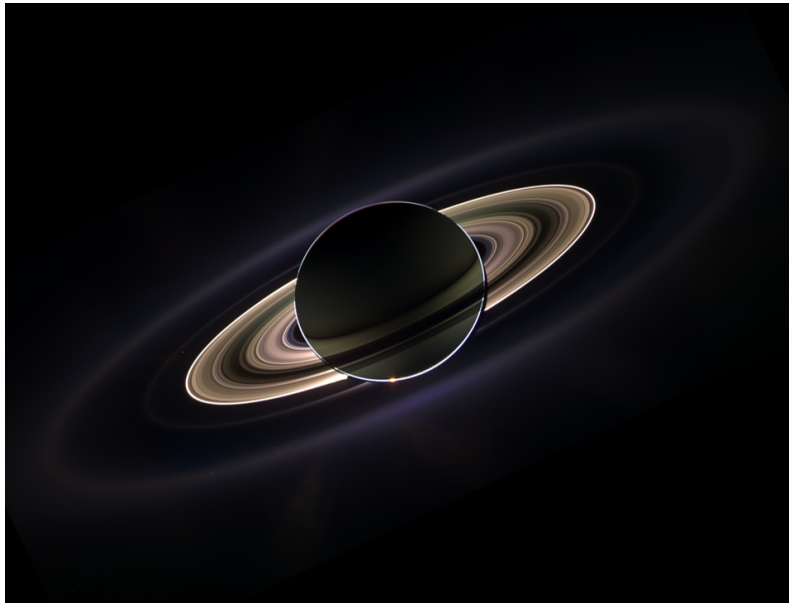
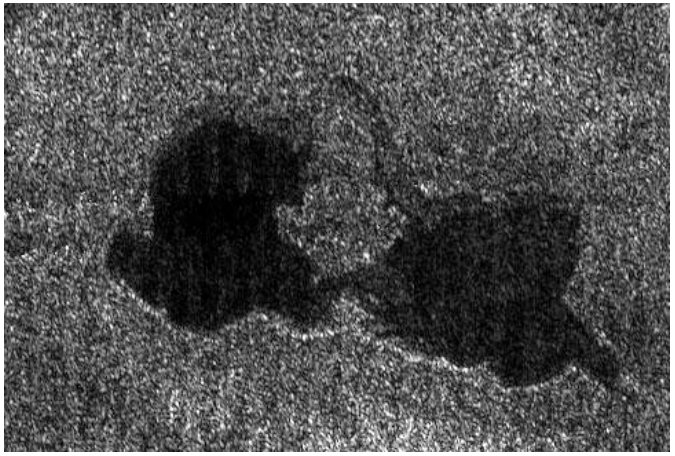
Linda Spilker
Project Scientist
Outer Planets Assessment Group
19 October 2011

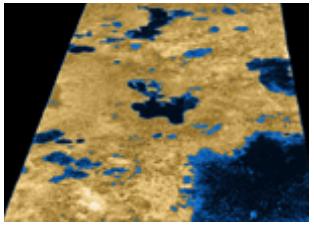
Cassini Solstice Science: Introduction

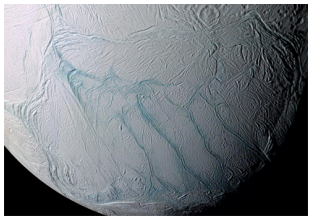
- Cassini Solstice Mission overview
- Latest Science Highlights
  - Saturn Storm
  - Recent Enceladus flyby
  - Tethys thermal anomaly
  - Ripples in Saturn's rings
  - Spring rain on Titan
  - Titan ice volcano
- New Cassini Sr. Review budget guidelines
- Past Senior Review comments
- Relative Mission Costs
- Requested recommendation from OPAG

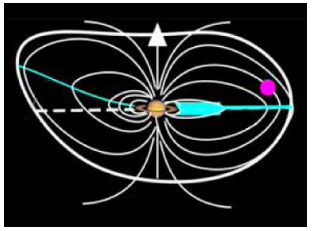


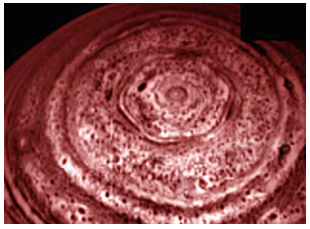


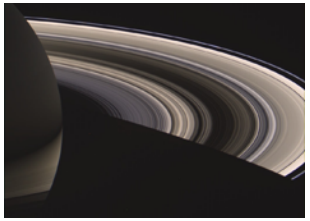
Cassini's Science Structure: 5 Science Disciplines







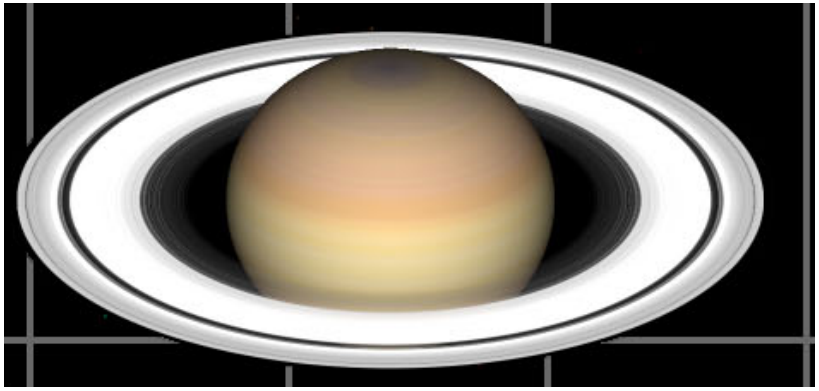


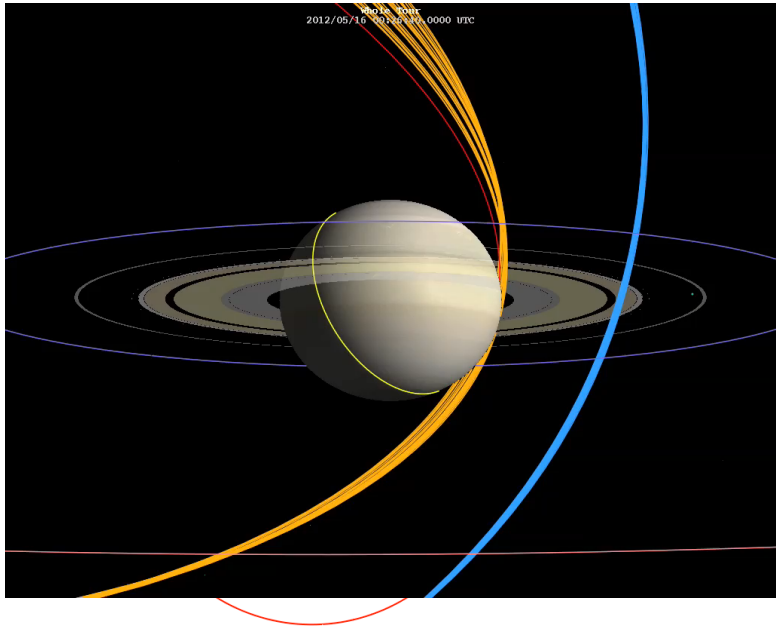


- Cassini's science structure
  - ➢12 Instrument Teams (2 European PIs)
  - ➢9 Interdisciplinary Scientists (3 Europeans)
  - ➢5 Disciplines (Saturn, Rings, Titan, Icy Satellites, Magnetospheres and Plasma Science)
  - ➢ 270 Scientists (associates and postdocs not included)
  - ➢ ~Half are European scientists
- ~2100 science publications in peer-reviewed journals as of October 2011

Each discipline is like a mission in its own right!

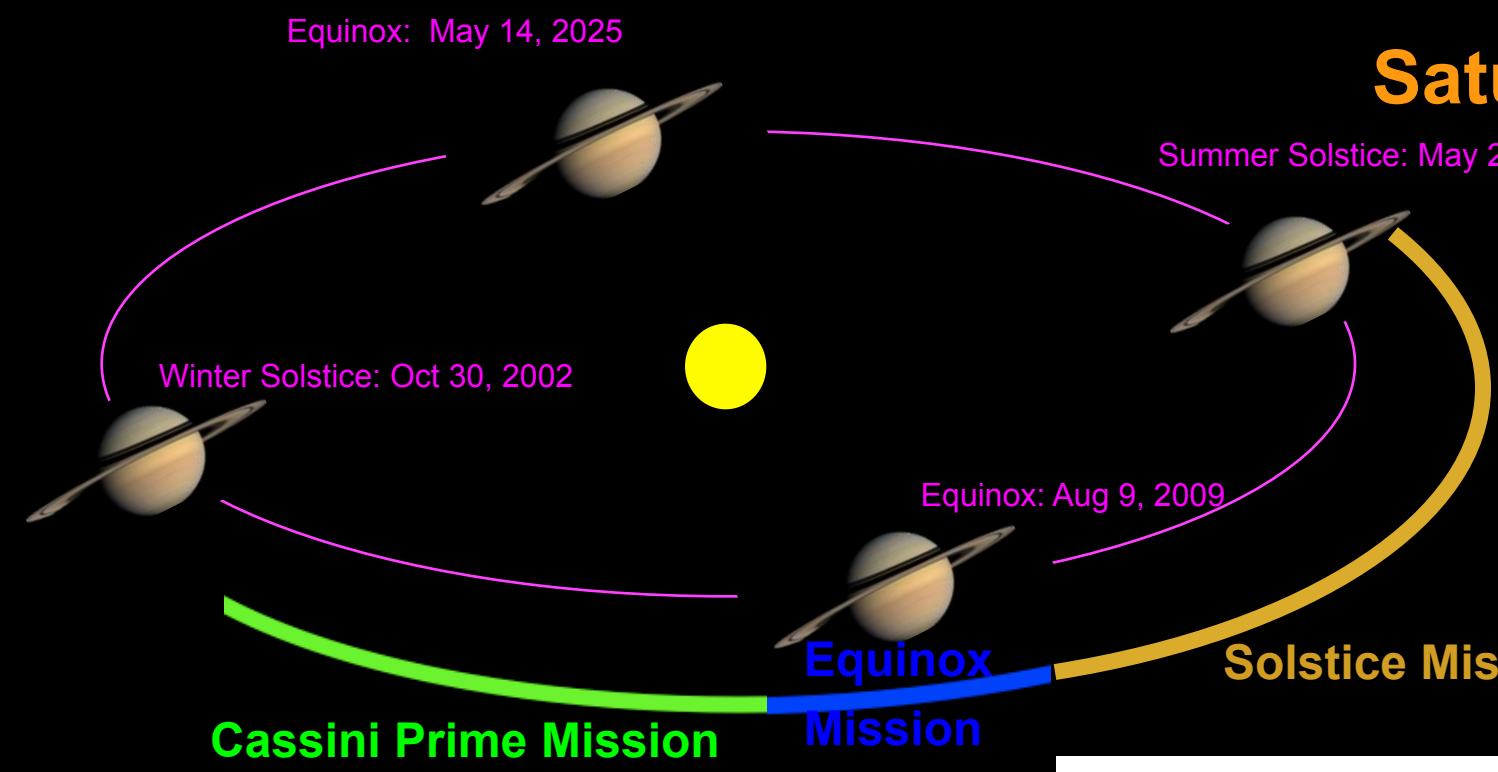
Cassini Solstice Mission

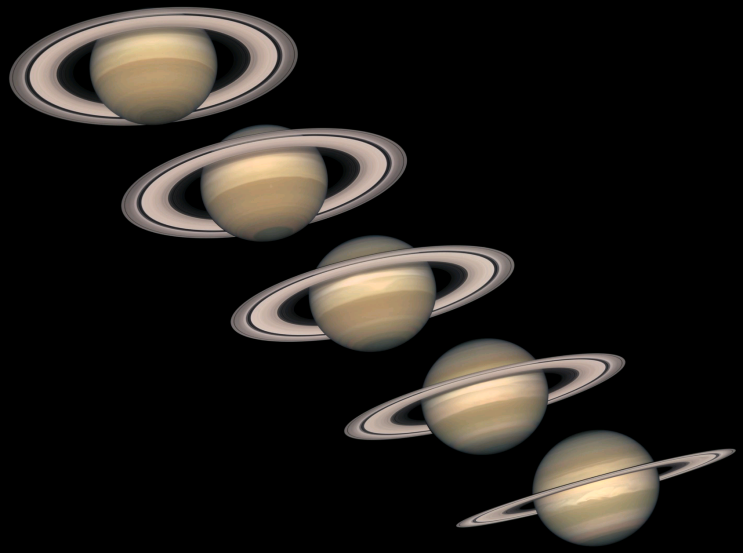


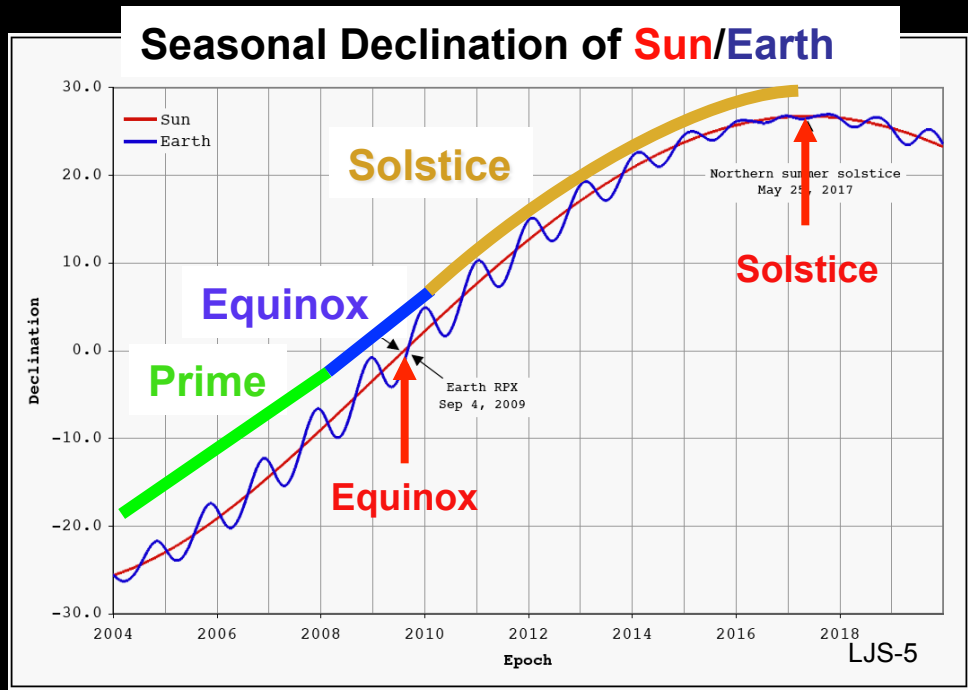


- Extends from October 2010 to September 2017 (Northern Summer Solstice)
- Solstice Goal:
  - Observe seasonal and temporal change in the Saturn system to understand underlying processes and prepare for future missions
- Science Objectives
  - Seasonal and Temporal Change
  - New Questions
  - End-of-mission Juno-like orbits to characterize Saturn's gravity and magnetic fields, and measure the mass of Saturn's rings

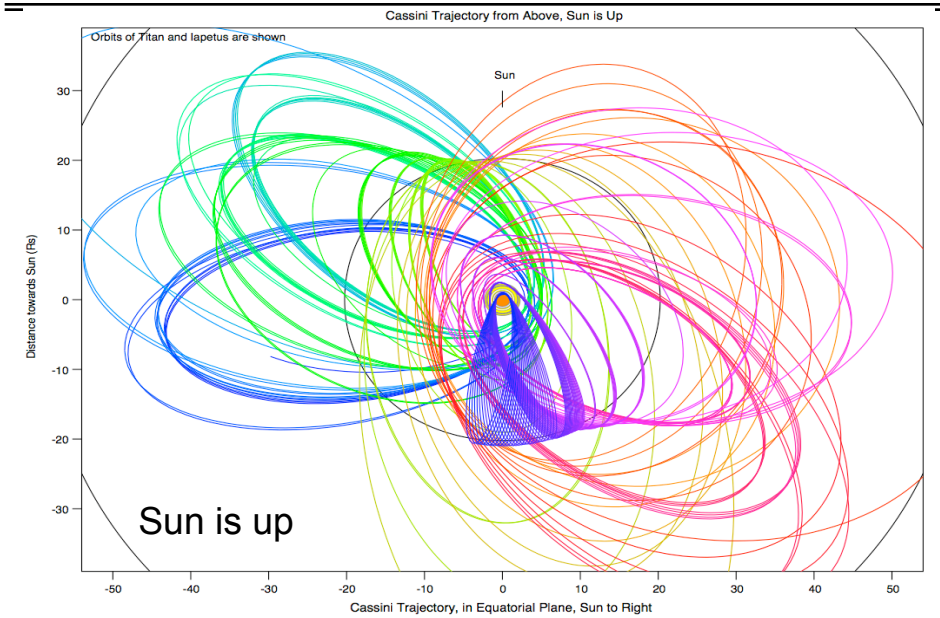
Saturn Year


Equinox: May 14, 2025
Summer Solstice: May 23, 2017
Winter Solstice: Oct 30, 2002
Equinox: Aug 9, 2009
Equinox Mission
Solstice Mission
Cassini Prime Mission




Seasonal Declination of Sun/Earth
Sun
Earth
Solstice
Equinox
Prime
Earth RPX
Sep 4, 2009
Northern summer solstice
May 23, 2017
Solstice
Equinox
Declination
Epoch
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
2004
2006
2008
2010
2012
2014
2016
2018

Cassini Solstice Mission Tour Overview

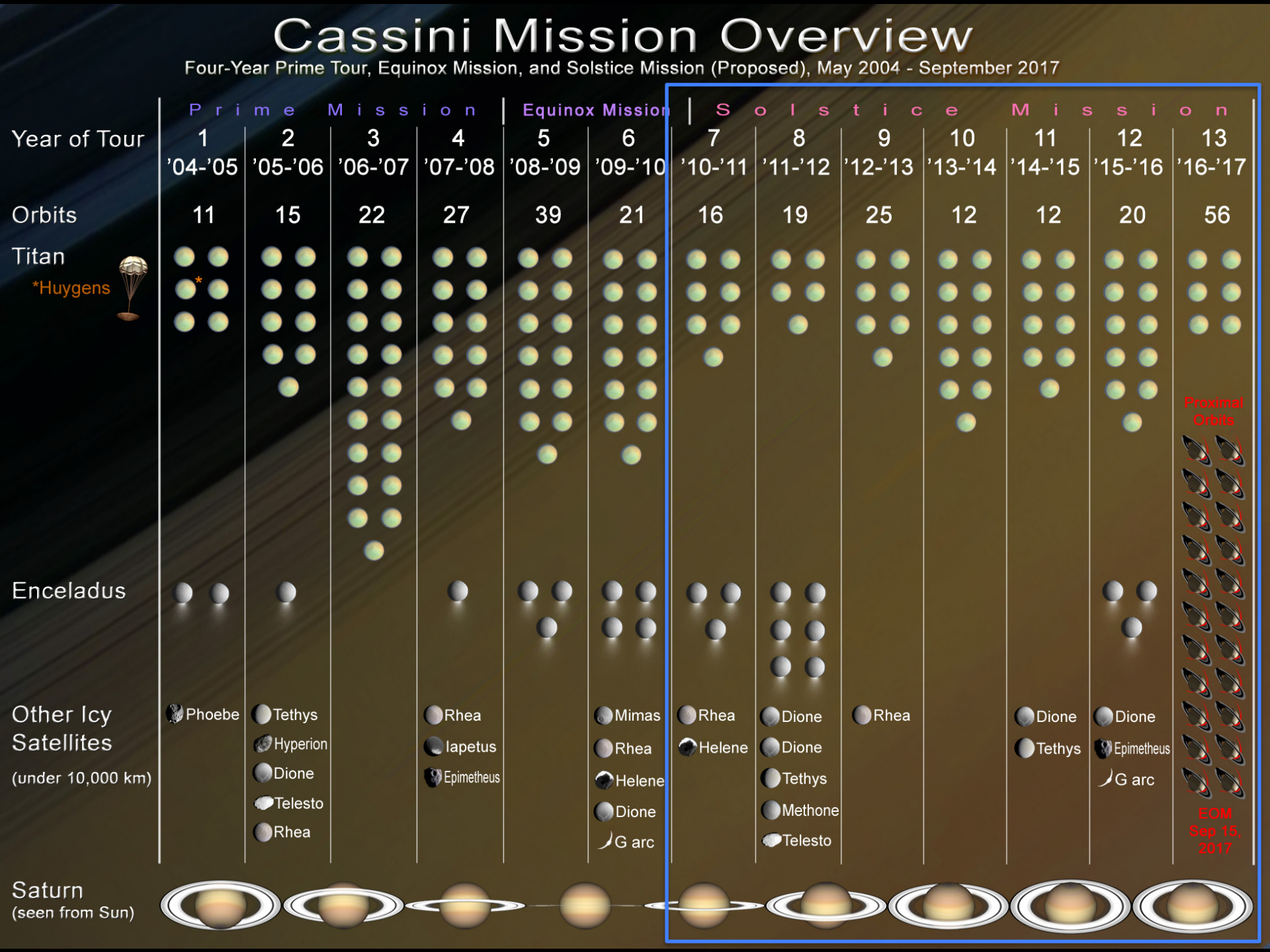


- 155 orbits (138 remaining)
  - 20 F ring, 24 proximal
- 54 Titan flybys (48 remaining)
- 12 Enceladus flybys (7 remaining)
  - 6 (3) plume passages
- 4 Dione flybys (3), 2 Rhea flybys (1)
- 2 Tethys flybys
- 4 smaller moon flybys
  - Telesto, Methone, Helene, Epimetheus
- 1 G ring arc flyby
- Many 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

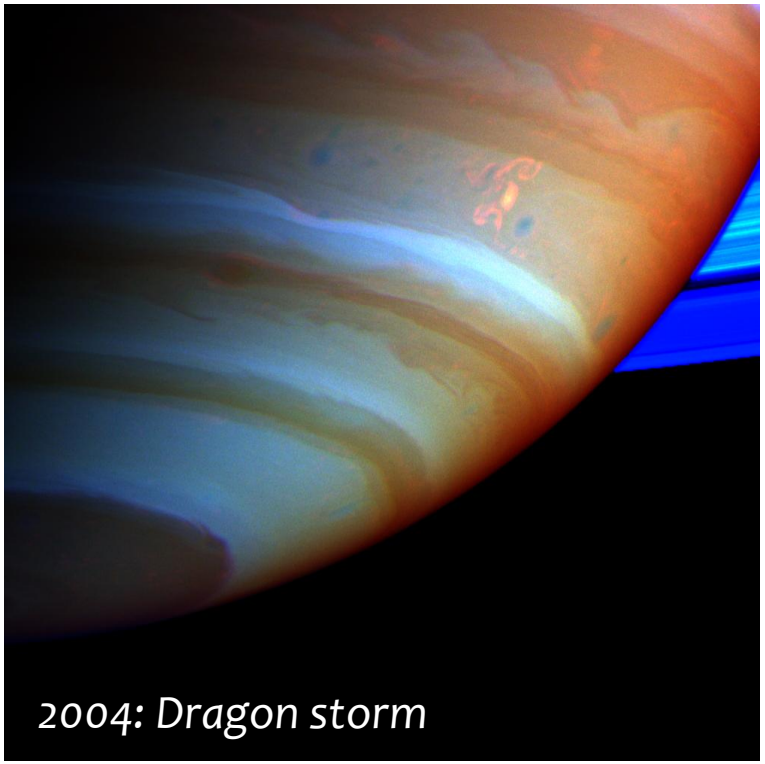
(Blue = remains to be done in next 6 years)

Cassini Mission Overview

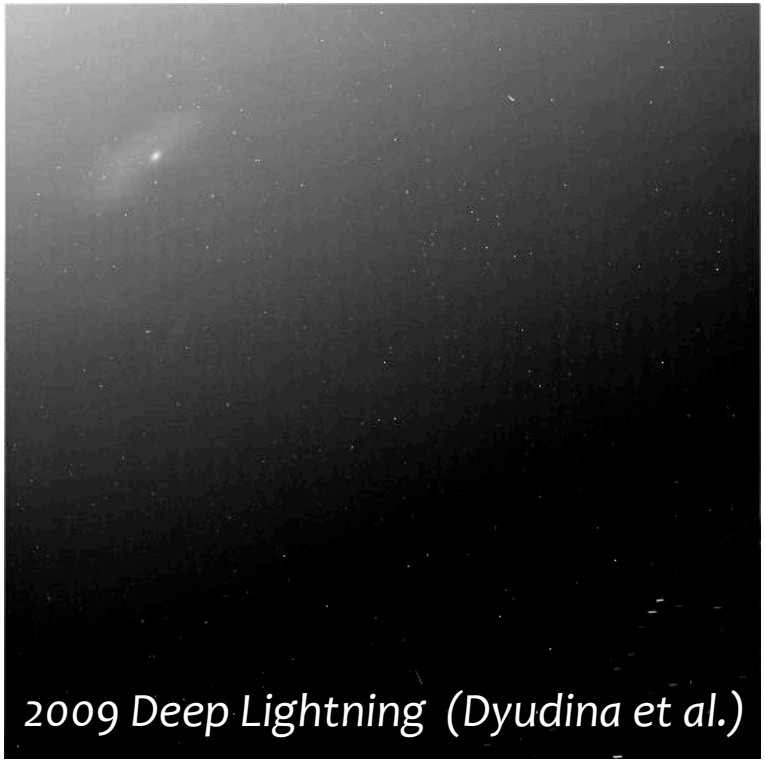
Four-Year Prime Tour, Equinox Mission, and Solstice Mission (Proposed), May 2004 - September 2017



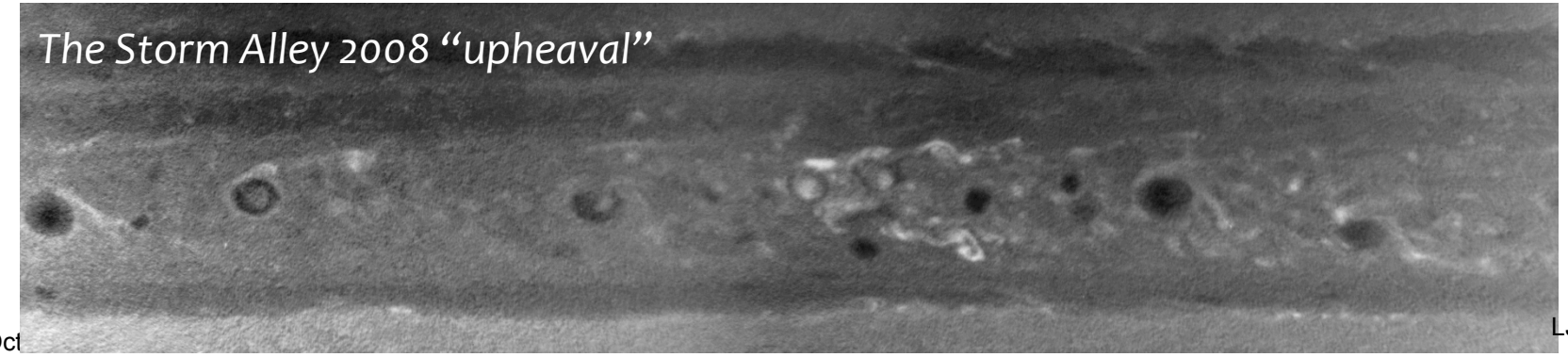
Small-Scale Storms…



2004: Dragon storm



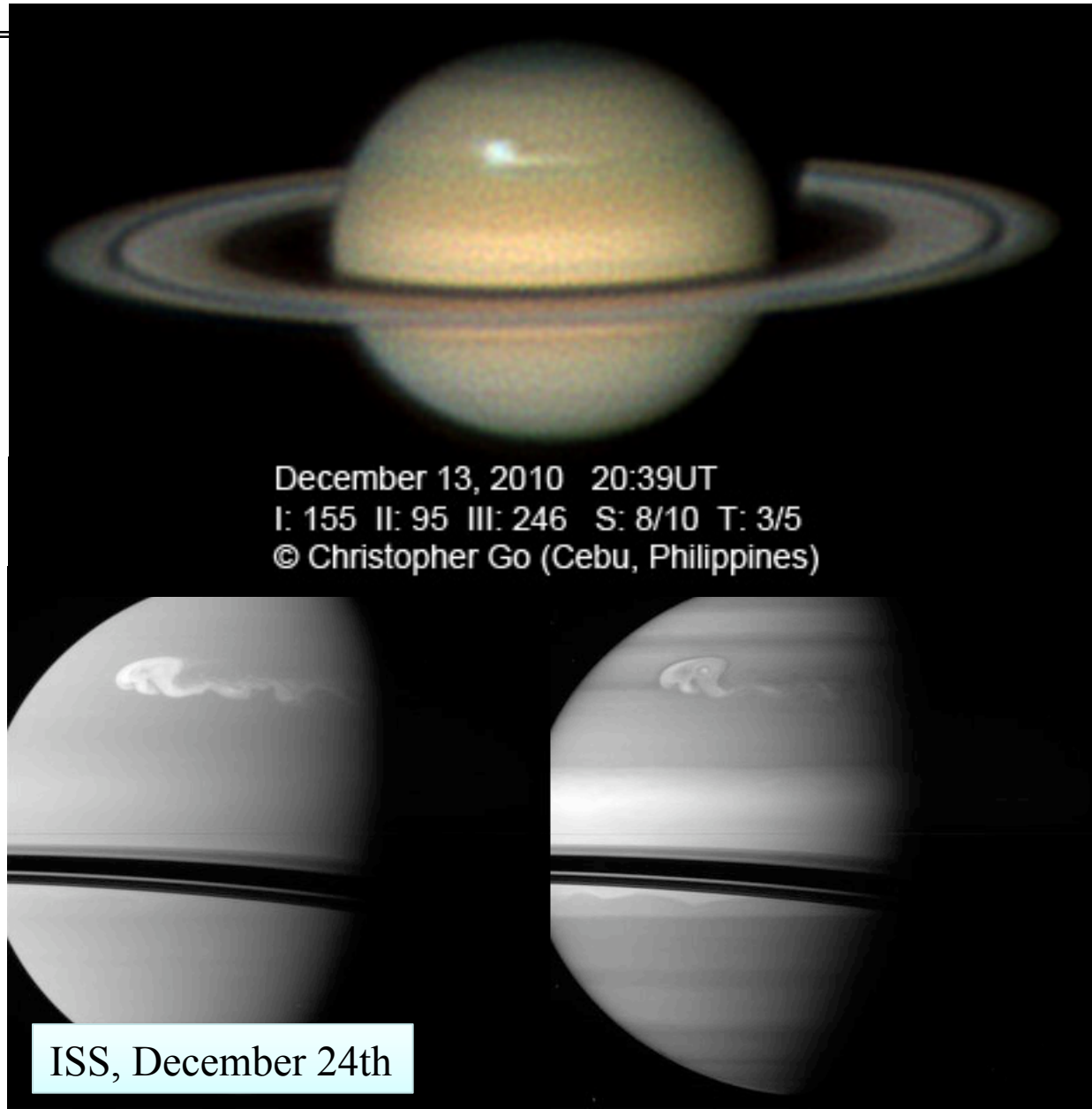
2009 Deep Lightning (Dyudina et al.)



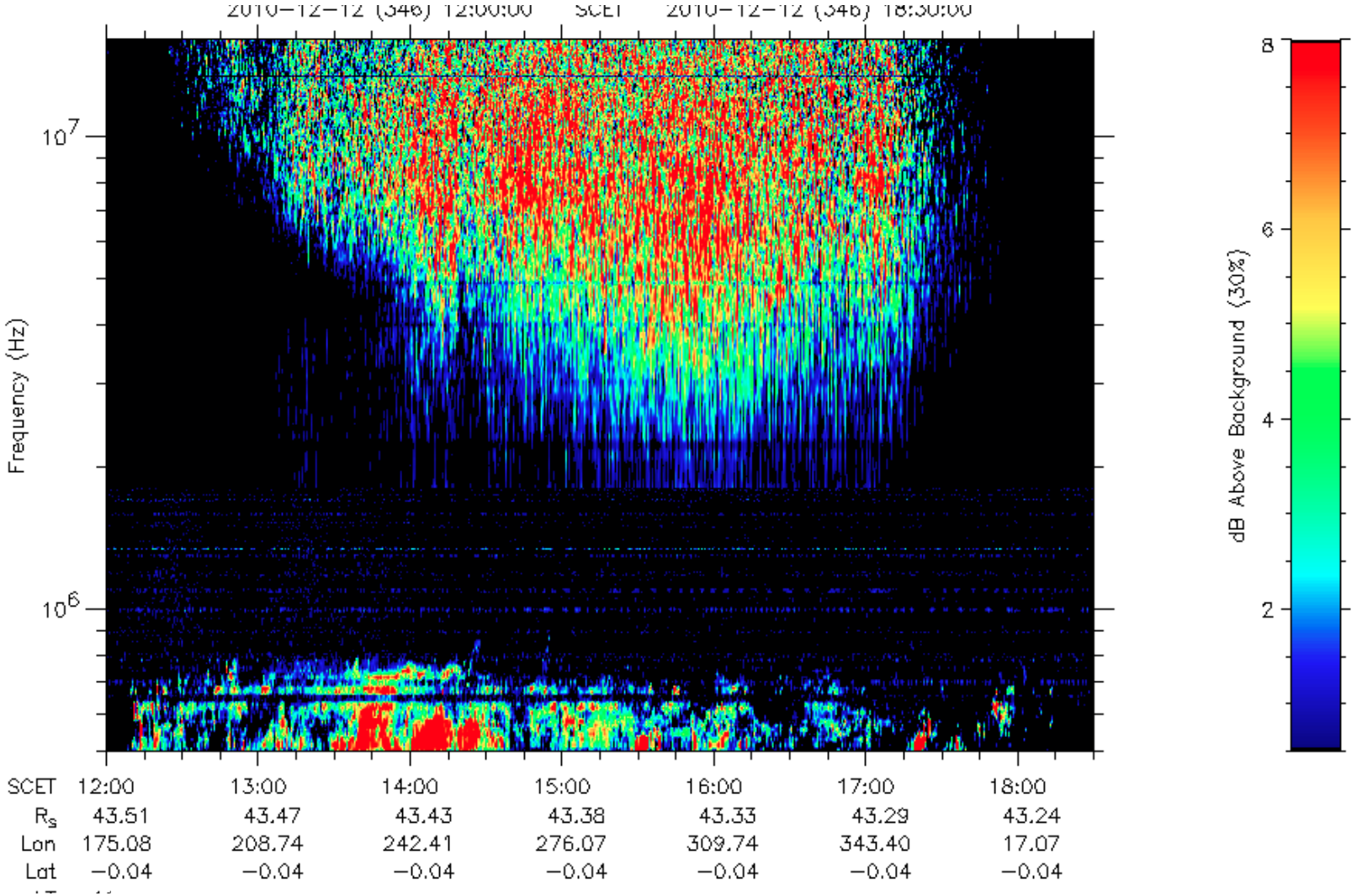
The Storm Alley 2008 "upheaval"

Birth of a New Storm: December 2010

- Cassini detected strong radio emissions indicative of lightning from a powerful thunderstorm on December 5th.
- Cassini and amateur images showed small white spot on this date.
- Storm core moved westward, with a tail expanding to the east observed from December 12th onwards.
- Motion of the storm core and the tail consistent with prevailing zonal flows:
  - Eastward at 32 and 47N;
  - Westward at 39N.



Lightning from Storm

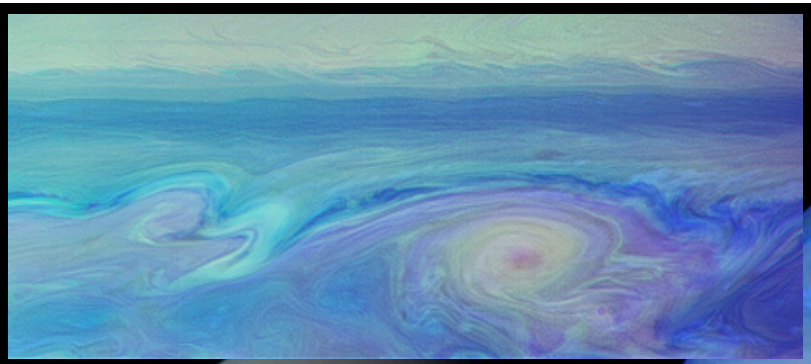


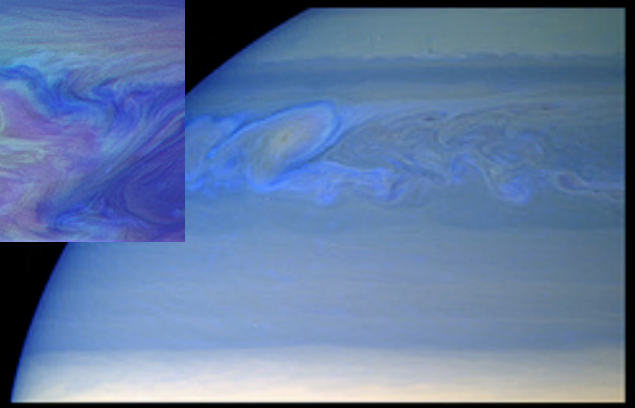
RPWS data show intense lightning activity from Saturn's northern hemisphere on Dec. 12, 2010

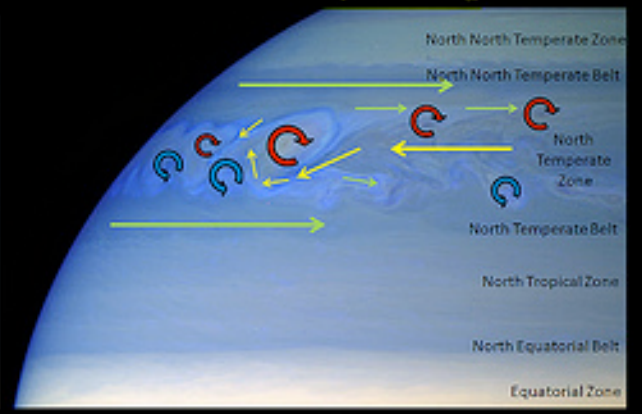
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Cassini Solstice Mission

Mature 'Serpent Storm' in 2011



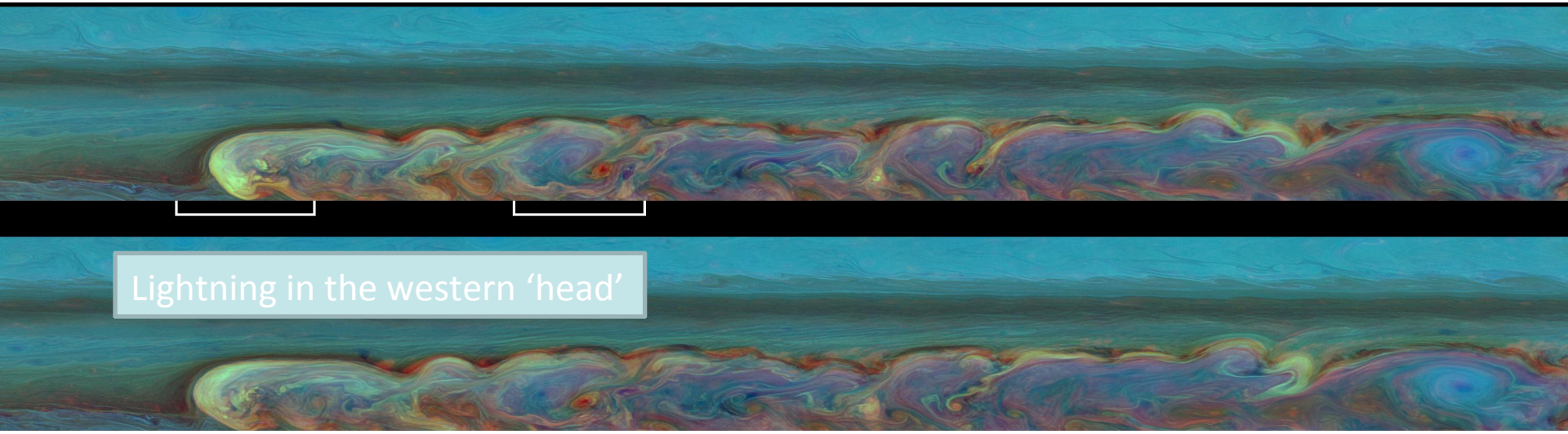




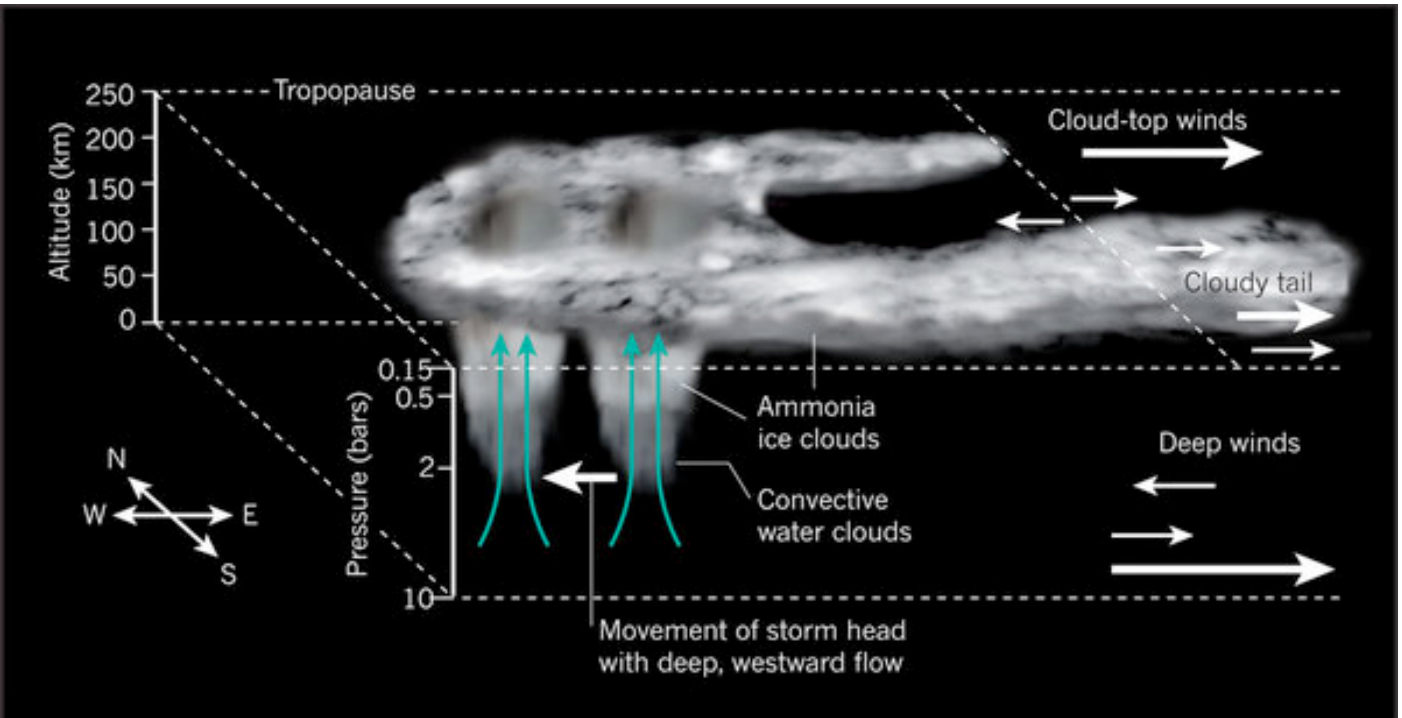
Composite assembled from Cassini raw images January 12, 2011

(annotated version)

Tropospheric Disturbance in Close-up



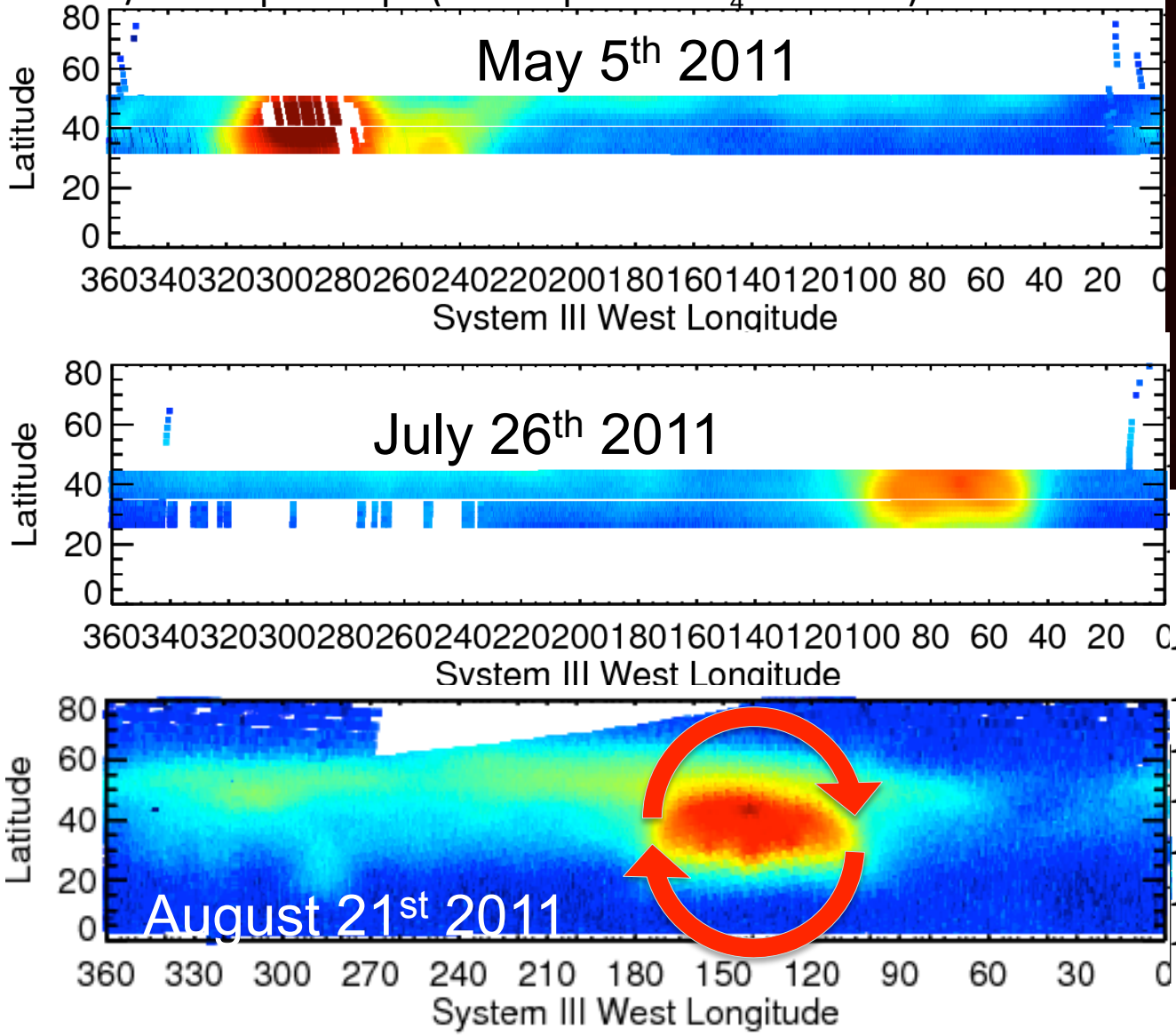
Lightning in the western 'head'

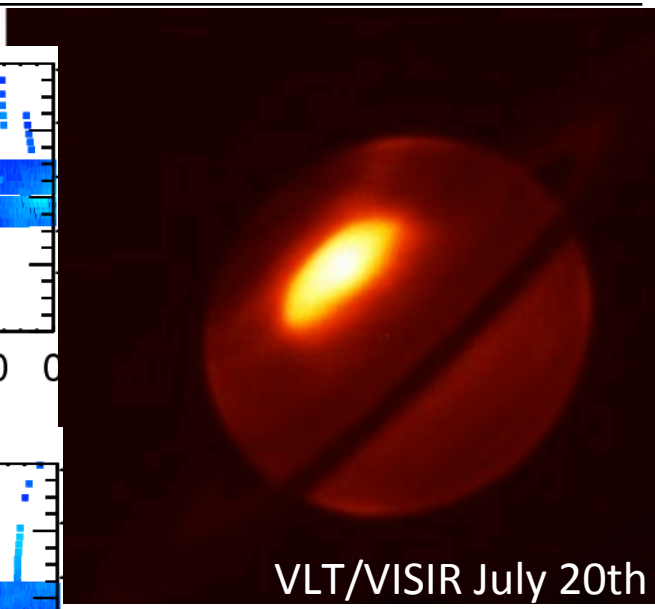


Storm core remains as a cold upwelling anticyclone

Big Surprise: Stratospheric Perturbations

Cassini/CIRS 7 μm maps (stratospheric CH_4 emission)

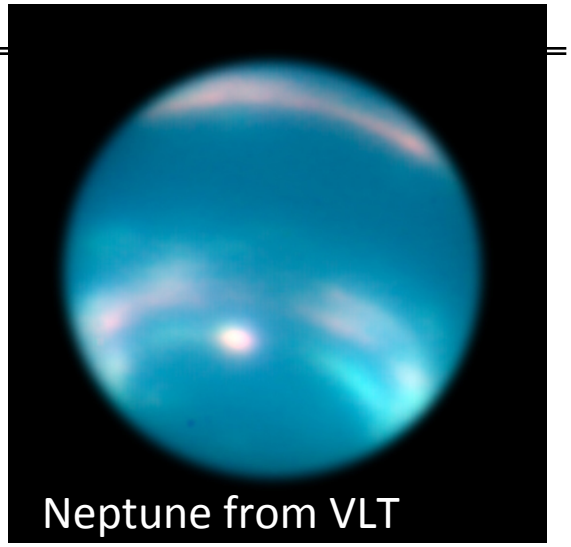


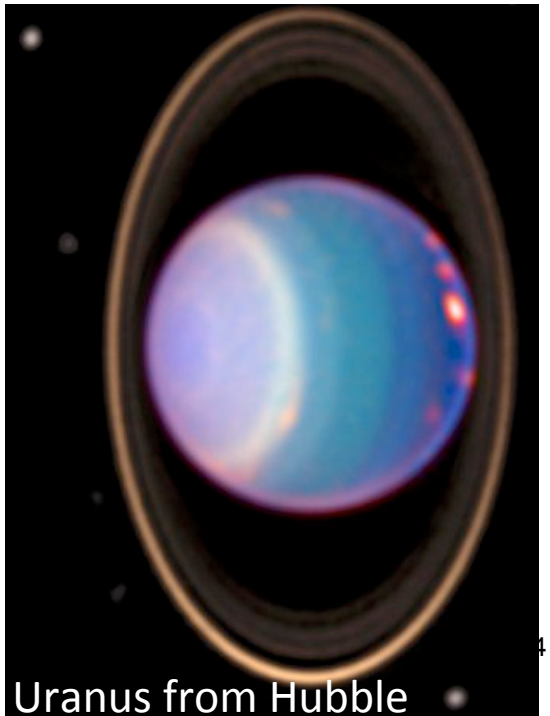


- Storm 'head' replaced by turbulent eddies throughout the band, appears cold in troposphere.
- No visible counterpart of hot beacon.
- Remaining warm band accelerates stratospheric jets

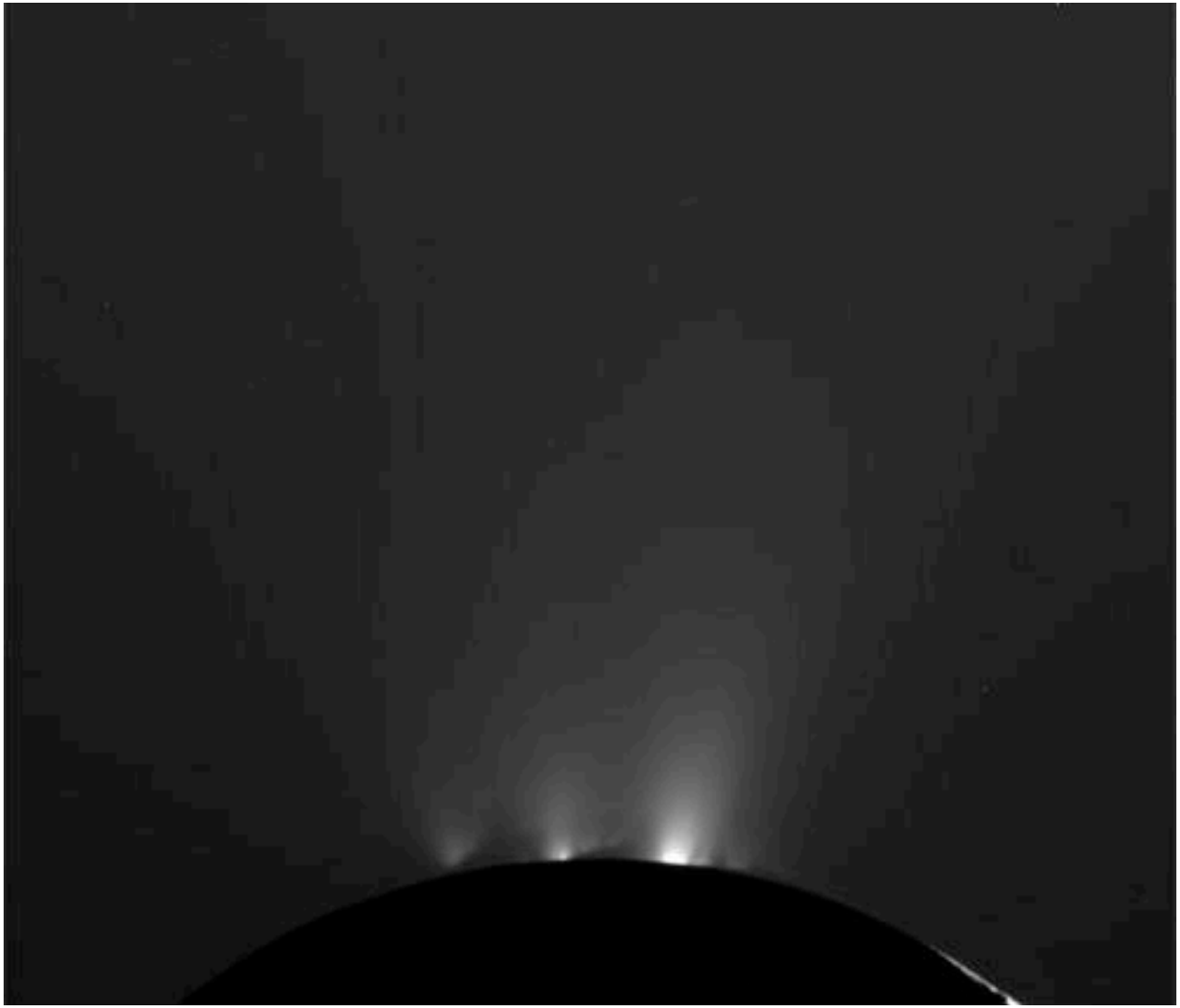
Open Questions

- **Why northern spring/summer?**
  - Saturn further from Sun in northern spring than southern spring, effect of energy input?
  - Sunlight doesn't penetrate to water clouds though…
  - Expect convective plumes to be active continuously, but environmental conditions are perfect for sustained updrafts through the hazes in spring.
- **What sustains the storm?**
  - Is this moist convection? Energy is from Saturn's internal heat, but is this enough?
- **What are the beacons?**
  - Evidence for a significant connection between troposphere and stratosphere, a 'stratospheric vortex' has evolved before our eyes…
- **What will the effects be long-term?**
  - Will temperature perturbations cool to normal 'quiescent' atmosphere in time?
  - Does this happen every year on Saturn?
- **Could the other giant planets show anything similar?**
  - Evidence of convective storms on Uranus/Neptune

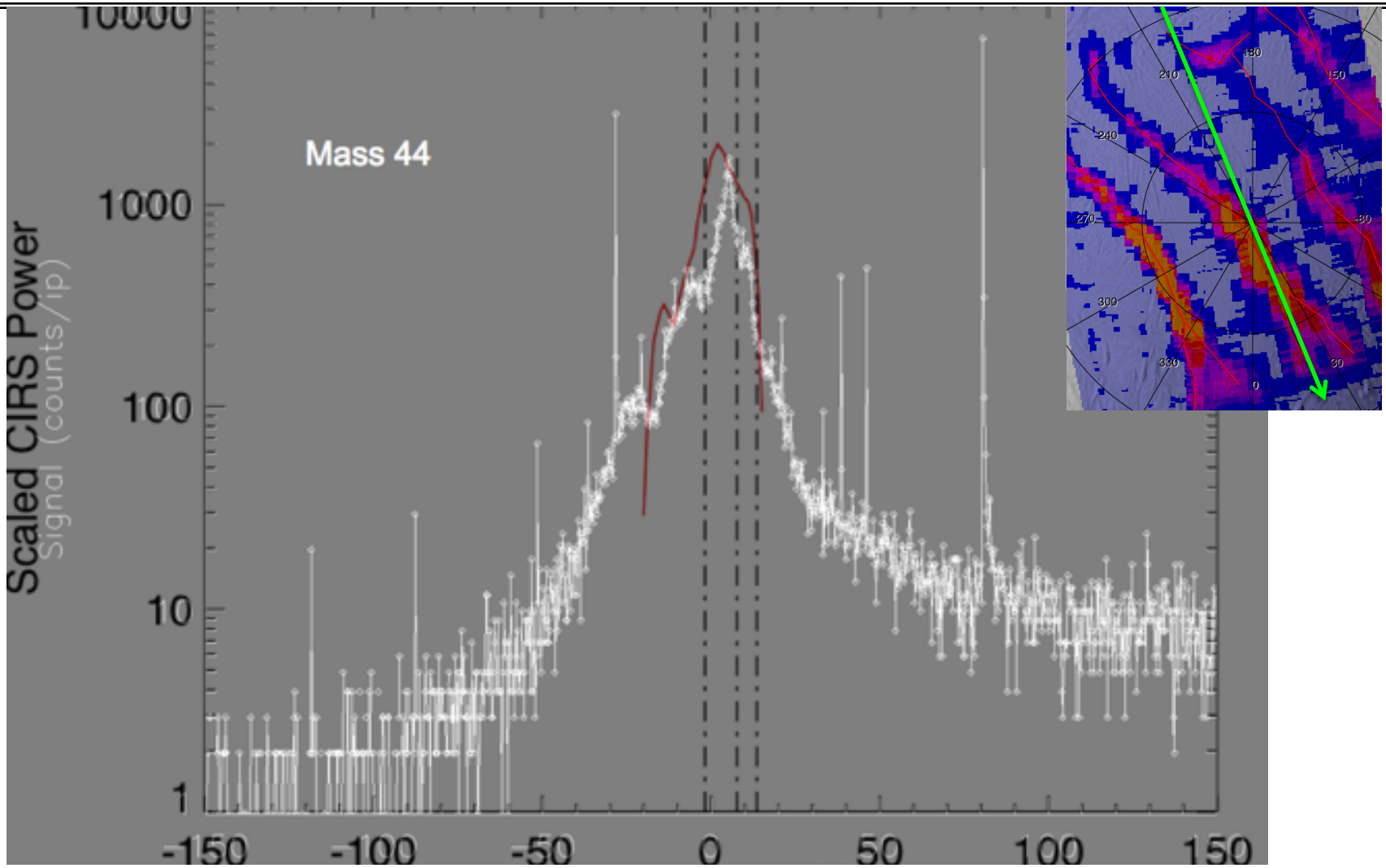

Neptune from VLT


Uranus from Hubble

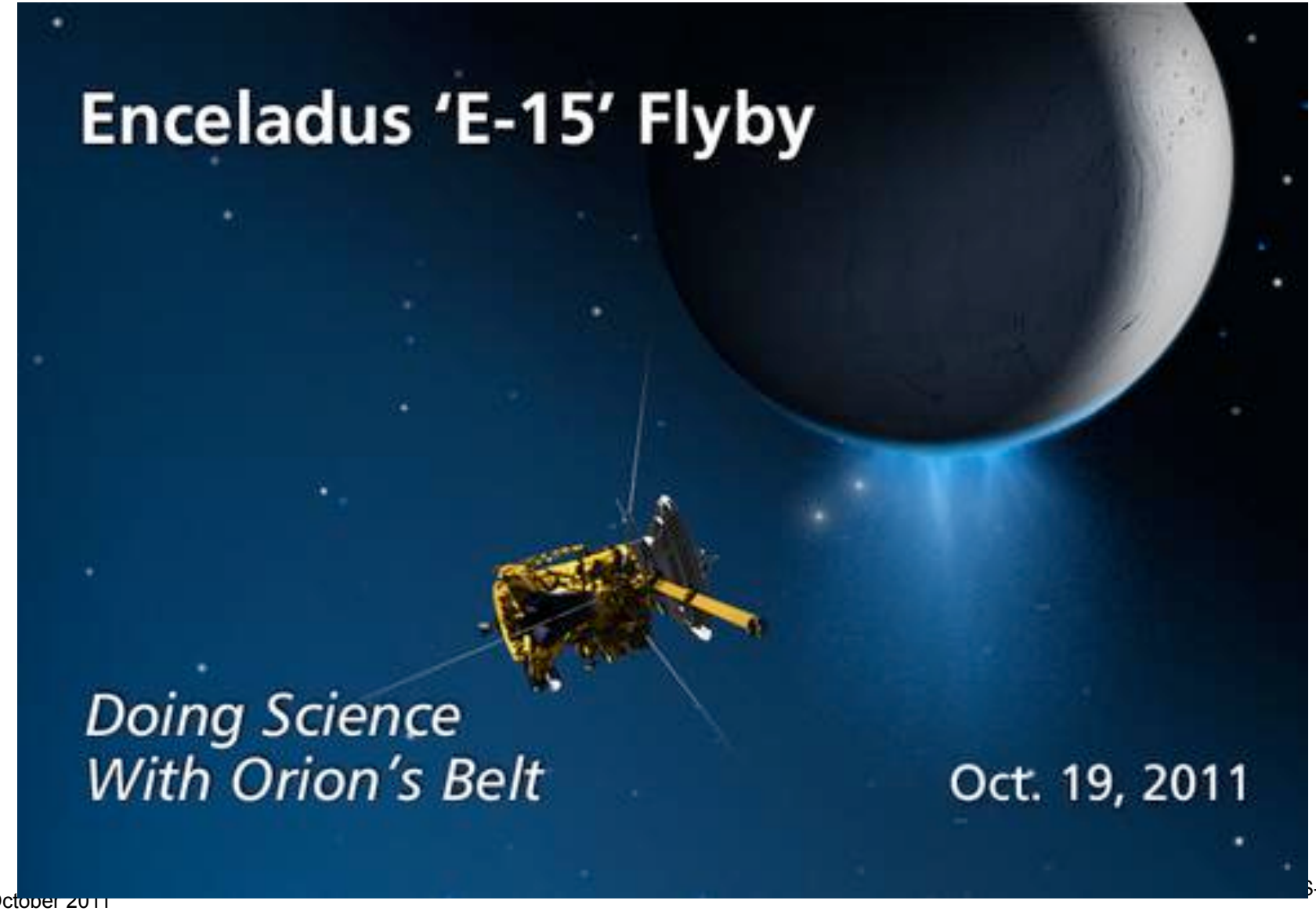
Plumes from Enceladus Flyby: Oct. 1, 2011



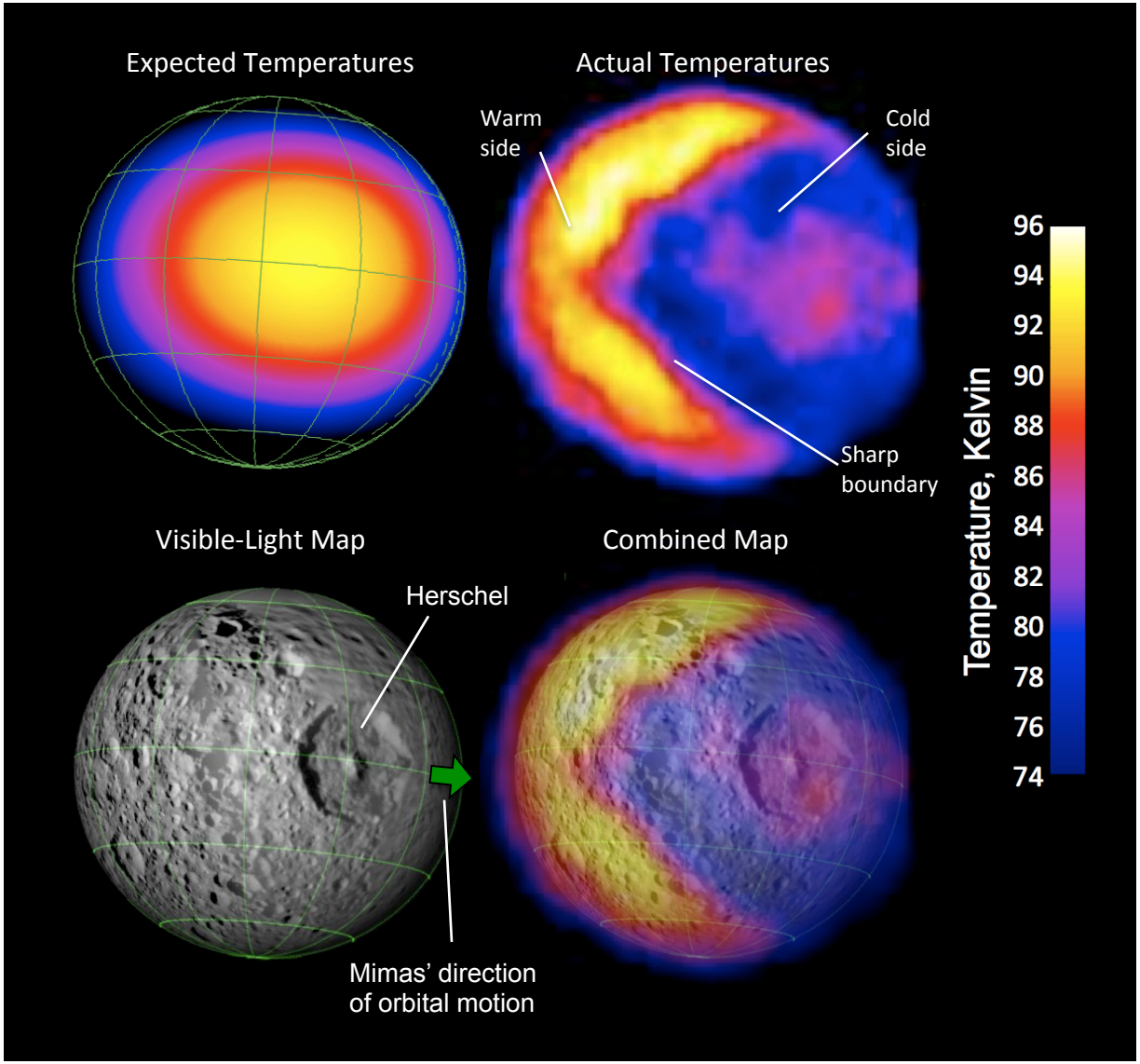
October 1st, 2011 Enceladus flyby



New INMS mode measuring carbon dioxide. It shows both thermal plume envelope and individual supersonic jets {the spikes} along Baghdad tiger stripe.


Enceladus 'E-15' Flyby
Doing Science
With Orion's Belt
Oct. 19, 2011

Mimas "Pac Man" Thermal Anomaly

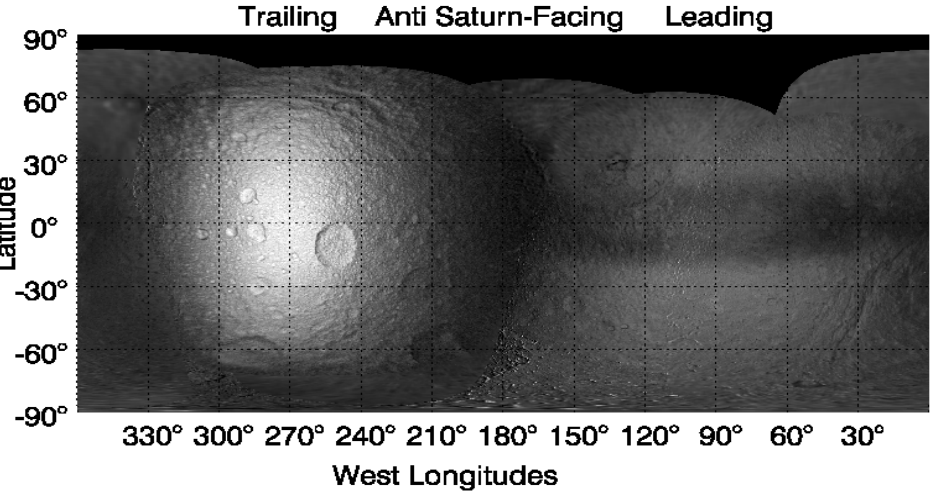


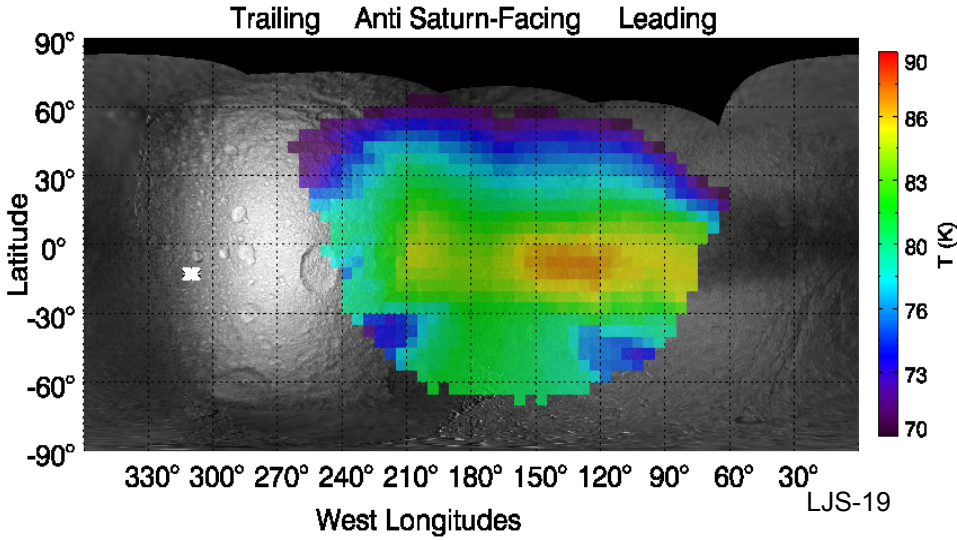
Another Thermal Anomaly on Tethys?

- Thermal anomaly recently discovered on Mimas' leading hemisphere in an region of low IR/UV color preferentially bombarded by high-energy electrons (Howett *et al*. 216, *Icarus* 221-226, 2011)

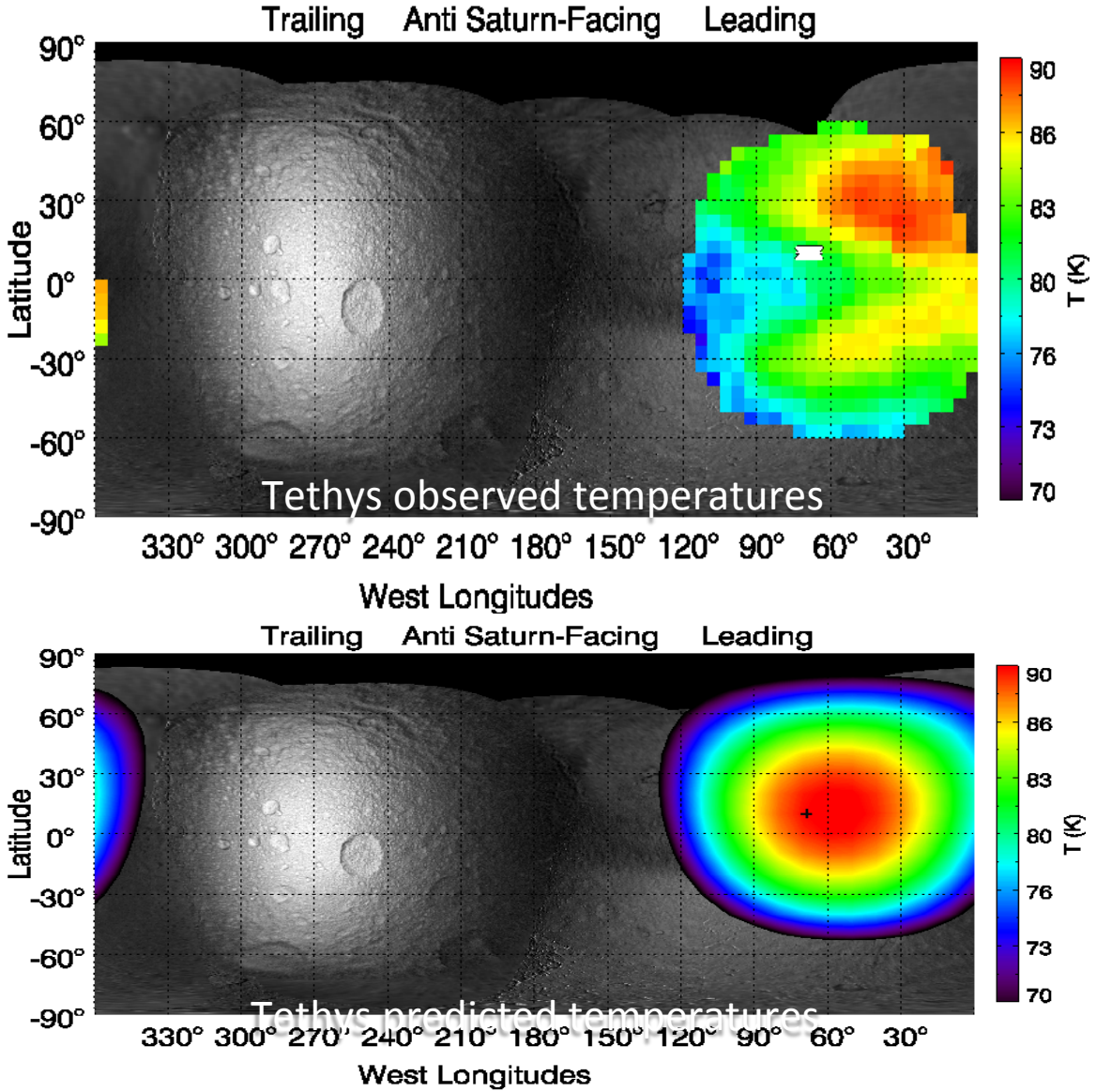
- Schenk *et al.* (2011) also show a low IR/UV color ratio region on Tethys' leading hemisphere, shown below.

- Tentative detection of a thermal anomaly in this region was determined from CIRS data obtained in June 2007 (nighttime)



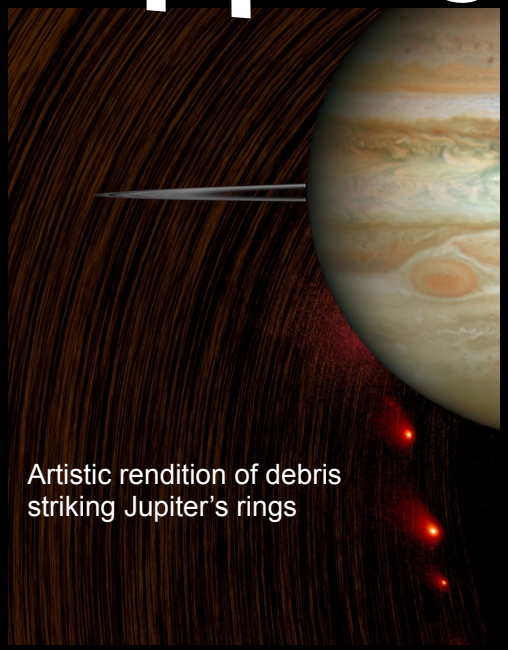


Another thermal anomaly on Tethys: Yes!



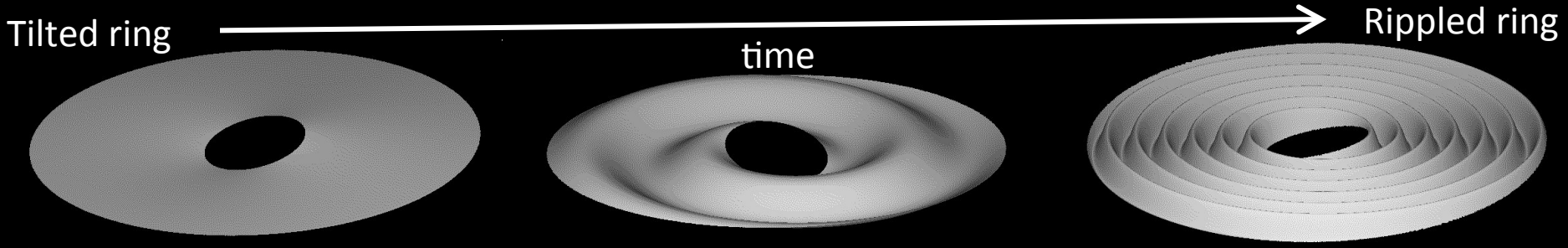
- Thermal anomaly has been confirmed on Tethys in Sept. 14th 2011 data
- Anomalous cooler daytime temperatures are observed at equatorial latitudes in an area of low IR/UV surface color.

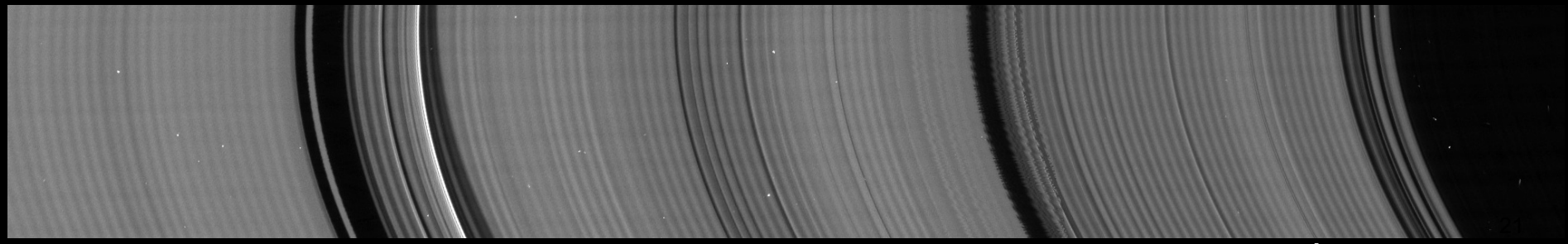
Ripples in Saturn's Rings



Artistic rendition of debris striking Jupiter's rings

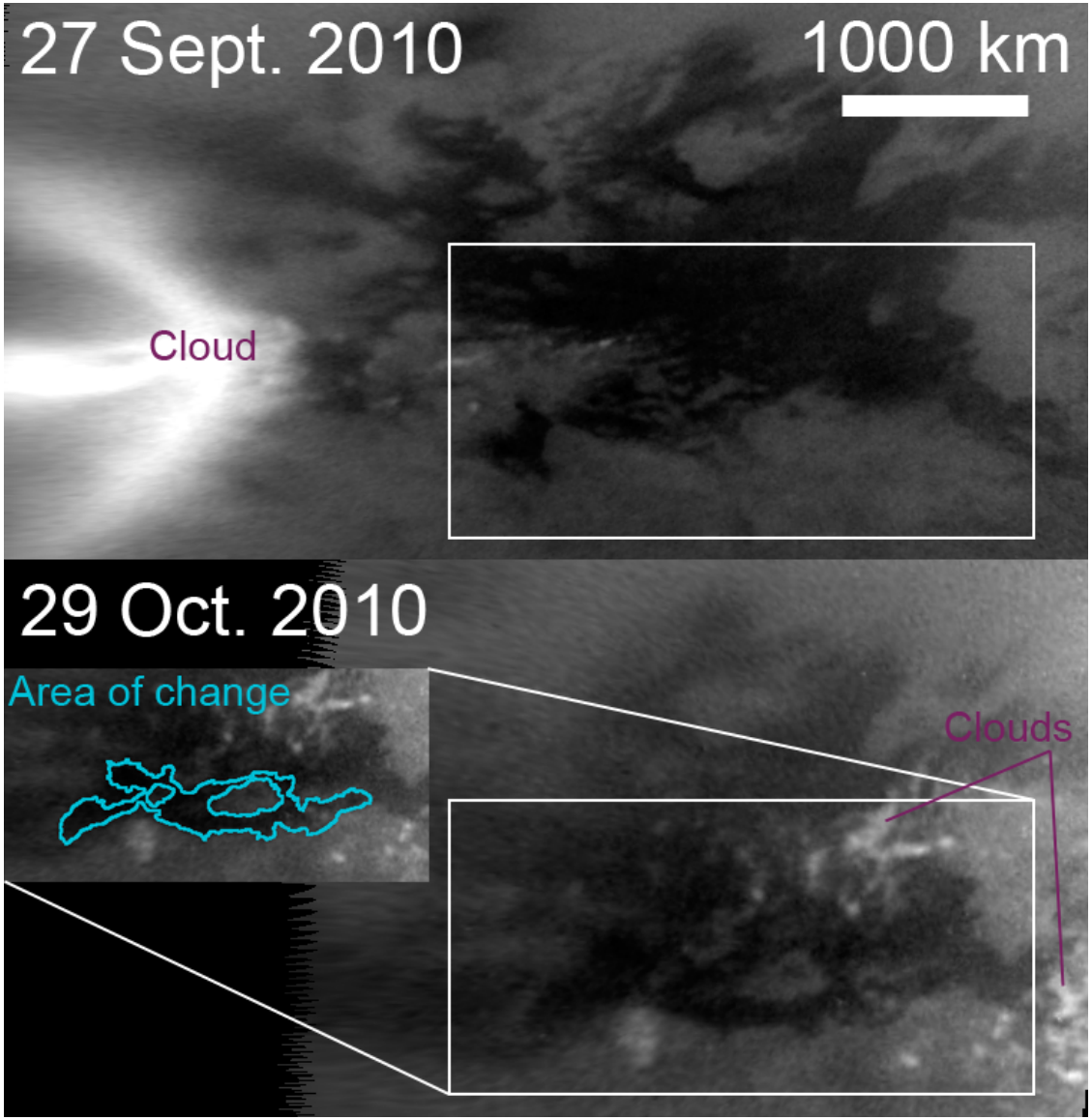
- Saturn's rings exhibit an extensive pattern of ripples, seen by Cassini cameras
- By unwinding the spiral, Cassini scientists have found that *debris from an unseen comet tilted the rings in 1983!*
- Jupiter's faint rings also show a ripple pattern – now known to have been caused by the collision of fractured comet Shoemaker-Levy 9 in 1994



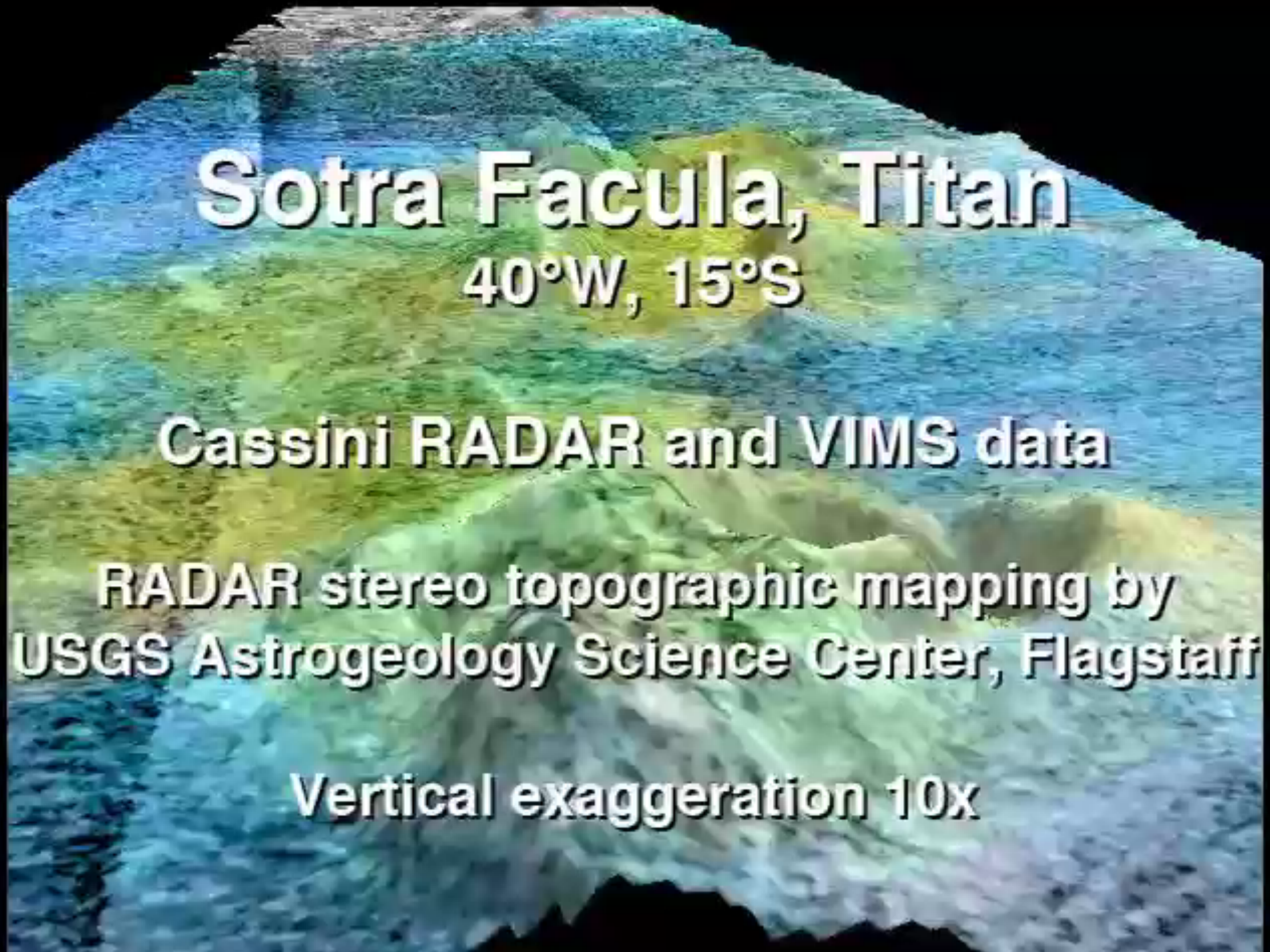


Cassini image of the ripples in Saturn's rings.

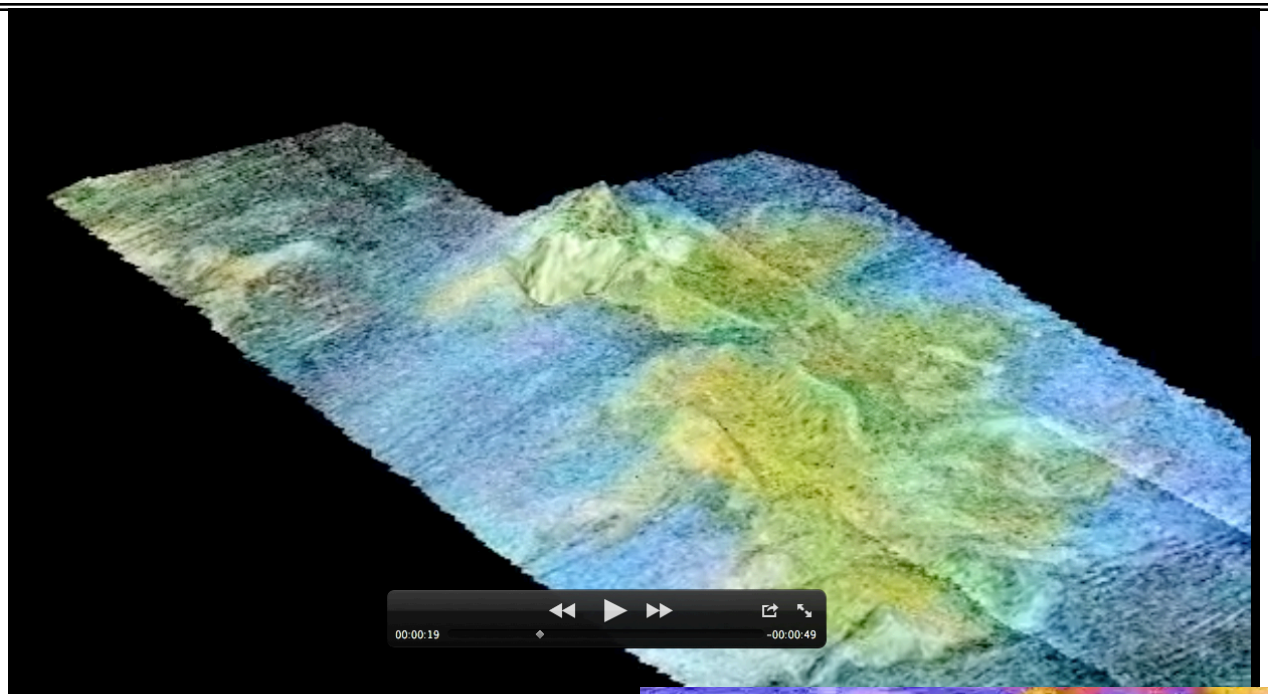
Spring Rain on Saturn's Moon Titan

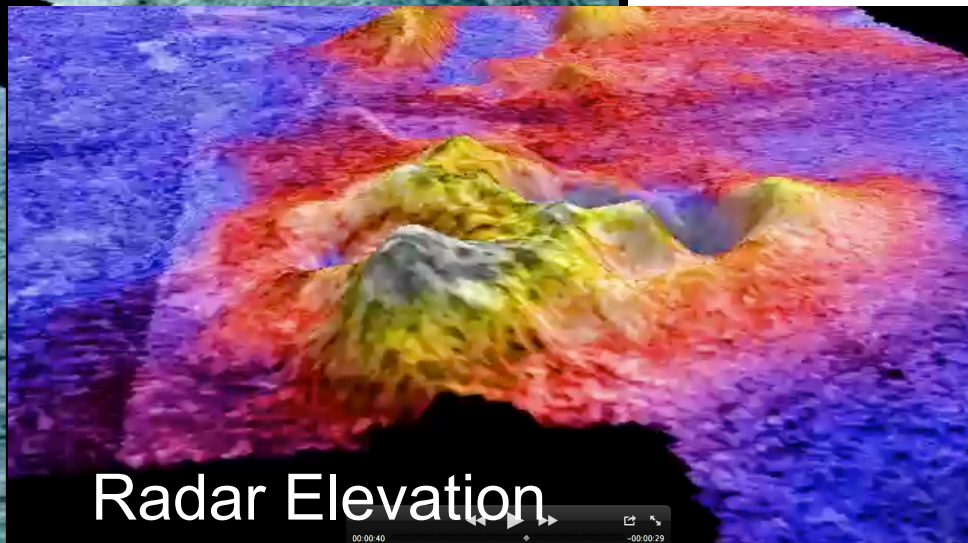


- Huge cloud observed on Titan in Sept. 2010 (top) was quickly followed (bottom) by extensive changes on the surface: >500,000 square km, roughly the combined area of Arizona and Utah.
- In these images bright features are methane clouds, shades of gray are surface features.
- Widespread methane rainfall from the storm makes the surface wet, perhaps even flooding it in some places.
- The observation of recent rain suggests that the climate here is similar to the southwestern U.S., where infrequent rain carves washes and riverbeds.
- Titan's weather is changing with the seasons, now early northern spring (~April on Earth), and storms have become more common at low latitudes.


Sotra Facula, Titan
40°W, 15°S
Cassini RADAR and VIMS data
RADAR stereo topographic mapping by
USGS Astrogeology Science Center, Flagstaff
Vertical exaggeration 10x

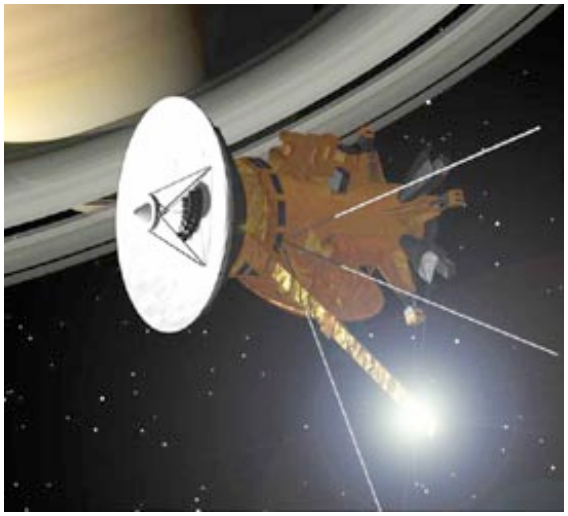
Titan's Sotra Facula: Ice Volcano?





New Cassini Participating Scientists

- ~10 new Cassini Participating Scientists (PSs) will be added soon!
  - Mix of U.S. and European scientists
- Competitively selected through Cassini Data Analysis Program (CDAP)
- PSs will participate on one or multiple science teams
- Additional Participating Scientists will be added over next several years
- New PSs represent a fantastic augmentation to Cassini teams!



Consolidated Senior Review Process

- Science merits and performance for 8 extended missions will be evaluated by a single review board
  - Cassini, GRAIL, LRO, MER, MEX, MRO, ODY and Deep Impact concepts
- 35-page proposal to address FY13 - FY14 extended mission describing 3 budget options
  - Guideline option provided by NASA
  - 80% Guideline option
  - Overguide option
- The information above is based on draft guidelines that were recently circulated for comment
- Proposal due to NASA HQ Jan. 31, 2012

Cassini Budget Guidelines

Cassini Budget Numbers

Prime	Equinox		Solstice			
FY08	FY09	FY10	FY11	FY12	FY13	FY14
$80.2M	$79.5M	$80.5M	$65.8M	$59.4M	$61M	$63M

- Cassini Guideline: FY13: ~$2M (3% cut), FY14: ~$13M (21% cut)
- 80% Guideline: FY13: ~$14M (22% cut) FY14: ~$23M (37% cut)
- Budget cuts are relative to our current Solstice mission budget

- **This level of reduction (21% - 37%) will have a major impact on Cassini's ability to operate and collect science data**

- **The Cassini Solstice Mission encompasses more than FY13 and FY14, it runs through FY17!**
  - **Cuts in funding in FY13 and FY14 will adversely ripple through the remainder of the mission**

2009 Senior Review Comments on Proposed 7-year Solstice Mission

- **The Cassini Solstice mission**
  - **robustly responds to the Decadal Survey and NASA's strategic objectives.**
  - **is essentially a new mission in its own right.**
  - **promises continued unexpected discoveries that will engage the general public.**
  - **will directly benefit preparations for any future mission to the Saturn system.**
  - **presents a unique opportunity to train the next generation of scientists, engineers, and operations personnel.**
  - **presents an opportunity to execute a "follow on" mission to respond to the findings and discoveries of its progenitor mission.**
    - Typically years to decades elapse before such a follow on mission can be executed, but the Solstice mission allows NASA to mount such an effort now in a very cost-effective way.

More 2009 Senior Review Board Comments

- **The selected tour is impressive and effectively balances the multitude of requirements, desires, and restrictions for the Solstice mission.**
- **The science value of the Solstice mission is very high.**
  - **Juno-like end of mission scenario is extremely compelling**
  - **All disciplines cited for high science value**
    - One example: **For the Titan discipline, the Solstice Mission can be considered a "stand-alone" mission** because it provides the opportunity to witness hydrological and atmospheric process in action on Titan, as the changing seasons force surficial, fluvial, and atmospheric changes on hemispheric scales.

2009 Senior Review Budget Recommendation

- *Recommendation #1: Accept the proposed Solstice Mission at a budget level of 60% for the engineering team and 75% for the science team*
- **This level of funding is considered the minimum to safely operate the spacecraft and a 75% budget for the science portion of operations.**
- **The Cassini team studied a 50% option and found that 50% of the Equinox mission funding was insufficient to support a mission of any significant science value. The review board agreed.**
- Specifically, the funding level for science enables the Cassini team to:
  - **execute an excellent and innovative mission plan that takes sufficient advantage of a productive, unique, and healthy asset to pursue both the discoveries Cassini has already made and those yet to be made**;
  - **fund a more adequate level of timely science analysis necessary to support operations and continue the science productivity of the team** (albeit at a lower level than during the prime and Equinox missions);
  - **retain early career scientists who would be disproportionately lost from the Cassini mission**, precluding using the Solstice mission as a continuing opportunity to train the next generation of scientists;

Cassini Budget Guidelines: Further Cuts

Cassini Budget Numbers

Prime	Equinox		Solstice			
FY08	FY09	FY10	FY11	FY12	FY13	FY14
$80.2M	$79.5M	$80.5M	$65.8M	$59.4M	$61M	$63M

- Cassini Guideline: FY13: ~$2M (3% cut), FY14: ~$13M (21% cut)
- 80% Guideline: FY13: ~$14 M (22% cut) FY14: ~$23M (37% cut)
- Overguide: FY13: Current budget FY14: Current budget

- **Cuts of 21 - 37% represent funding below the 50% Equinox mission funding when adjusted for inflation**
- **Science collection and research cuts will be more than the percent cuts above** because the engineering budget is already near the minimum to safely operate the spacecraft
- Early career scientists will be significantly impacted with budget reductions

Relative Mission Costs: Value of Solstice Mission

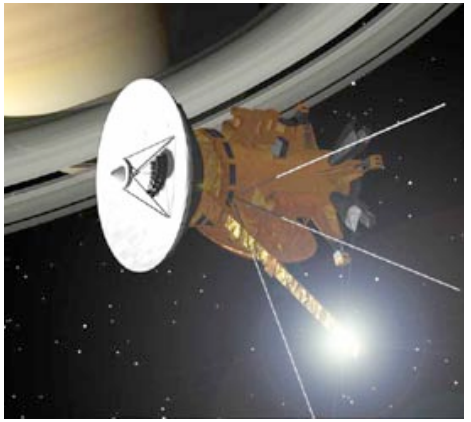
- Cassini Solstice Mission baseline cost approved by 2009 Senior review board
  - **FY13 – FY17 baseline cost from previous Senior Review: ~$320 M**

- **Remaining Cassini Solstice mission at $320 M is a worthwhile investment!**
  - Provides a Saturn orbiter mission with novel seasonal configuration
  - Provides a Juno-like mission with multiple highly inclined orbits at very close range to Saturn

- Challenges of returning to the Saturn system with a new spacecraft
  - Distant destination with long flight times
  - Saturn has a long "year"—northern spring-to-summer progression will not repeat for another 30 years!
  - Solstice Goals:
    - Observe seasonal and temporal change in the Saturn system to understand (1) hemispherically asymmetric behavior on Titan, (2) Role of sunlight in Enceladus plume activity, (3) Origin of surprising asymmetry in Saturnian polar circulation
    - Complete the goal of long-baseline observations revealing phenomena not discernable with short baselines/limited data sets.

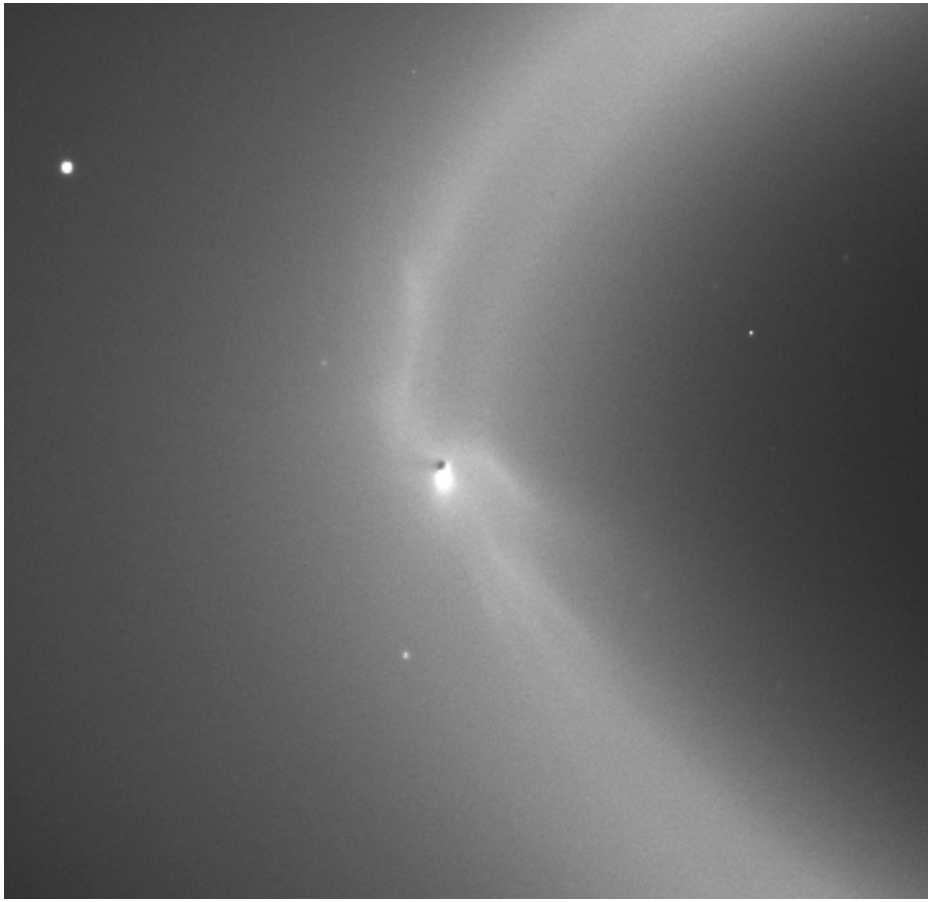
Requested Recommendation from OPAG

- Cassini will be the only outer planet Flagship mission flying through the mid- to late- portion of this decade
- Recommend that Cassini be funded through the planned 2017 end of mission
  - at a level that will maintain the current scientifically rich tour,
  - keep all of the science instruments on,
  - continue healthy international collaboration, and
  - return multidisciplinary, synergistic data as only a Flagship can do
- Support the scientific goals of the Solstice mission including:
  - seasonal and temporal studies until Solstice of the Saturn system,
  - capability to address new discoveries, and
  - end-of-mission Juno-like orbits to characterize Saturn's gravity and magnetic fields, and measure the mass of Saturn's rings.
- Because the current Solstice mission has been well-scrubbed, this funding level should be at or close to the current FY12 budget level.



Cassini Solstice Science

- Cassini Solstice Mission enables unprecedented opportunities for unique, groundbreaking science
- Unique, compelling Juno-like end of mission science
- Direct relevance to the Planetary Decadal Survey and NASA's exploration program
- New Participating Scientist program actively involves broader science community



END

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	Temperature, clouds, composition.	Spokes studies.	Enceladus plumes: temporal variability.	Enceladus: south polar region, jets, and plumes.	The methane-hydrocarbon hydrological cycle: lakes, clouds, aerosols.
		Wind studies.	Variability of ring phenomena on decadal timescales.	Magnetosphere over a solar cycle.		High-latitude atmosphere.
	Priority 2	Magnetosphere, ionosphere, aurora.	F Ring structure.	Titan's ionosphere.		Titan's plasma interaction.
NEW QUESTIONS	Priority 1	Rotation rate and internal structure.	The age of the rings.	Magnetotail dynamics.	Enceladus: ocean and endogenic activity.	Surface units and materials, especially lakes.
		Atmospheric waves, south polar hurricane, north polar hexagon.	Embedded moonlets, gap edges.	*In situ* studies of ionosphere and inner radiation belt.	Mimas studies.	Internal and crustal structure.
		Trace gases and isotopes.	Particle compositional variations.	Magnetospheric periodicities.	Dione: low-level activity?	Aerosol and heavy molecule layers and properties.
	Priority 2	Lightning storms.	Ring microstructure, e.g. self-gravity wakes.	Coupling between rings and ionosphere.	Rhea: ring material?	Atmospheric density measurements.
			"Propeller" objects.		Tethys studies.	Icy shell topography and viscosity.
					Internal structure, especially Rhea and Dione.	Surface temperature and cloud distribution.
					Hyperion studies.	Surface and tropospheric winds.
					Small satellites.	
					Iapetus studies.	

No cuts: Full Cassini Solstice mission science

Decadal Survey Statements

- **Fund currently flying missions**
  - **Ensure a level of funding that is adequate for successful operation, analysis of data, and publication of the results of these missions, and for extended missions that afford rich new science return.** (p. S-4)

- **Cassini is a superb example of international collaboration**
  - The joint NASA-ESA Cassini-Huygens mission to explore the saturnian system is a superb example of international cooperation of this scale (Flagship missions). (p. 2-12)

Cassini Achievements mapped to Decadal Survey

- **Cassini discoveries make up ¼ (3 of 12) of those highlighted.**
  - An active meteorological cycle involving liquid methane on Titan.
  - Geothermal and plume activity at the south pole of Enceladus.
  - Dramatic changes in the atmospheres and rings of the giant planets and the discovery of rapid changes in their ring systems. (p. 1-9. RECENT ACHIEVEMENTS IN PLANETARY SCIENCE)

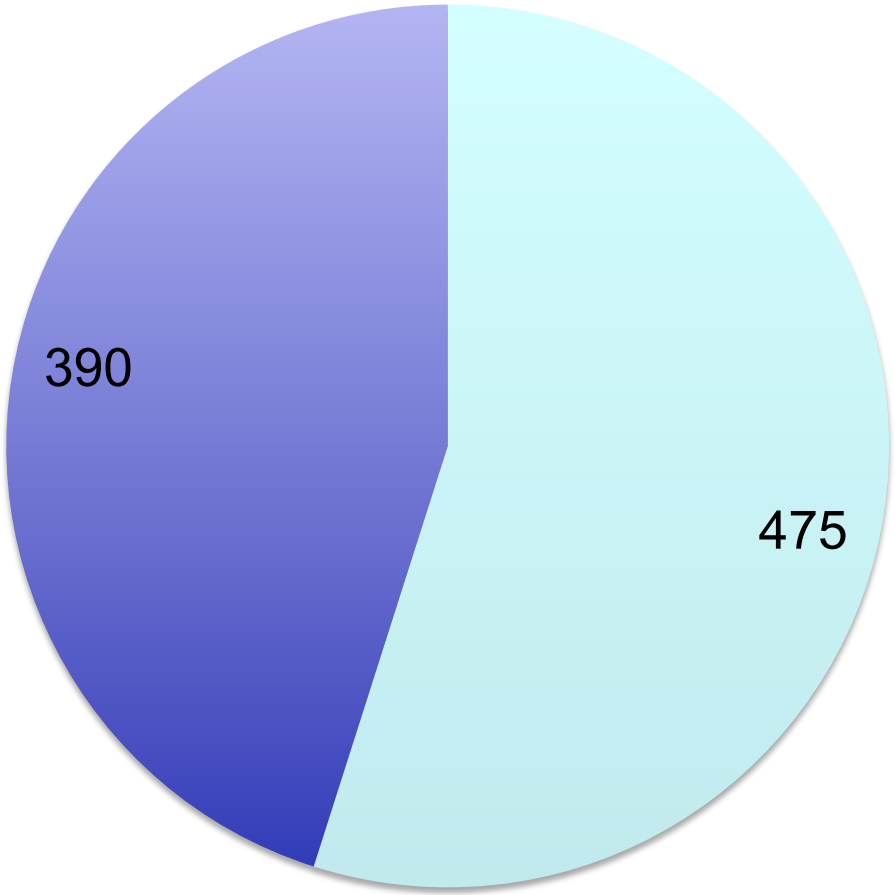
- **The science return from the Cassini mission has been phenomenal.** (p. 8-10)

Decadal Survey: Important Science Return from Cassini

- **Continuation of Cassini is cost-effective**
  - The planned continuation of the Cassini mission through 2017 is the **most cost-effective and highest priority way to advance our understanding of planetary satellites in the near-term**. **(**p. 8-37 (top bullet of Summary of SATELLITES chapter)

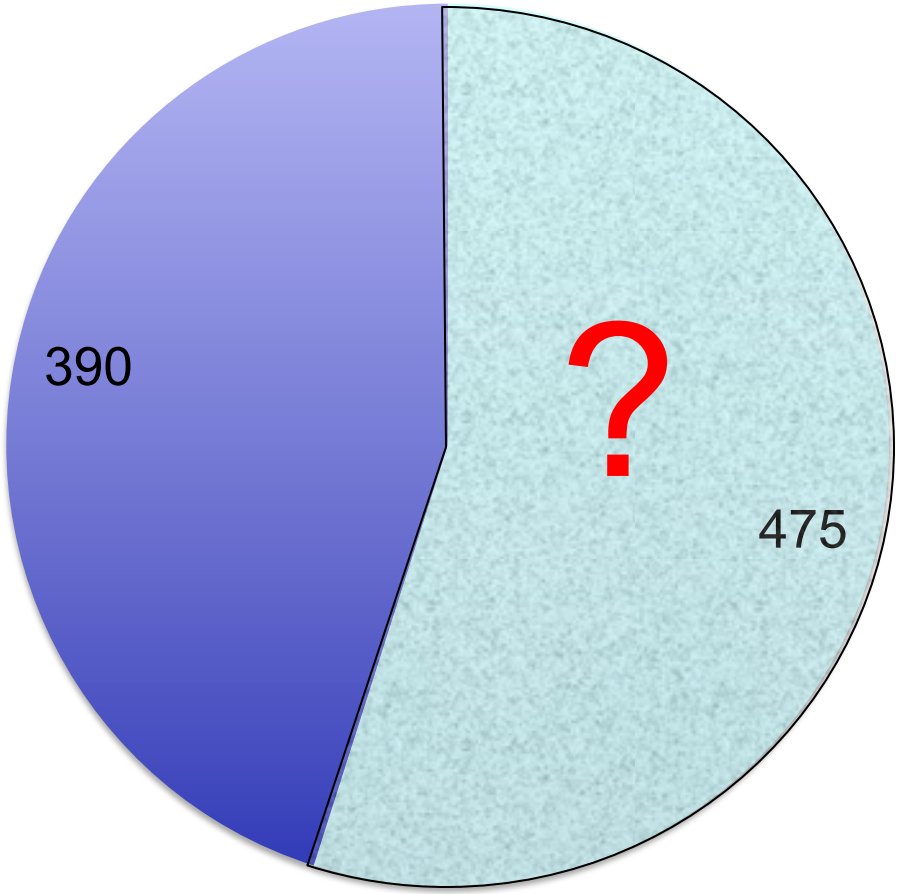
- **Titan, one of the most important objectives for planetary science**
  - Continued exploration of this fascinating Earth-like atmosphere, both from orbit and in situ, **remains one of the most important objectives for planetary science**. (p. 3-14 (chapter entitled PRIORITY QUESTIONS IN PLANETARY SCIENCE FOR THE NEXT DECADE))

Number of Cassini Science Collaborators



- Collabs on Cassini Teams
  (Associates, postdocs, collaborators, does NOT include PIs, TLs, Co-Is, and TMs)
- Collabs not on Cassini Teams
  (No official, funded affiliations with any Cassini team)

Loss of Cassini Collaborators and Early Career Scientists



- Collabs on Cassini Teams
  (Associates, postdocs, collaborators, does NOT include PIs, TLs, Co-Is, and TMs)
- Collabs not on Cassini Teams
  (No official, funded affiliations with any Cassini team)