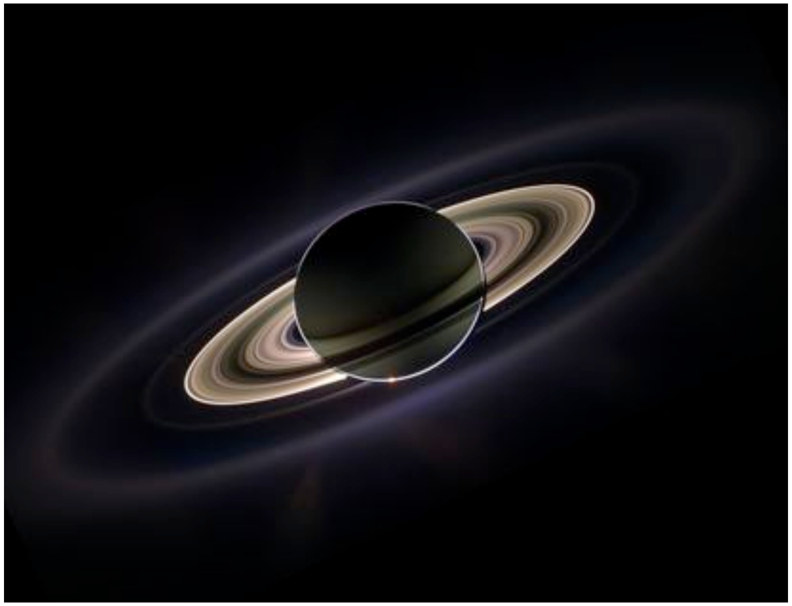
Giant Planets Decadal Panel

24 August 2009

Cassini Equinox and Solstice Science: Introduction

- Cassini's science structure
  - 12 Instrument Teams
  - 9 Interdisciplinary Scientists (IDSs)
  - 5 Disciplines
  - >250 Scientists world-wide
- Outstanding Science Questions
  - Saturn
  - Rings
  - Magnetosphere

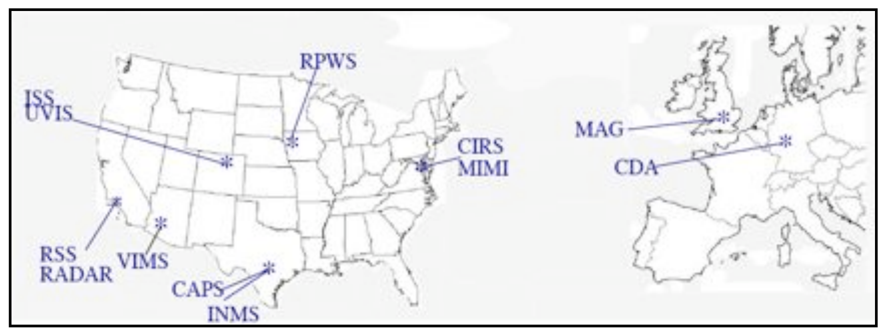


- Proximal Science
- Proposed Solstice Goal:
  - Observe seasonal and temporal change in the Saturn system to understand underlying processes and prepare for future missions.
- Objectives Categories:
  - Seasonal-temporal change
  - New Questions

Cassini's Science Structure: 12 Instrument Teams

Investigation (Acronym)	Principal Investigator (PI) or Team Lead (TL)
Cassini Plasma Spectrometer (CAPS)	D. Young (PI), Southwest Research Institute
Cosmic Dust Analyzer (CDA)	R. Srama (PI), Max Planck Institute
Composite Infrared Spectrometer (CIRS)	M. Flasar (PI), NASA Goddard
Ion and Neutral Mass Spectrometer (INMS)	H. Waite (PI), Southwest Research Institute
Imaging Science Subsystem (ISS)	C. Porco (TL), Space Science Institute
Magnetometer (MAG)	M. Dougherty (PI), Imperial College
Magnetospheric Imaging Instrument (MIMI)	S. Krimigis (PI), Applied Physics Laboratory
Cassini Radar (RADAR)	C. Elachi (TL), Jet Propulsion Laboratory
Radio and Plasma Wave Science (RPWS)	D. Gurnett (PI), University of Iowa
Radio Science Subsystem (RSS)	A. Kliore (TL), Jet Propulsion Laboratory
Ultraviolet Imaging Spectrograph (UVIS)	L. Esposito (PI), University of Colorado
Visible and Infrared Mapping Spectrometer (VIMS)	R. Brown (TL), University of Arizona

- 6 fields and particles teams
  CAPS, CDA, INMS, MAG, MIMI, RPWS
- 4 optical remote sensing teams
  CIRS, ISS, UVIS, VIMS
- 2 teams using high-gain antenna
  RSS, RADAR

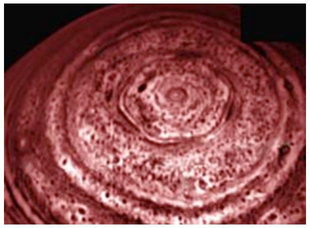


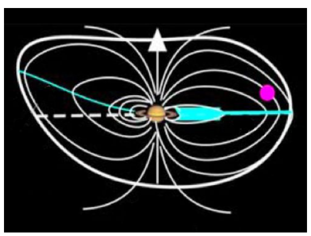
Cassini's Science Structure: 9 Interdisciplinary Scientists

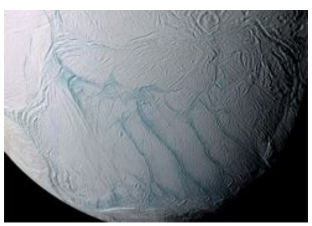
Science Investigation	Scientist, Affiliation
Magnetosphere and Plasma	M. Blanc (IDS), Observatoire Midi-Pyrénées
Rings and Dust	J. Cuzzi (IDS), NASA Ames Research Center
Titan Aeronomy	D. Gautier (IDS), Observatoire de Paris-Meudon
Magnetosphere and Plasma	T. Gombosi (IDS), University of Michigan
Titan Atmosphere and Surface	J. Lunine (IDS), University of Arizona
Atmospheres	T. Owen (IDS), University of Hawaii
Titan Organic Chemistry	F. Raulin (IDS), Université Paris - Val de Marne
Satellites	L. Soderblom (IDS), US Geological Survey
Aeronomy & Solar Wind	D. Strobel (IDS), Johns Hopkins University

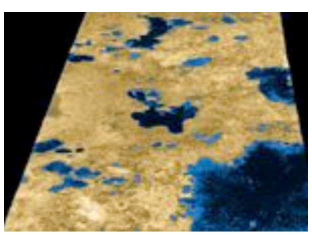
- Interdisciplinary Scientists lead the 5 Cassini Discipline Working Groups.

Cassini's Science Structure: 5 Science Disciplines



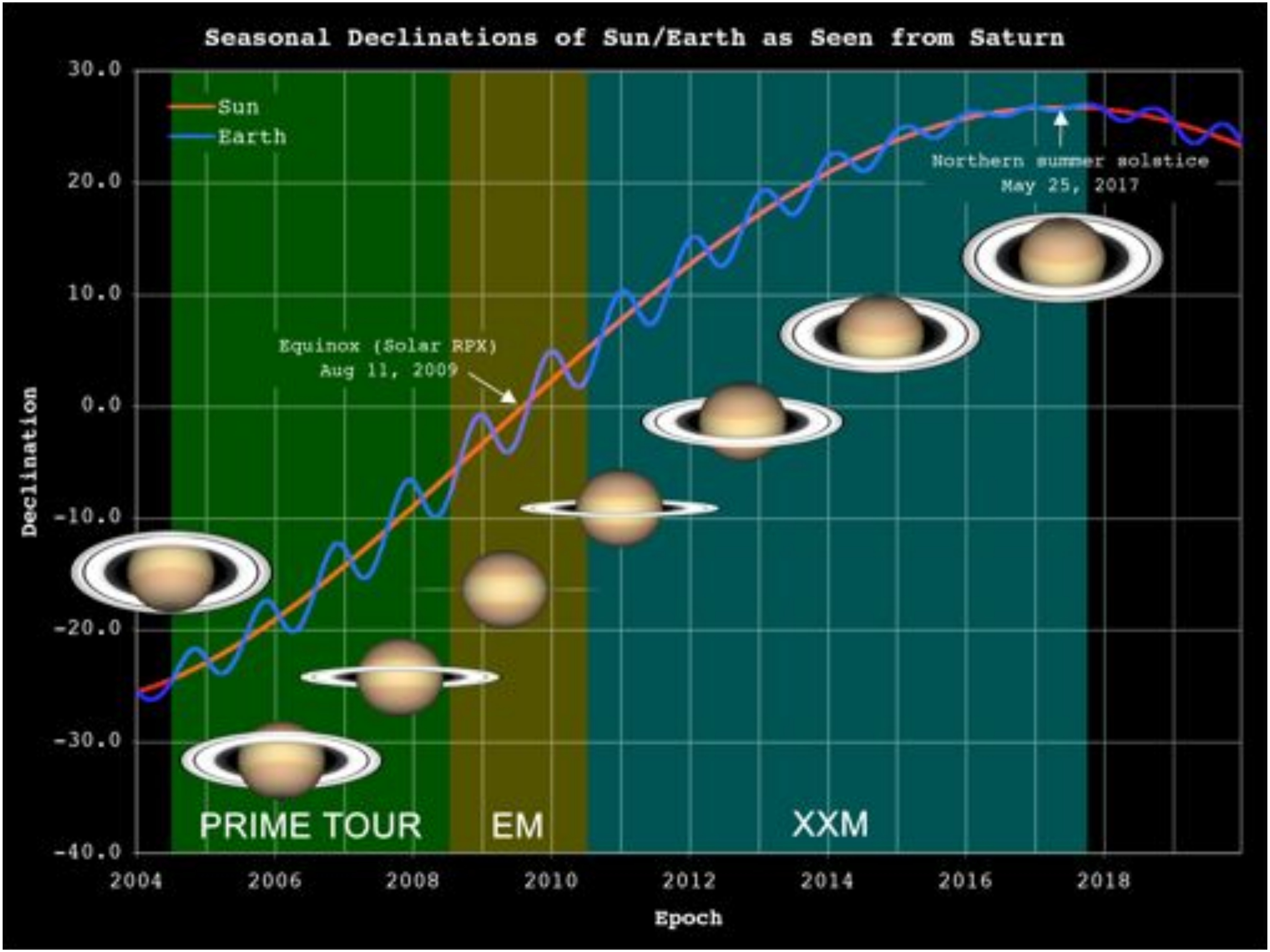






- Saturn
- Rings
- Magnetosphere and Plasma Science (MAPS)
- Icy Satellites
- Titan

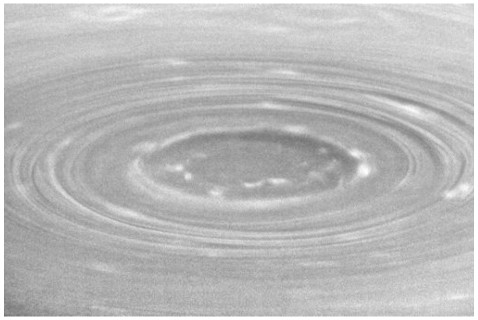
Each discipline is like a mission in its own right!

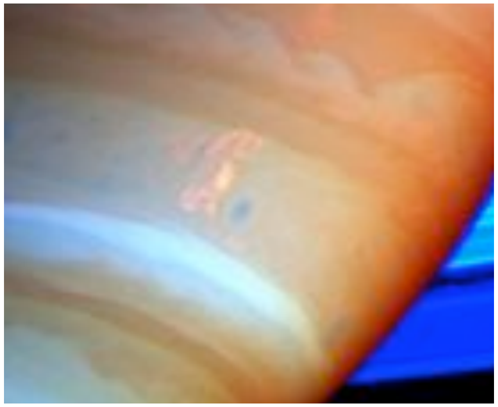

Seasonal Declinations of Sun/Earth as Seen from Saturn
Sun
Earth
Northern summer solstice
May 25, 2017
Equinox (Solar RPX)
Aug 11, 2009
PRIME TOUR
EM
XXM
Declination
Epoch
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
2004
2006
2008
2010
2012
2014
2016
2018

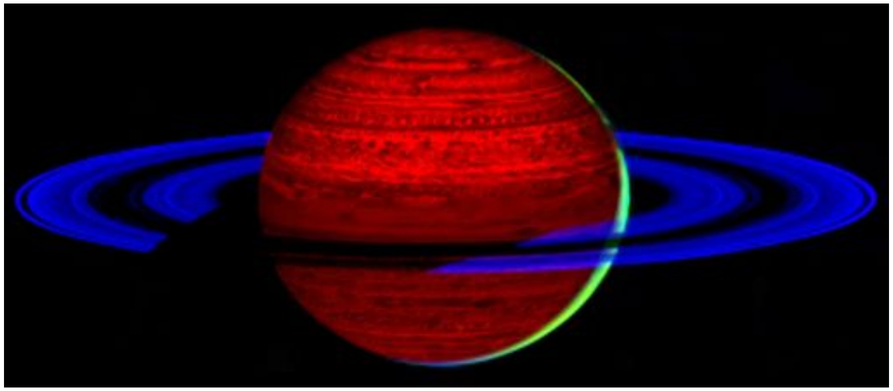
Cassini Mission Overview
Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), July 2004 - July 2017
Prime Mission
Equinox Mission
Solstice Mission
Year of Tour
1 '04-'05
2 '05-'06
3 '06-'07
4 '07-'08
5 '08-'09
6 '09-'10
7 '10-'11
8 '11-'12
9 '12-'13
10 '13-'14
11 '14-'15
12 '15-'16
13 '16-'17
Orbits
11
15
22
27
39
21
16
19
25
12
12
20
56
Titan
Enceladus
Other Icy Satellites (under 10,000 km)
Phoebe
Tethys
Hyperion
Dione
Telesto
Rhea
Rhea
Iapetus
Epimetheus
Rhea
Helene
Dione
G arc
Rhea
Helene
Dione
Dione
Tethys
Methone
Telesto
Rhea
Dione
Tethys
Dione
Epimetheus
G arc
Saturn (seen from Sun)

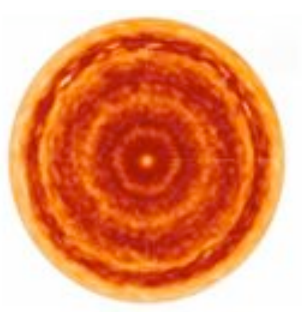
Saturn Discoveries of Prime and Equinox Missions

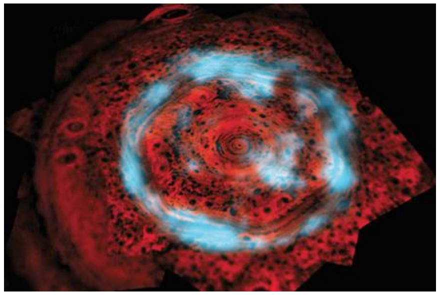
- South Polar "hurricane" found, complete with eye wall
- Lightning storms detected in plasma wave data, confirmed in images
- Deep clouds revealed below the visible layers by thermal emission at 2 cm and VIMS 5-micron imaging reveals and gases below the visible layers
- Giant hexagon circling the north pole is re-discovered after going unobserved since Voyager discovered it in 1981
    - Alternation in zonal wind velocity at equator is analogous to Earth's Quasi-Biennial Oscillation (QBO)





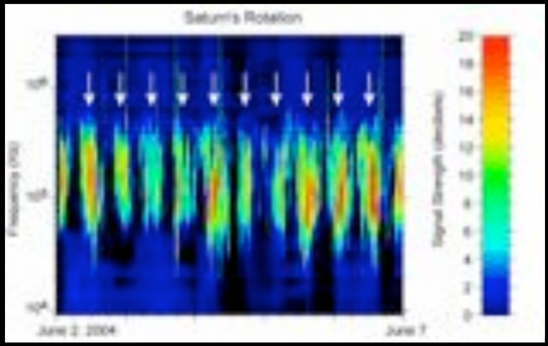




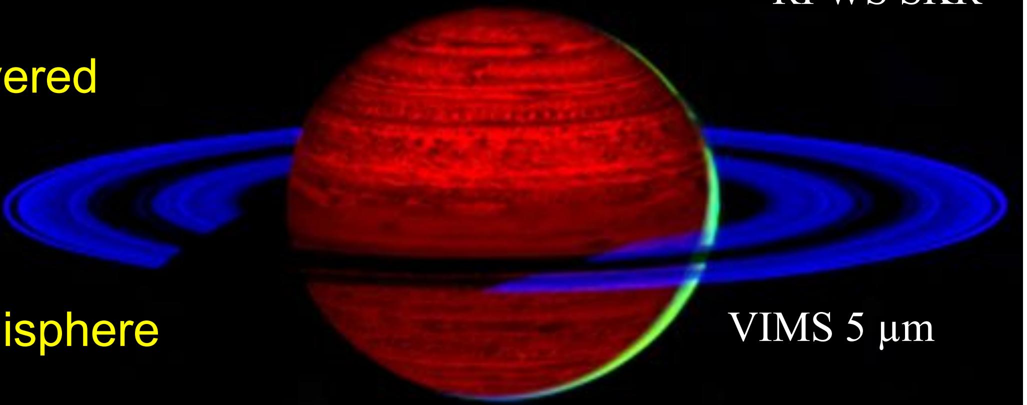


Equinox Mission Science Objectives: Saturn

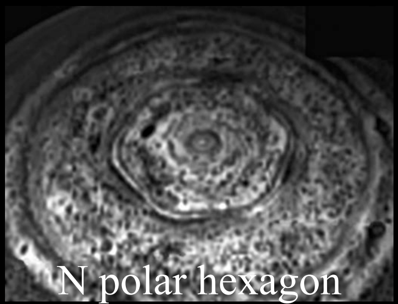
- Search for non-zonal components of magnetic field and determine internal rotation of Saturn
- Image deep atmosphere below visible clouds using IR and cm wavelengths
- Study changes in the clouds, temperatures, composition, and winds during the transition to northern spring
- Study the evolution of newly discovered atmospheric features
- Monitor changes in the auroras with seasons and solar cycle
- Increase coverage of northern hemisphere as it emerges from behind rings
- Monitor lightning storms, which are rare occurrences, when and if they appear



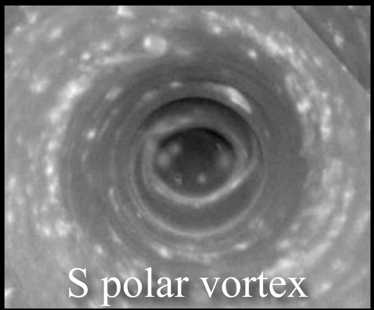
RPWS SKR



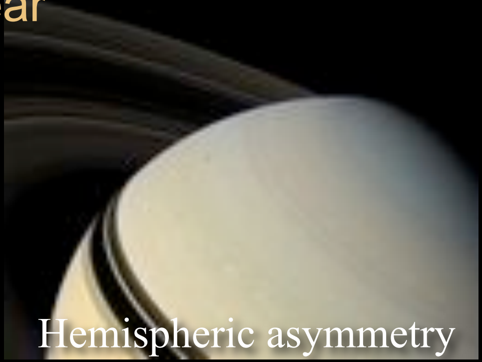
VIMS 5 µm



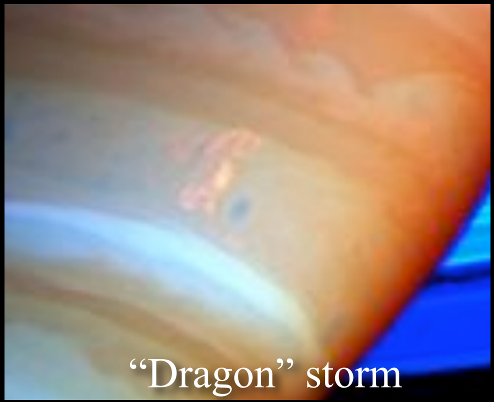
N polar hexagon



S polar vortex



Hemispheric asymmetry



“Dragon” storm

Saturn Science Goals and Objectives for CSM

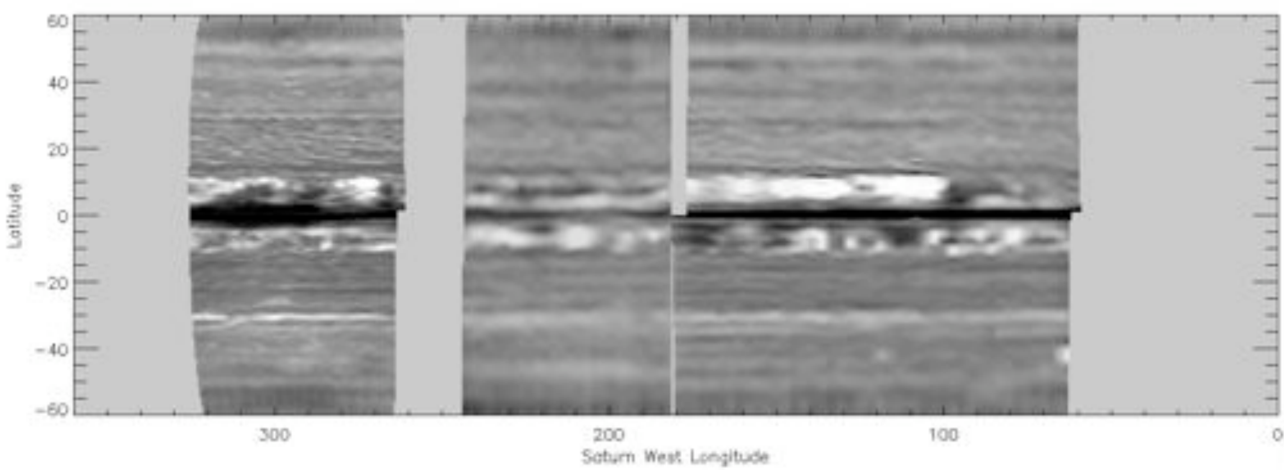
Seasonal/Temporal Variations

- **SC1a**. *Seasonal variations in temperature, clouds and composition* Observe seasonal variations in temperature, clouds, and composition in three spatial dimensions.
- **SC1b**. *Seasonal changes in winds* Observe seasonal changes in the winds at all accessible altitudes coupled with simultaneous observations of clouds, temperatures, composition, and lightning.
- SC2a. *Variations in magnetosphere, ionosphere and aurora* Observe magnetosphere, ionosphere, and aurora as they change on all timescales – minutes to years – and are affected by seasonal and solar cycle forcing.

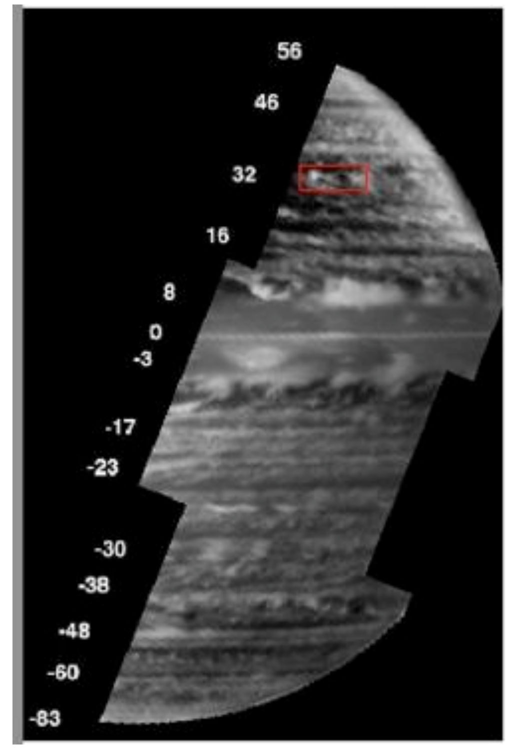
New Questions

- **SN1a**. *Saturn rotation rate and internal structure* Determine Saturn's rotation rate and internal structure despite the planet's unexpected high degree of axisymmetry.
- **SN1b**. *Atmospheric waves* Study life cycles of Saturn's newly discovered atmospheric waves, south polar hurricane, and newly rediscovered north polar hexagon.
- **SN1c**. *Trace gases and isotopes* Measure the spatial and temporal variability of trace gases and isotopes.
- SN2a**.** *Lightning* Observe Saturn’s newly detected lightning storms

SC1a. Seasonal variations in temperature, clouds, and composition



- Thermal emission at 2 cm – a new view of Saturn
- Bright areas: low ammonia abundance
- Dark band at equator is due to rings



VIMS 5-micron imaging in thermal emission reveals deep clouds below the visible layers

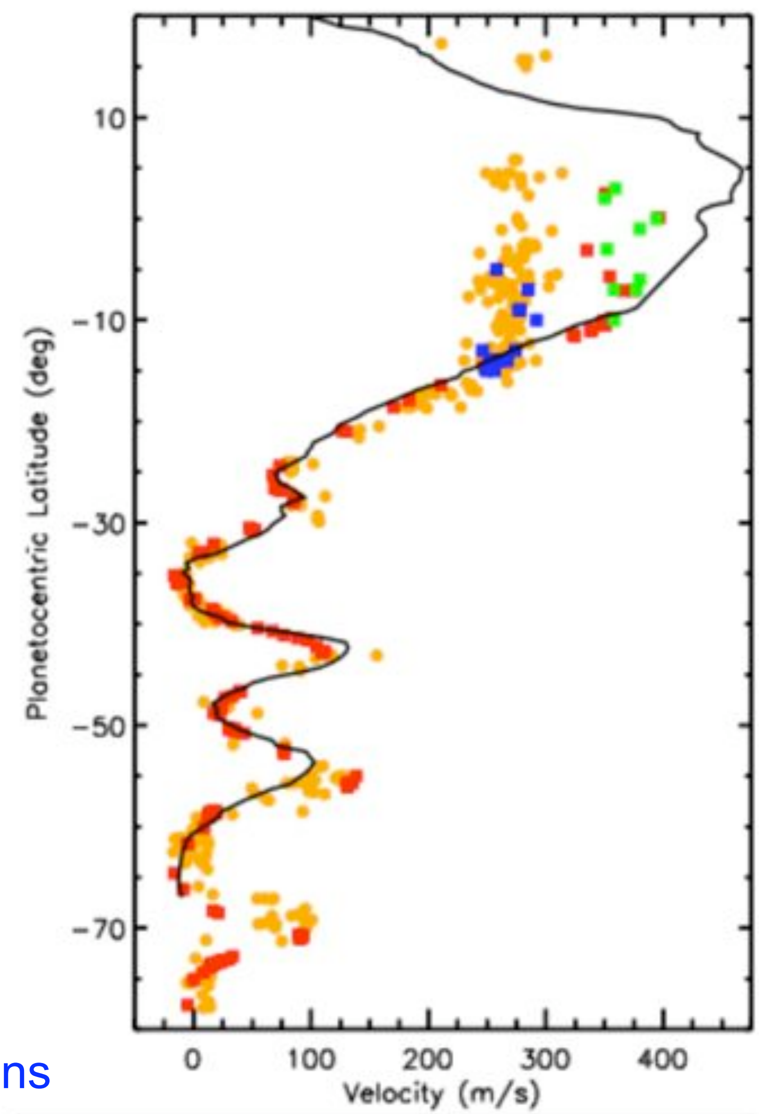
SC1b. Seasonal changes in the winds

Winds are measured relative to the internal rate of rotation

Are the winds changing, or are we seeing wind shear?

Black line: Voyager
Orange: HST

Red & Green: ISS Cassini continuum
Blue: ISS Cassini methane

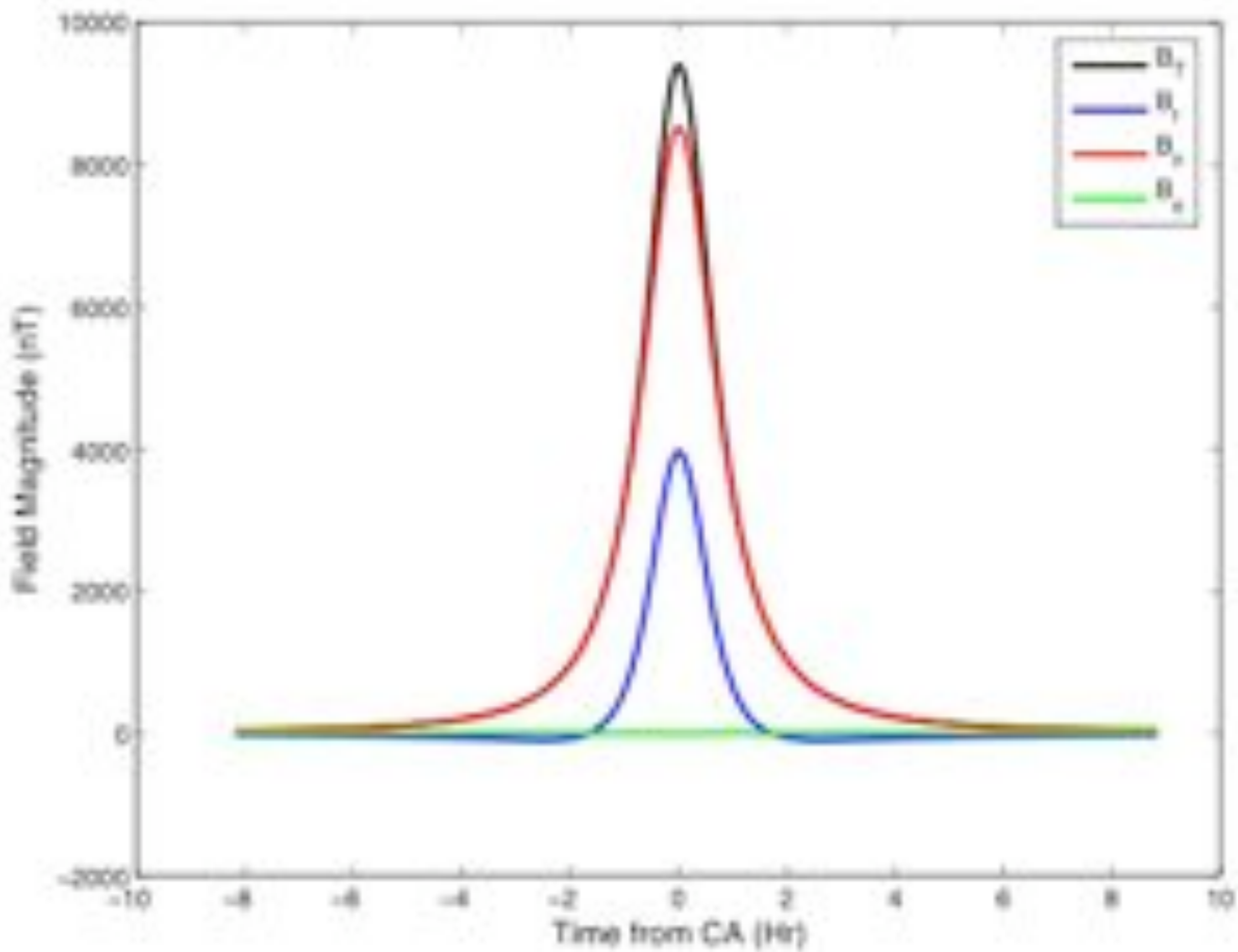


SN1a. Saturn's rotation rate and internal structure

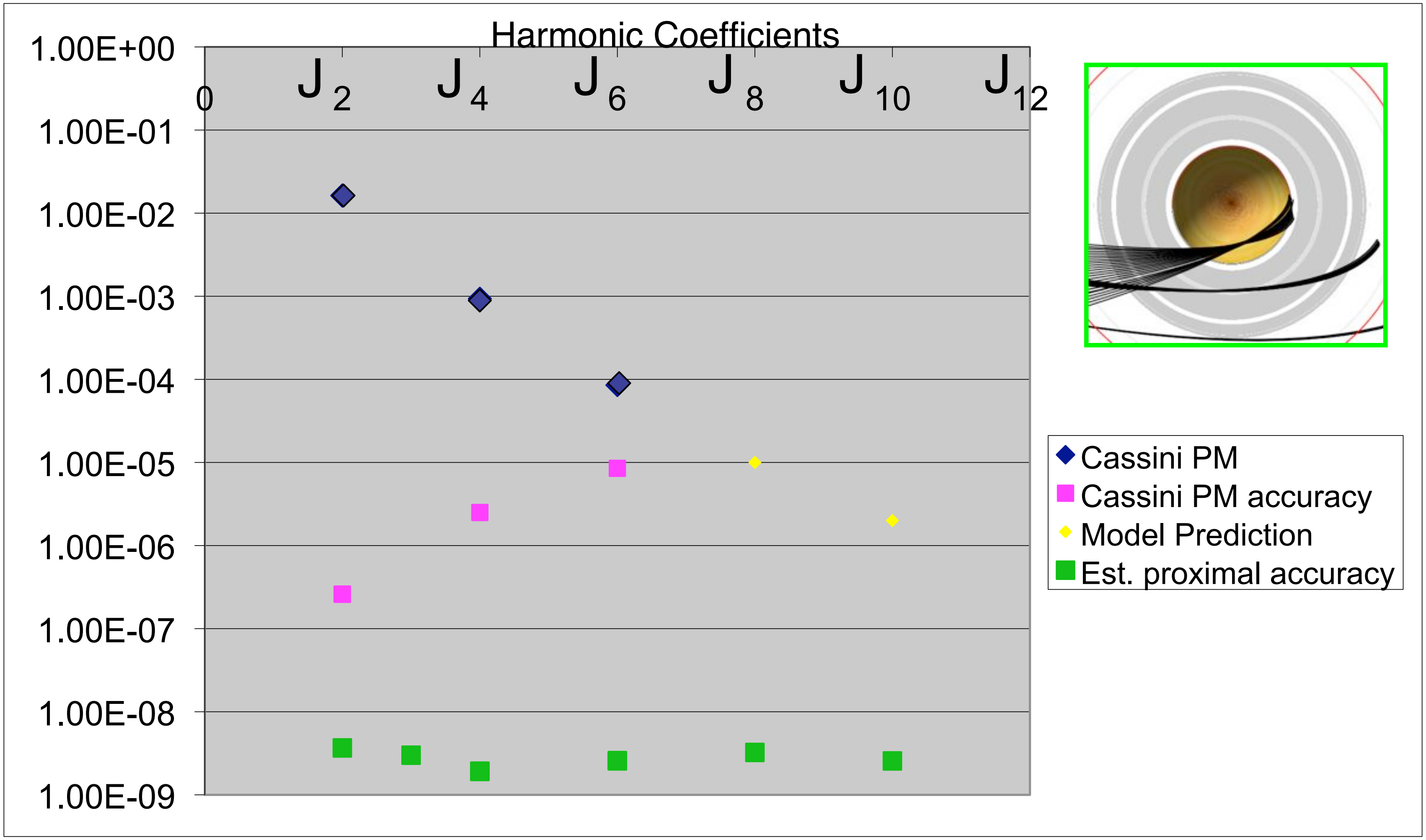
MAG data during Saturn Orbit Insertion – field is axisymmetric

Deep rotation rate still unknown

Measure during end-of-mission Orbits to degree 6



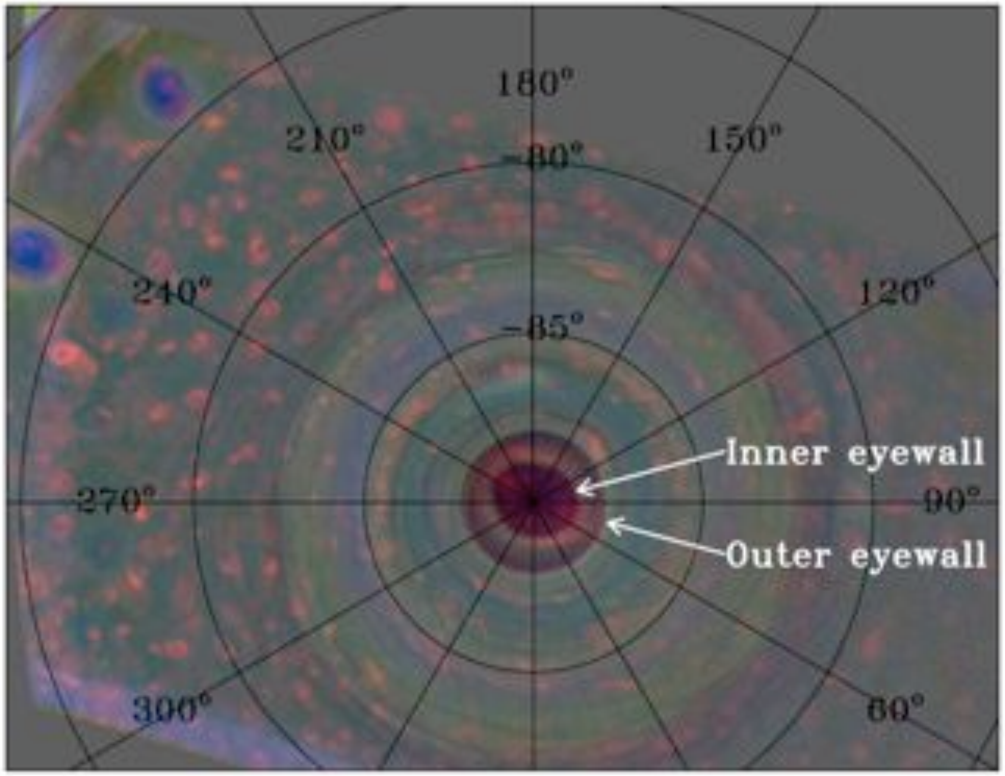
SN1a. Saturn Internal Structure: Gravity Harmonics

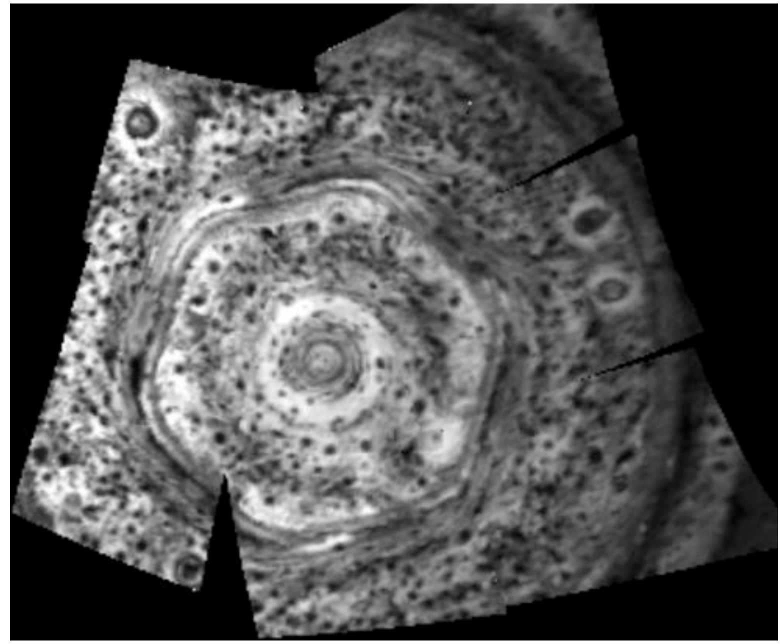


- Saturn gravity harmonics (zonal) up to degree 10 can be estimated with an accuracy < 10^{-8} (with multiarc solution using 6 proximal orbits for gravity passes)

New Questions

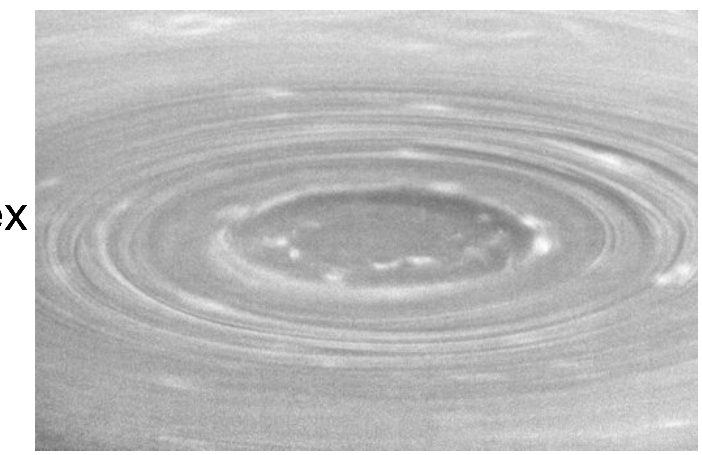
SN1b. Atmospheric waves, south polar hurricane, and north polar hexagon





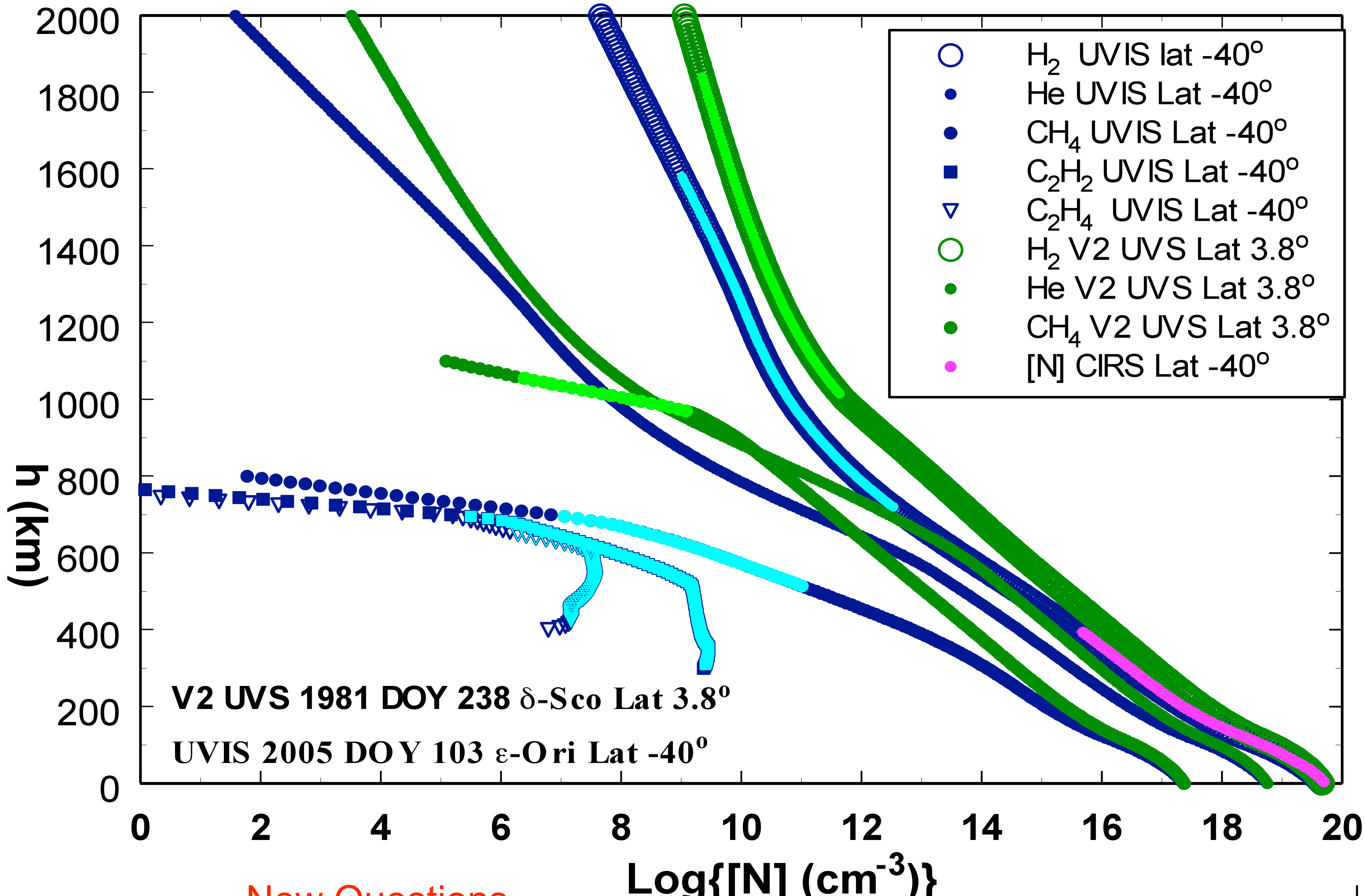
North polar hexagon

South polar vortex



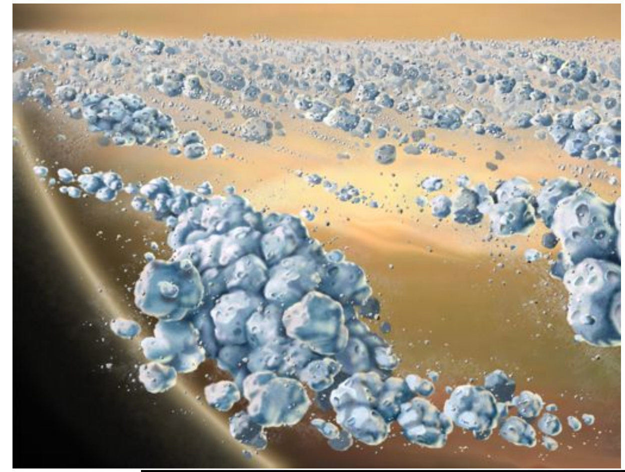
New Questions

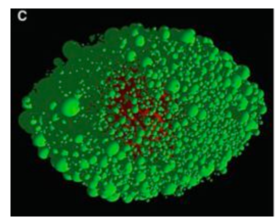
SN1c. Spatial and temporal variability of trace gases and isotopes

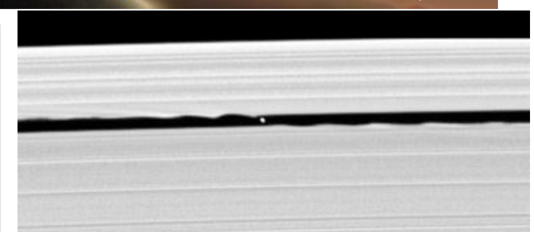


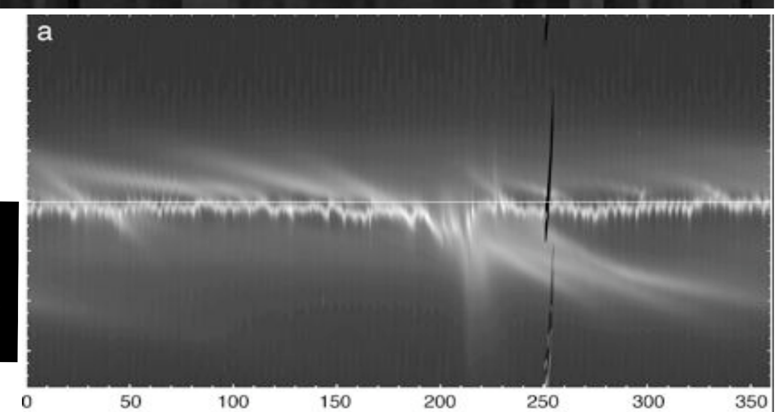
Ring Discoveries of Prime and Equinox Missions

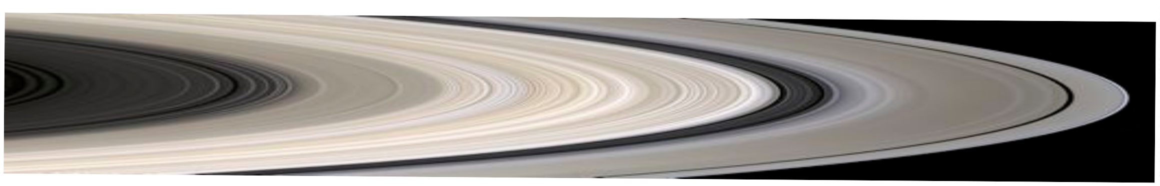
- Ring microstructure on length scales of 10 – 100 m permeates moderate optical depth rings (A and B rings)
- Vertical thickness of main ring (A, B, C, Cassini Division) is only 10 – 30 meters
- Masses of close in moons determined
  - Densities ~ 0.5 g/cm^3; some objects are rubble piles
- TIny moon Daphnis (3.5 km radius) found in Keeler gap in outer A ring
- New dusty rings found co-orbiting with most close in moons
- Propeller objects, the signature of 100 – 500 m ring particles, reside in the A ring
- Narrow F ring is dynamically chaotic, varying on timescales of days, weeks, years and decades
  - Unseen objects move through F ring causing jets and spikes





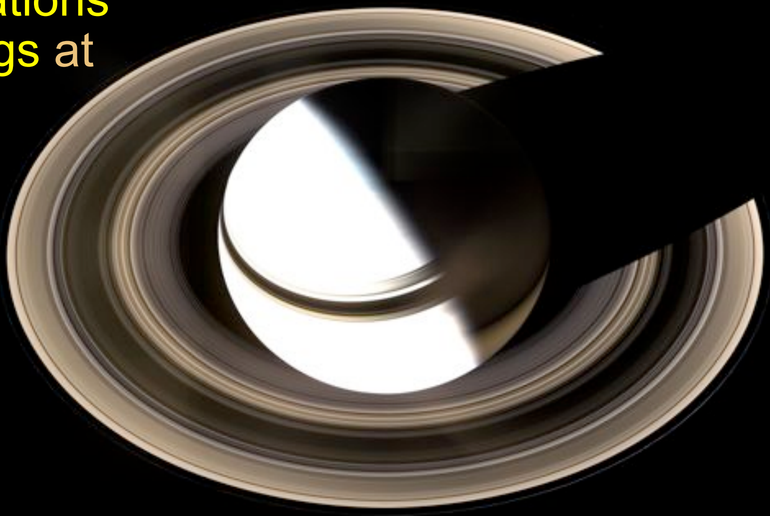


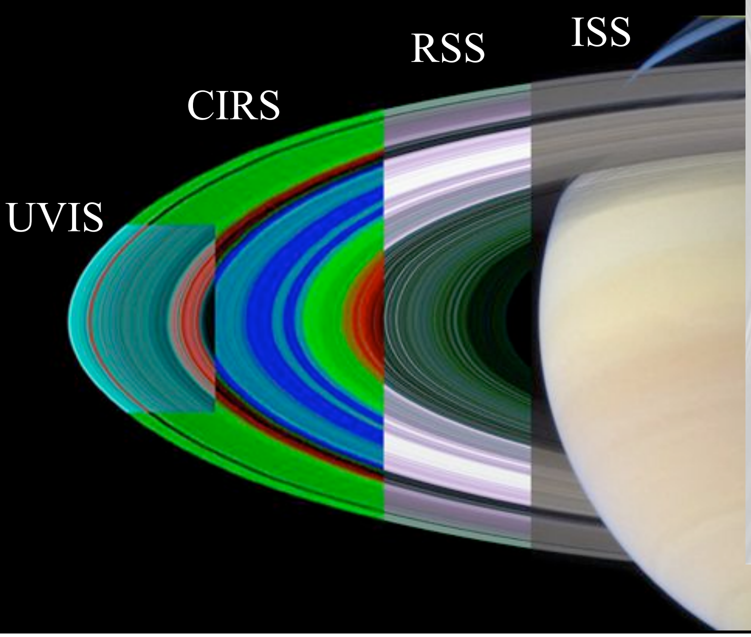




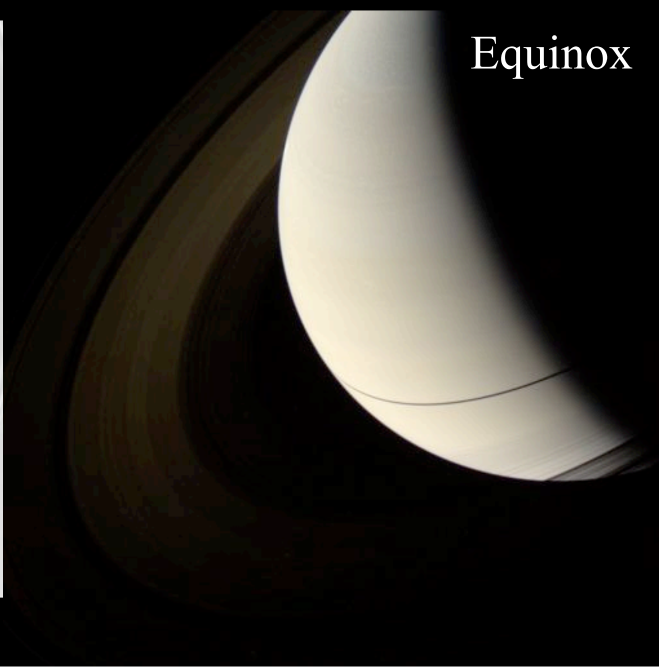
Equinox Mission Science Objectives: Rings

- Use unique low-solar-incidence angle observations to study three-dimensional structure of the rings at visible, near-IR, and thermal wavelengths, provided by solar equinox geometry, search for embedded moonlets, and observe the seasonal evolution of spokes;
- Probe low optical depth regions and ring microstructure by radio and stellar occultations;
- Constrain incoming meteoroid flux by conducting a close flyby of Rhea.





Encke gap with Pan ringlet



Ring Science Goals and Objectives for CSM

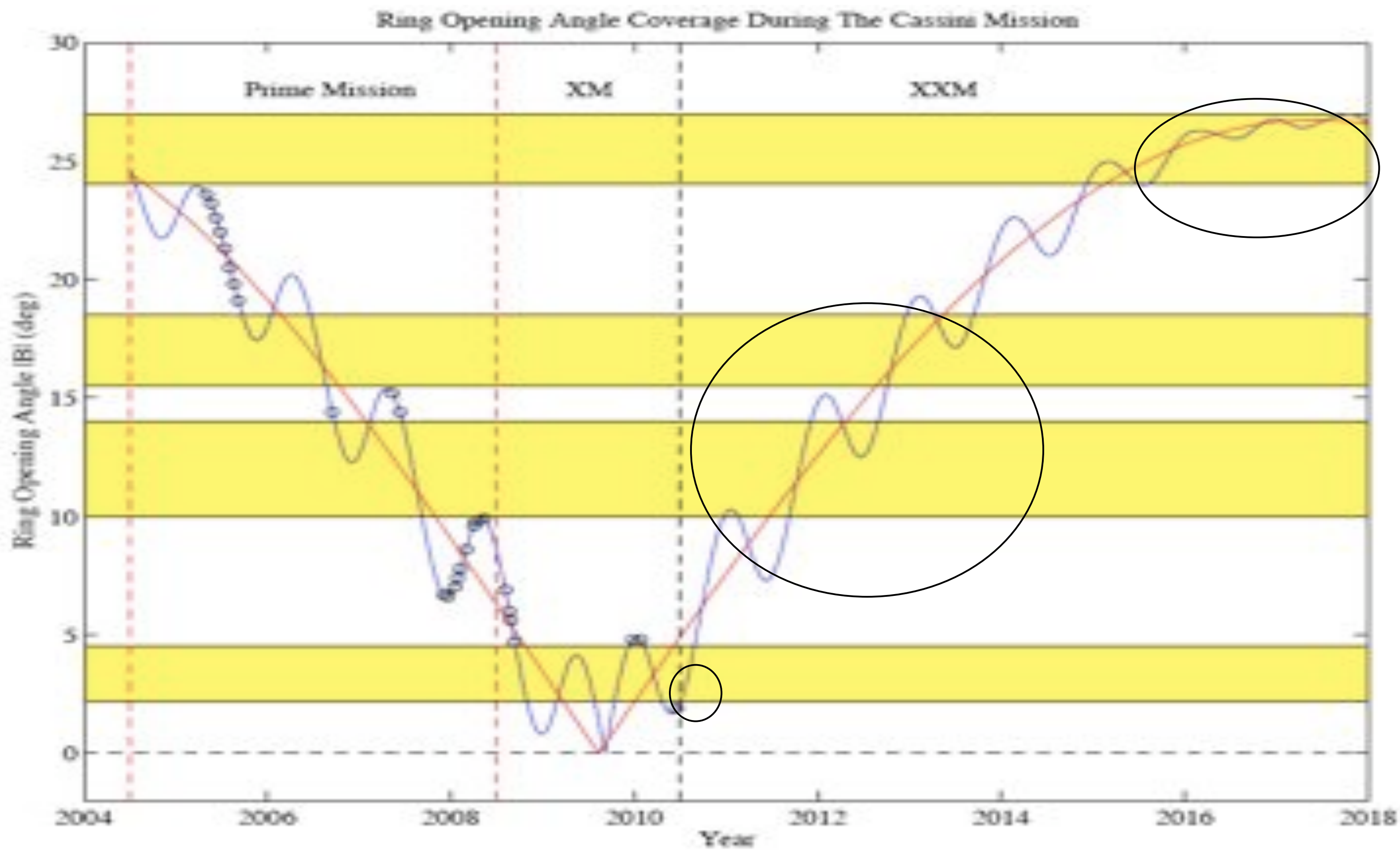
Seasonal/Temporal change

- **RC1a**. *Seasonal change* Determine production mechanism of spokes, and microscale properties of ring structure, by observing the seasonally maximum opening angle of the rings near solstice.
- **RC1b.** *Temporal Change* Understand time variability of ring phenomena on decadal timescales (Encke gap, D ring, ring edges, etc.) by substantially increasing time baseline of observations.
- RC2. *F Ring campaign* Focus on F Ring structure, and distribution of associated moonlets or clumps. Sparse observations show clumps, arcs, and possibly transient objects appearing and disappearing.

New Questions

- **RN1a**. *Ring age* Constrain age of rings by determining meteoroid mass infall contamination rate, and by measuring ring mass.
- **RN1b**. *Moonlet Search* Focus on still-unresolved puzzle of how narrow gaps are cleared, by performing deep searches for small embedded moonlets and studying gap edges.
- **RN1c**. *Ring Composition* Determine particle compositional variations at high resolution across selected ring features of greatest interest.
- RN2a. *Microstructure* Conduct In-depth studies of ring microstructure such as self-gravity wakes, which permeate rings.
- RN2b. *Propellers* Perform focused studies of the properties of newly discovered “propeller” objects.

RC1a. Seasonal change in the rings



Opening angle affects insolation, ring temperature, RSS transmission, spoke occurrence frequency, diffuse ring structure

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

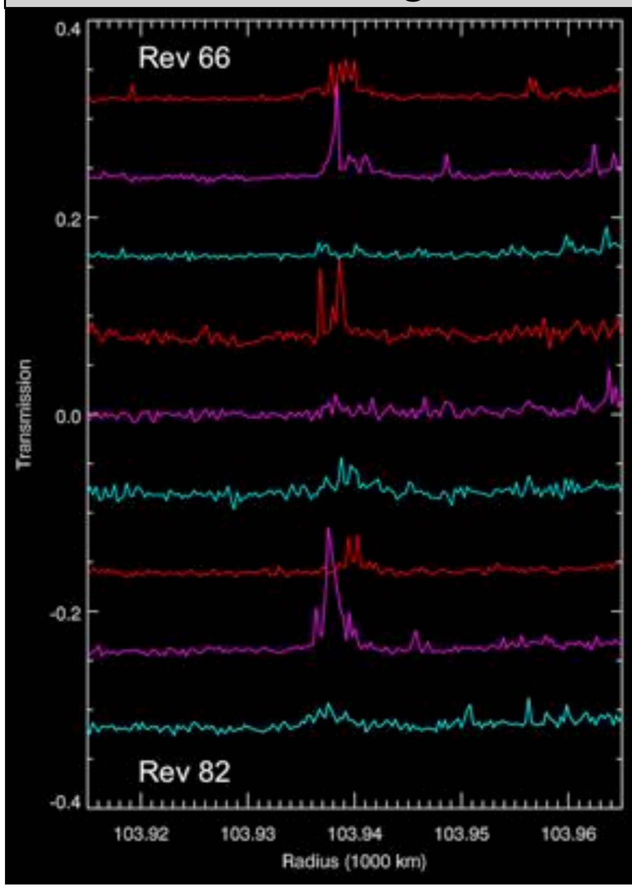
Cassini Equinox and Solstice Missions

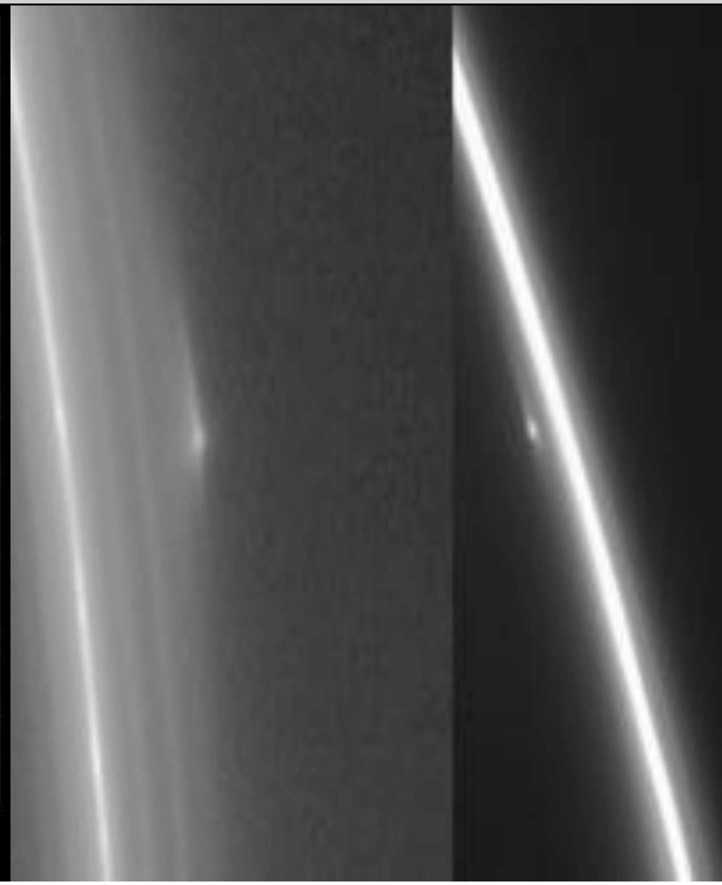
RC1b. Temporal Change

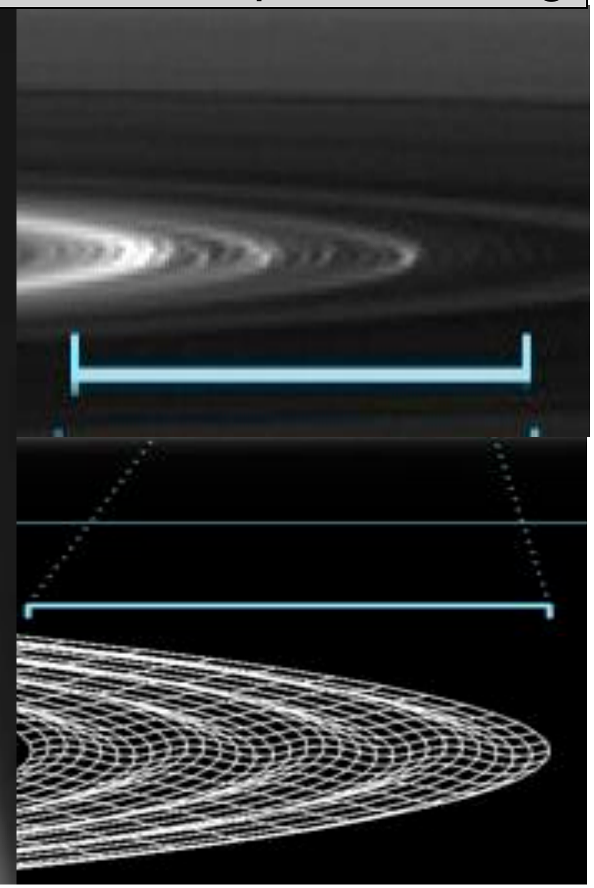
- Saturn's rings are ever-changing, vary on timescales of weeks, years and decades
- Temporal variations cry out for continued study
- Some of these variations (holes in B ring core, F ring clumps, D ring impact) are recent discoveries

Seasonal/Temporal Variations

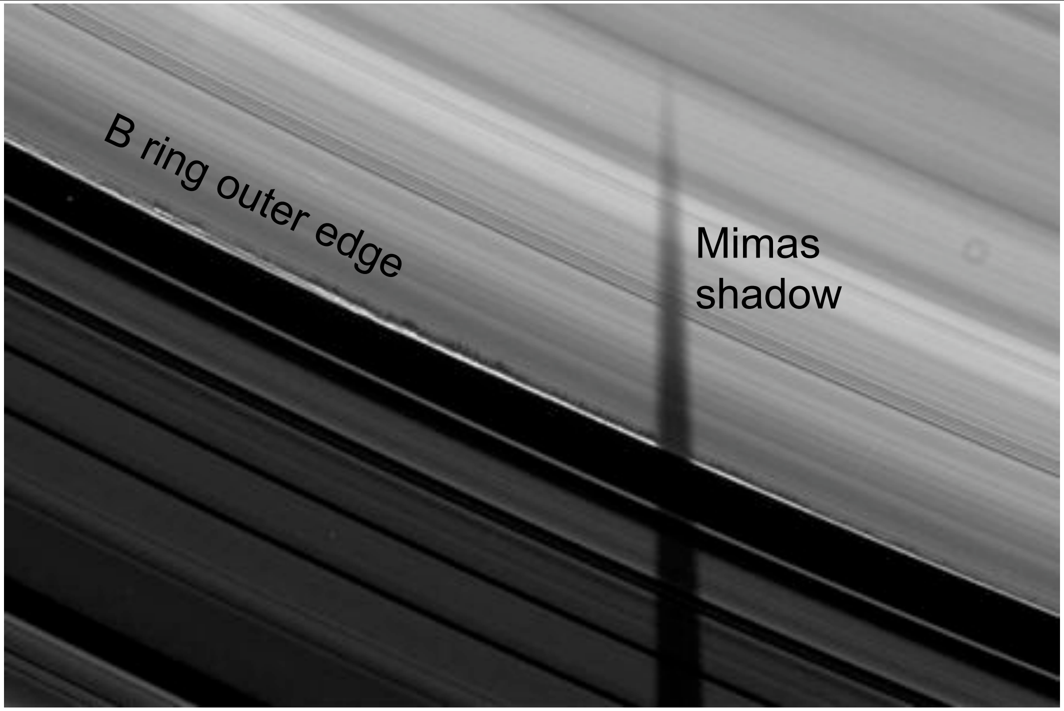
Holes in B ring core	Transient clumps near F ring	1984 impact in D ring

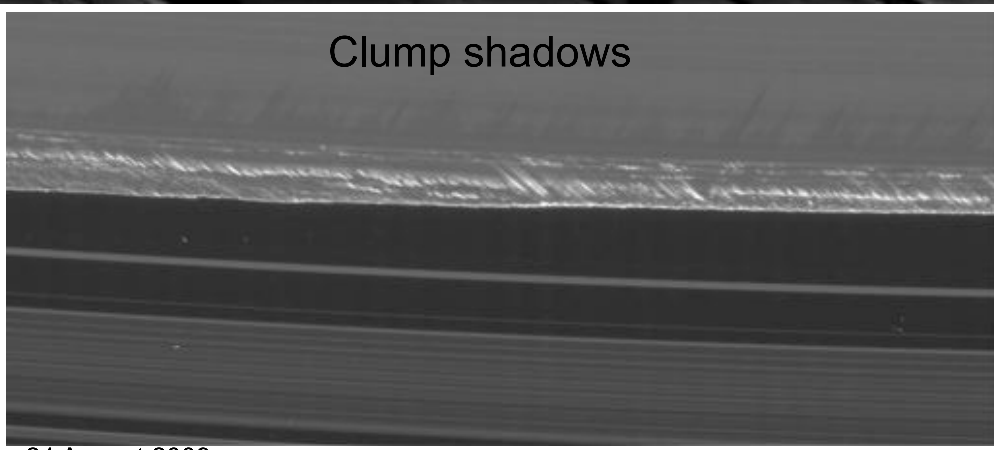






RC1b. Temporal Change: B ring clumping

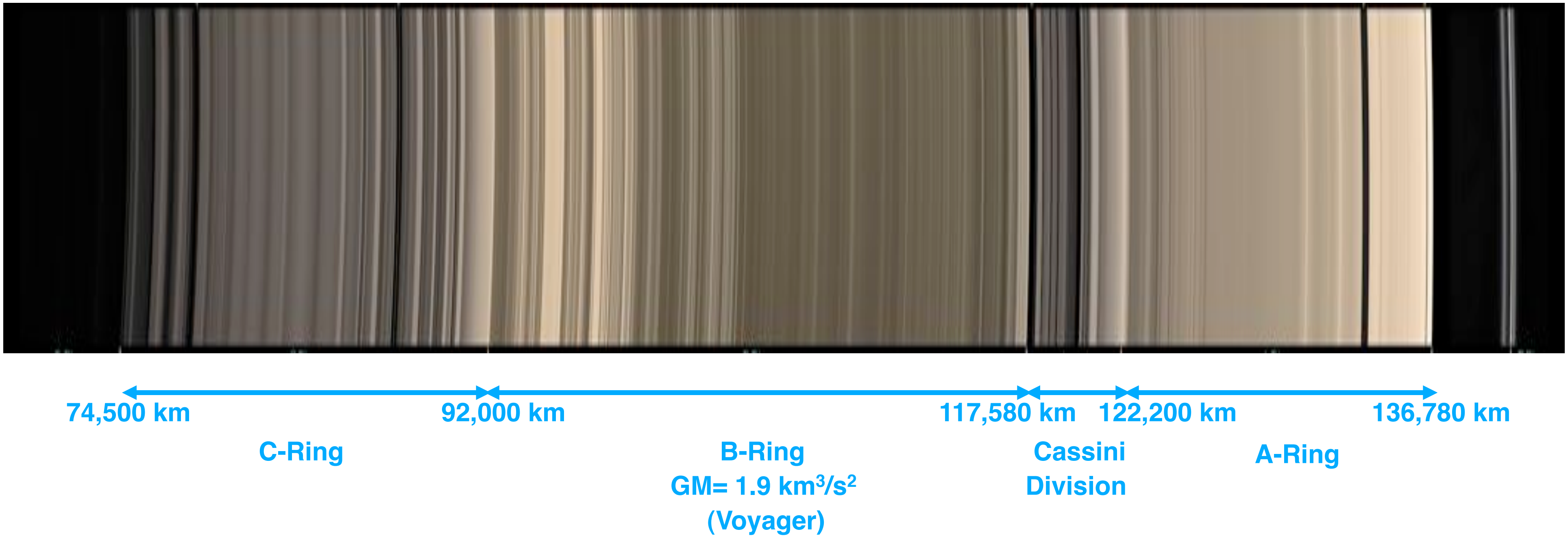




- At equinox B ring clumps detectable by their shadows in ISS images (New!)
- B ring outer edge shows major time and longitude variability in UVIS stellar occultation data (New!)
- Amount of sub-km structure is increasing since 2004! (New!)
- UVIS occultations will continue to track this structure after equinox
- May resemble planetary accretion processes

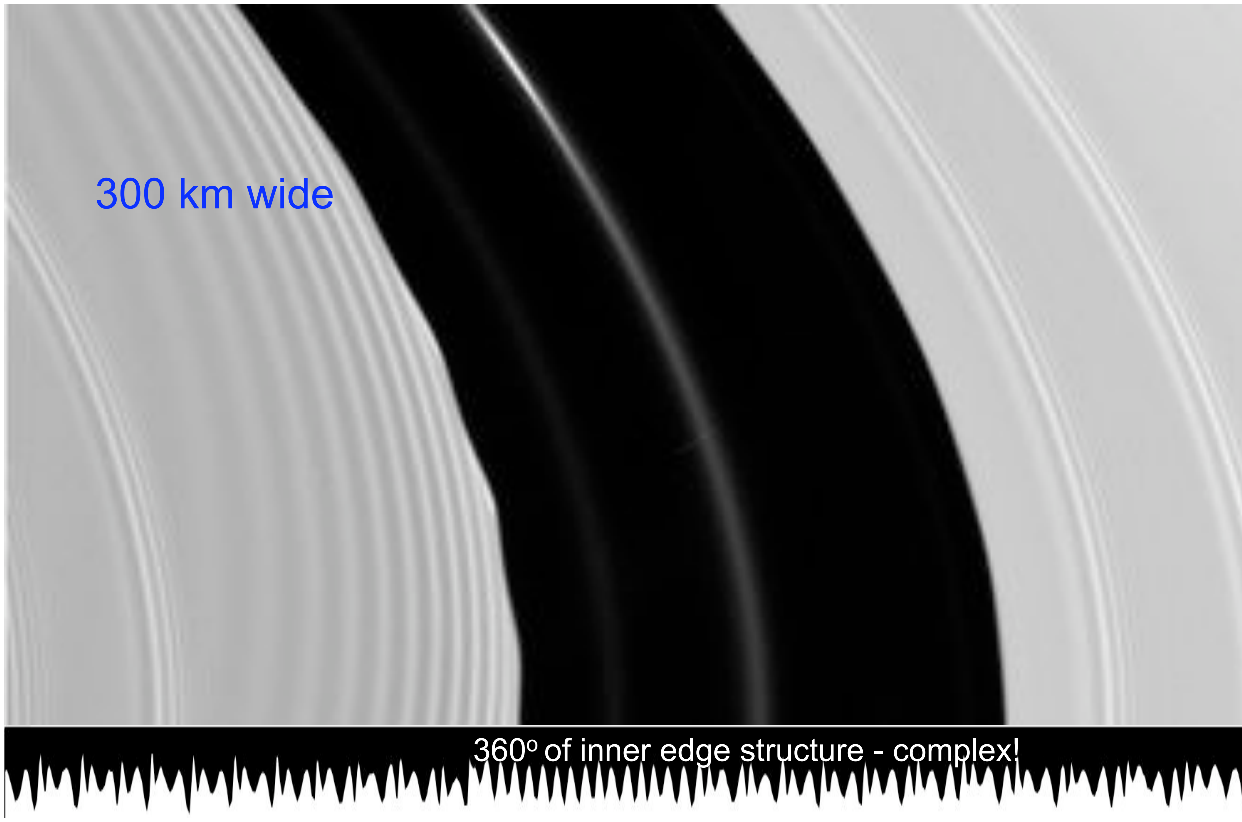
(Note: The UVIS and ISS results have not yet been released.)

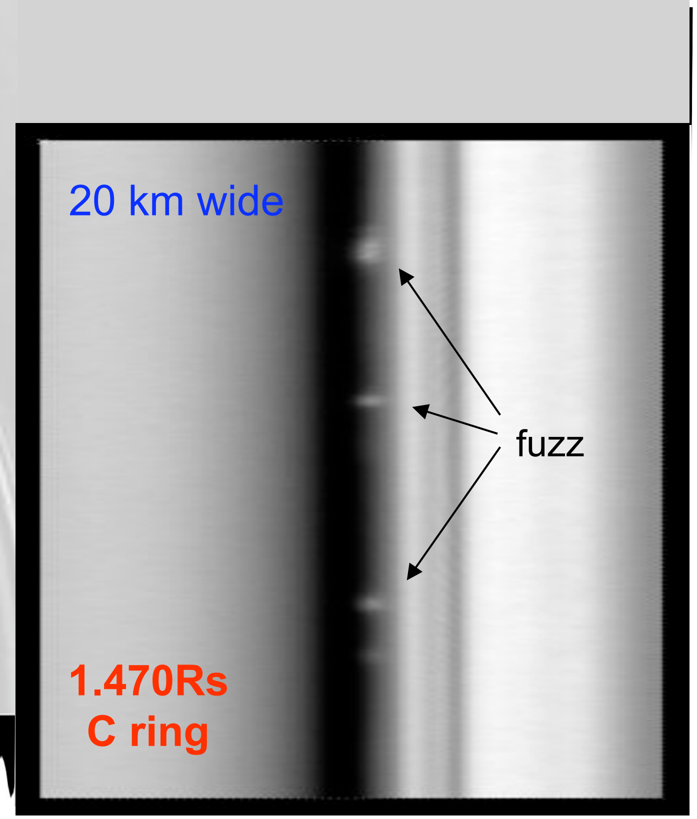
RN1a. Ring Mass: Constrain age of rings

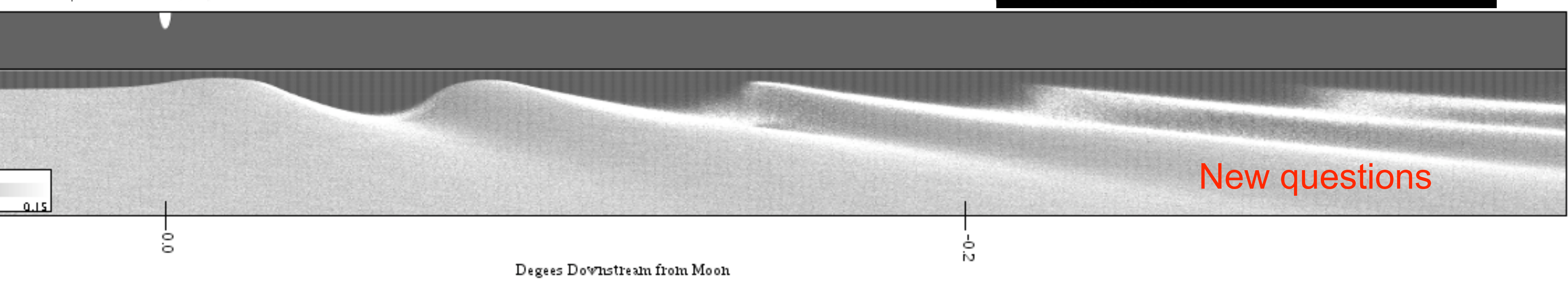


- Without proximal orbits, a-priori ring mass uncertainty is 100% of nominal values
- Knowledge of ring mass will help constrain ring age
- 6 orbital arcs for ring mass (and Saturn gravity) provide estimation accuracy for total ring $\delta GM \sim 0.34\ km^3/s^2$ (~5%)

RN1b. Moonlet search: What keeps C ring and Cassini Division gaps open?



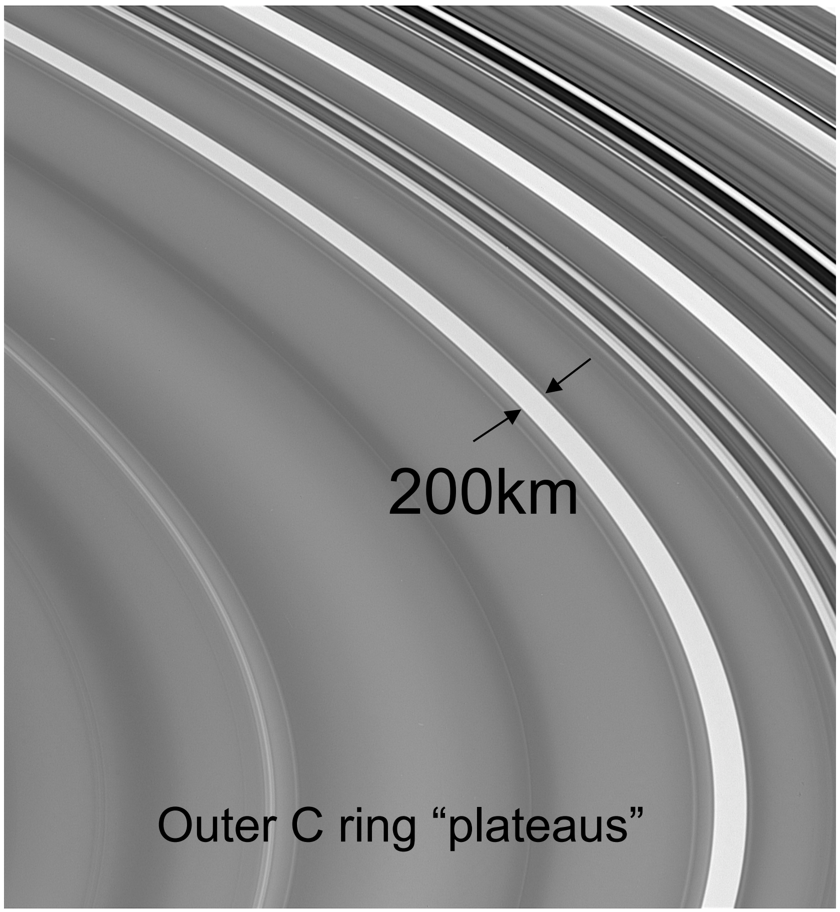




RN1c. Ring Composition

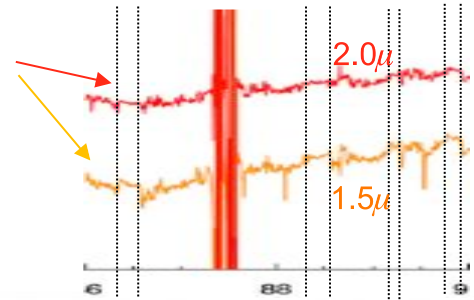
Ring particle color varies on small scales; Buried objects? Evolutionary effect?

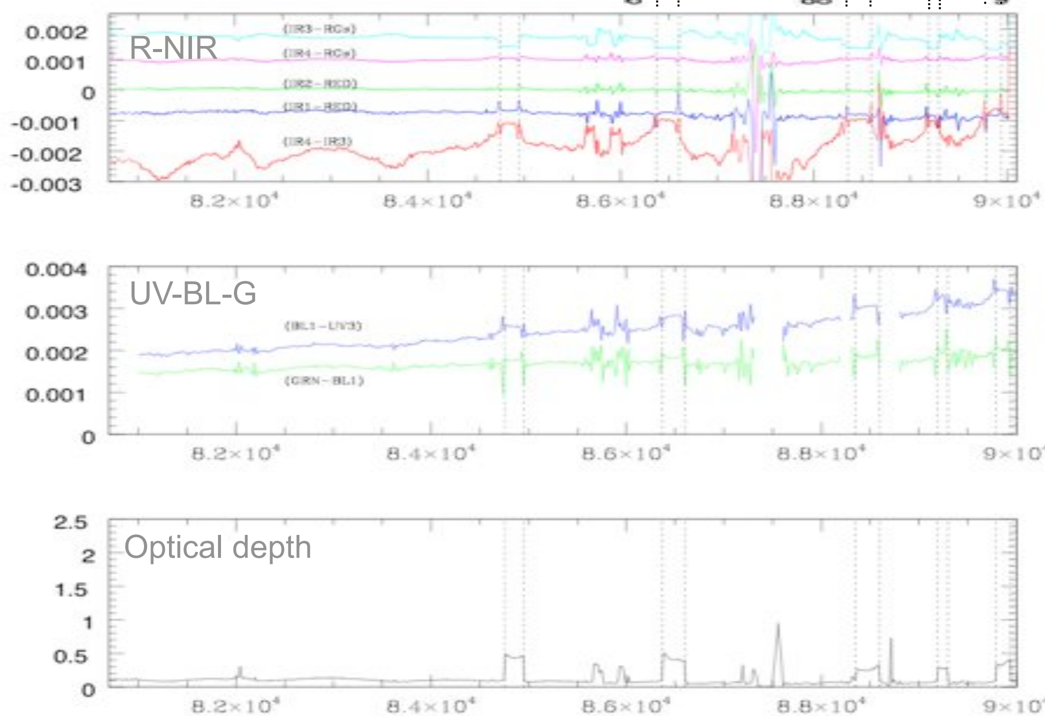
Color variations throughout B ring. Need greatly expanded high-res coverage with VIMS & CIRS; "F-ring" and "proximal" revs provide the best geometry



New questions

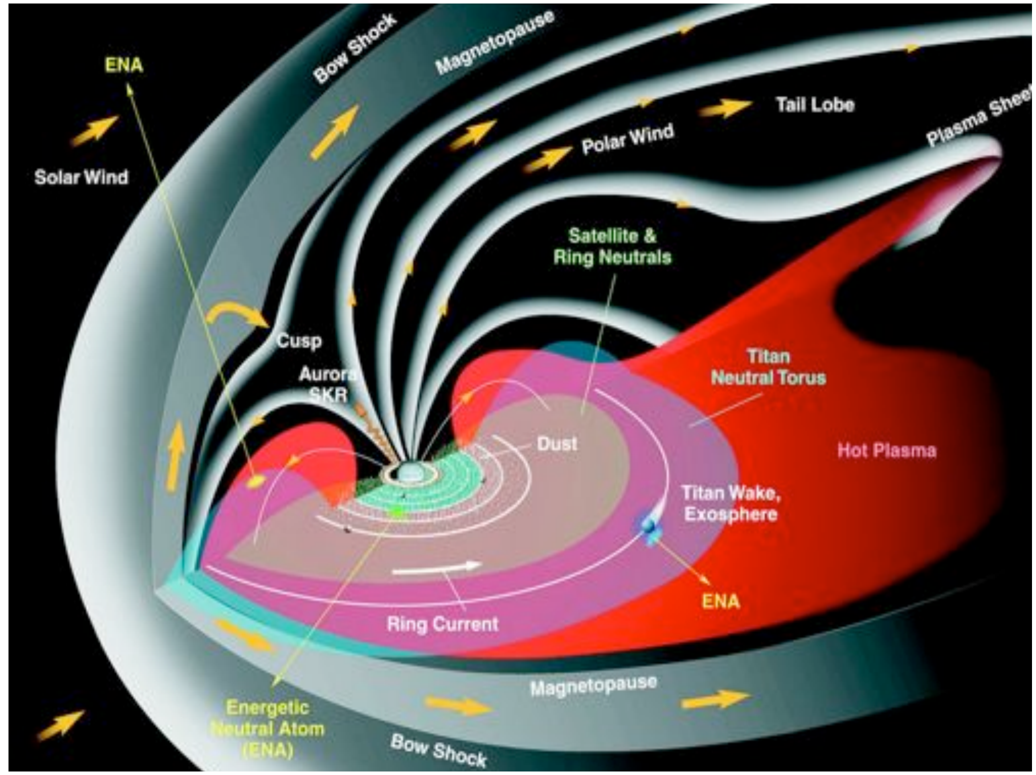
VIMS SOI scan at 20km/pxl (here showing water ice band depths) was limited to only parts of the rings, and taken on the unlit face at very short exposure time.





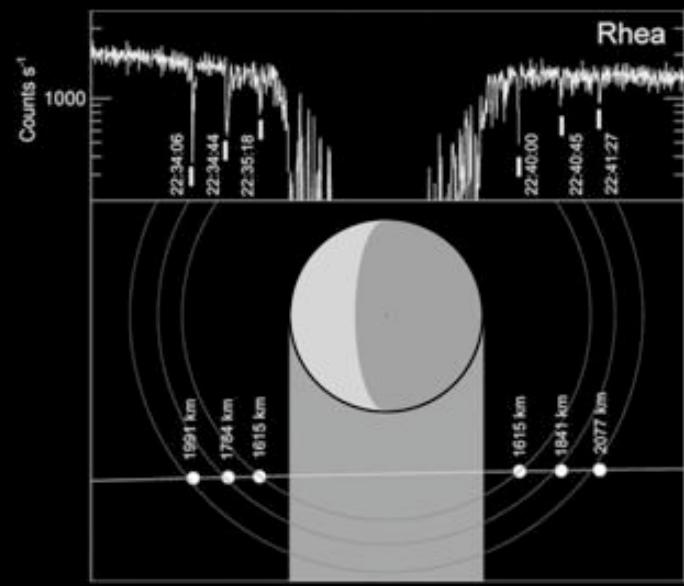
Magnetosphere and Plasma Discoveries of Prime and Equinox Missions

- Magnetic field draping at Enceladus led to discovery of Enceladus plumes
- Enceladus' plumes are major source of neutrals and plasma for magnetosphere
- Magnetosphere swimming in water from Enceladus and rings
- Heavy negative ions (up to 10,000 amu) in Titan's homopause discovered by CAPS
- Magnetospheric convection pattern of Saturn falls somewhere between that of Earth (slow planetary rotation; solar wind dominated) and Jupiter (fast planetary rotation; strong plasma source (Io); controlled by internal processes)

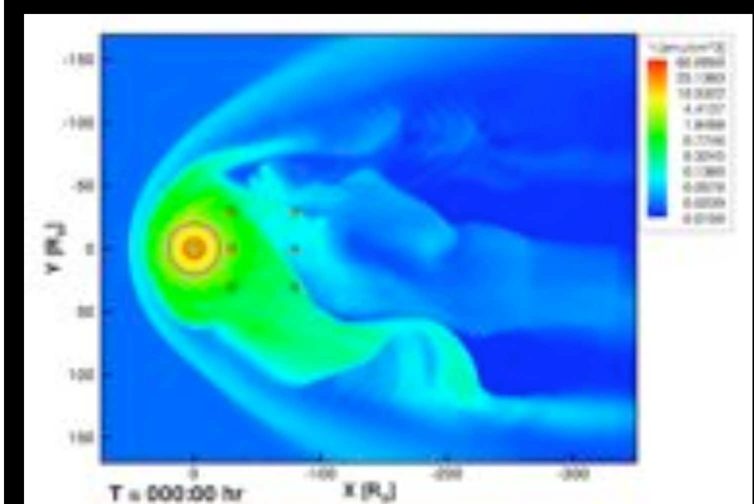


Equinox Mission Science Objectives: Magnetosphere

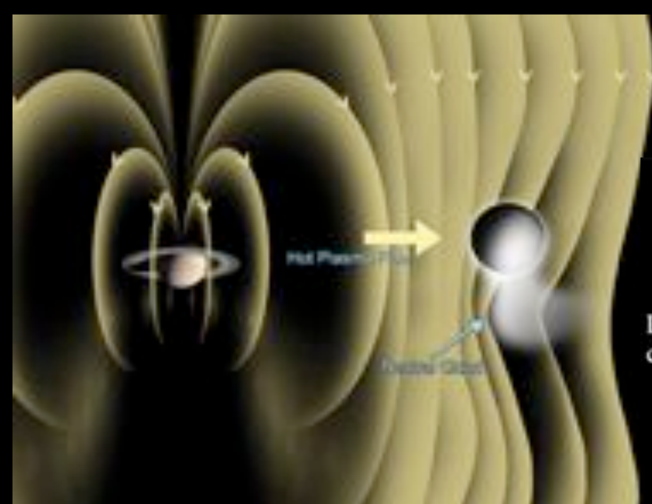
- Explore Saturn's magnetospheric dynamics; measure fields (magnetic field, plasma waves, and radio emissions), charged particles (ions and electrons), energetic neutrals, and dust in Saturn's high-latitude magnetosphere and magnetotail
- Investigate the interaction between high speed plasma and solid objects in the Saturnian system; measure fields, charged particles, neutrals, and dust in the vicinity of rings and planetary satellites



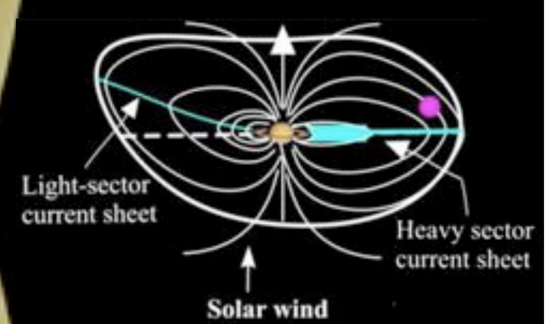
Rhea rings



Plasma flow



Perturbed magnetosphere



Warped magnetosphere

MAPS Solstice Goals and Objectives for CSM

Seasonal/Temporal Change

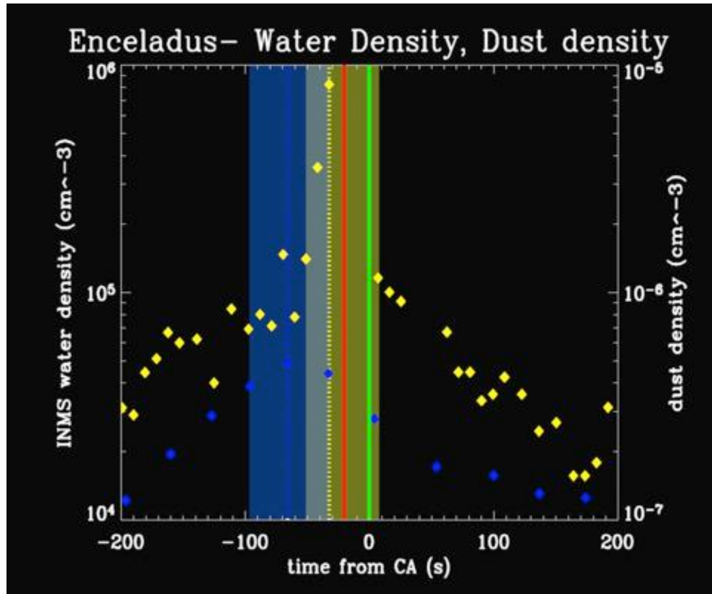
- **MC1.**: *Temporal variability of Enceladus' plumes*
  - Tour offers 6 plume flybys
- **MC1b**. *Magnetosphere over solar cycle* Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.
  - Solar Maximum is in 2012, Solar Minimum is in 2017
  - Good Local Time coverage of the inner magnetosphere (<15 R_S)
- MC2a. *Titan's Ionosphere* Observe seasonal variation of Titan's ionosphere, from (almost) one Solstice to the next
  - Encounters <1200 km near equinox and summer

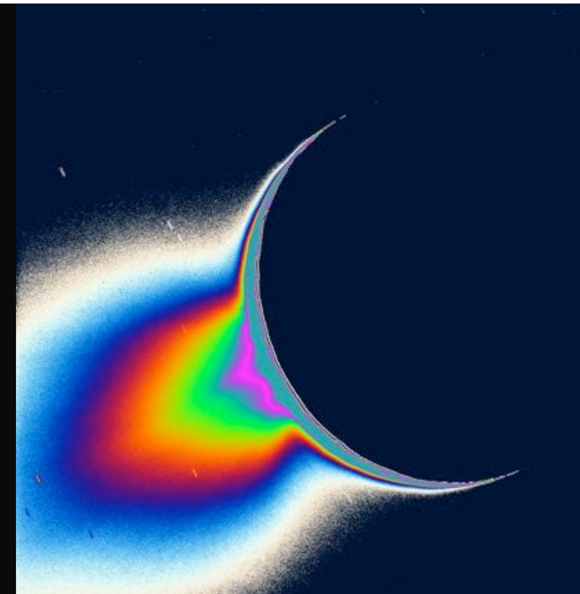
New Questions

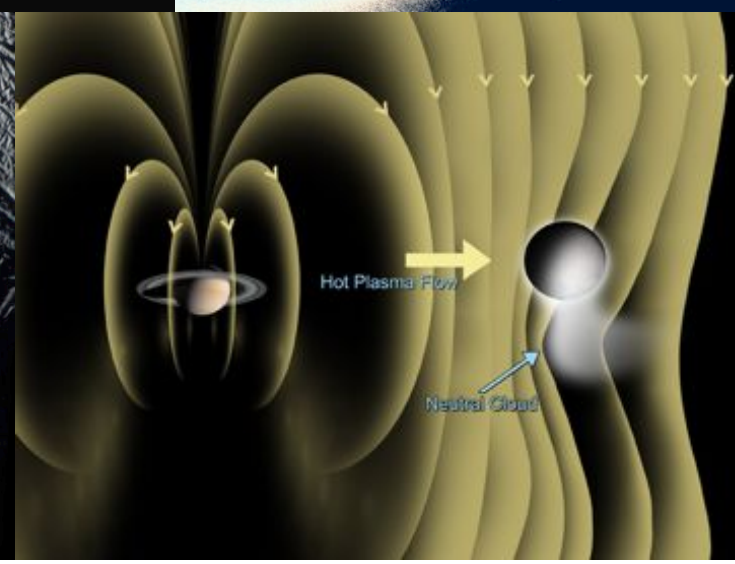
- **MN1a**. *Dynamics of Saturn's magnetotail*
  - ~2 month in the tail (22^h<LT<02^h, >30 R_S, ±2° latitude)
- **MN1b.** *In situ studies of Saturn's ionosphere and inner radiation belt*
  - D ring/Juno-like EOM proximal orbits
- **MN1c**. *Magnetospheric periodicities* Investigate magnetospheric periodicities, 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
- MN2a. *Coupling between Saturn's rings and ionosphere*

MC1a. Temporal variability of Enceladus' plumes

- Is Enceladus gas production changing with solar cycle or seasons?
- Is plume composition changing with time?
- How does the magnetosphere react to changes of gas production rate?
- How does gas to dust mass ratio vary?
    - Indication of conditions inside vents

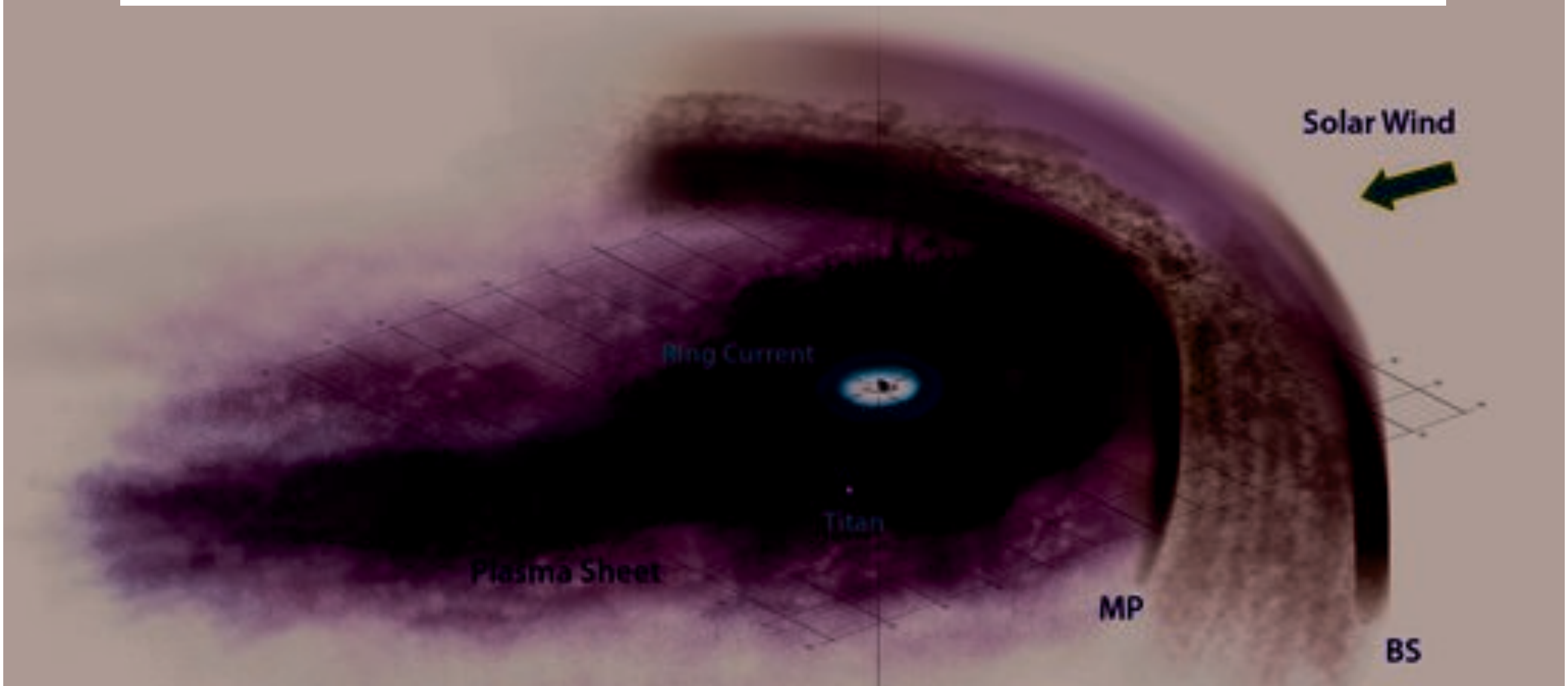






Seasonal/Temporal Variations

MC1b. Magnetosphere over one solar cycle
MN1a. Dynamics of Saturn's magnetotail



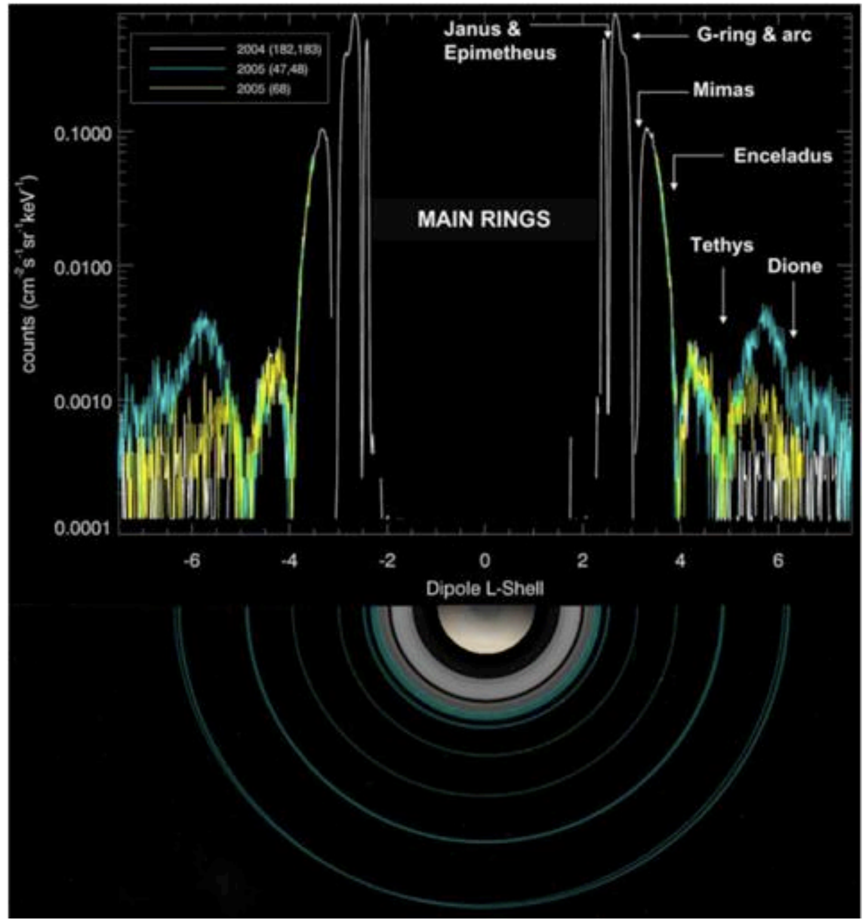
- What is the solar cycle dependence of the magnetospheric dynamics?
- What are the physical processes controlling radial mass transport in the magnetosphere?
- What controls the periodic mass release to the magnetotail?

Seasonal/Temporal Variations

Proximal Orbit Science

MN1b. In situ studies of Saturn's ionosphere and inner radiation belt
MN2a. Coupling between Saturn's rings and ionosphere

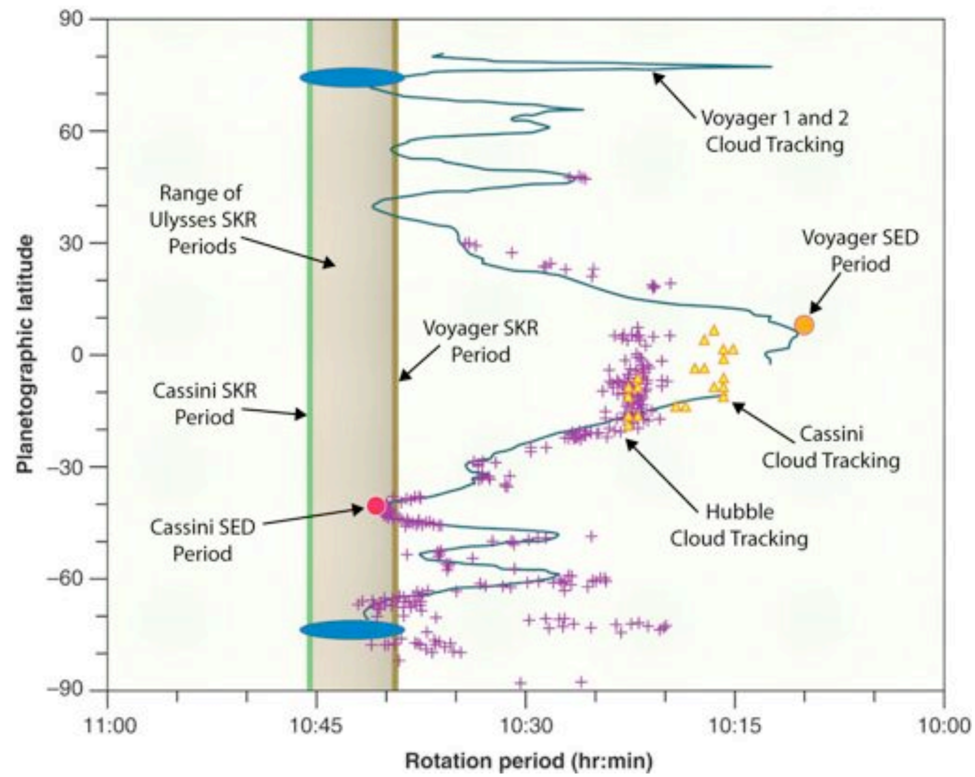
- In situ
  - Ionospheric composition
  - Inner radiation belt
  - Ring composition from dust moving toward Saturn
  - Mid-plane of Saturn's D-ring
- Questions:
  - Does solar wind control the aurora?
  - How are field aligned currents coupled to rings?
  - Is there a significant polar outflow from Saturn's high latitude ionosphere that varies seasonally or with solar cycle?



New questions

MN1c. Magnetospheric periodicities

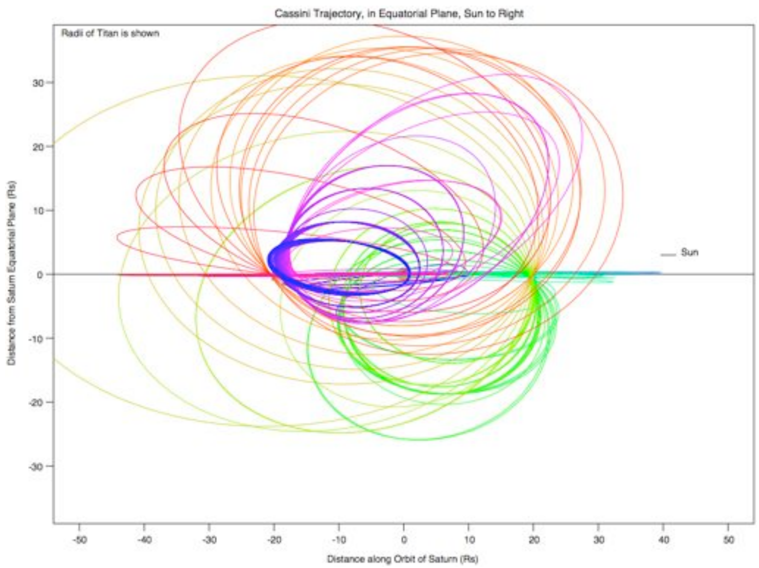
- SKR period is slowly changing in time and it does not agree with the internal rotation rate of Saturn
- Questions
  - What controls the SKR period? Is there a solar cycle and/or seasonal variation?
  - What is the coupling mechanism between the SKR period and the internal rotation rate?
  - Is the ionosphere and/or thermosphere differentially rotating?

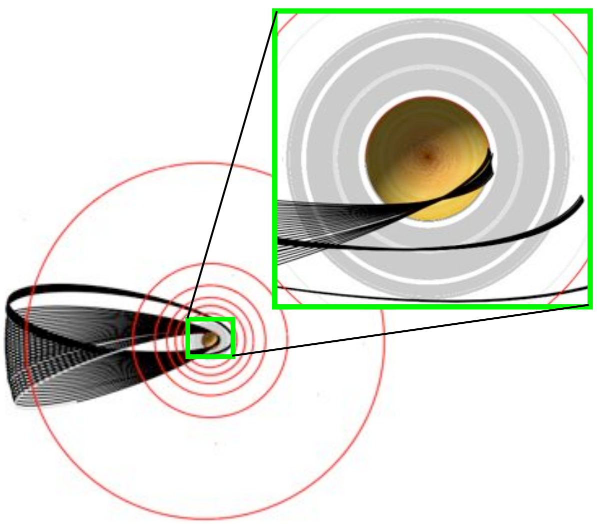


Sanchez-Lavega, Science 2005

New questions

Proposed Solstice Mission Tour

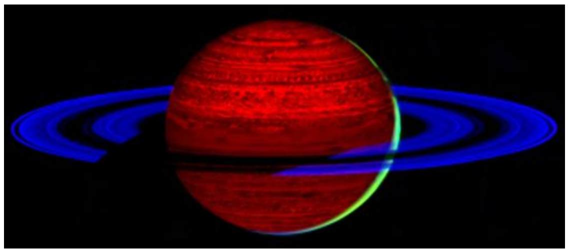


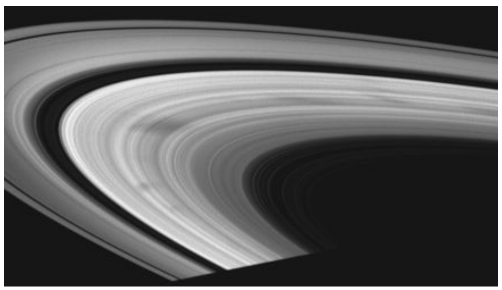


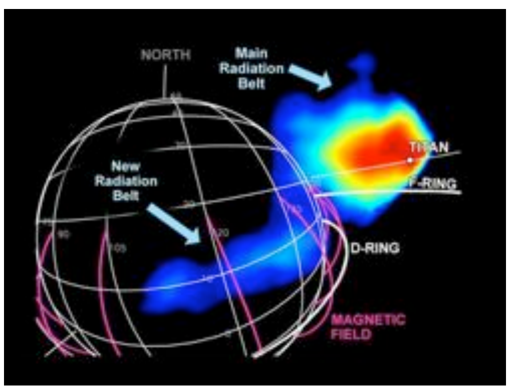
- Solstice Tour
  - 10/1/2010
  - 7 years
  - 160 orbits
  - 56 Titan flybys
  - 12 Enceladus flybys
  - 5 Other Icy flybys

- Proximal Orbits
  - 42 short period orbits from Nov. 2016 to Sept. 2017
  - 20 F ring orbits with periapses just outside Saturn's F ring
  - 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
  - Current impact date: 15 September 2017

Key science objectives during Proximal Orbits

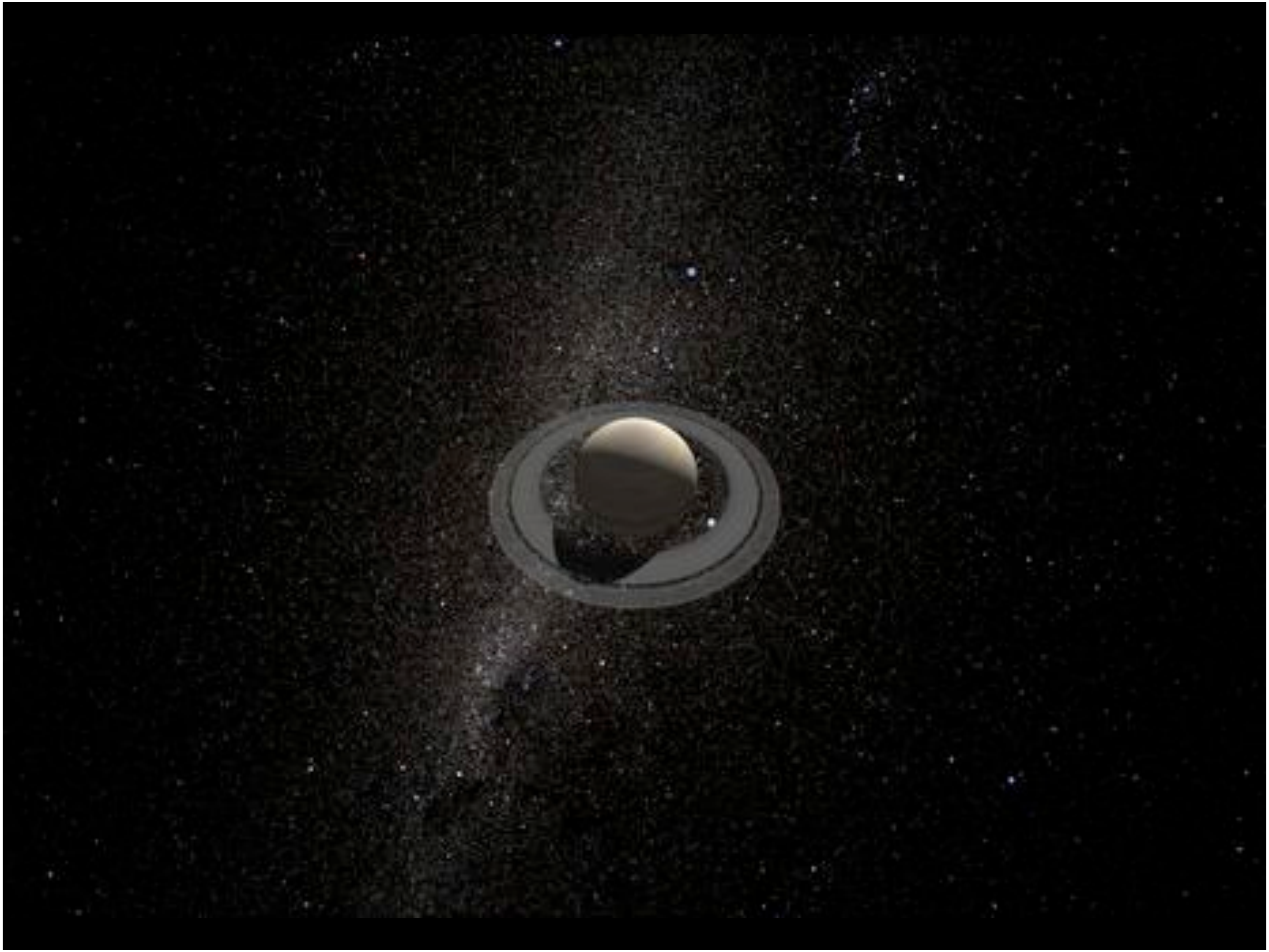


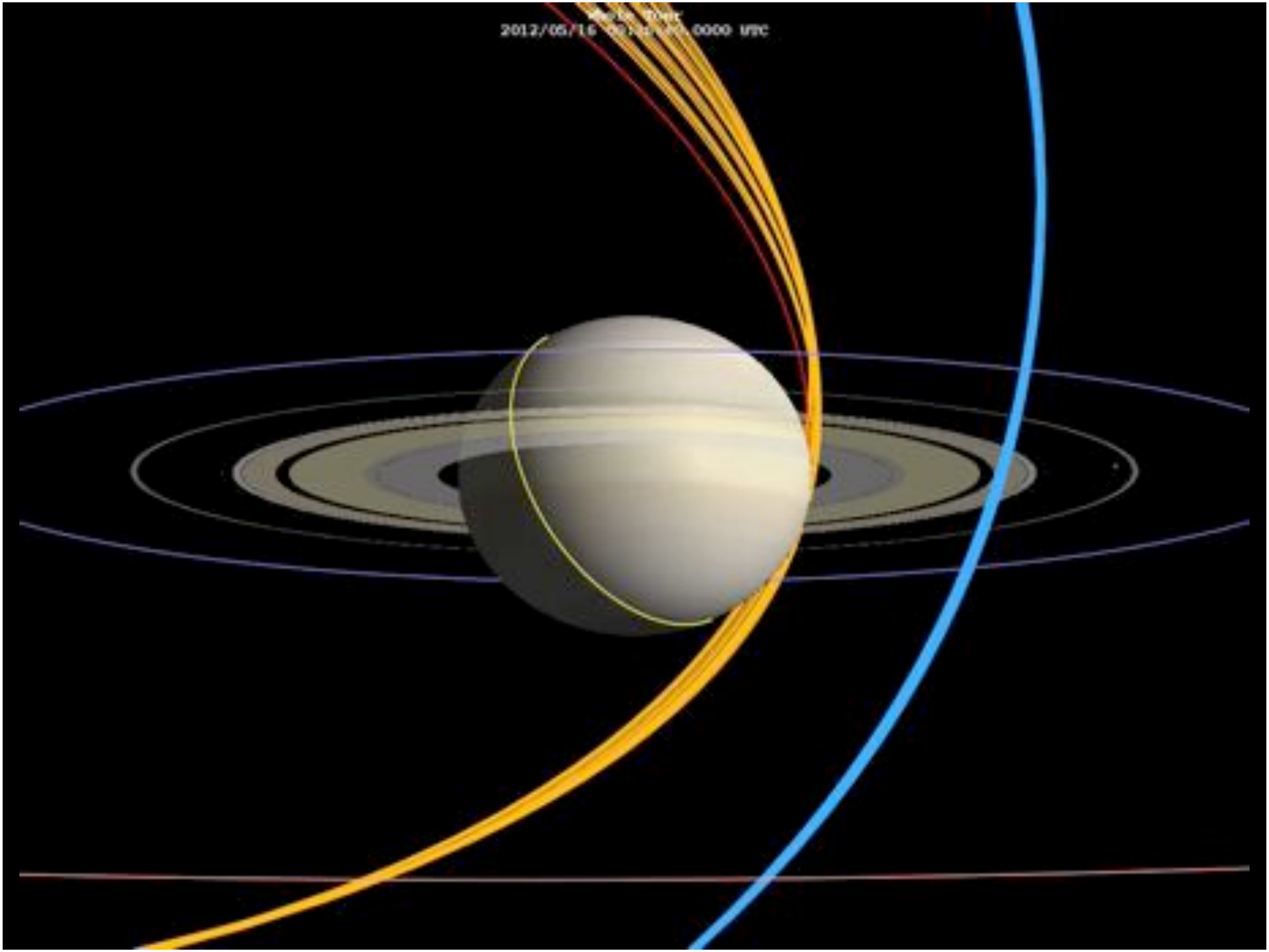




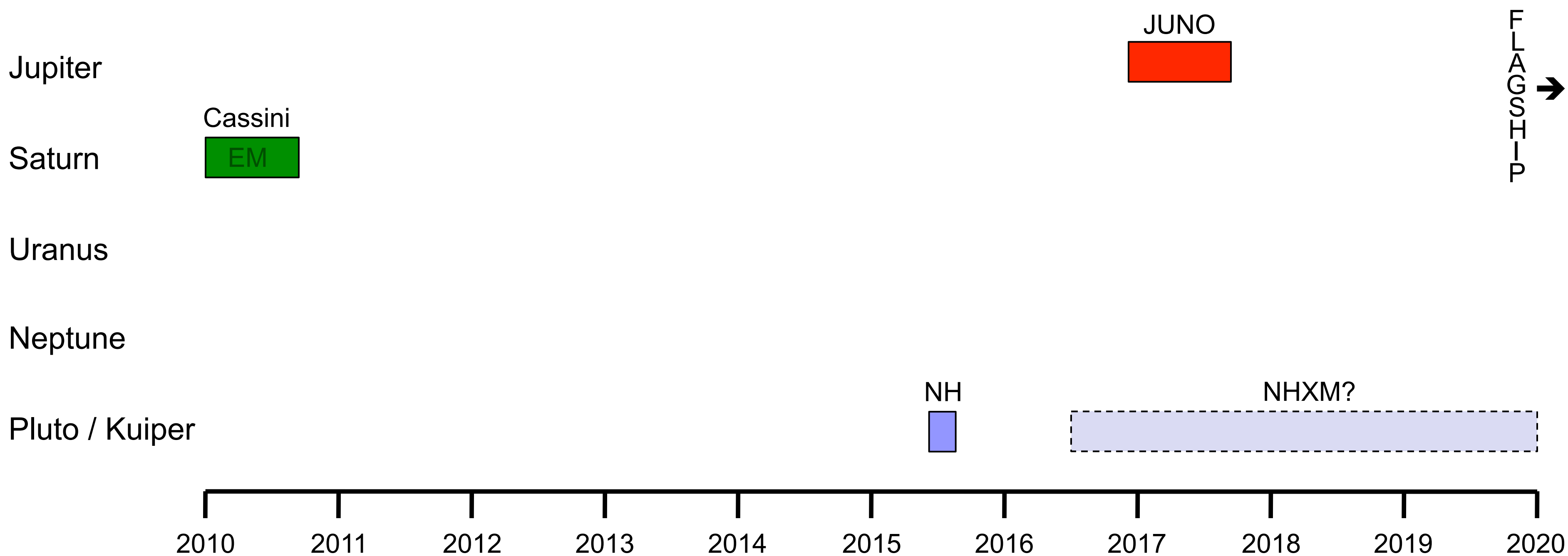
- Saturn internal structure
  - Determine Saturn's gravity field to J_{10}
  - Determine Saturn's higher order magnetic field components to degree 6
  - Measure internal rotation rate for Saturn
- Ring mass
  - Estimate mass of main rings to 5% to address age of main rings
- Saturn's ionosphere, innermost radiation belts & D ring
  - Measure *in situ* plasma of Saturn's ionosphere, innermost radiation belts and D ring for the first time
  - *In situ* observations of Saturn's auroral magnetosphere at solstice
- Highest resolution main ring studies
- High resolution Saturn atmospheric studies

Cassini Saturn science complements that from Juno mission to Jupiter

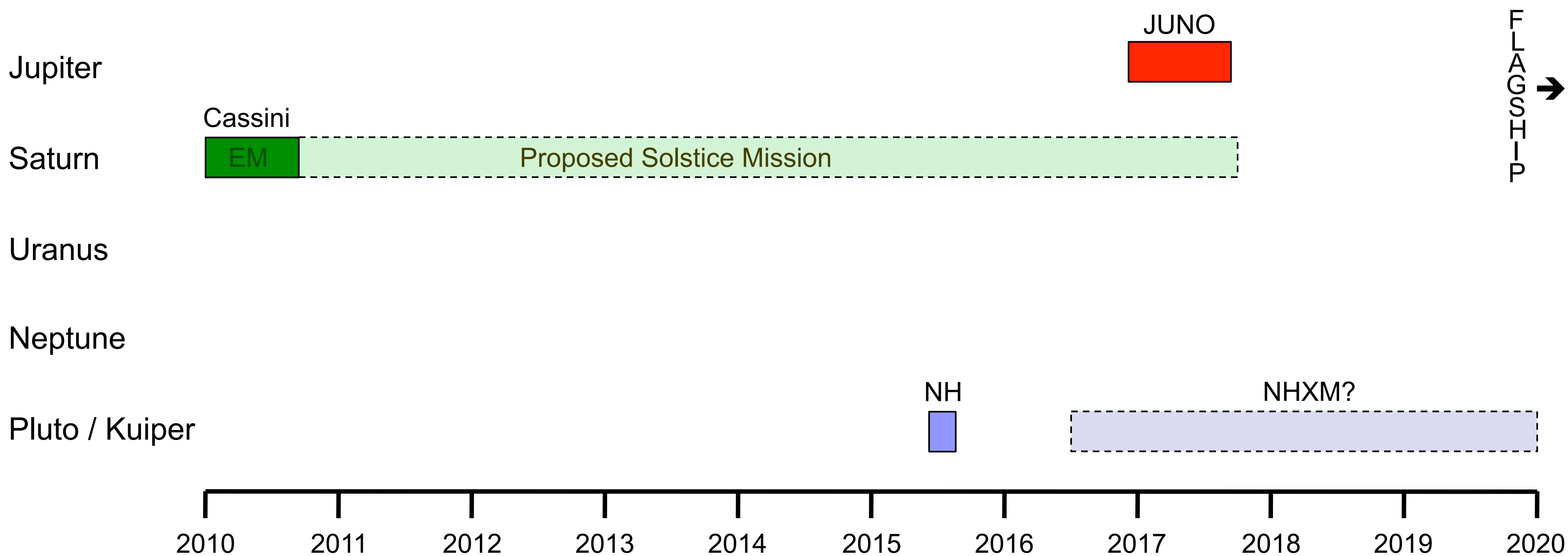




Outer Planets Missions, 2010-2020



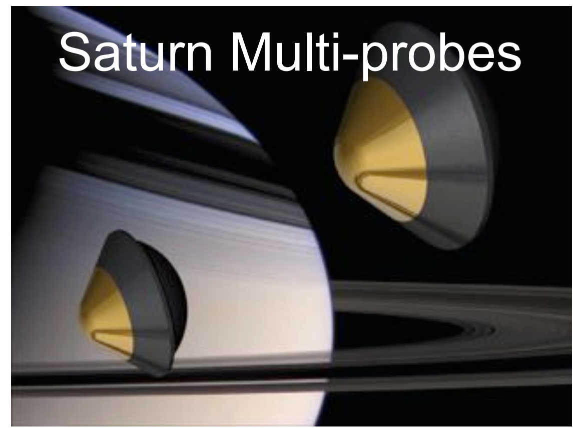
Outer Planets Missions, 2010-2020

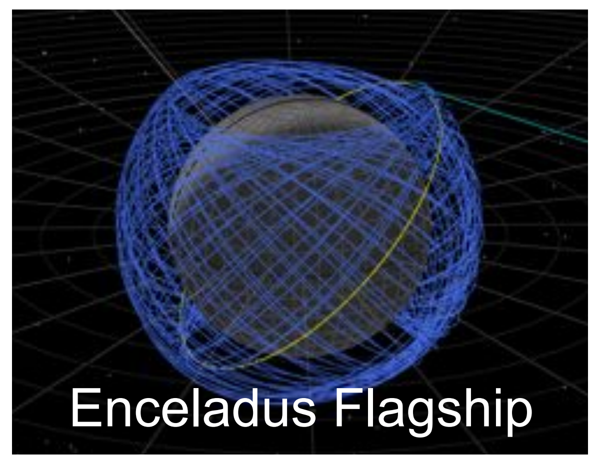


Cassini CSM will fill a critical gap in NASA's outer solar system exploration.

Proposed Cassini Solstice Goal and Objectives

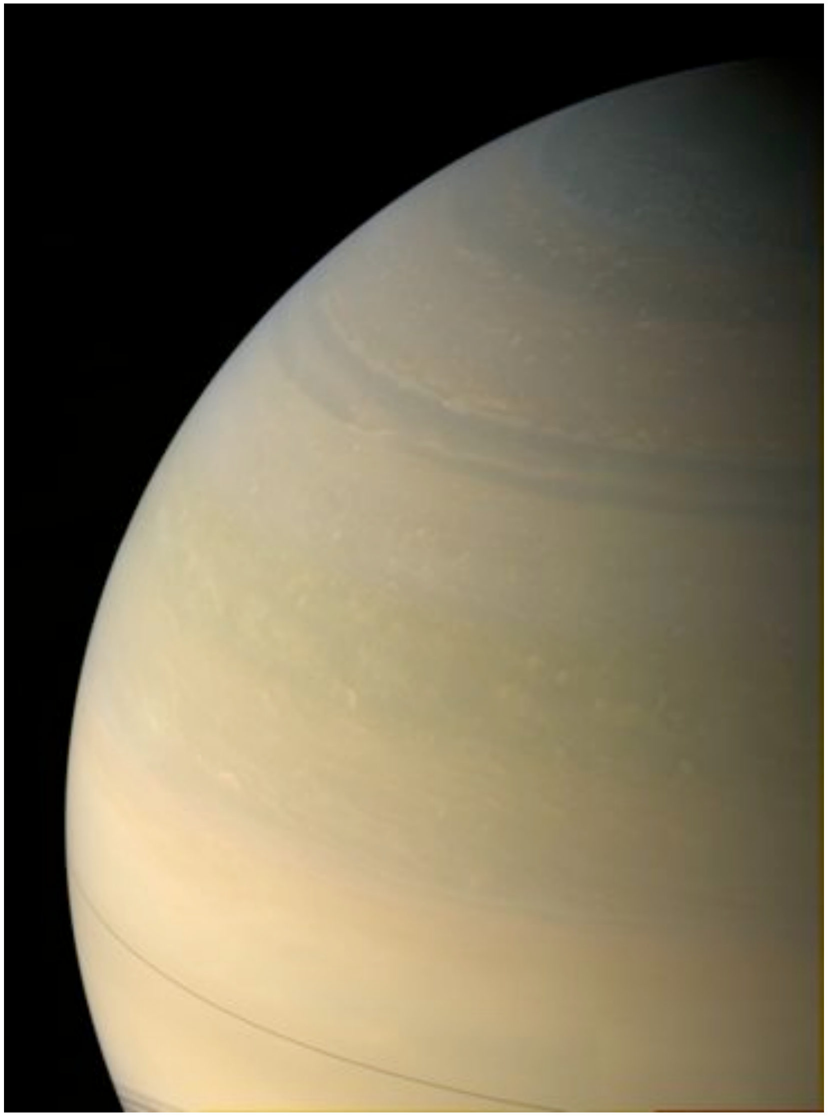
- Proposed Solstice Goal:
  - ➢Observe seasonal and temporal change in the Saturn system to understand underlying processes and prepare for future missions.
- Objectives Categories:
  - ➢Seasonal-temporal change
  - ➢New Questions





Cassini Solstice Science

- Proposed Cassini Solstice Mission enables unprecedented opportunities for unique, groundbreaking science
- Proximal science unique
- Direct relevance to the Planetary Decadal Survey and NASA's exploration program.



Backup Slides

		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.	

Proposed Cassini CSM Objectives

first letter = Discipline (**S**aturn, **R**ings, **M**APS, **I**cy, **T**itan)
second letter = Objective Type (**C**hange or **N**ew question)
third number = Priority Level (**1**, **2**)
fourth letter = Distinction within Priority Level (**a**, **b**, **c**, etc.)

Giant Planet Questions - Atmospheres

Decadal Survey Questions	Measurement	Instrument	Why Now
What energy source maintains the zonal winds, and how do they vary with depth?	Negative eddy viscosity, thermal winds	ISS/VIMS/CIRS cloud tracking, temperatures	Seasonal change, new oscillations
What role does water and moist convection play?	Lighting/dragon storms	RPWS/ISS/VIMS	Statistics – only 3 in PM
How and why does atmospheric temperature vary with depth, latitude, and longitude?	Limb profiles of T, latitude coverage	CIRS equat limb, RSS & UVIS occ	Seasonal change, new equat waves
What physical and chemical processes control the atmospheric composition and the formation of clouds and haze layers?	T, clouds, winds, chemistry	All remote sensing instruments, phase angles	Seasons, go to solstice, all latitudes
How does the aurora affect the global composition, temperature, and haze formation?	Aurora time scales minutes to years	All remote sensing, polar passes	Solar cycle, seasons, experience
What produces the intricate vertical structure of giant planet ionospheres?	Electron/ions $H/H_2/He$ all latitudes	RSS/UVIS radio solar/stellar occultations	Latitude & seasonal coverage

Giant Planet Questions - Interiors

Decadal Survey Questions	**Measurement**	**Instrument**	**Why Now**
What is the nature of convection **and winds** in giant planet interiors?	Higher harmonics of gravity field (?)	RSS (gravity) End of Mission orbits	No chance in PM or XM
How does the composition vary with depth? **Probe below the visible clouds**	NH_3 and deep clouds, relation to visible clouds	RADAR/VIMS low equatorial orbits	Capability dis-covered at end of PM
What is the nature of phase transitions within the giant planets?	Core mass and radius, J_2, J_4, J_6,	RSS (gravity) - End of mission orbits	No chance in PM or XM
How is energy transported through the deep atmosphere? Do radiative layers exist?	T, clouds, winds, chemistry	All remote sensing instruments	Seasonal change – go to solstice
How and where are planetary magnetic fields generated? **Use B field to determine rotation**	B field, structure and rotation	MAG - End of mission orbits	No chance in PM or XM

Comparison to 2003 Decadal Survey High Level Rings Objectives

What are the current physical properties (size distribution, shapes, strength, and nature of aggregations) of particles in the various rings and of distinct regions within the rings?

RC1a (seasonal variation by RSS occs)

What are the most important mechanisms for ring evolution on long and short time scales?

RC1b (time variability), RC2 (F ring campaign), RN1a (Measure ring mass and mass flux)

What are the underlying kinematics and dynamics of the various ring systems? How do self-gravity, viscosity, ballistic transport, and collisions interact?

RN1b (Moonlets clearing gaps), RN2a (microstructure and wakes), RN2b (propellers)

What is the chemical composition of the various rings and of distinct regions within the rings?

RN1c (composition at high resolution)

What is the current mass flux into the various ring systems? What are the current size, mass, velocity, and composition distributions of the influx population? How did these change with time?

RN1a (measure Mass flux by close satellite flybys)

What are the influences of the magnetospheric and plasma environments of the various rings?

RC1a (formation mechanisms of spokes)

What do the differences among ring systems tell us about differences in ring progenitors and/or differences in initial and subsequent processes?

RN1c (composition at high resolution)

What is the relationship between local ring properties and properties observable by remote sensing?

What do planetary rings teach us about nebulae around other stars?

RN1b (Moonlets clearing gaps), RN2a (microstructure and wakes), RN2b (propellers)

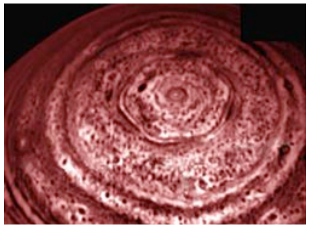
NRC Solar System Exploration Survey (2003) Key Measurement Objectives for Giant Planet Exploration and the CSM MAPS Objectives

- Determine the Mass and Size of Jupiter's Core
- Measure Elemental Abundances (H, He, O, C, N, S)
  - MN1b: Conduct in situ studies of Saturn's ionosphere and inner radiation belt
- Investigate Deep Winds and Internal Convection
- Map the Structure of Magnetic Field
  - MC1b: Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.
  - MN1a: Determine the dynamics of Saturn's magnetotail
- Explore Polar Magnetospheres
  - MC1b: Observe Saturn's magnetosphere over a solar cycle, from one solar minimum to the next.
  - MN1c: 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
- Determine the Properties of Planetary Rings
  - MN2a: Determine the coupling between Saturn's rings and ionosphere.
- Map Atmospheric Properties as Functions of Depth, Latitude, and Longitude
- Origin and Evolution of Satellite Systems
- Origin and Evolution of Water-rich Environments in Icy Satellites
  - MC1a: Determine the temporal variability of Enceladus' plumes.
- Exploring Organic-rich Environments
  - MC2a: Observe seasonal variation of Titan's ionosphere, from (almost) one Solstice to the next
- Understanding Dynamic Planetary Processes

Mapping of Cassini Solstice 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	✓	✓	✓		

Prime Mission Science Objectives: Saturn



1. **Determine temperature field, cloud properties, and composition of the atmosphere of Saturn.**
2. **Measure the global wind field, including wave and eddy components; observe synoptic cloud features and processes.**
3. **Infer the internal structure and rotation of the deep atmosphere.**
4. **Study the diurnal variations and magnetic control of the ionosphere of Saturn.**
5. **Provide observational constraints (gas composition, isotope ratios, heat flux, etc.) on scenarios for the formation and the evolution of Saturn.**
6. **Investigate the sources and the morphology of Saturn lightning (Saturn Electrostatic Discharges (SED), lightning whistlers).**

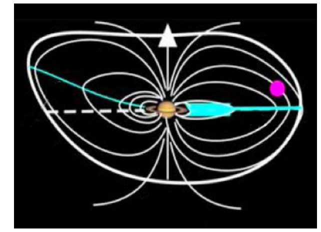
	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.			✔		✔					✔	✔	✔	
2.			✔		✔					✔		✔	
3.			✔			✔			✔	✔		✔	
4.	✔					✔	✔		✔	✔	✔		
5.	✔		✔		✔					✔	✔	✔	
6.					✔				✔				

Prime Mission Science Objectives: Rings

1. Study configuration of the rings and dynamical processes (gravitational, viscous, erosional, and electromagnetic) responsible for ring structure.
2. Map composition and size distribution of ring material.
3. Investigate interrelation of rings and satellites, including imbedded satellites.
4. Determine dust and meteoroid distribution in the vicinity of the rings.
5. Study interactions between the rings and Saturn's magnetosphere, ionosphere, and atmosphere.

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.			✔		✔	✔				✔	✔	✔	
2.	✔	✔	✔	✔	✔					✔	✔	✔	
3.	✔	✔	✔		✔					✔	✔	✔	
4.		✔			✔				✔			✔	
5.		✔	✔		✔		✔	✔	✔		✔	✔	✔

Prime Mission Science Objectives: MAPS



1. **Determine the configuration of the nearly axially symmetric magnetic field and its relation to the modulation of Saturn Kilometric Radiation (SKR).**
2. **Determine current systems, composition, sources, and sinks of magnetosphere charged particles.**
3. **Investigate wave-particle interactions and dynamics of the dayside magnetosphere and the magnetotail of Saturn and their interactions with the solar wind, the satellites, and the rings.**
4. **Study the effect of Titan's interaction with the solar wind and magnetospheric plasma.**
5. **Investigate interactions of Titan's atmosphere and exosphere with the surrounding plasma.**

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.						✔			✔				
2.	✔					✔	✔		✔		✔		
3.	✔					✔	✔		✔				
4.	✔			✔		✔	✔		✔	✔	✔		
5.	✔			✔		✔	✔		✔	✔	✔		