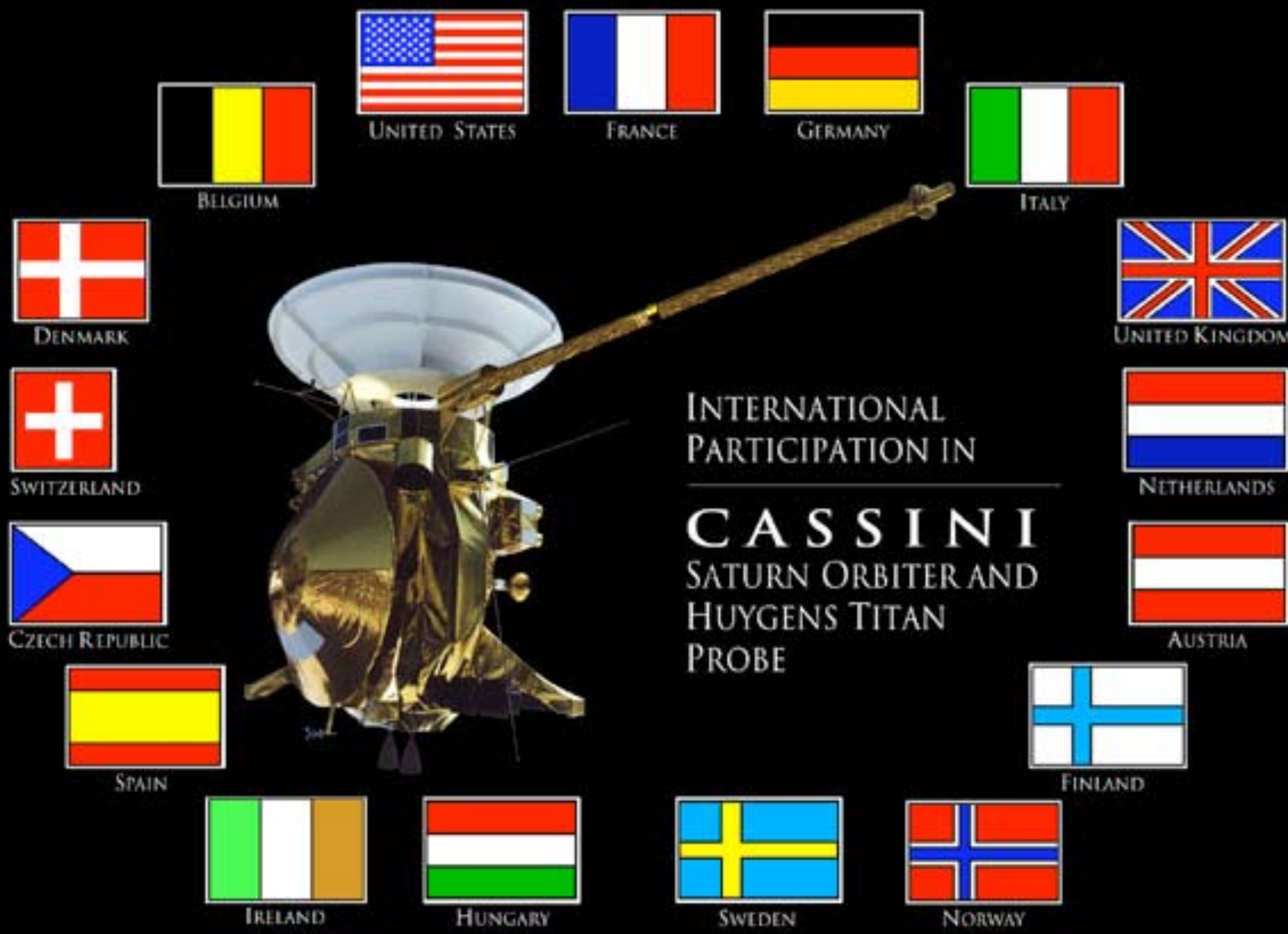
June 26, 2007

Cassini-Huygens Mission to Saturn 3rd Anniversary

Mission Overview

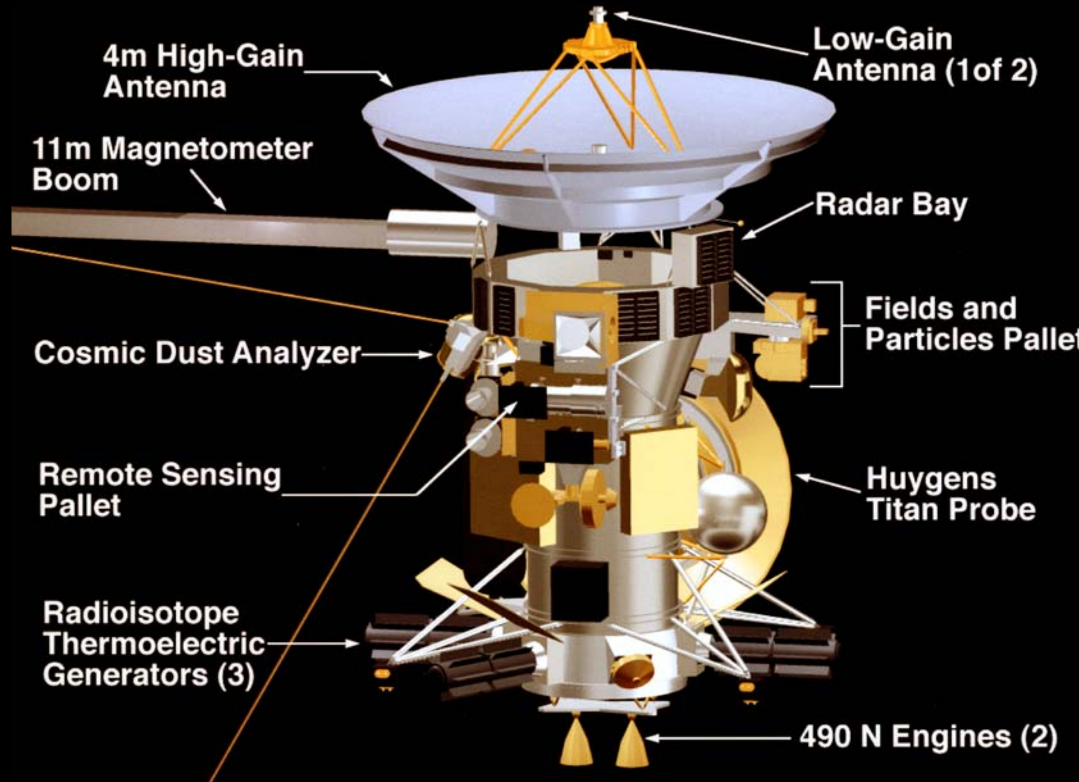


INTERNATIONAL PARTICIPATION IN
CASSINI
SATURN ORBITER AND HUYGENS TITAN PROBE
UNITED STATES
FRANCE
GERMANY
ITALY
UNITED KINGDOM
NETHERLANDS
AUSTRIA
FINLAND
NORWAY
SWEDEN
HUNGARY
IRELAND
SPAIN
CZECH REPUBLIC
SWITZERLAND
DENMARK
BELGIUM

Cassini Spacecraft

<u>Cassini Spacecraft Specs</u>
Height: 6.8 m (22 ft)
Diameter: 4 m (13 ft)
Mass: 2.5 Kg (2.8 tons)
(fueled): 5.6 Kg (6 tons)
Power: 700 Watts at SOI

<u>Cassini Mission Overview</u>
Launched Oct 15, 1997
SOI July 1 2004
4 Year Prime Mission
75 orbits
45 targeted Titan flybys
9 targeted icy satellite

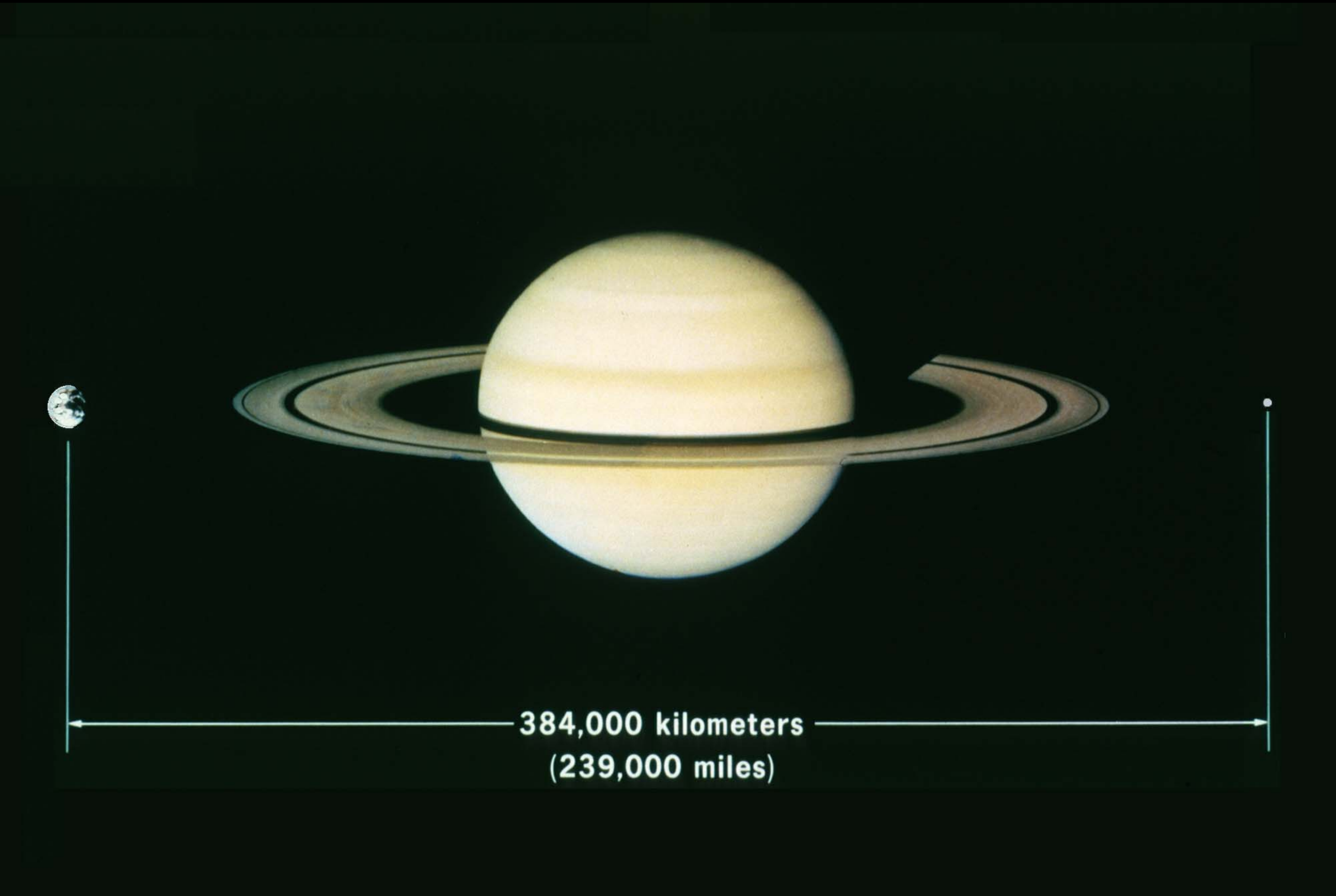


<u>Cassini Instruments:</u>

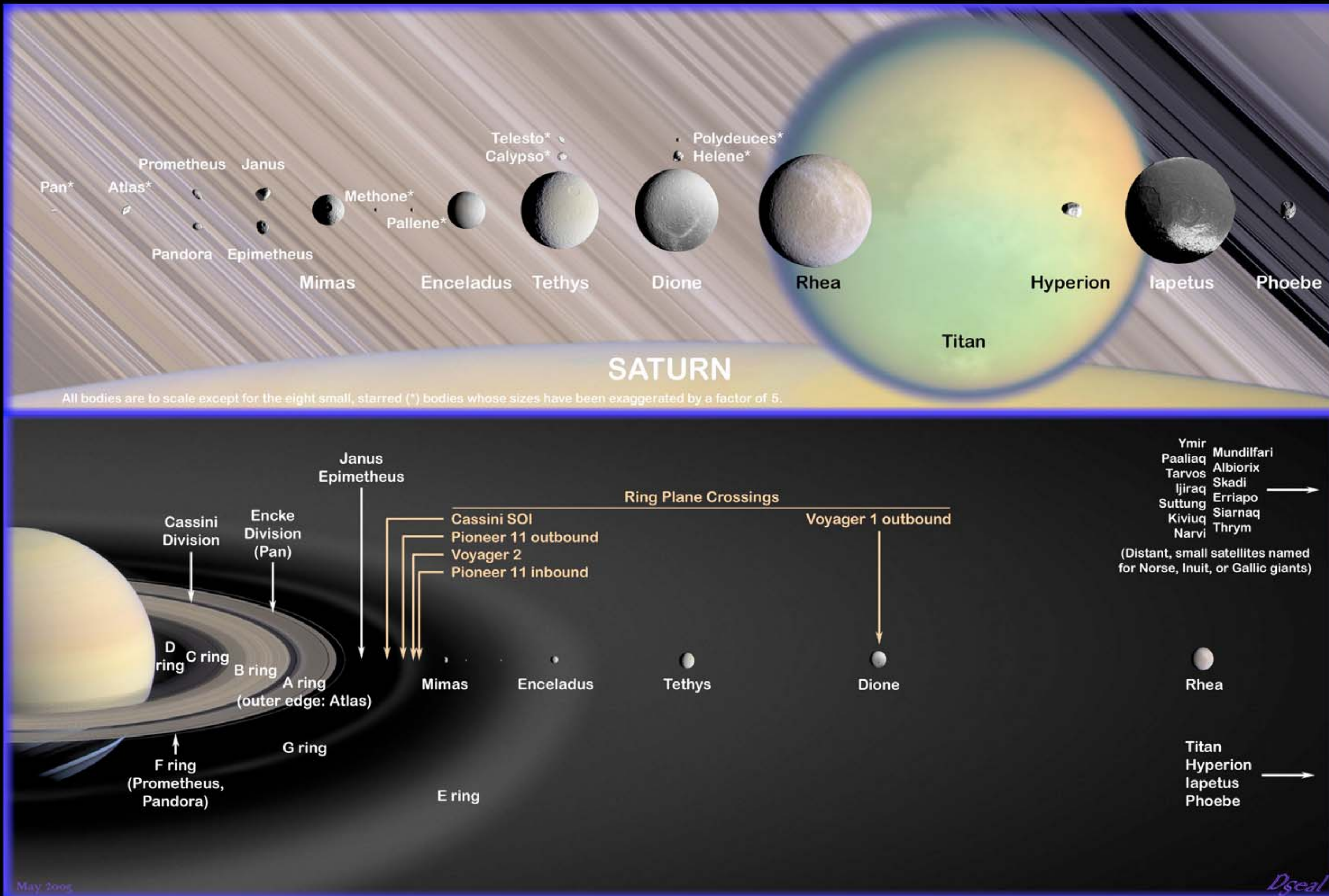
<u>Optical Remote Sensing (ORS)</u>
CIRS: Composite Infrared Spectrometer
ISS: Imaging Science Subsystem
UVIS: Ultraviolet Imaging Spectrograph
VIMS: Visual and Infrared mapping Spectrometer

<u>Microwave Remote Sensing</u>
RADAR: Cassini Radar
RSS: Radio Science Subsystem

<u>Magnetospherie and Plasma Science (MAPS)</u>
CDA: Cosmic Dust Analyzer
INMS: Ion and Neutral Mass Spectrometer
MAG: Dual Technique Magnetometer
MIMI: Magnetospheric Imaging Instrument
RPWS: Radio and Plasma Wave Science


384,000 kilometers
(239,000 miles)

THE SATURNIAN SYSTEM



Mission Overview - 3rd year of tour
Our Titan-ian Year

- The Cassini orbiter has completed the third of its four-year orbital tour of the Saturn system.
  - All orbiter systems are performing normally.
  - All consumables usage are running per predict.
- We arrived at the magnetotail and then proceeded with the 180 degree transfer. The 180 degrees transfer achieves three goals at once:
  - Rotates the petals from midnight towards noon
  - Has <u>many</u> low altitude Titan flybys
  - Achieves high inclination orbits (~54 degrees)
- The spacecraft has returned a staggering amount of data in the last year, ~68 Gbytes.
- ~22 orbits completed, 19 targeted flybys - almost all of Titan, 35 non-targeted (120,000km or less) icy satellite opportunities

Mission Summary Chart

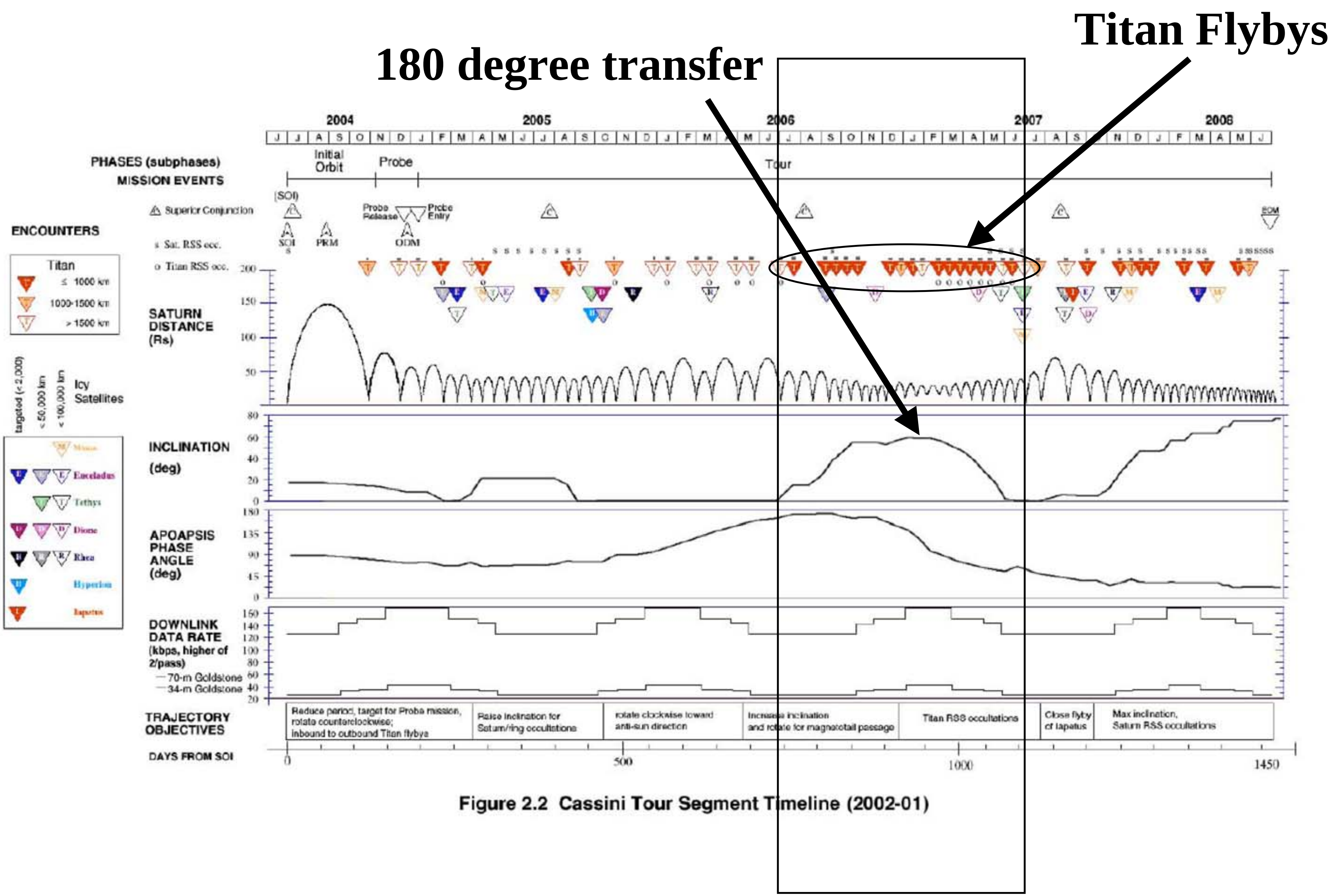


Figure 2.2 Cassini Tour Segment Timeline (2002-01)

Targeted Flyby Summary - 3rd year

Seq	Rev	Name		Event	Epoch (SCET)	Date
S12	11	11EN (t)	[E2]	ENCELADUS	2005-195T19:55	Jul-14
S21	25	25TI (t)	[T15]	TITAN	2006-183T09:21	Jul-02
S22	26	26TI (t)	[T16]	TITAN	2006-203T00:25	Jul-22
S23	28	28TI (t)	[T17]	TITAN	2006-250T20:17	Sep-07
S24	29	29TI (t)	[T18]	TITAN	2006-266T18:59	Sep-23
S24	30	30TI (t)	[T19]	TITAN	2006-282T17:30	Oct-09
S25	31	31TI (t)	[T20]	TITAN	2006-298T15:58	Oct-25
S26	35	35TI (t)	[T21]	TITAN	2006-346T11:42	Dec-12
S26	36	36TI (t)	[T22]	TITAN	2006-362T10:05	Dec-28
S27	37	37TI (t)	[T23]	TITAN	2007-013T08:39	Jan-13
S27	38	38TI (t)	[T24]	TITAN	2007-029T07:16	Jan-29
S28	39	39TI (t)	[T25]	TITAN	2007-053T03:12	Feb-22
S28	40	40TI (t)	[T26]	TITAN	2007-069T01:49	Mar-10
S28	41	41TI (t)	[T27]	TITAN	2007-085T00:23	Mar-26
S29	42	42TI (t)	[T28]	TITAN	2007-100T22:58	Apr-10
S29	43	43TI (t)	[T29]	TITAN	2007-116T21:33	Apr-26
S30	44	44TI (t)	[T30]	TITAN	2007-132T20:10	May-12
S30	45	45TI (t)	[T31]	TITAN	2007-148T18:52	May-28
S31	46	46TI (t)	[T32]	TITAN	2007-164T17:46	Jun-13
S31	47	47TI (t)	[T33]	TITAN	2007-180T17:03	Jun-29

Mission Overview - continued

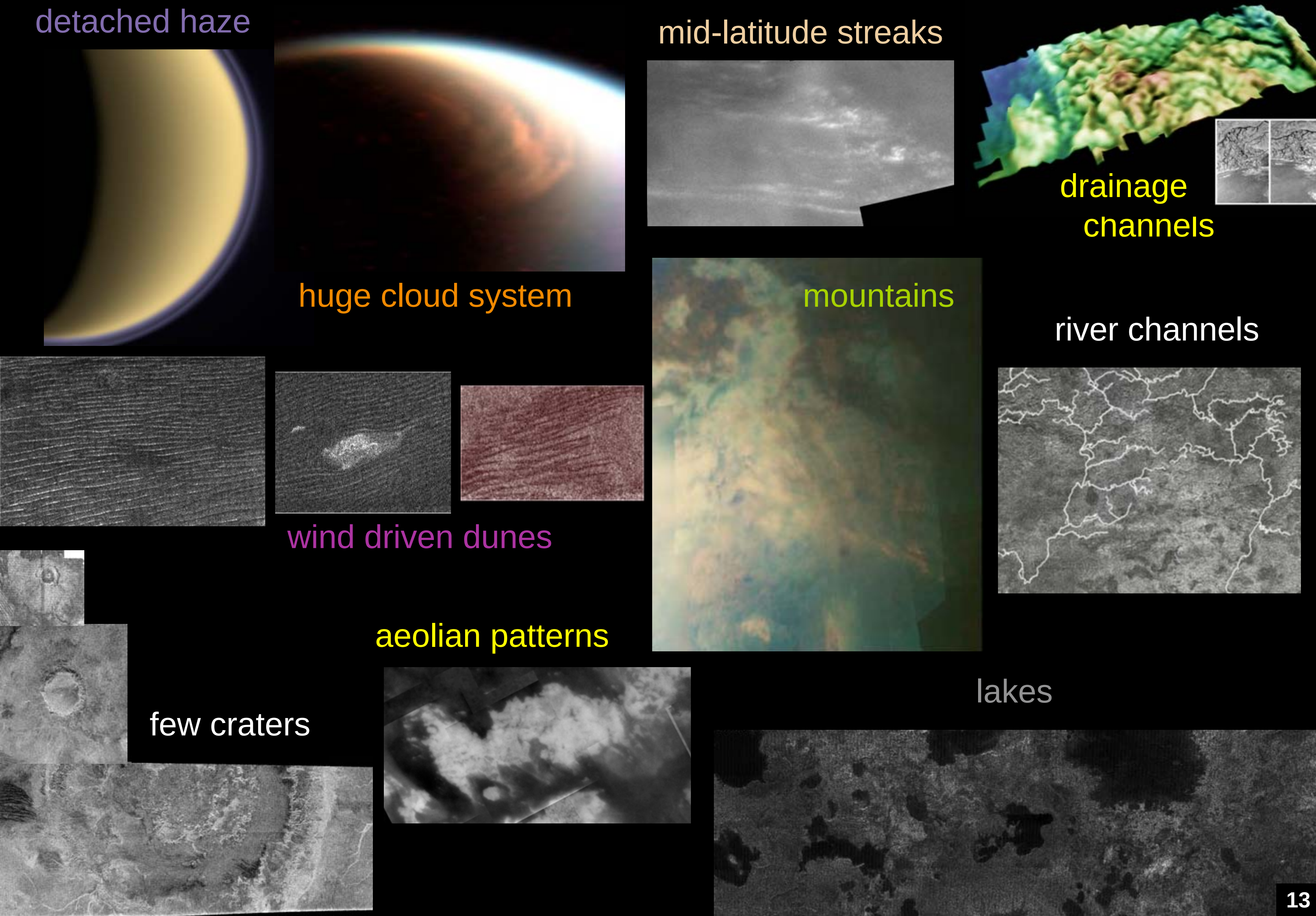
- The Project completed the extended mission (XM) planning and selected a candidate tour in January of 2007.
  - The proposed extended mission tour starts on July 1, 2008 and goes through July 1, 2010.
  - There are over 2 dozen Titan flybys and 7 Enceladus flybys, plus an inclined period near the equinox.
  - Recall the Saturn Season
    - Winter Solstice = June 2002
    - Spring Equinox = August 2009
    - Summer Solstice = December 2016
    - Winter Solstice = October 2031
  - NASA Headquarters is in the process of reviewing the extended mission proposal

Missing graphic

Titan

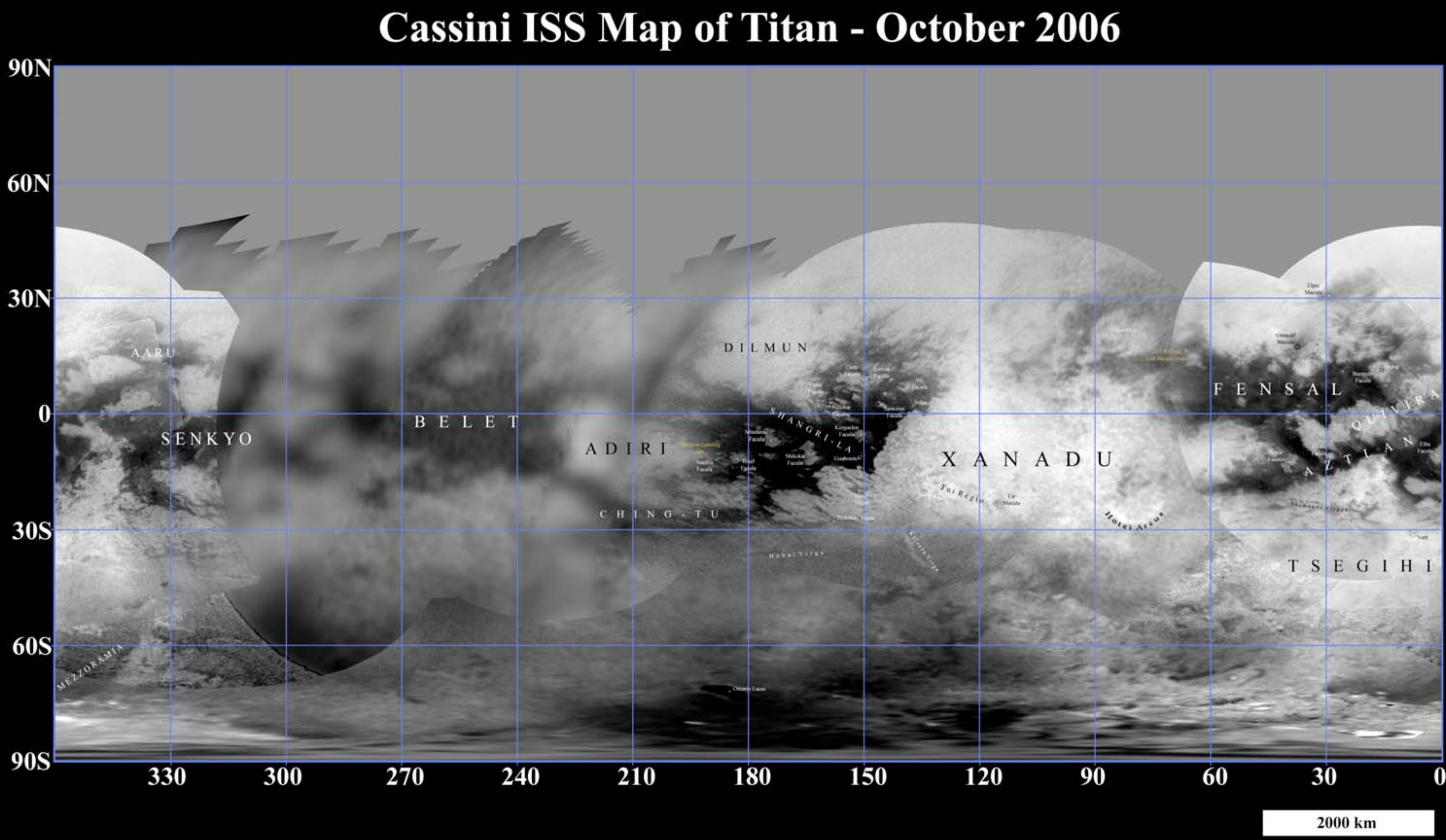
- Titan is the largest satellite of Saturn, and the second largest moon in the solar system. It is larger than the planet Mercury.
- The bulk density of Titan is ~1.8 g/cm^3, and D=5, 150 miles.
- Titan has the second-densest atmosphere of the solid bodies of the solar system (1) Venus (2) Titan (3) Earth (4) Mars.
  - It consists basically of nitrogen-methane → organic chemistry
  - Hydrocarbons cover the surface
- The surface P,T=1.5bars, 95K
- The surface is covered in frozen water, modified by impact cratering, erosion, tectonics, and volcanism
  - BUT another molecule on Titan acts just like water on the Earth - that molecule is methane (CH_4)

Titan: the most Earth-like body in the Solar System

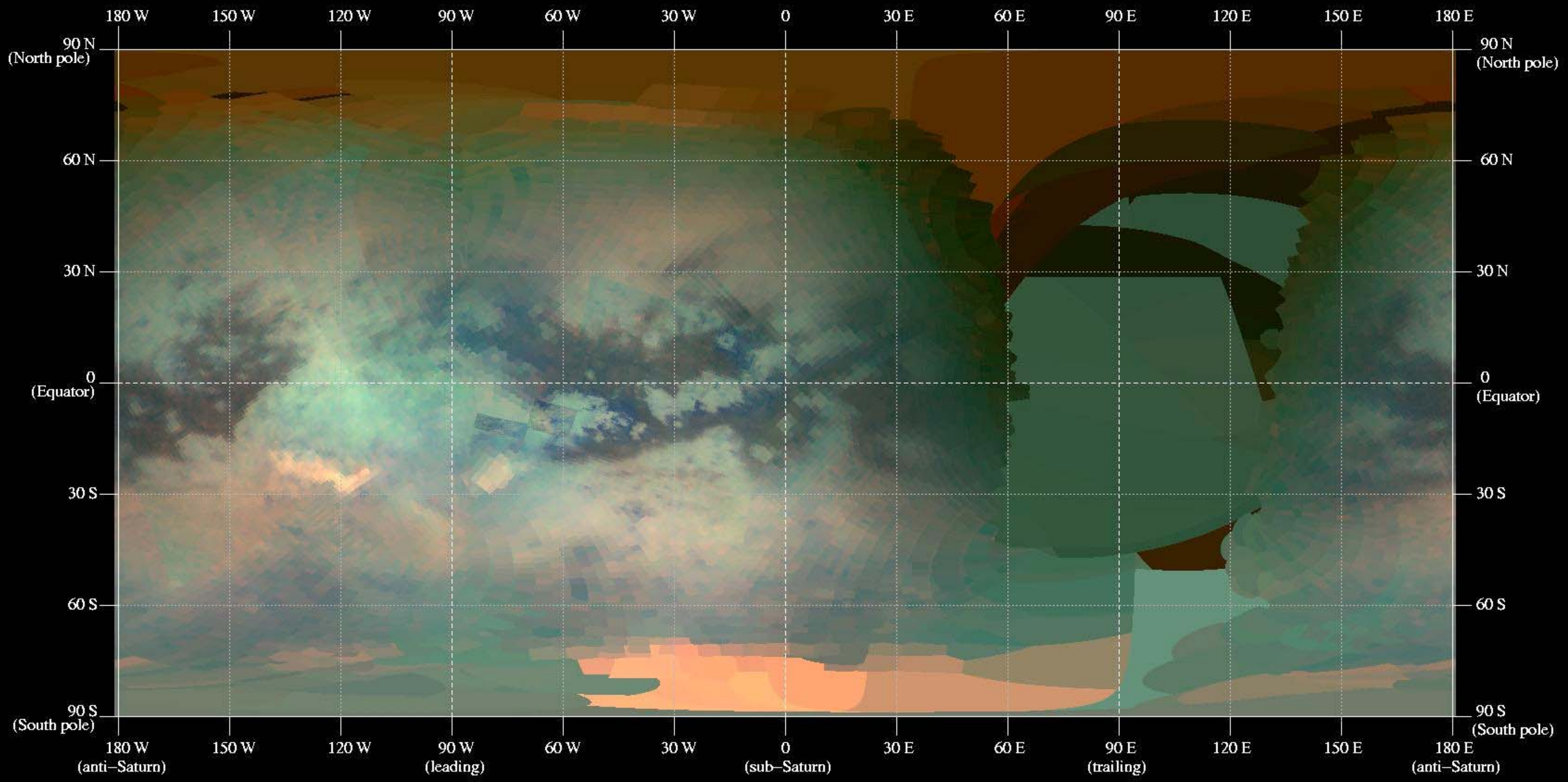


ISS map

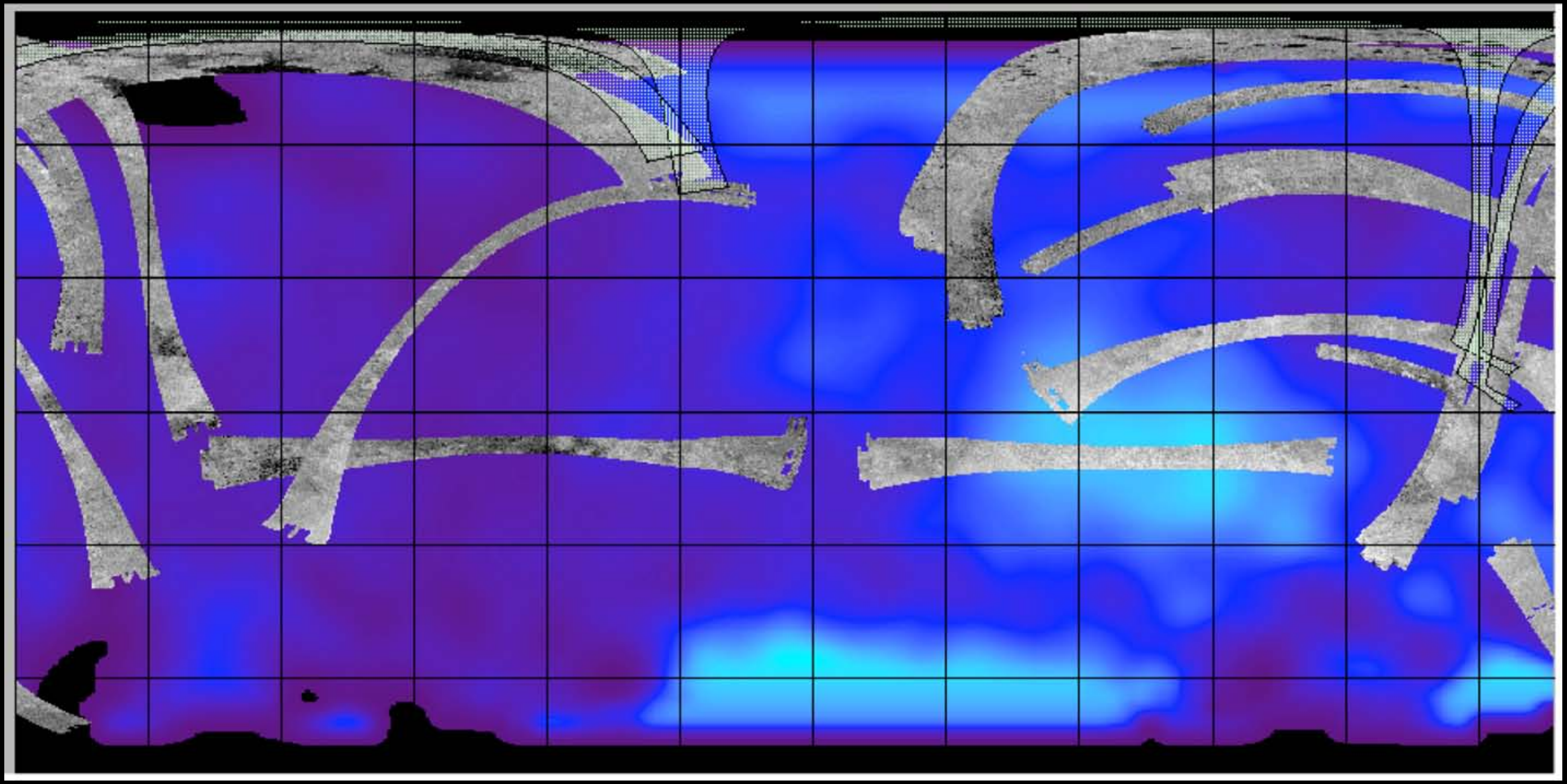
Titan @ 938 nm



VIMS map (r = 5 μm; g = 2 μm; b = 1.6 μm)

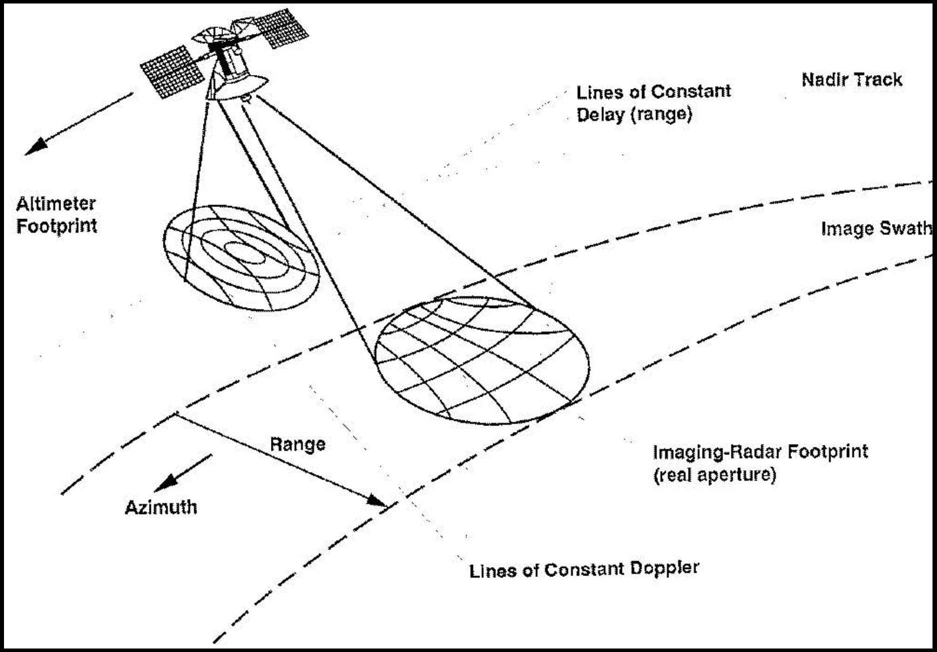


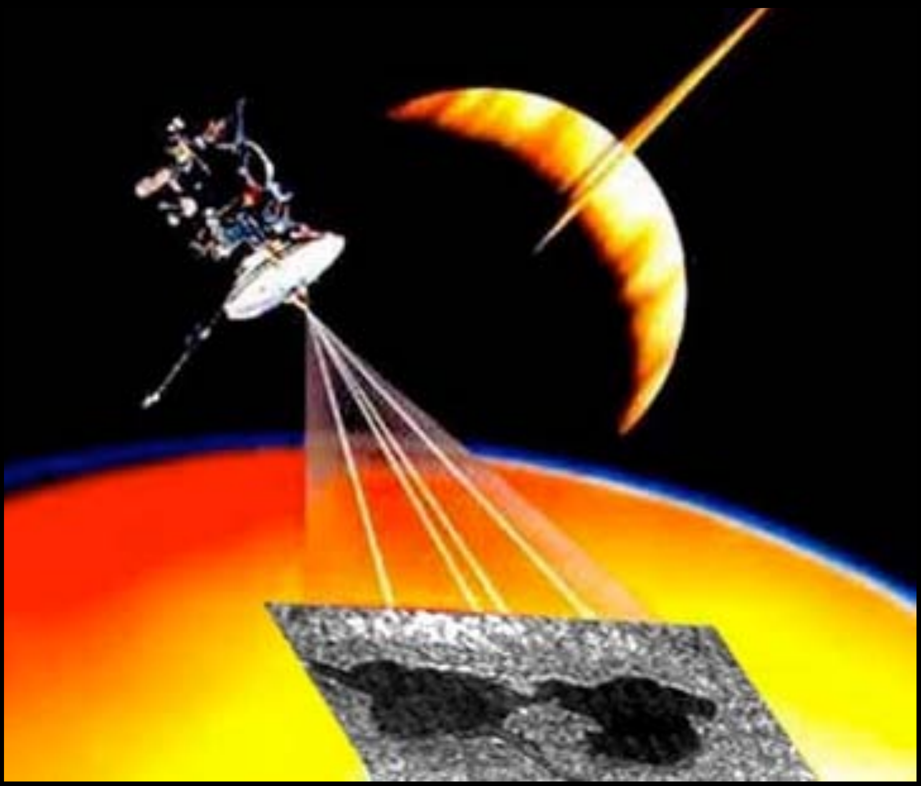
RADAR map (TA-T30)



Titan's Geology as Viewed by the Cassini Titan Radar Mapper

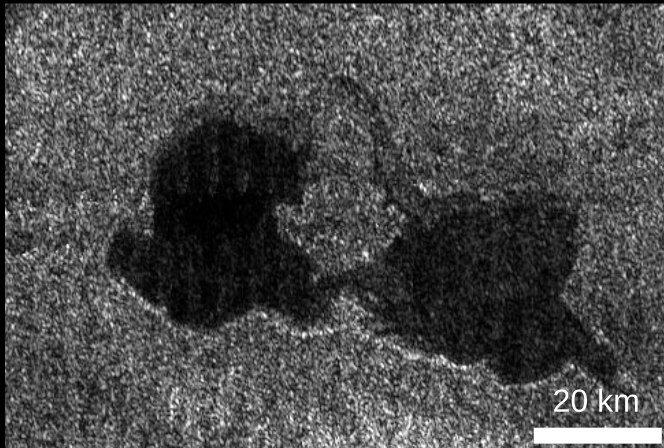
Cassini RADAR: uses the five-beam Ku-band (13.78 GHz, wavelength = **2.17 cm) antenna feed associated with the Cassini high-gain antenna to direct radar pulses towards Titan**

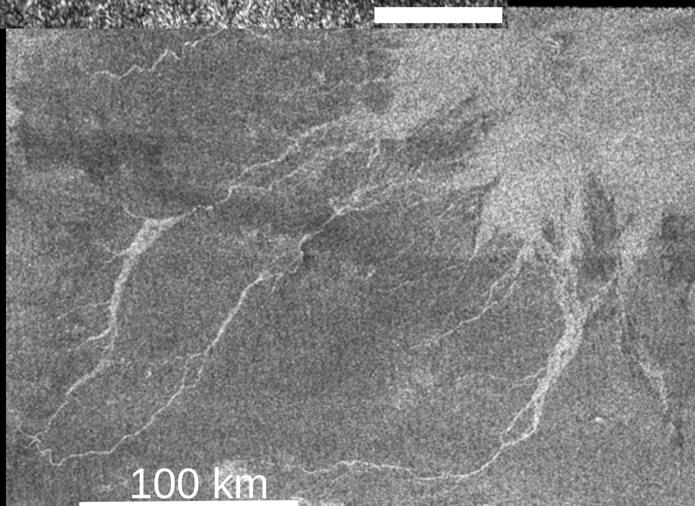


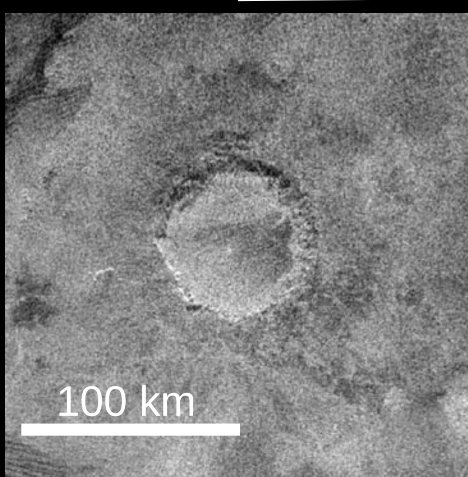


SAR mode is used at altitudes below 4000 km, spatial resolution ~ 300 m to 1 km. Produces swath 120-450 km wide from 5 antenna beams.

Lakes from T17







Geology of Titan from RADAR

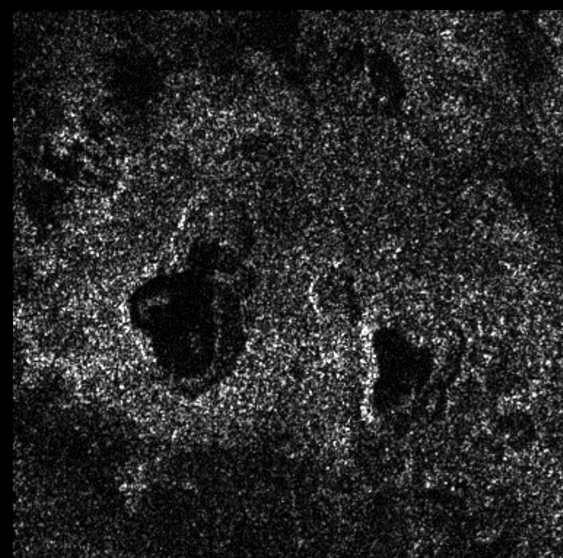
- Surface is surprisingly young and dynamic (only 3 impact craters definitely identified so far)
- Geological processes similar to Earth's, but driven by methane cycle
- Geological processes: endogenic and exogenic/surficial
  - Cryovolcanism
  - Tectonism (mountains)
  - Erosion and deposition, including channels and dunes
  - Impact Craters
  - Lakes at high N latitudes

Endogenic Processes: cryovolcanism

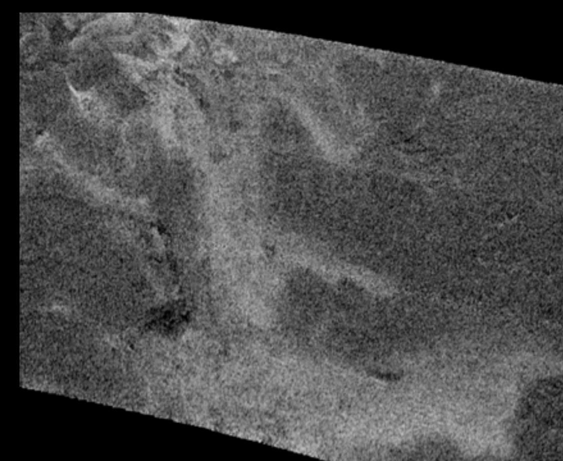
Ganesa, calderas, flows, VIMS Tortola Facula/Tsui Regio? Possibly detected over a wide lat and long range, but most distinct features so far concentrated in possible “Tharsis-like” region around Ganesa

Ganesa, 180 km diameter

Tortola Facula, 30 km diameter

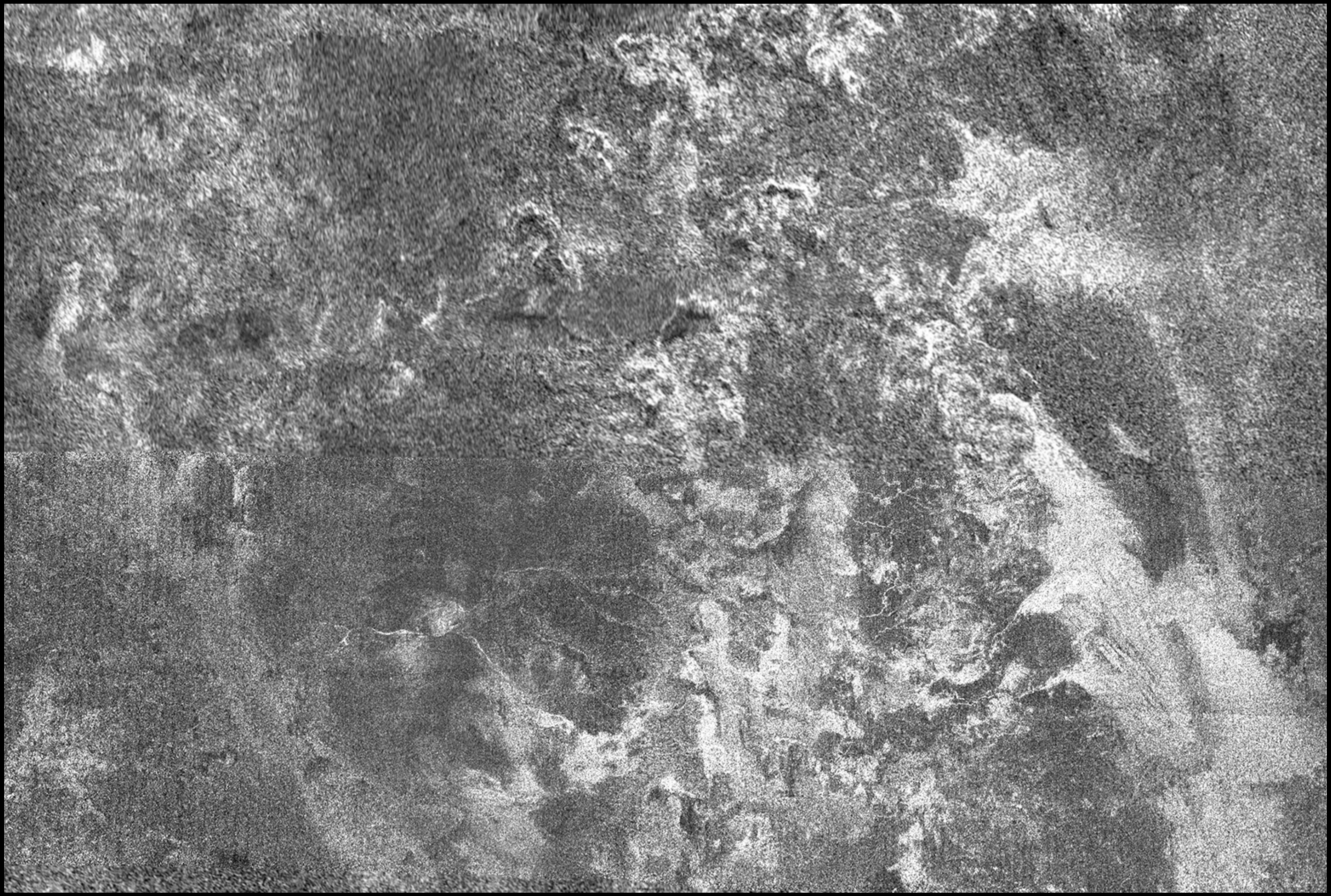


High latitude calderas? 20-30 km diameter



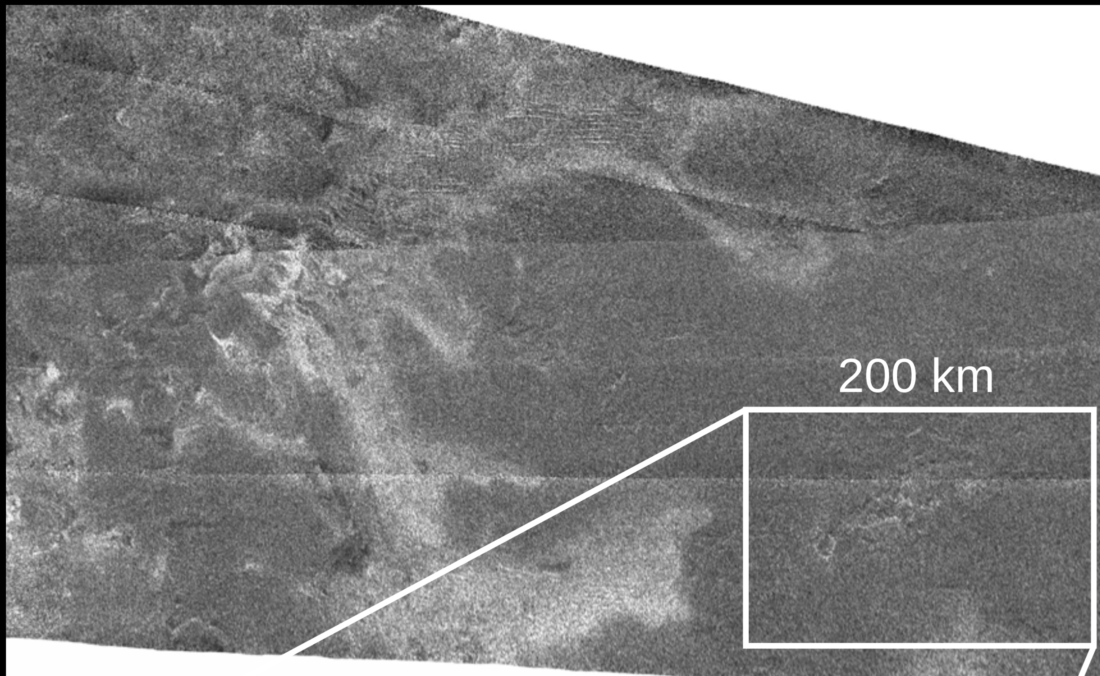
Flow (Ta), > 200 km long

Ganesa Macula region



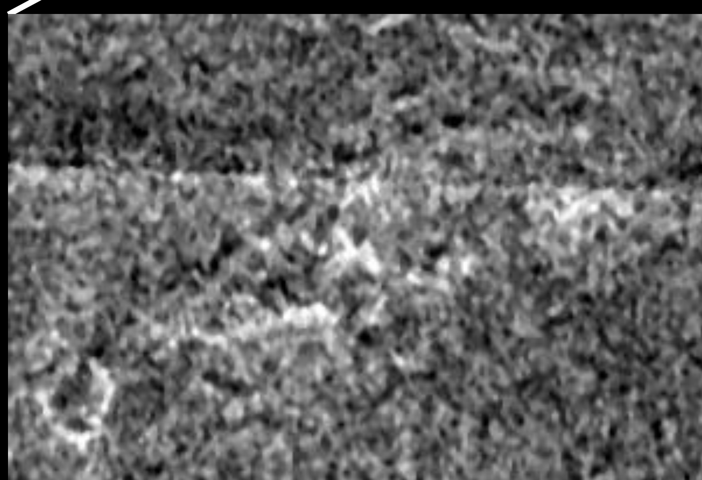
570 km

Identification of Cryovolcanic flows (vs alluvial)



Winia Fluctus,
area > 90,000 km²

Mosaic of images from Ta flyby (Oct 2005) and T23 flyby (January 2007)

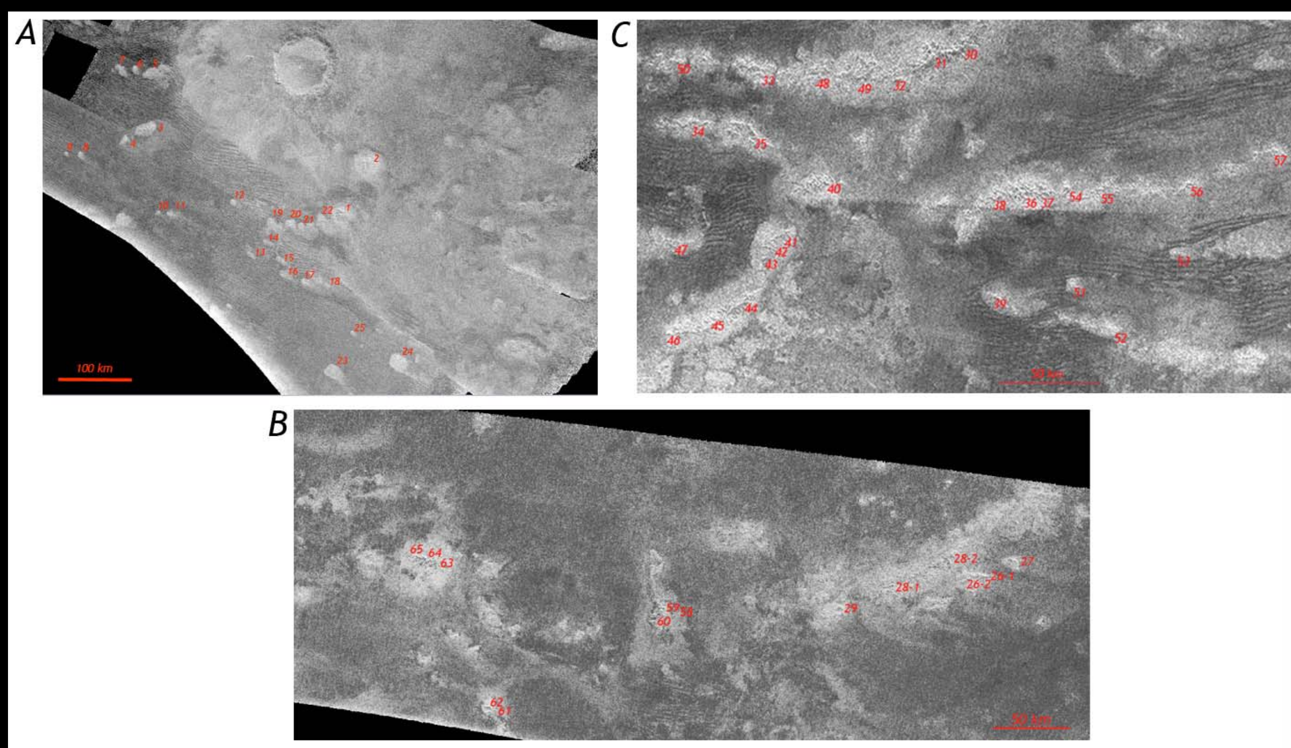


Rohe Fluctus, area ~ 3,800 km²

- **Association with a vent (crater, caldera or fissure)**
- **Form constructs such as domes and shields**
- **Flows form lobate deposits**
- **Geological context**

Endogenic processes: tectonism

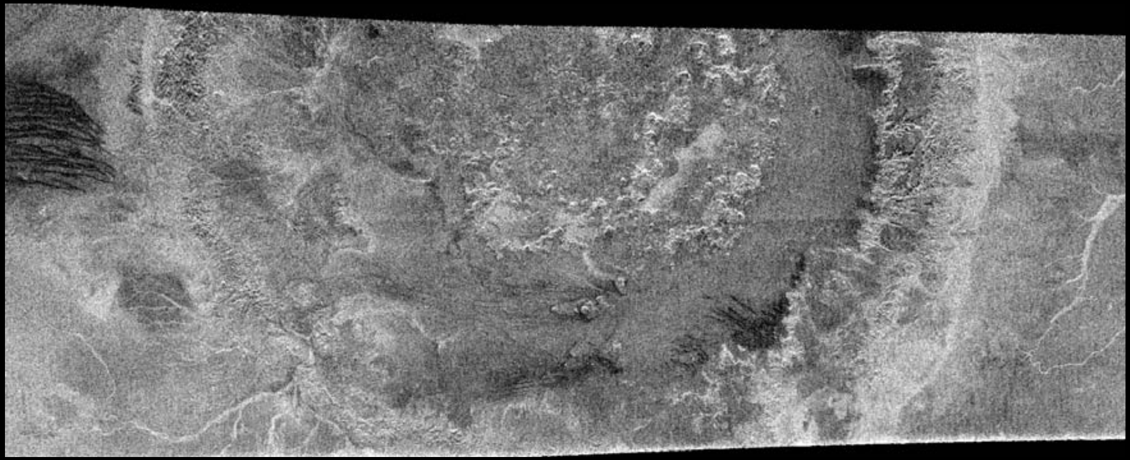
- Mountains and ridges: mostly in lower latitude swaths. A few mountains at higher latitudes, also some isolated blocks. Radebaugh et al. (Icarus, in press) favor crustal compression thrusting up blocks (ice) from below and, for Xanadu a pre-existing layer of icy material stripped away to leave mesas and pinnacles.
- Most of Titan’s topography is very subdued. Mountain heights measured from RADAR 50m to > 1km
- Fewer mountain chains at higher latitudes?



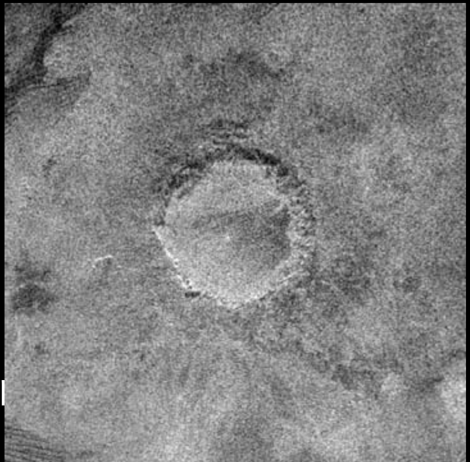
Exogenic processes:

- Impact craters (3 definite identifications so far): surface appears to be young, though there are numerous "suspiciously circular features" (various hypothesis – impact, volcanic, other collapse (karst)?
- Any "cratered terrains" on Titan?

Ksa, ~40 km diameter

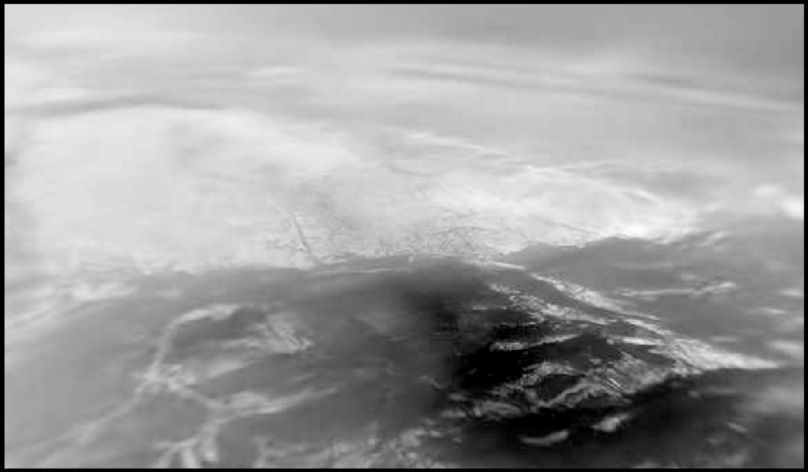


Mernva, ~450 km diameter

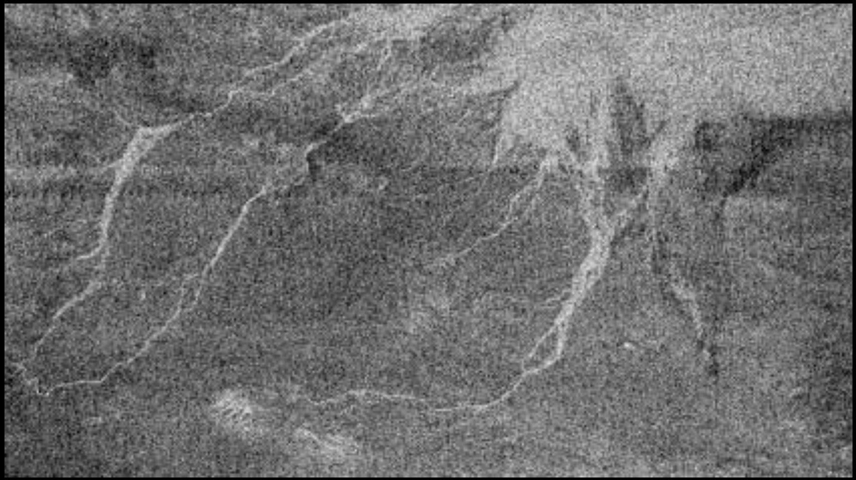


Sinlap, ~80 km diameter

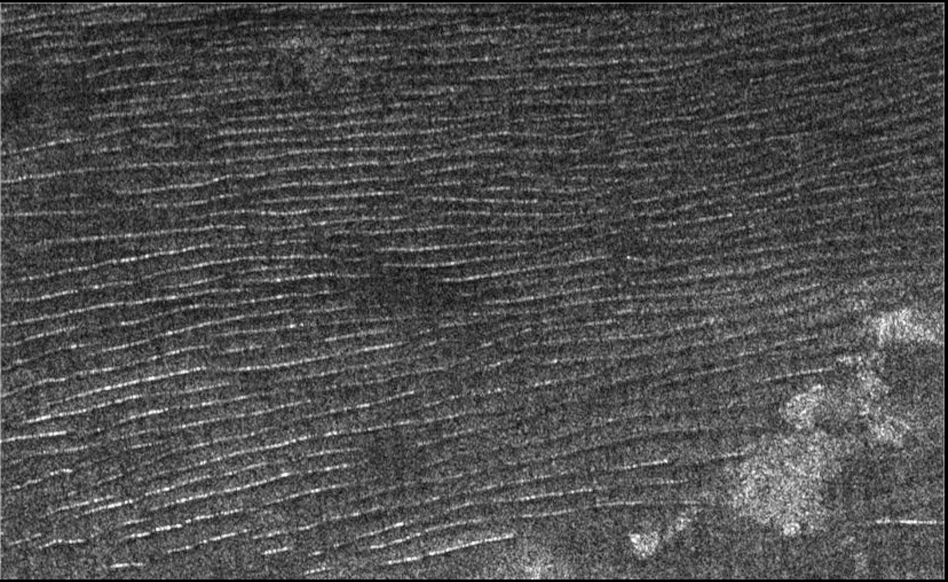
Erosion: Titan's Landscape is being actively modified by Earth-like processes, forming sand dunes, river channels and lakes



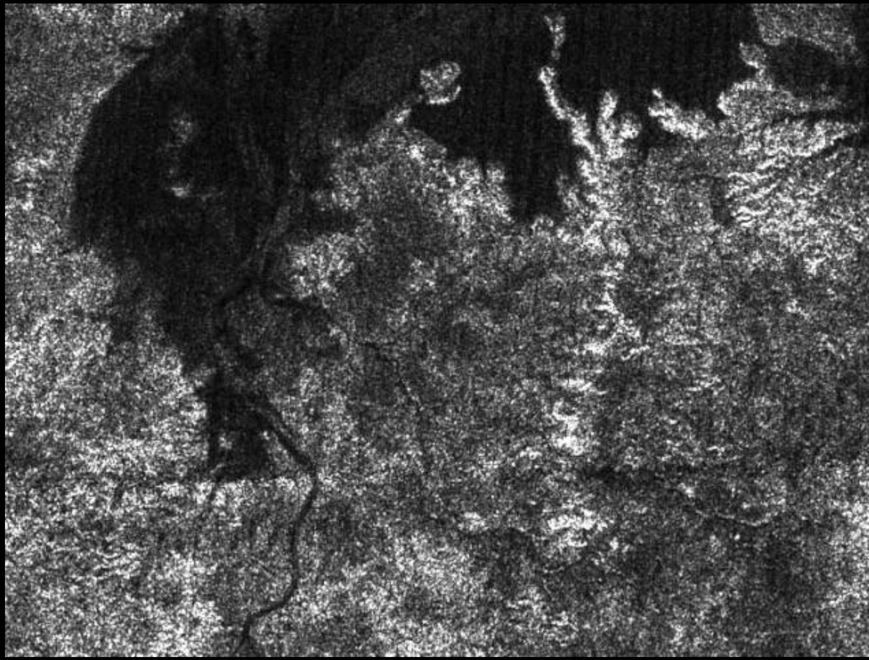
Huygens probe mosaic from 8km altitude



(dry) river channels at midlatitudes



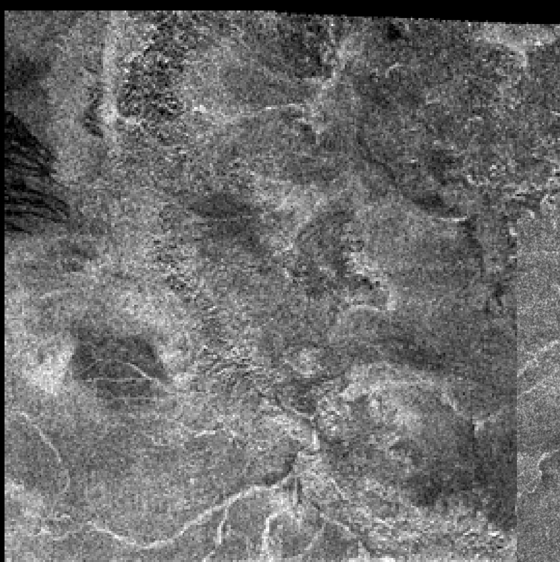
Giant organic sand dunes, 10's km long, 150m high, near Titan's Equator (Cassini RADAR)



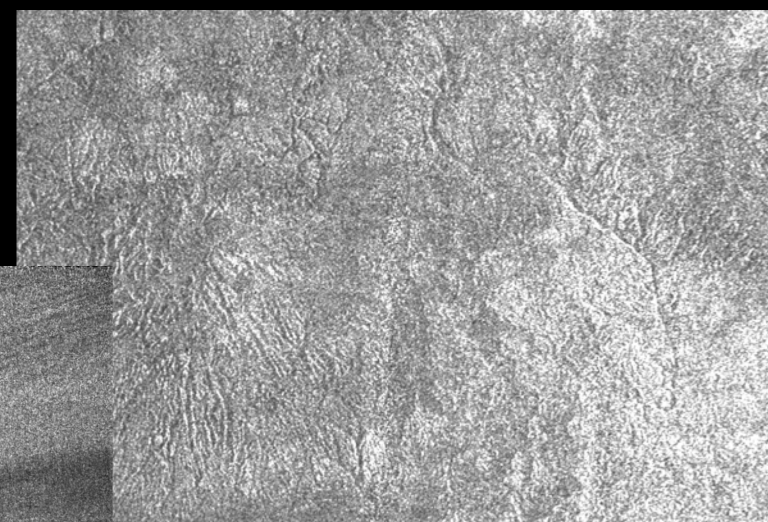
Lake and river channel near North pole

Surficial processes: fluvial erosion

- Numerous channels distributed over all swaths, also seen at Huygens landing site
- Surface of Titan cut by young fluvial channels (Lorenz et al., Submitted). Fluvial activity may be most recent geologic process



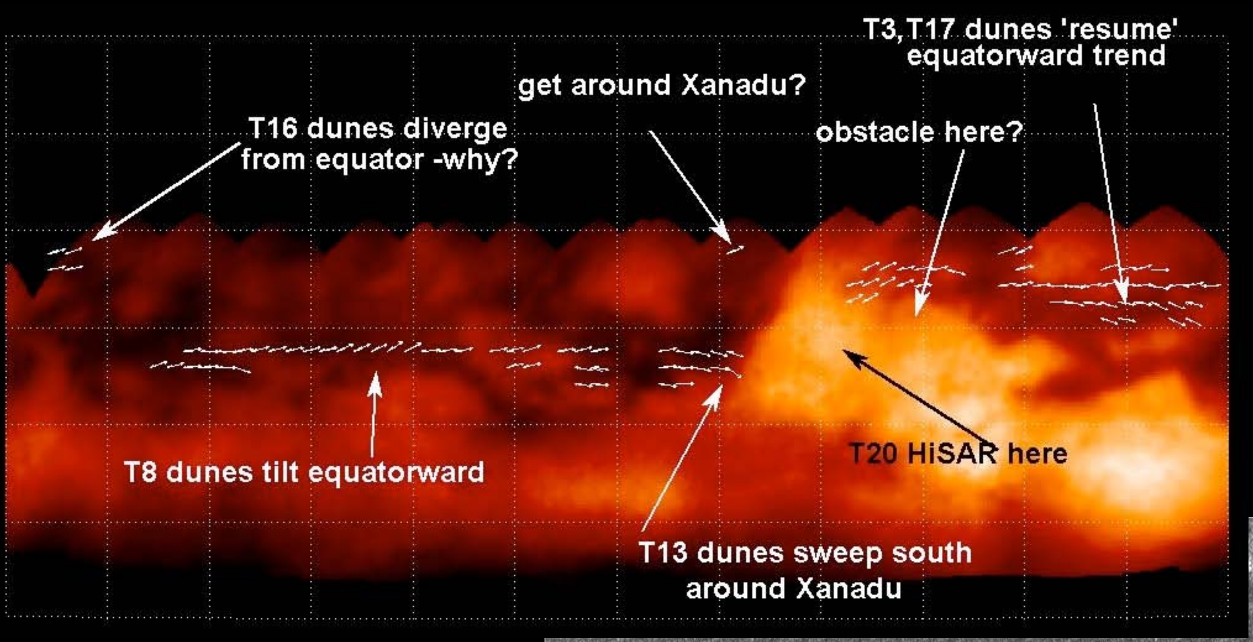
T3: low latitudes



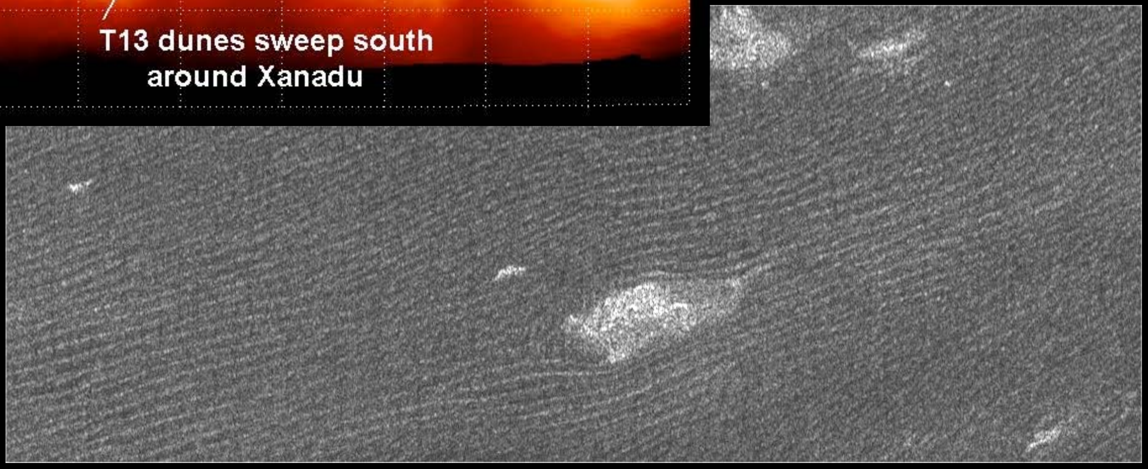
T7: high latitudes

Surficial processes: aeolian deposition

- Vast fields of dunes mostly at lower latitudes, within 20 degrees of equator (Lorenz et al 2006, Radebaugh et al., Icarus, submitted), but can extend up to ~ 60 degrees latitude
- Most (or all) equatorial dark (in visible) regions covered by dunes –consistent with lower latitudes being relatively dry (Rannou et al., 2006)



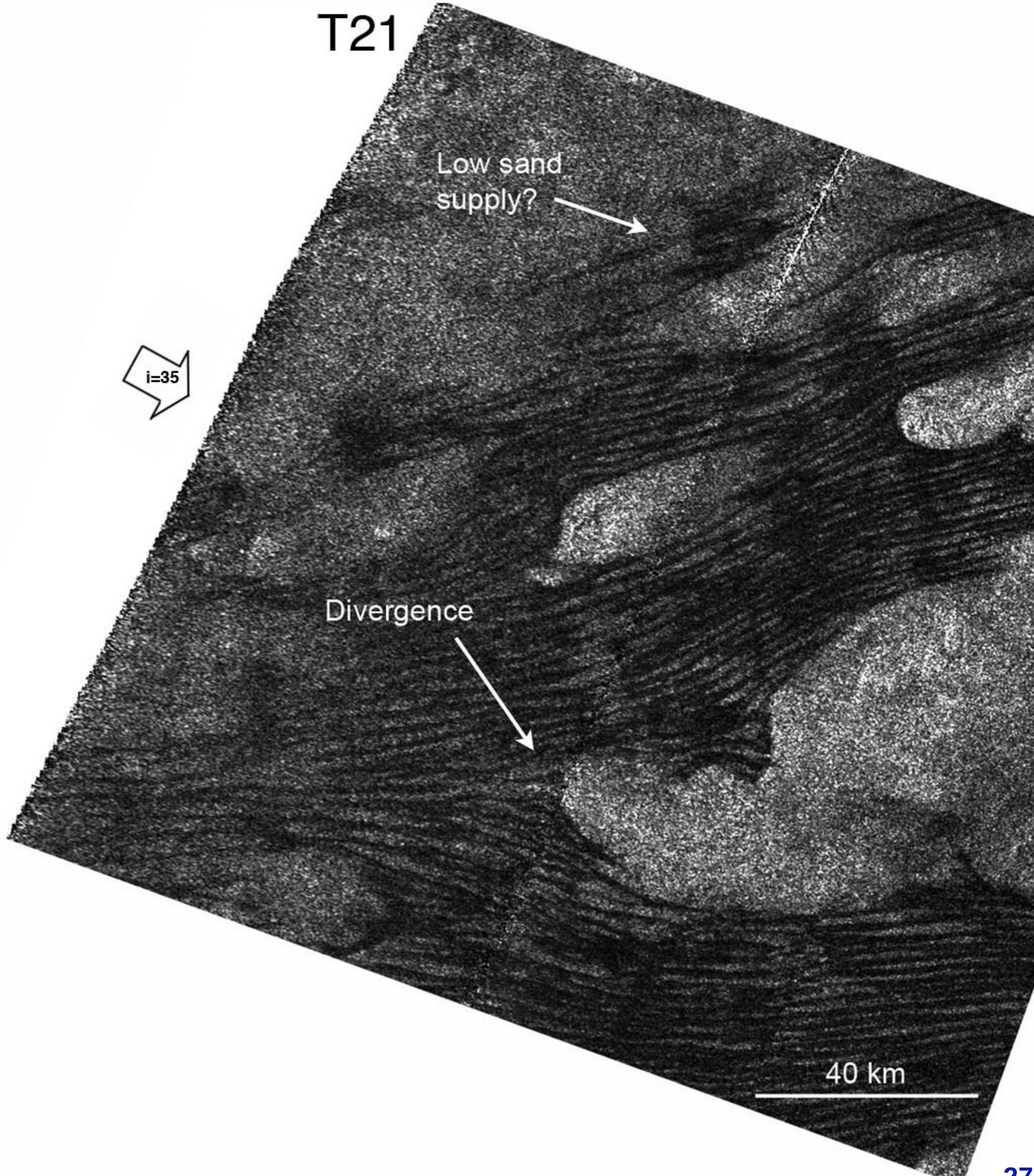
Winds generally W-E, with local variations



70km

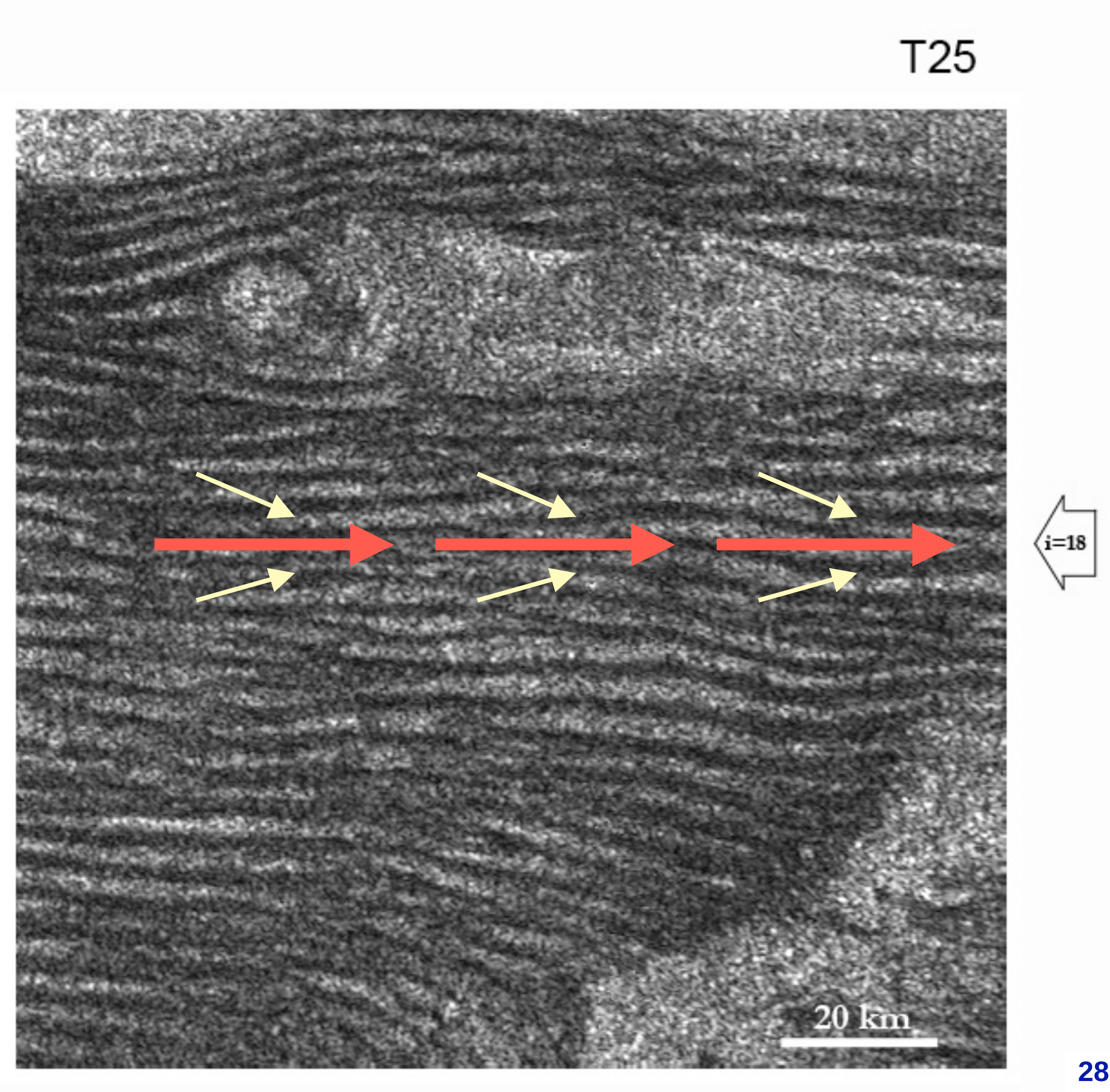
Thousands of dunes on Titan

- Diverge around regions of high topography
- 1-2 km wide
  1-3 km apart
  tens-100s km long



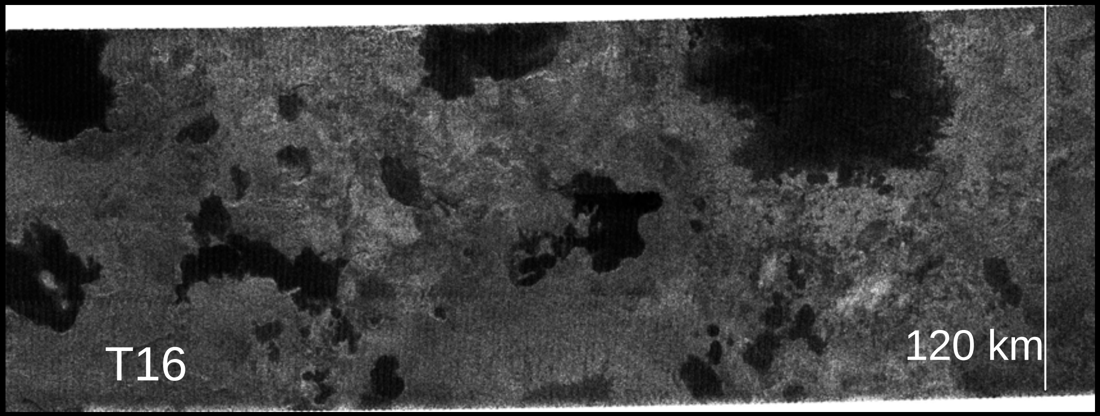
Longitudinal (linear) dune type

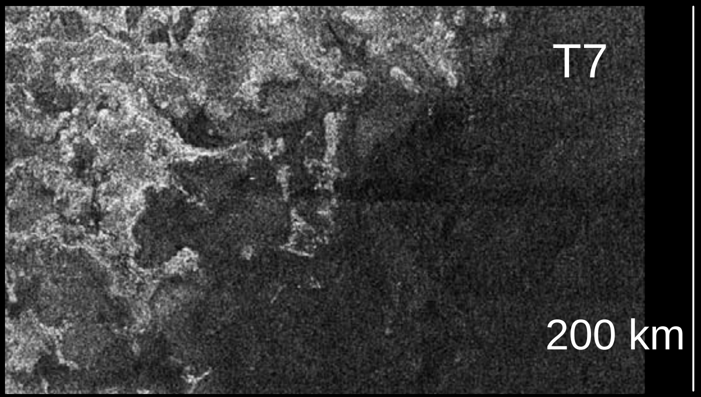
- One dominant wind direction aligned with axis = W-E
- Minor off-axis components “shepherd” the dune and sweep interdune areas clear
- e.g., Fryberger and Dean 1979, Lancaster 1995

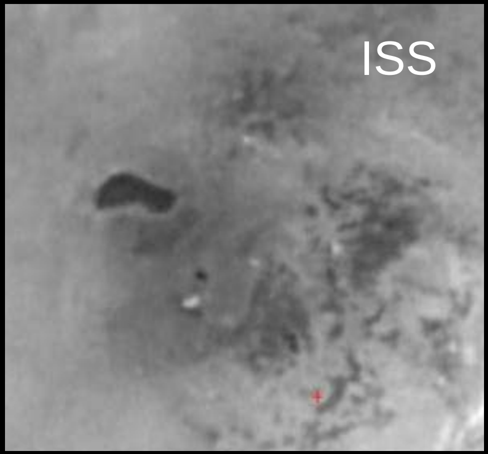


Distribution of lakes

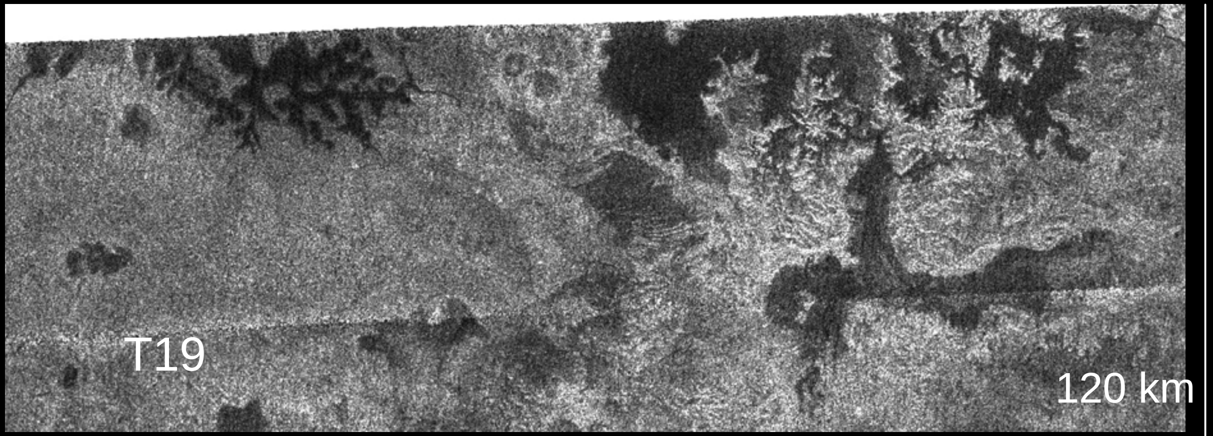
- Lakes (T16, T18) above 68 N latitude, shoreline (T7) ~ 66 S, Ontario Lacus (ISS) 72 S.



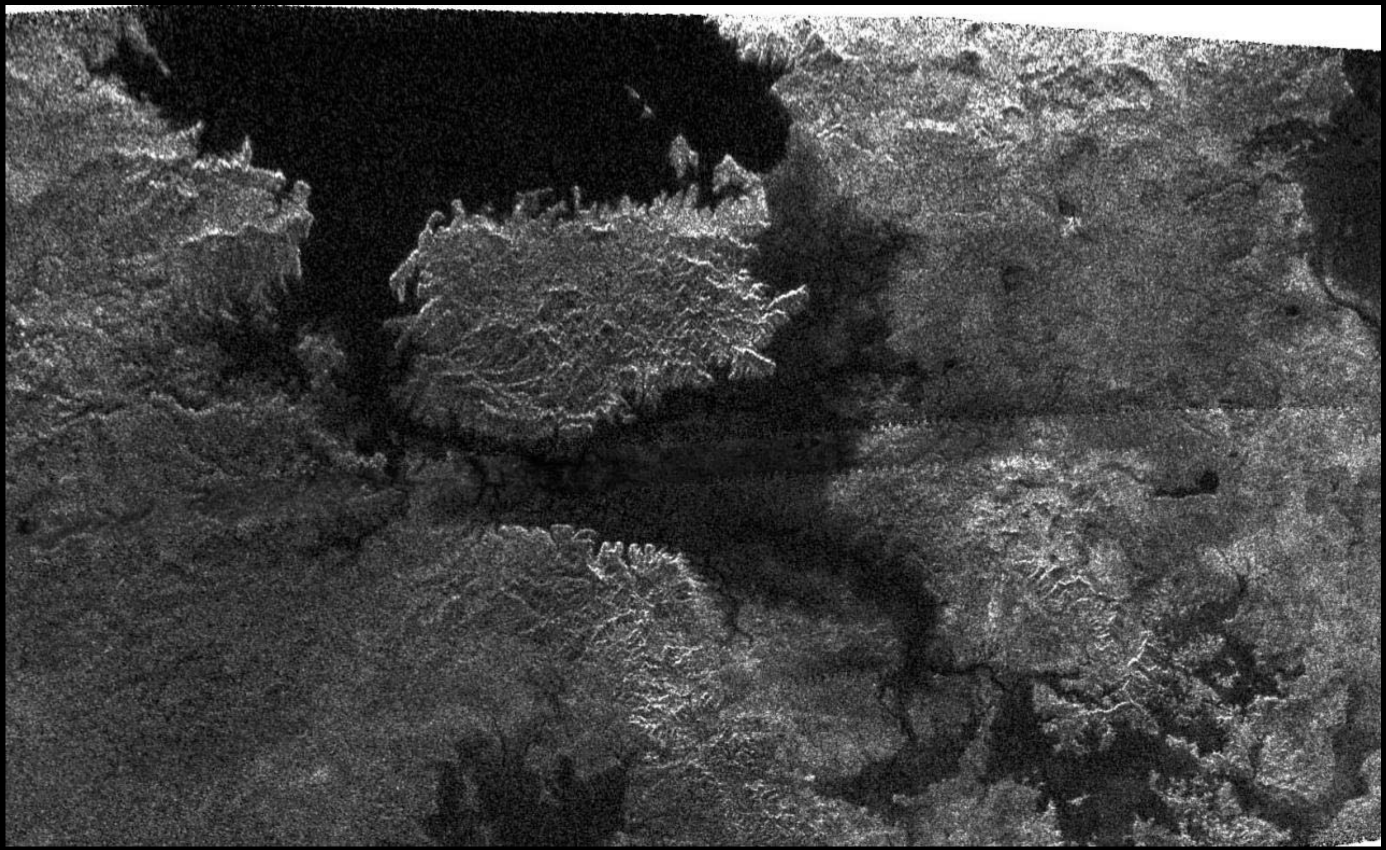




Lake ~234 x 73 km



Large lakes ("seas") discovered on Feb 2007

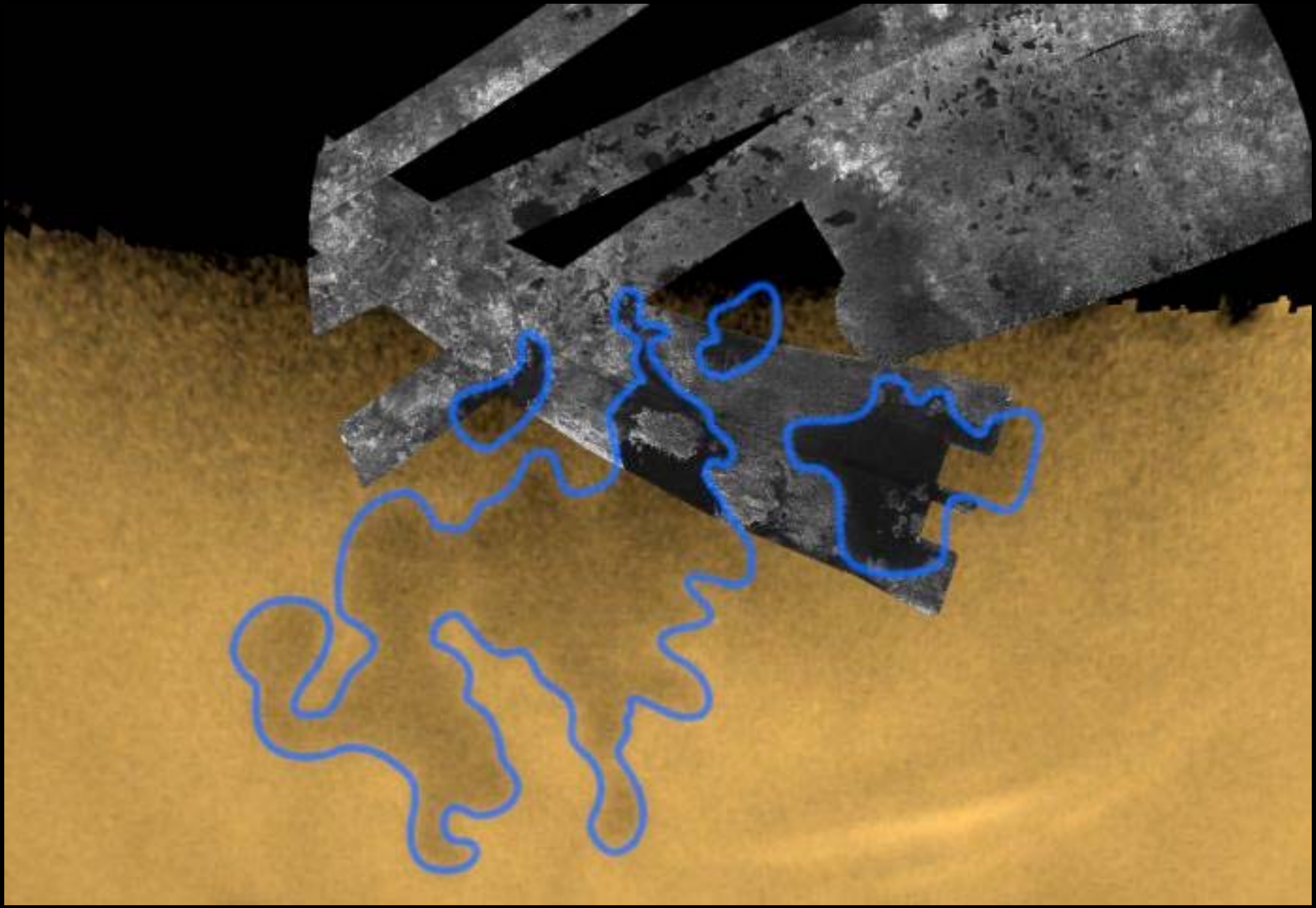


Island is 90 x 150 km, the size of Kodiak Island, Alaska, or the Big Island of Hawaii

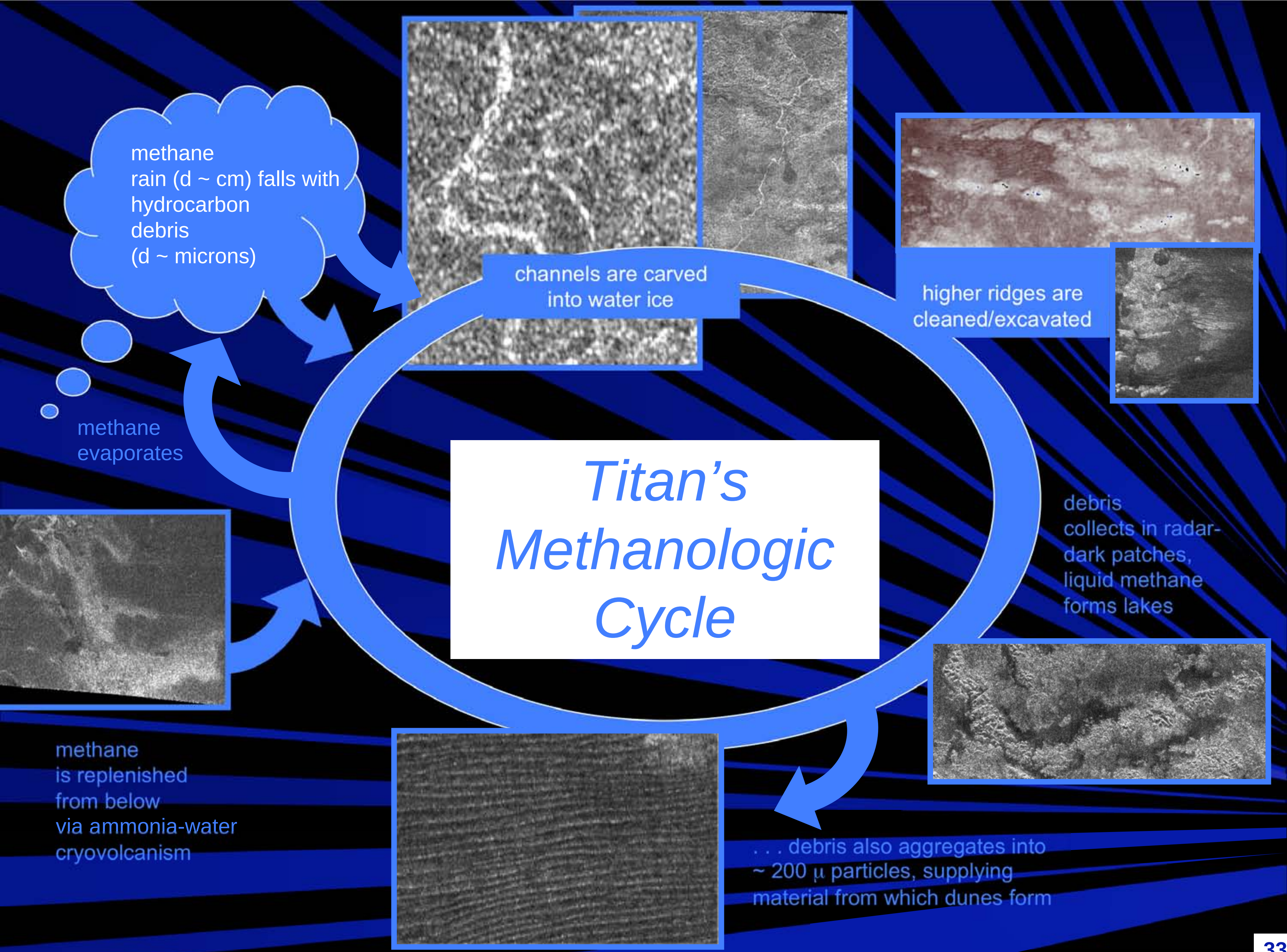
Comparison of Titan lake and Lake Superior

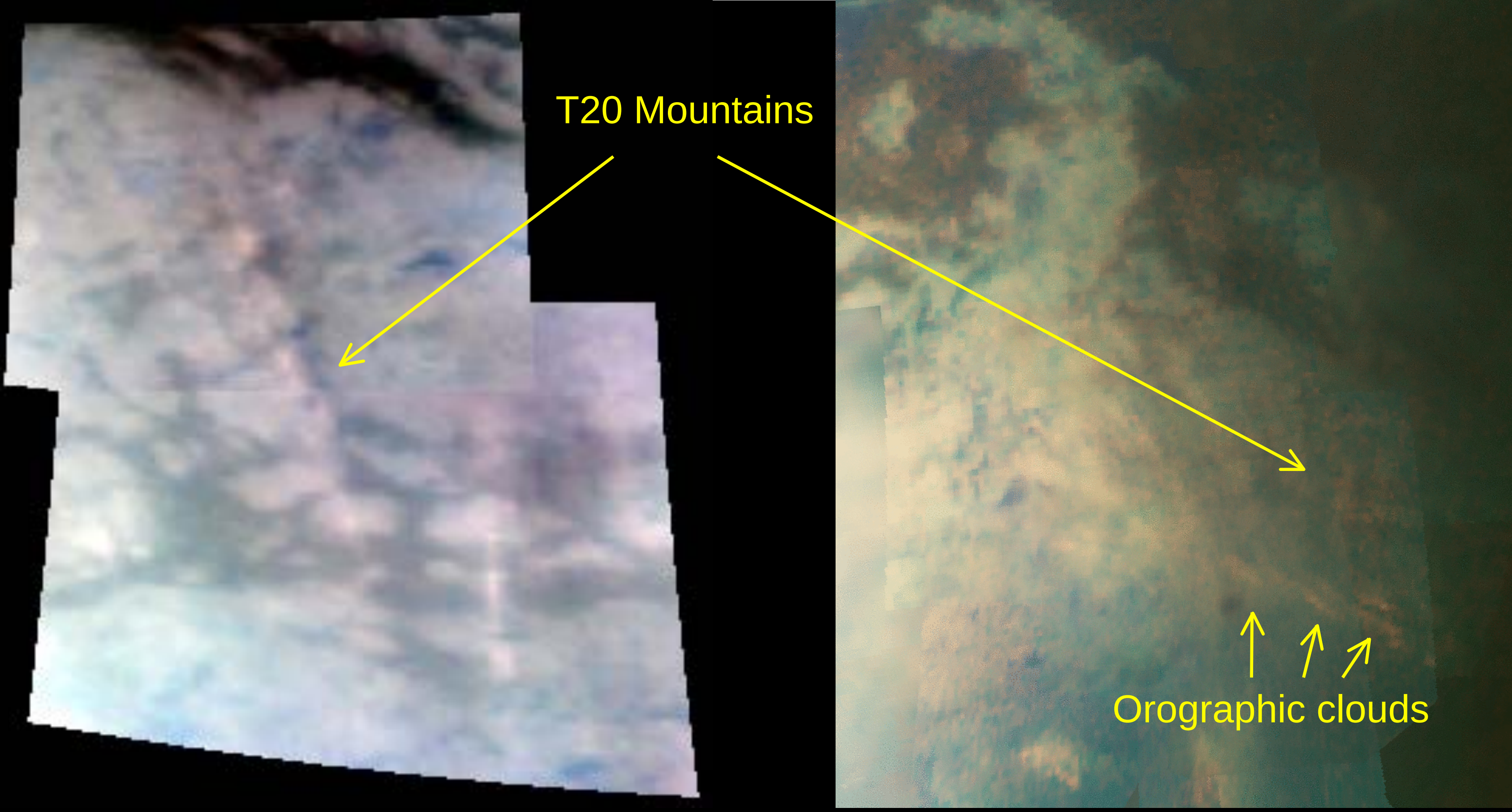
Titan lake is > 100,000 km^2, Lake Superior is 82,000 km^2

Lakes on north polar regions: RADAR data over ISS



See movie at http://photojournal.jpl.nasa.gov/catalog/PIA08365


Titan's Methanologic Cycle
methane rain (d ~ cm) falls with hydrocarbon debris (d ~ microns)
channels are carved into water ice
higher ridges are cleaned/excavated
debris collects in radar-dark patches, liquid methane forms lakes
. . . debris also aggregates into ~ 200 μ particles, supplying material from which dunes form
methane is replenished from below via ammonia-water cryovolcanism
methane evaporates



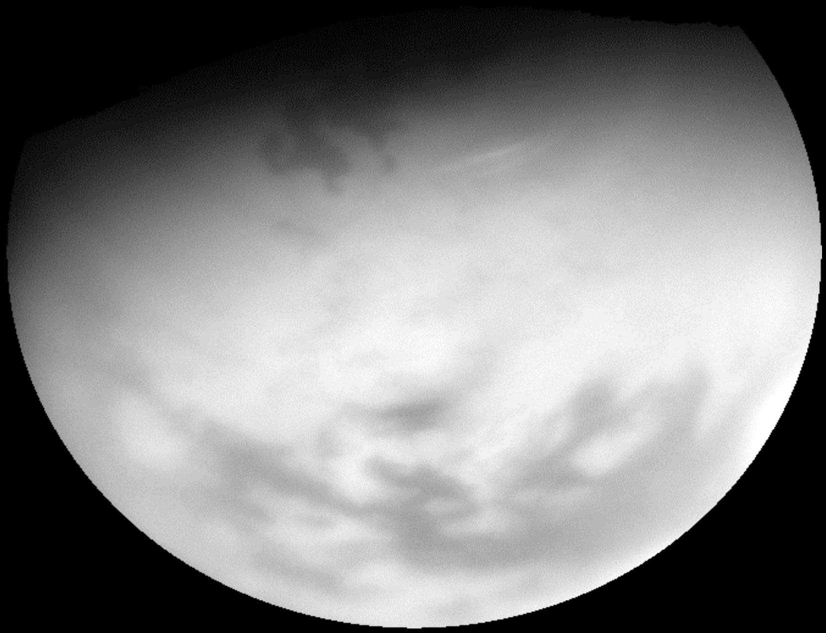
- Largest range is ~150 km long, ~30 km wide, ~1.5 km high
- This mountain region may be cause of southern mid-latitude clouds

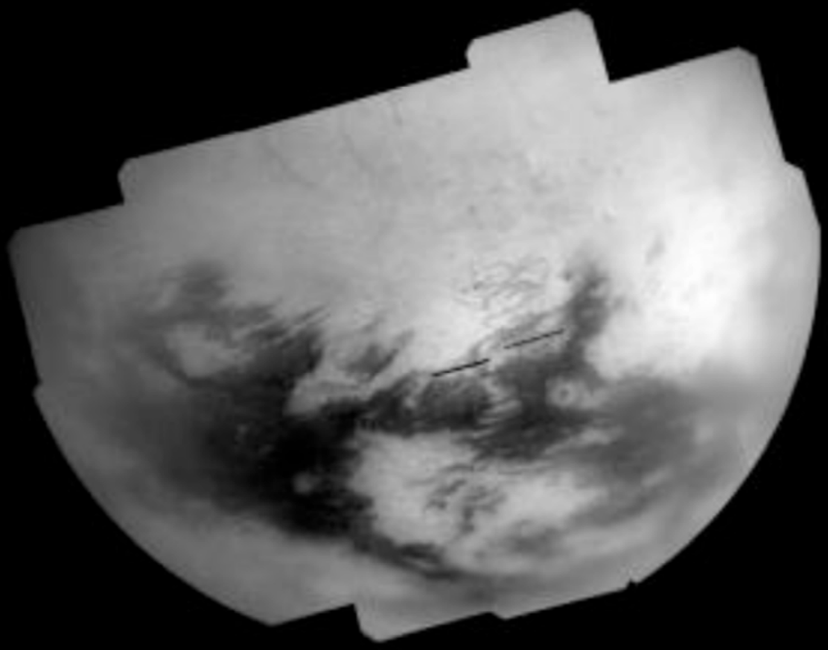
New territory at high northern latitudes

Remember Saturn's Season

Winter Solstice = June 2002

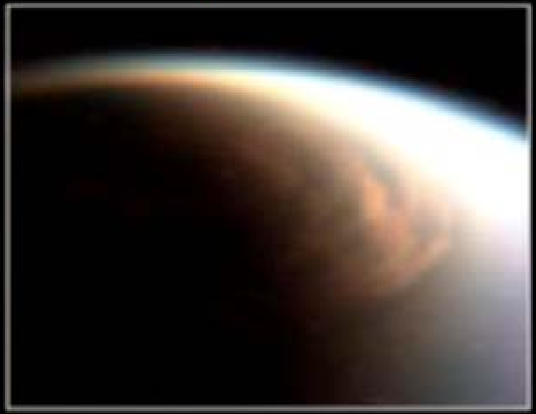
Spring Equinox = August 2009



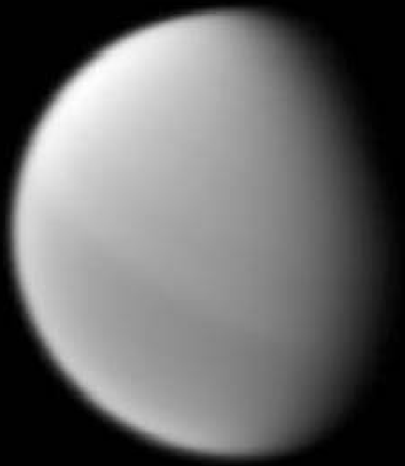


Titan's Atmosphere

Huge cloud system covering the north pole of Titan

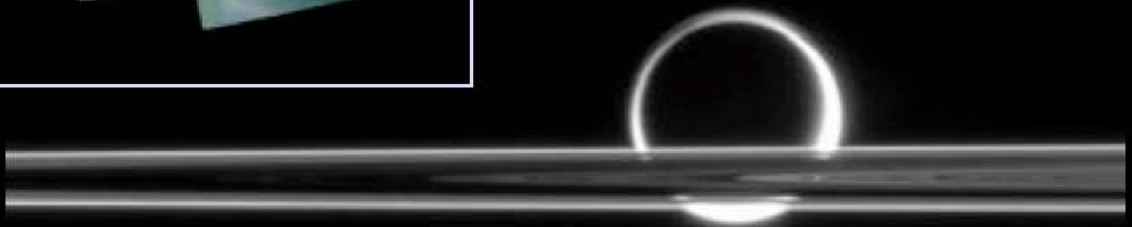


north-south asymmetry



mid latitude clouds

North polar stratosphere exhibits a banded appearance - fast-moving clouds



Just plain neat…

What Would the INMS Measure in Other Ionospheres?

Ion Composition at the Electron Density Peak in Solar System Ionospheres

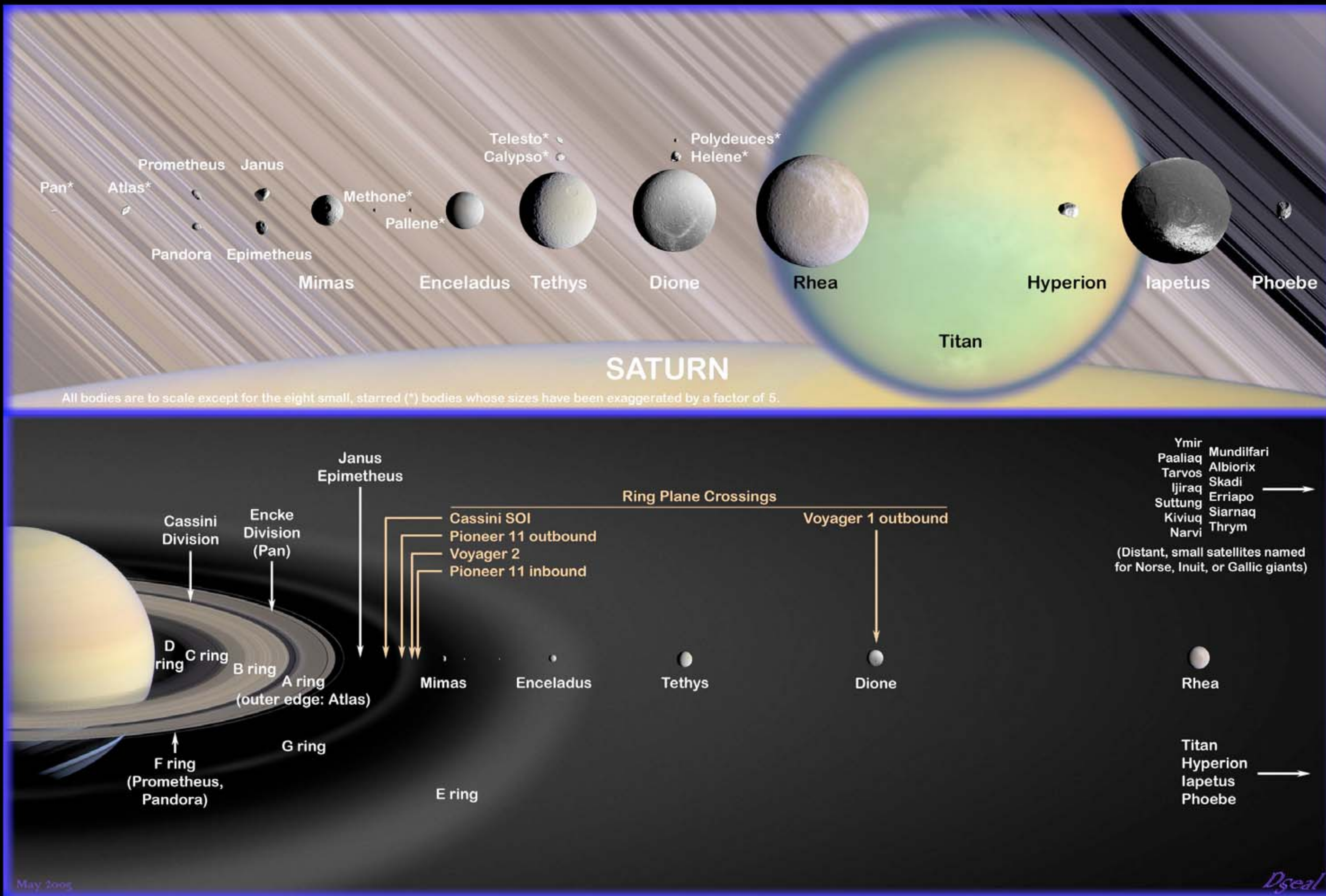
Body	Primary Ions
Venus	O_2^+, O^+, N^+, H^+, He^+, NO^+, CO_2^+, CO^+, $\mathit{N_2}^+$
Earth	O^+, NO^+, O_2^+, N_2^+, N^+
Mars	O_2^+, CO_2^+, NO^+, O^+, H^+, CO^+, $\mathit{N_2}^+$
Jupiter	H^+, H_3^+, $\mathit{H_2}^+$, He^+, HeH^+
Titan	$HCNH^+$, $C_3H_3^+$, $C_3H_5^+$, HC_3NH^+, $C_5H_7^+$, CH_3NH^+, $C_2H_5^+$, $C_7H_7^+$, CH_3CNH^+, $C_2H_3CNH^+$, $C_5H_5^+$, $C_4H_3^+$, $CH_3NH_3^+$ NH_4^+, $CH_3NH_2^+$, $C_6H_7^+$, N_2^+, $CHNC^+$, CH_3^+, CH_5^+, $C_3H_5CNH^+$, $C_4H_5^+$, $C_2H_3^+$, $C_2H_4^+$, $C_2H_5CNH^+$, $C_4H_7^+$, $C_5H_3^+$, $C_6H_5^+$, CH_3CN^+, N^+, N_2H^+, $C_2H_7^+$, $CHCNH^+$, $C_6H_3^+$, $C_4H_4N^+$, $C_4H_9^+$, $C_5H_4N^+$, $C_3H_7^+$, CNC^+, $C_3H_4^+$, CH_2^+, CH_4^+, HCN^+, $CHCN^+$, HC_3N^+

We have discovered that Titan has the most chemically complex ionosphere in the solar system. There are likely strong connections to neutral chemistry; these are still being explored.

Icy Satellites

- The Saturn system has 47 confirmed satellites, most are small and far away from the planet.
- There are 8 major icy satellites (not including Titan)
  - Mimas, Enceladus, Tethys, Dione, Rhea, Hyperion, Iapetus, and Phoebe
- They are located outside the major ring system and vary in size from tiny Phoebe (D=137 miles) up to Rhea (D=950 miles) the seventh largest moon in the solar system)
- Their surfaces are dominated by water ice and shaped by the forces of tectonics, impact cratering, erosion, and even volcanism.
- The densities range from .6 g/cm^3 (Hyperion) to 1.6g/cm^3 (Enceladus).

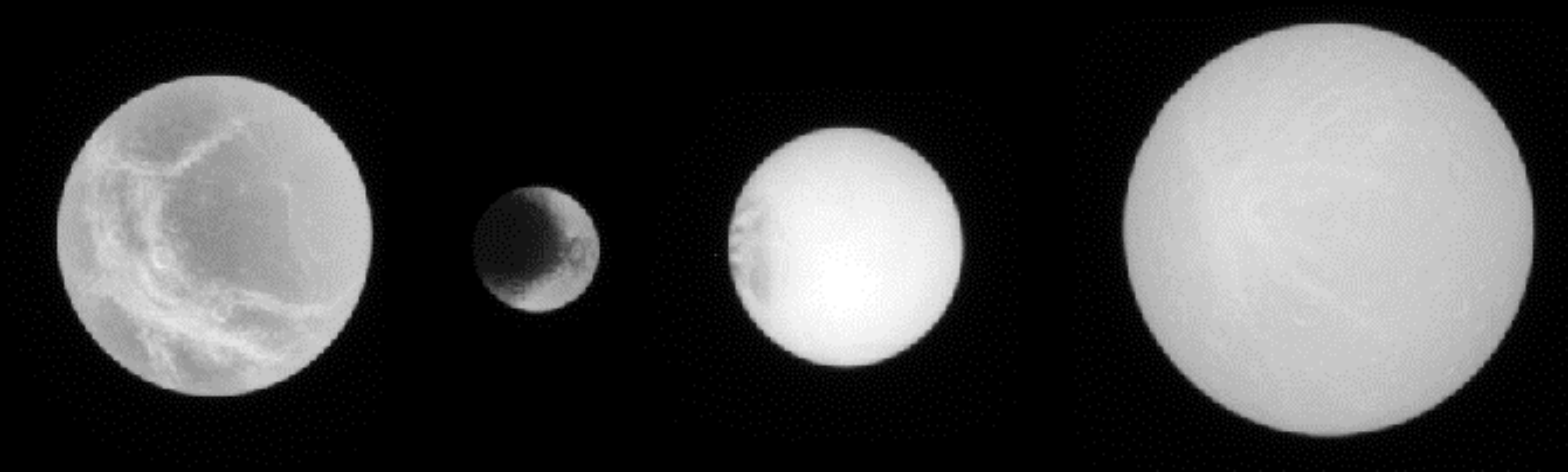
THE SATURNIAN SYSTEM



Icy Satellites: New Images

- "Zero Phase" coverage of Dione, Iapetus, and Enceladus
  - Most accurate measurements of albedo & color
  - Ties to Earthbased observations
  - Defines the "opposition effect" for each satellite
- New closeup views of Tethys, Dione, Rhea, Mimas
  - Help complete global mapping
  - Provides new geological details and topography
- New Enceladus Plume Observations
  - View direction parallel to "Tiger Stripes"
  - Look for temporal changes associated with tides

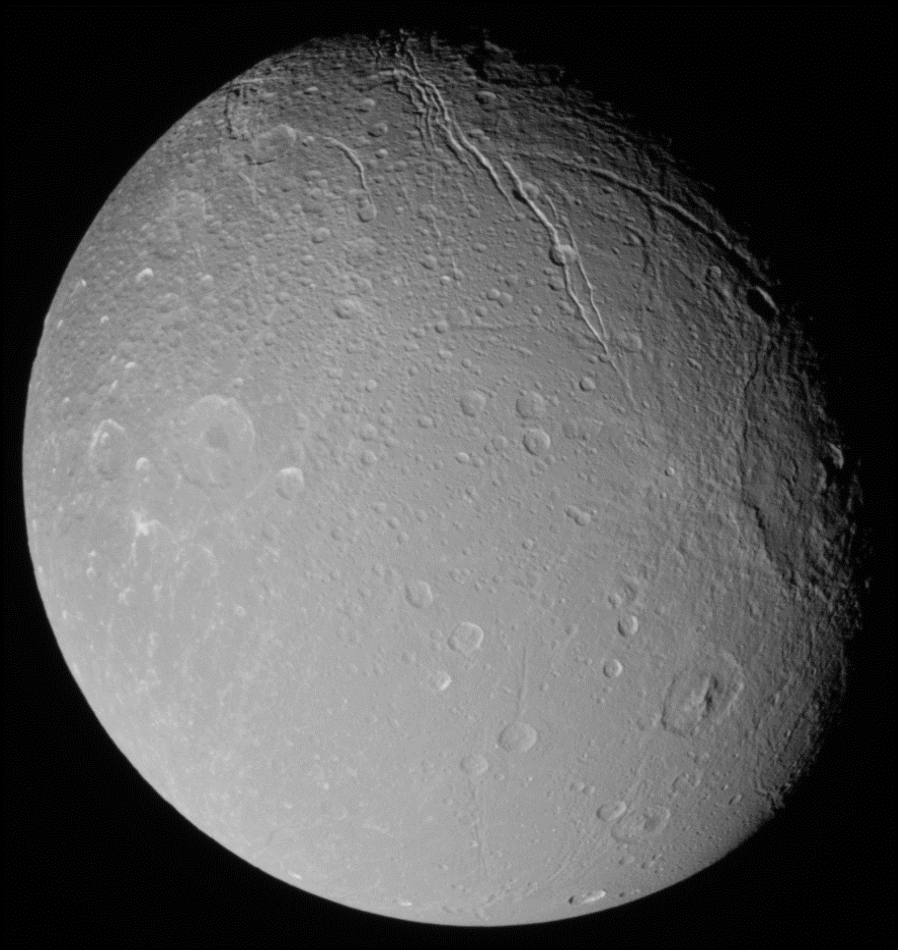
Satellites at Opposition

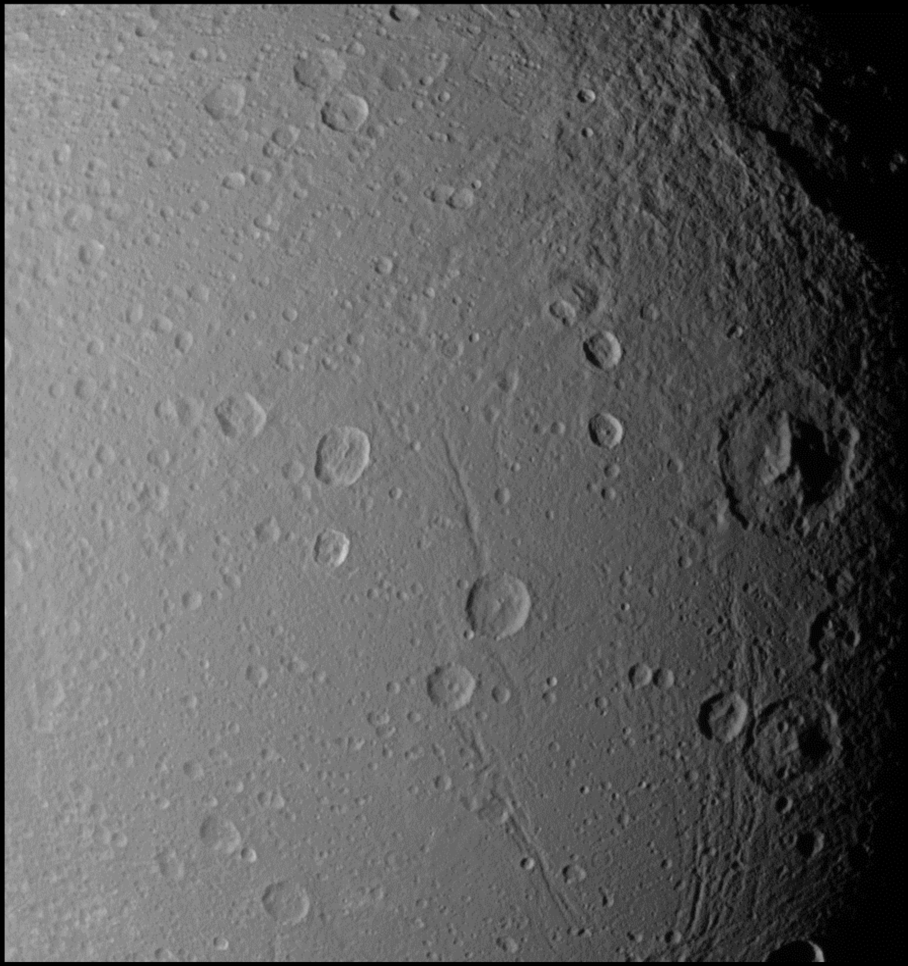


Dione Iapetus Enceladus Rhea

NOTE: Satellite disks not scaled to proper relative size

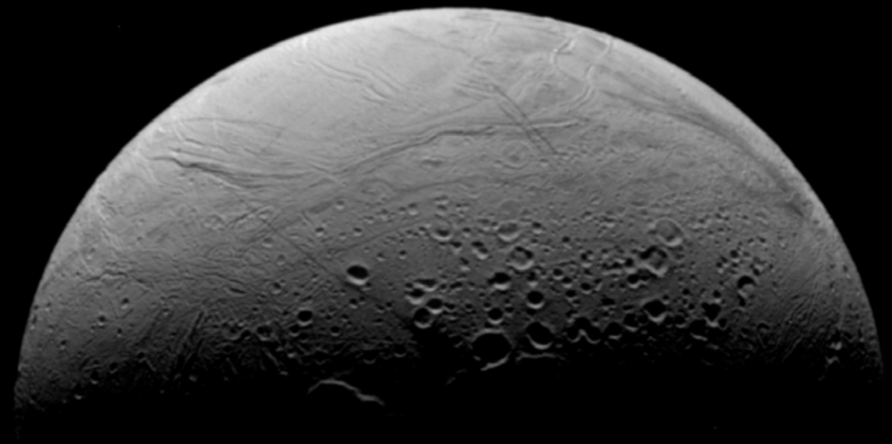
New Closeups Views: Dione Example





Enceladus Basic Properties

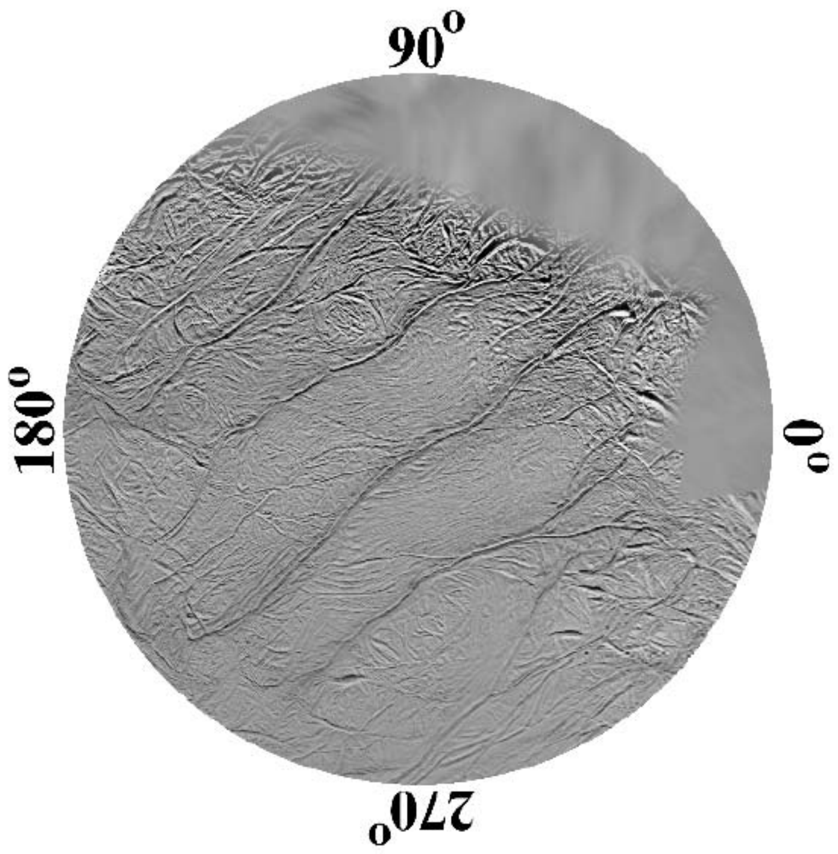
Triaxial Shape: 256.6 x 251.4 x 248.3 km
Mean Radius: 252.1±0.2 km
Mean Density: 1.608±0.005 g/cm^3
Gravity: 11.3 cm/sec^2
Orbit & Rotation (Synch.): 1.370218 days
Orbital Distance: 238,020 km
Mean Surface Temp.: 72°K (-201°C, -330°F)
Visual Albedo: 1.375±0.008

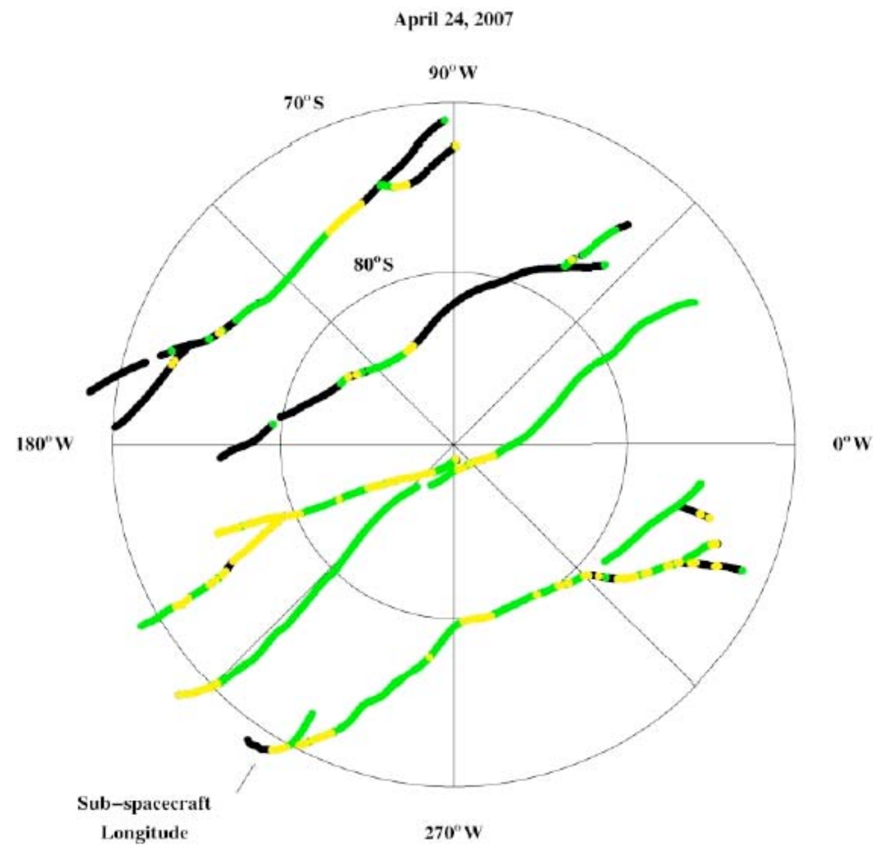


Enceladus Plume Eruptions

April 24, 2007

Tidal Control of Vent Sites

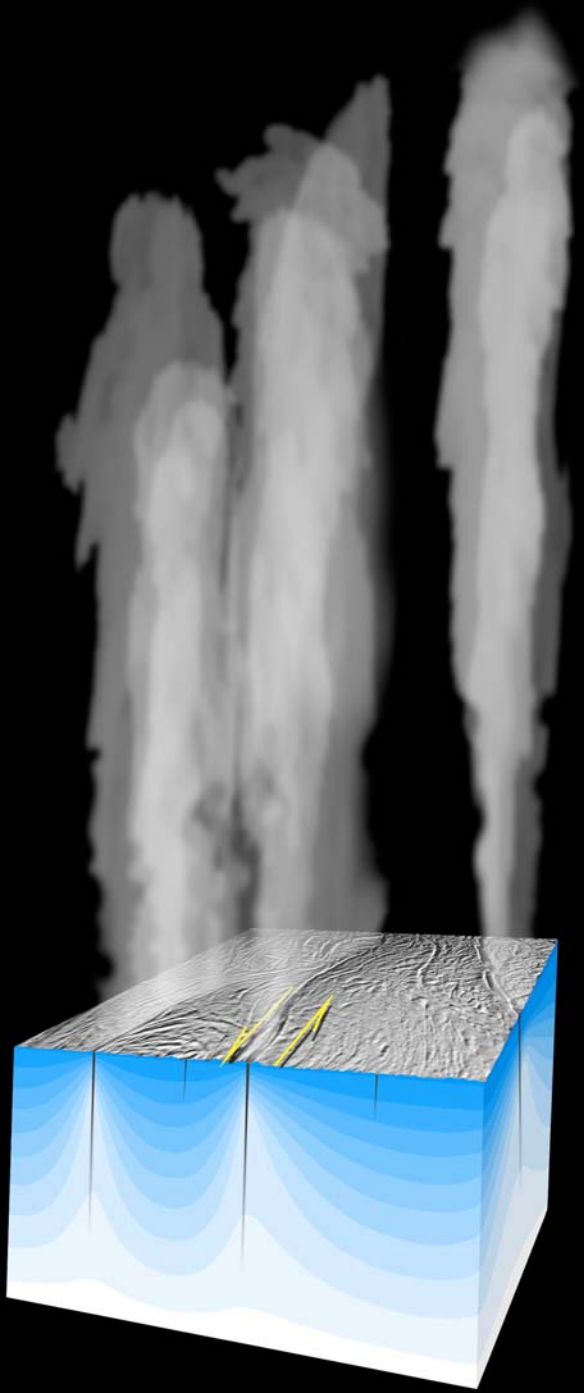




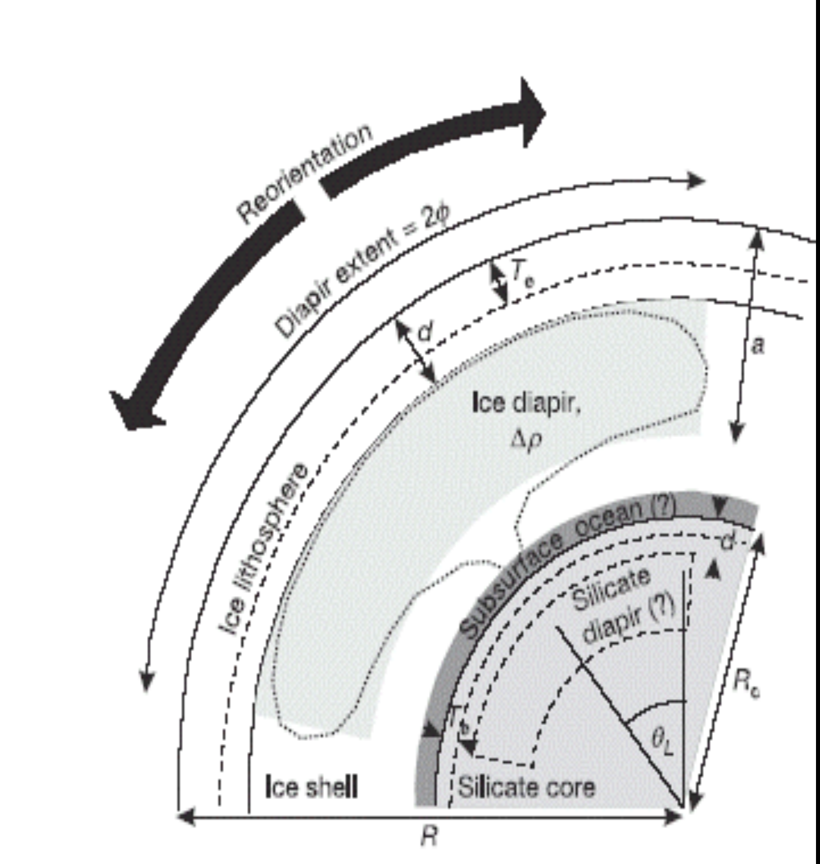
Hurford et al. 2007

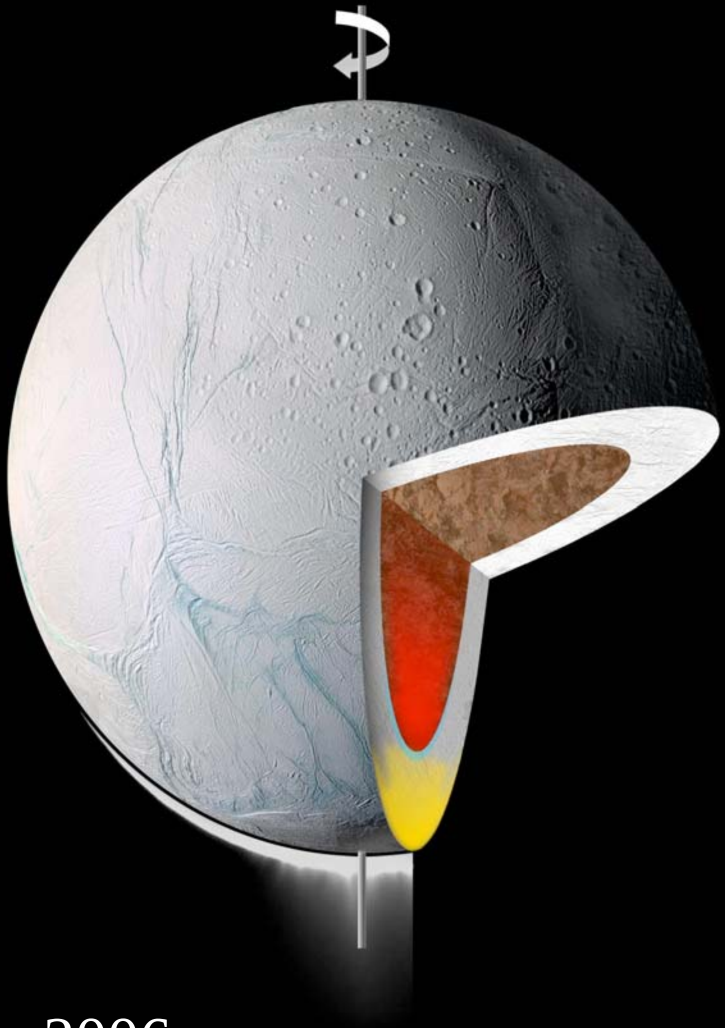
Tidal Heating of Vent Sites by Shear Friction

Nimmo et al 2007



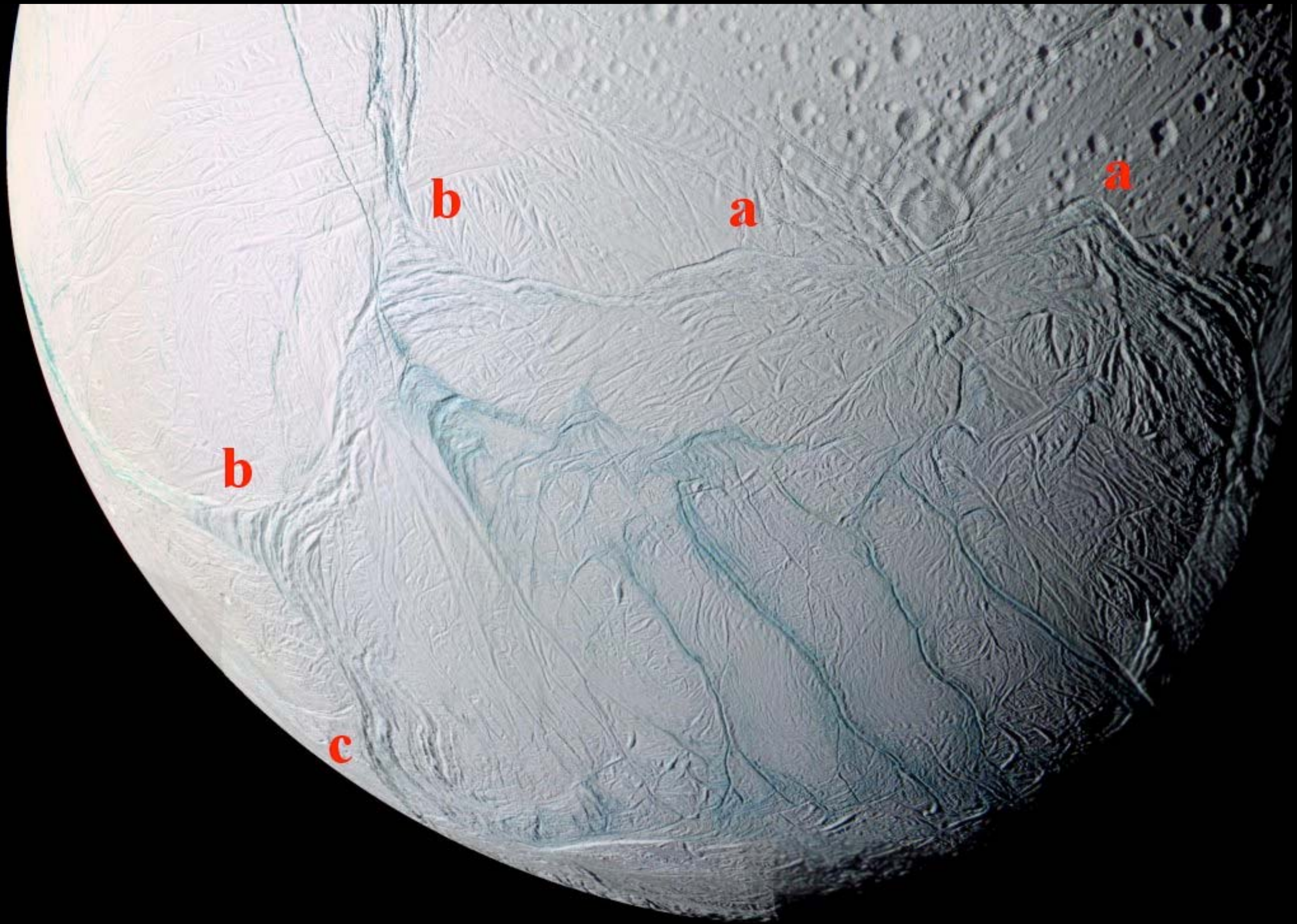
Enceladus Polar Wander?



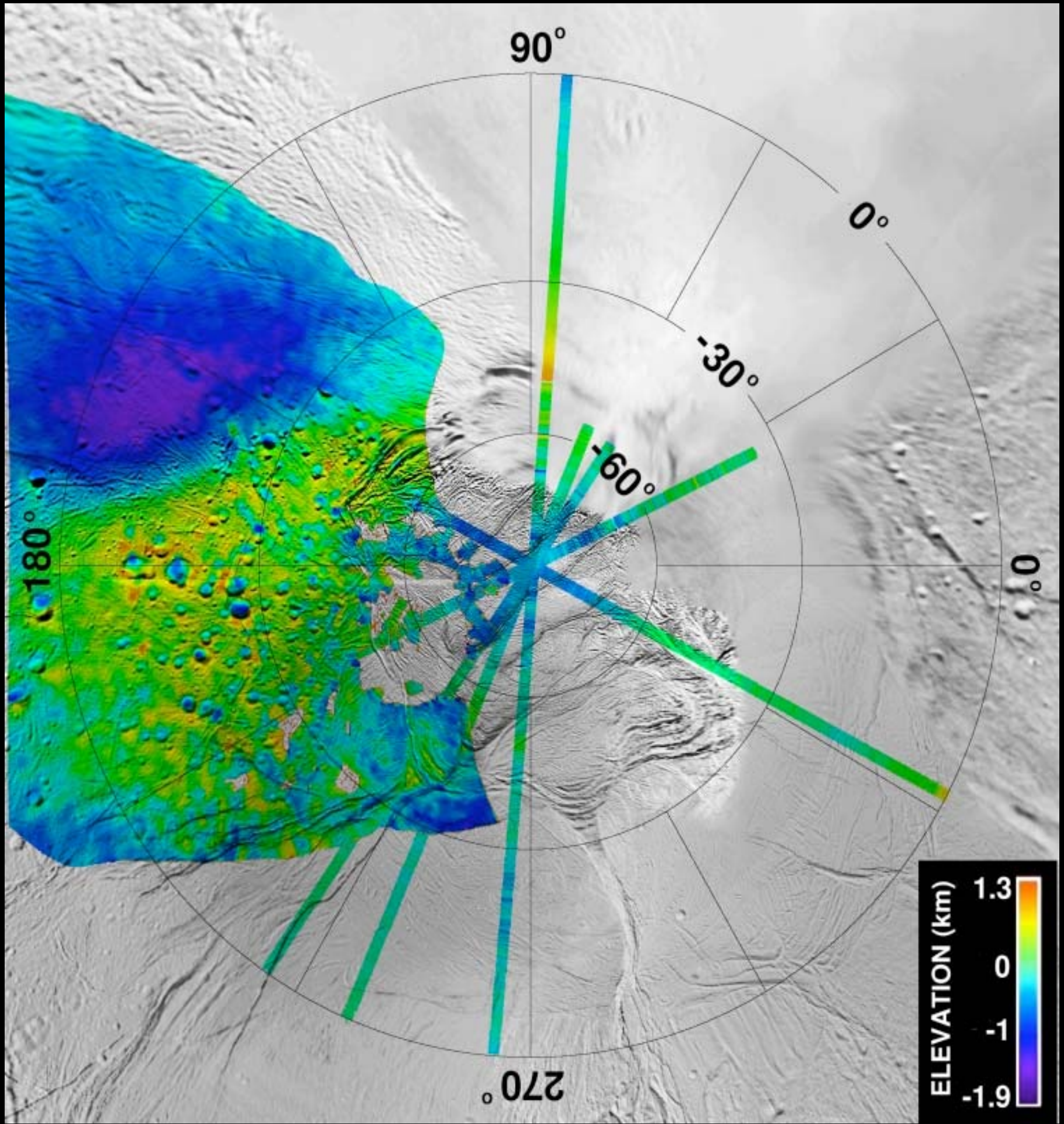


Nimmo and Pappalardo, 2006

South Polar Tectonism

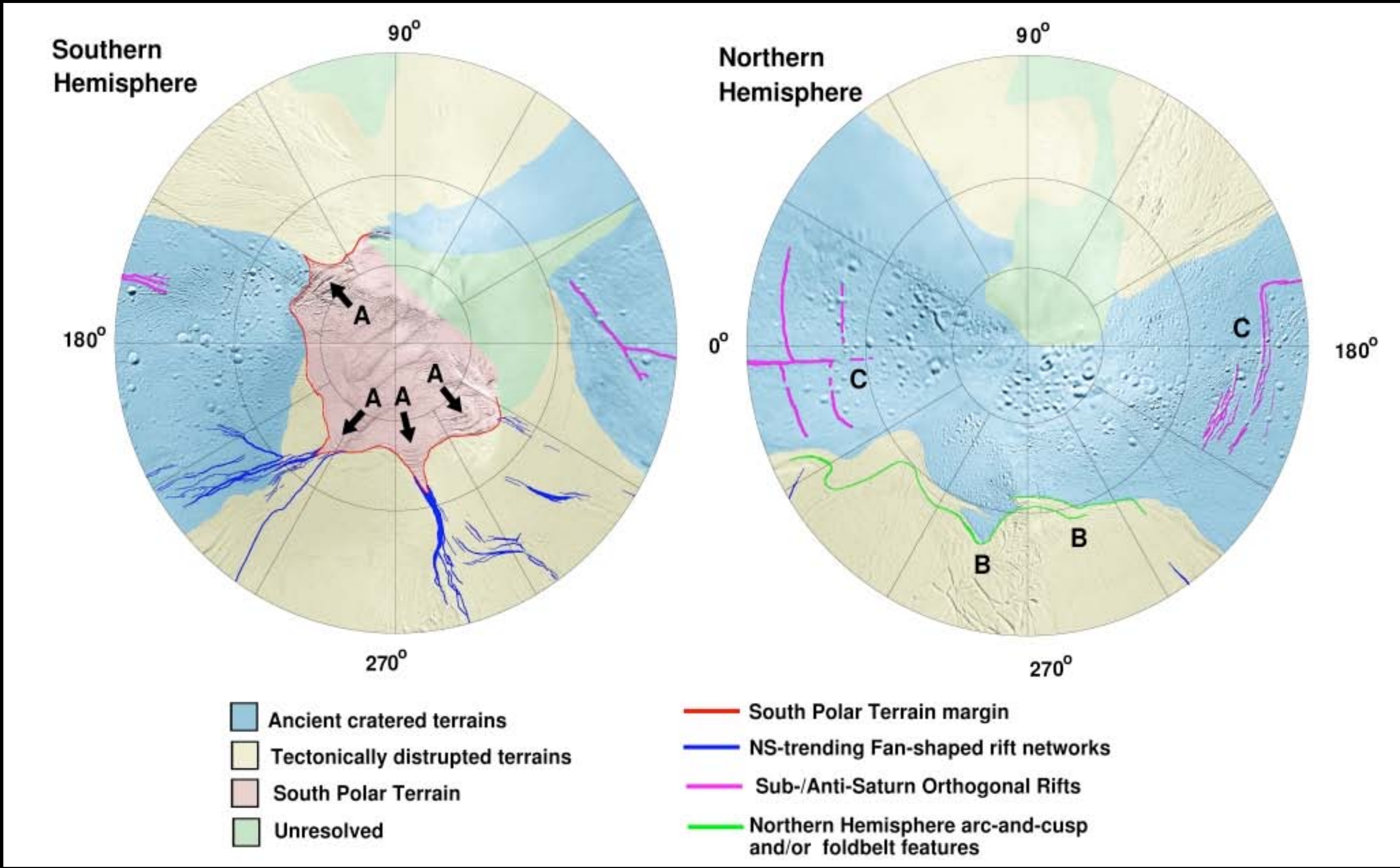


South Polar Topography

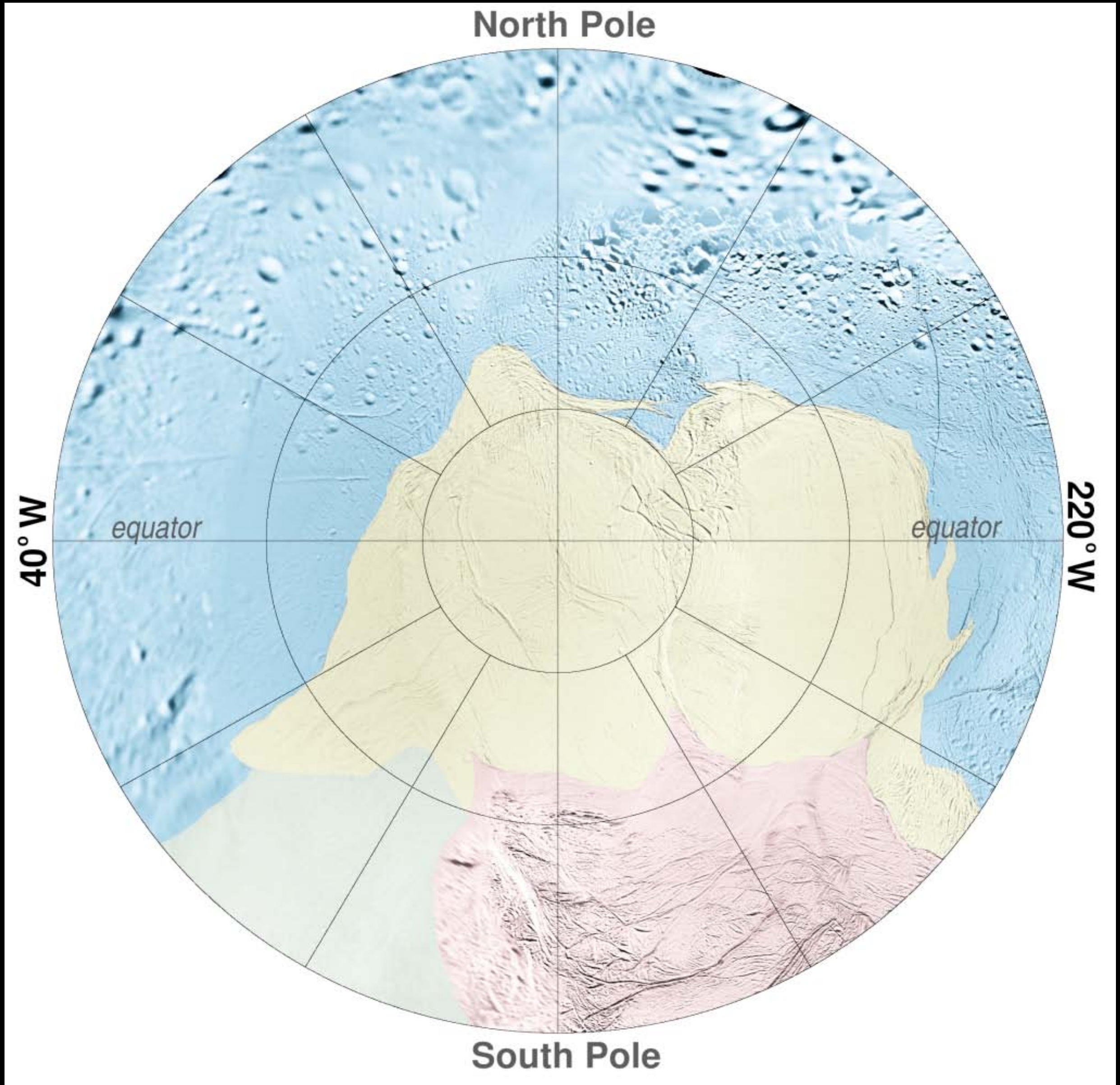


Helfenstein et al. 2007

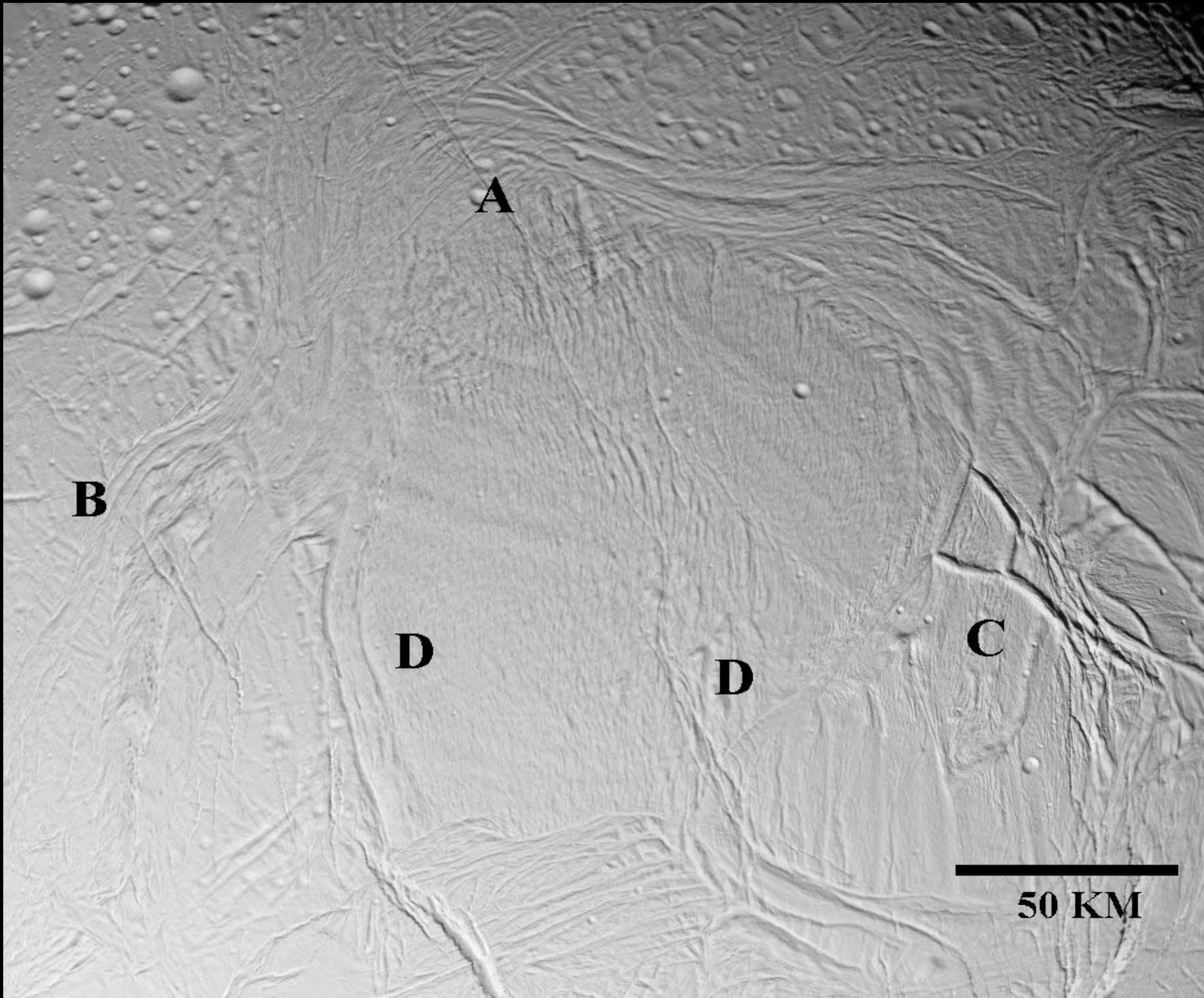
Global Geological Sketchmap



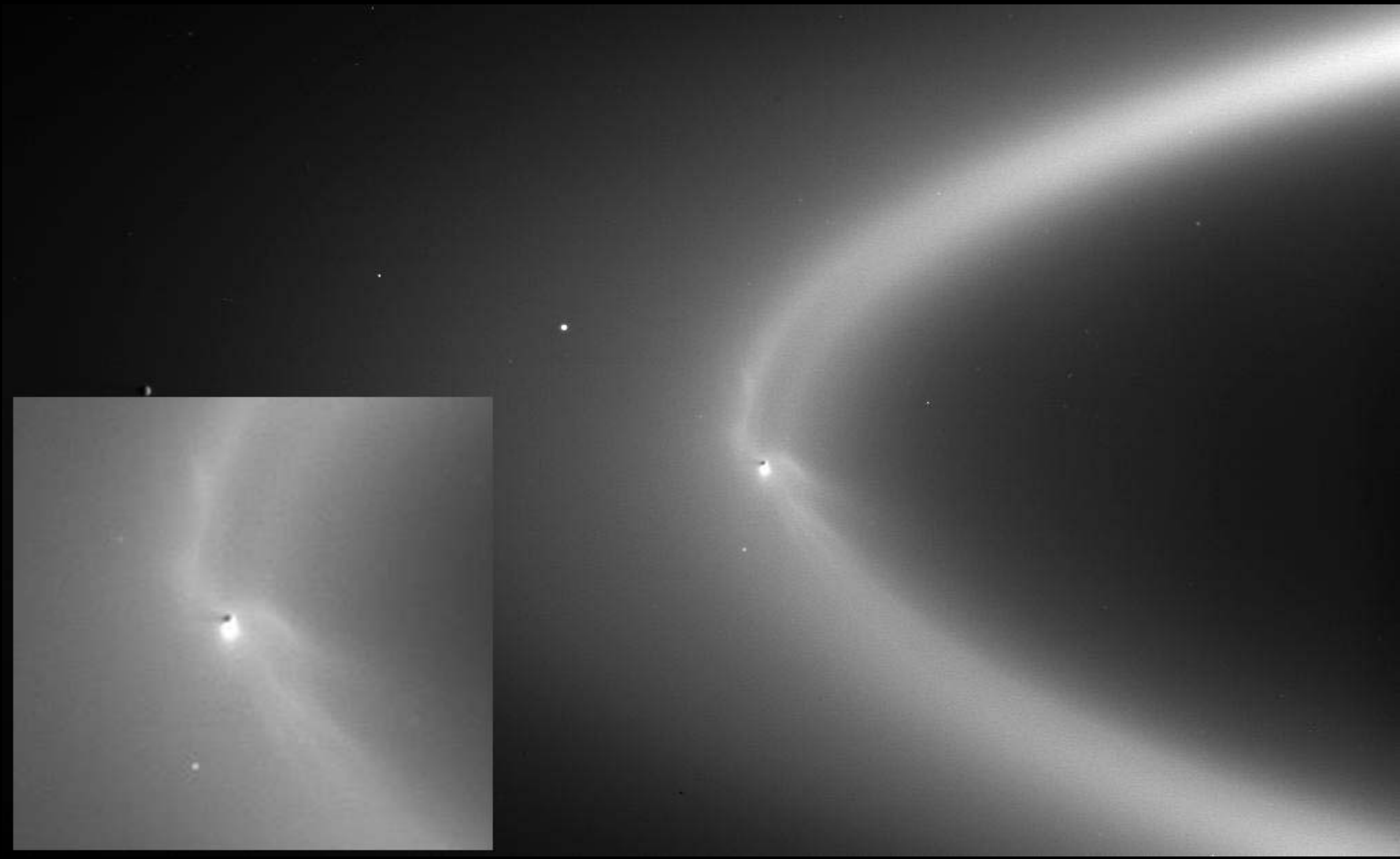
Fossil Tectonovolcanic Centers?



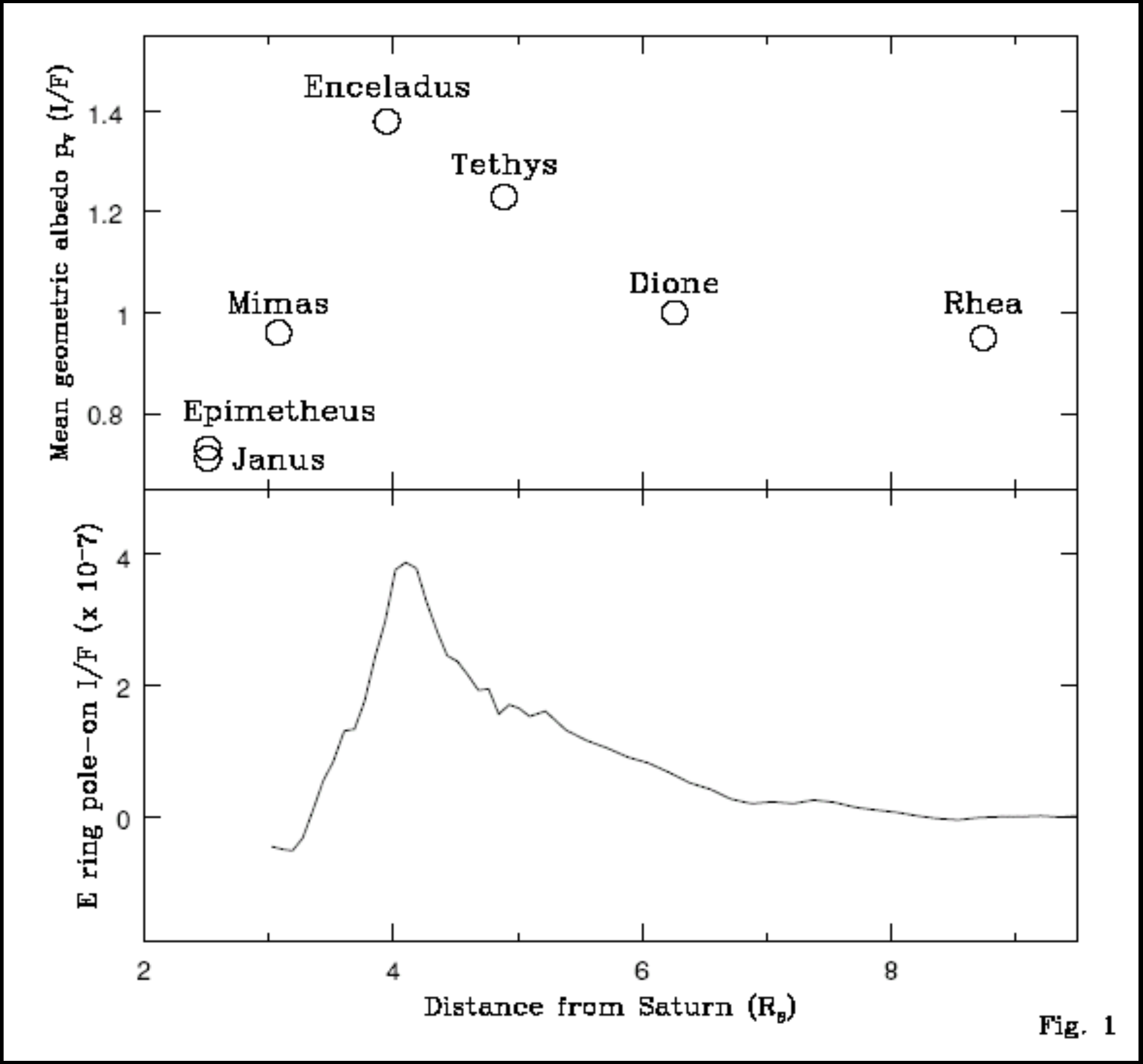
Helfenstein et al. 2007


A
B
D
D
C
50 KM

Enceladus Plumes and E-Ring



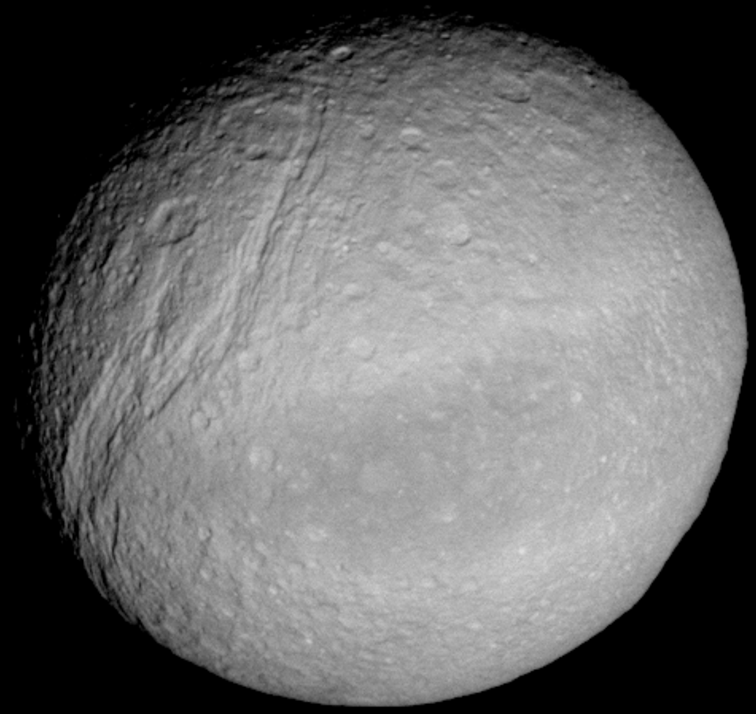
Enceladus the Graffiti Artist



Verbiscer et al 2007

Mimas and Tethys

MIMAS

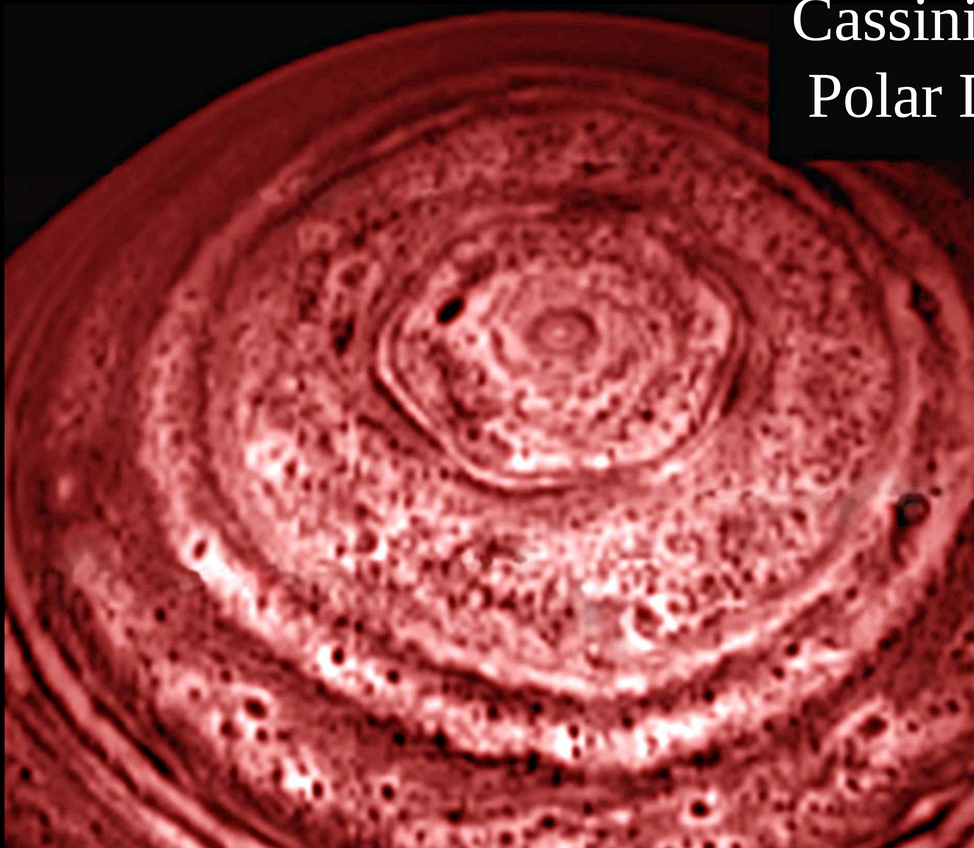


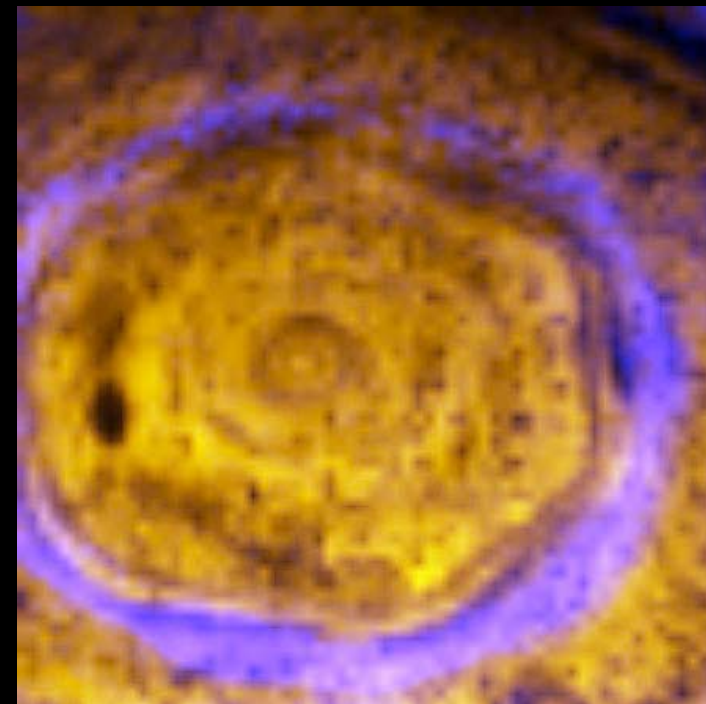
TETHYS

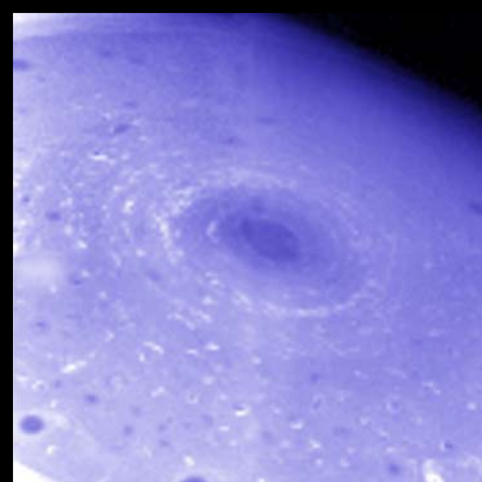
Saturn

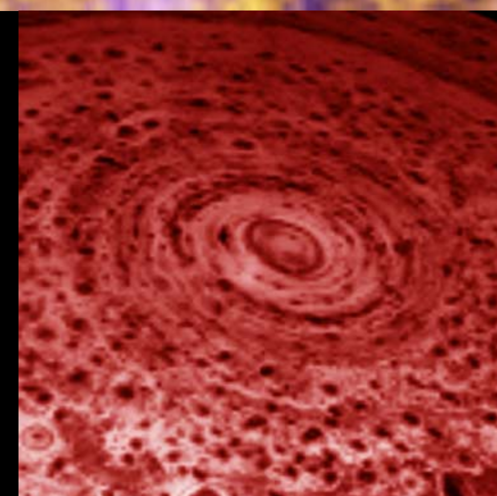
- Saturn is the 6th planet from the Sun. It is a giant gas planet, the 2nd largest in the solar system.
- Known since ancient times it is named after the Roman god of agriculture (Greek god “Cronus”), and “Saturday” is the only day of the week to retain it’s Roman origin in the English language.
- Saturn consists mostly of Hydrogen (H) and Helium (He), and has a density of .7 g/cm^3 (less than that of water).
- Saturn’s atmosphere exhibits a banded pattern similar to Jupiter, but the bands are much fainter and wider.
- Saturn’s winds are the fastest in the solar system.

Cassini Year 3 at Saturn:
Polar Discoveries and Other Surprises

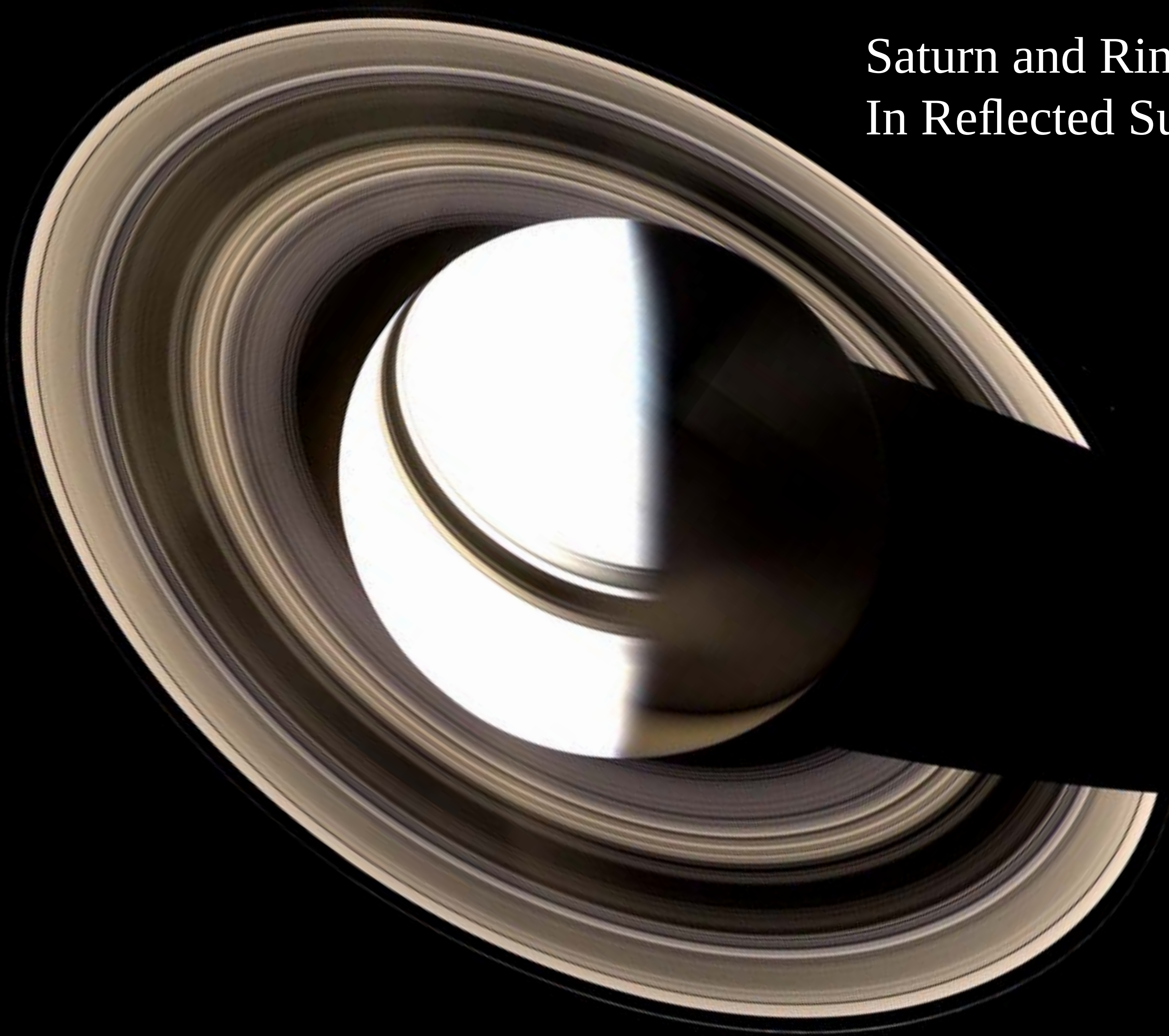




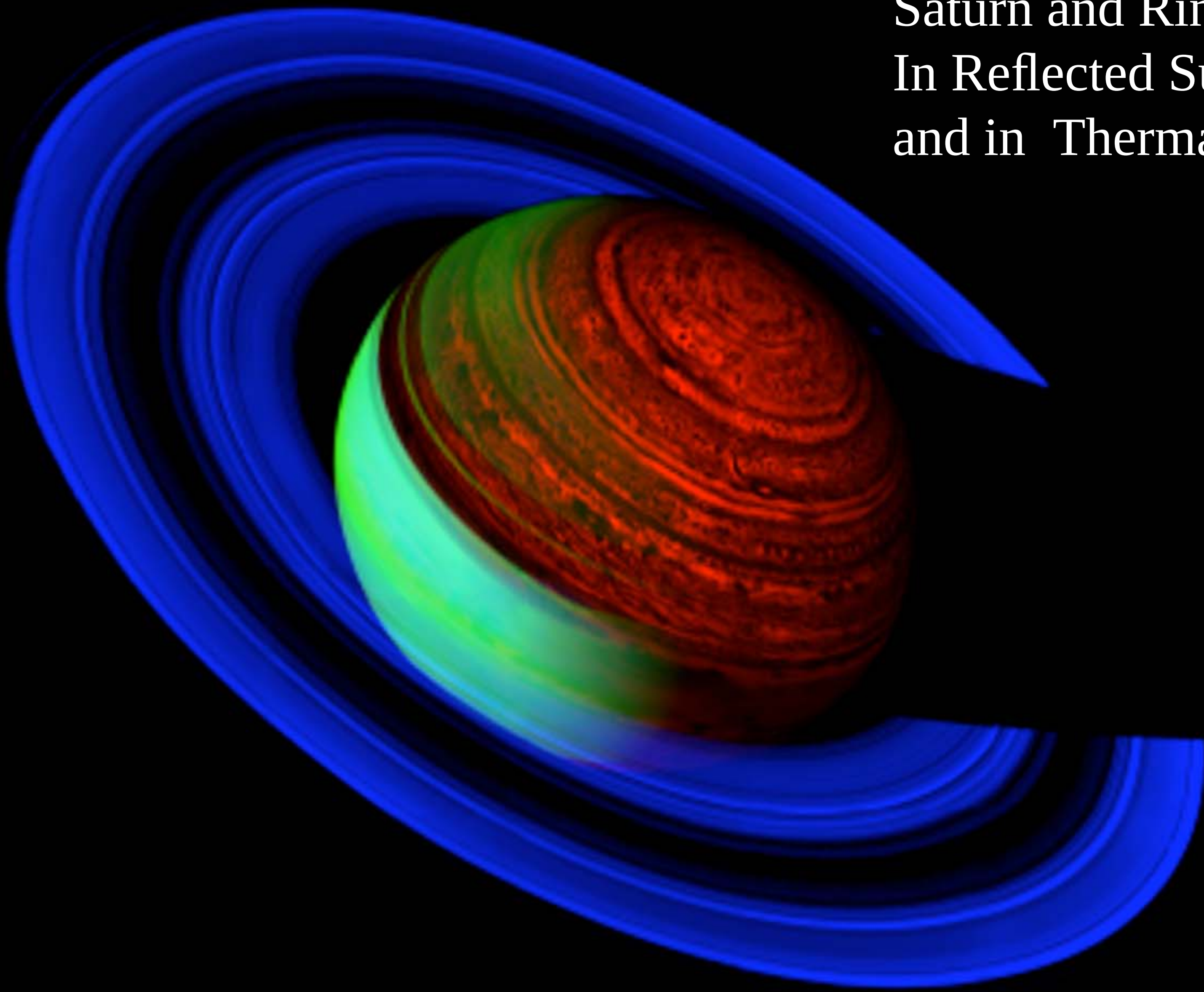


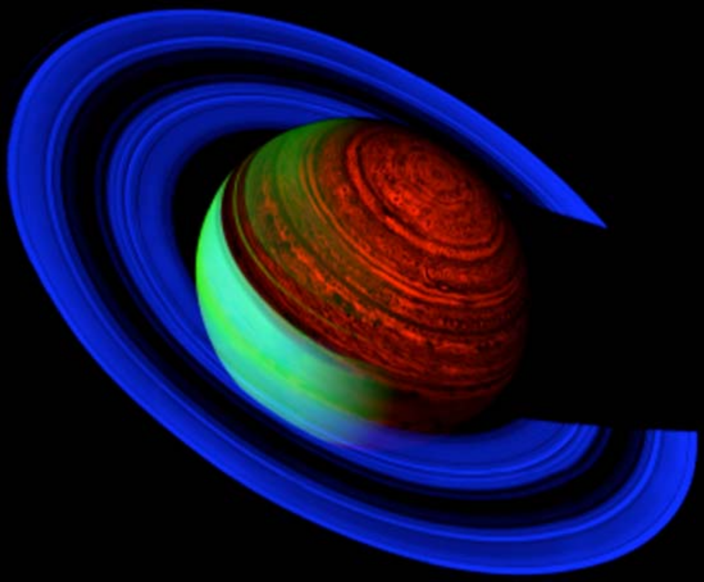


Saturn and Rings
In Reflected Sunlight



Saturn and Rings
In Reflected Sunlight
and in Thermal Glow





Neon Saturn

Red = 5–μm (5 micron wavelength) thermal glow of Saturn

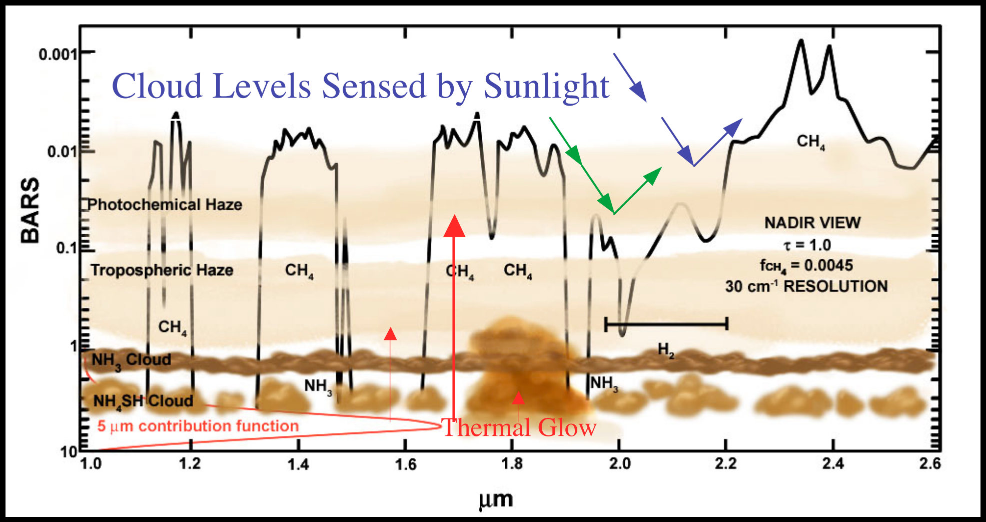
- Light generated at depth by Saturn's heat
- Senses clouds both in daylight and in nighttime conditions
- Senses well big-particle clouds, including those underneath small-particle clouds, down to the 5-bar level
- In rings, light is absorbed by water ice

Green = 3.0-μm reflected sunlight

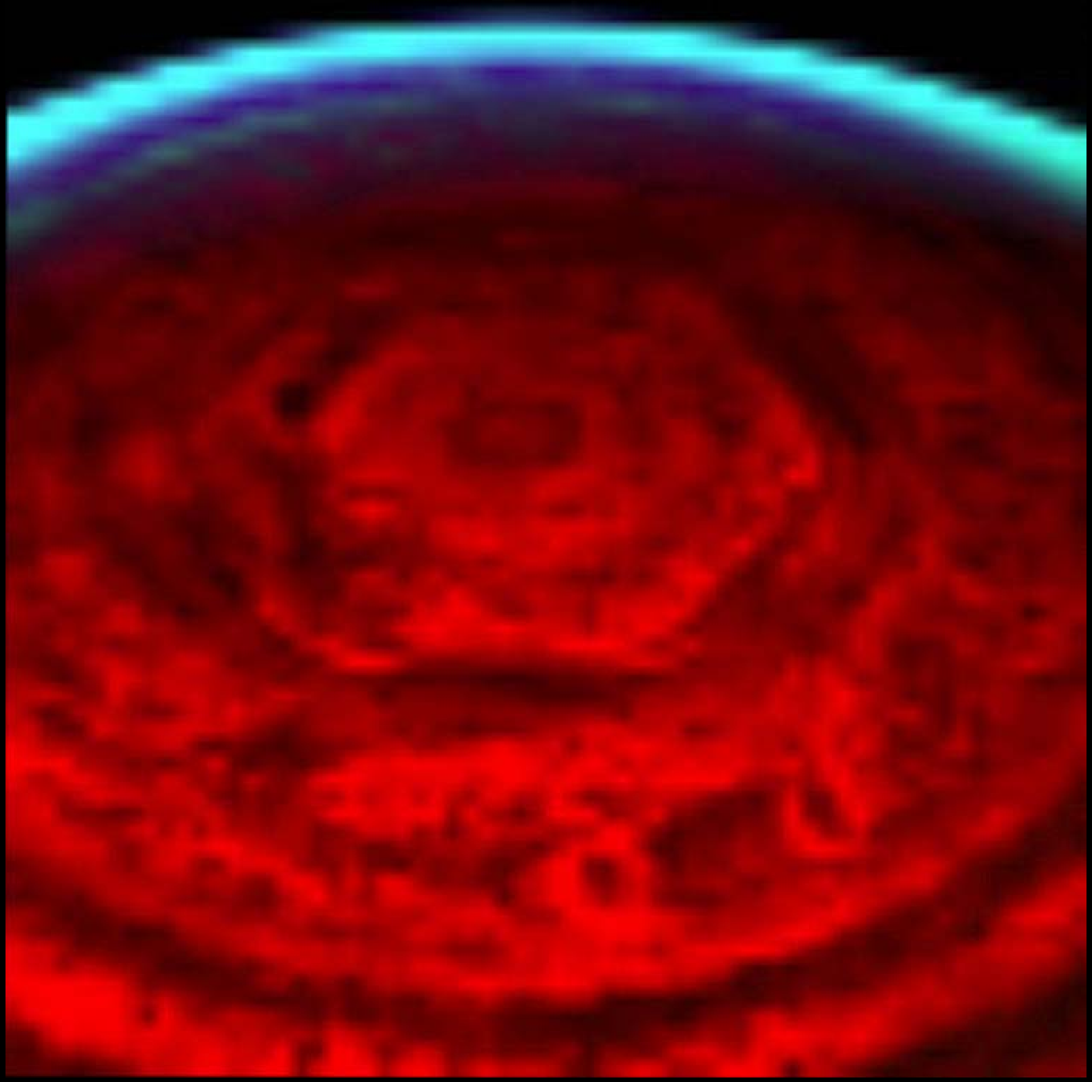
- Senses only in daylight
- Senses both mid and high-altitude clouds above ~ 0.1 bar level
- In rings, light is absorbed by water ice

Blue = 2.3 -μm reflected sunlight

- Senses only in daylight
- Senses only high-altitude clouds in above 0.02-bar level
- In rings, light is reflected by water ice



Saturn's North Polar Hexagon
Seen at Night In Saturn's Thermal Glow



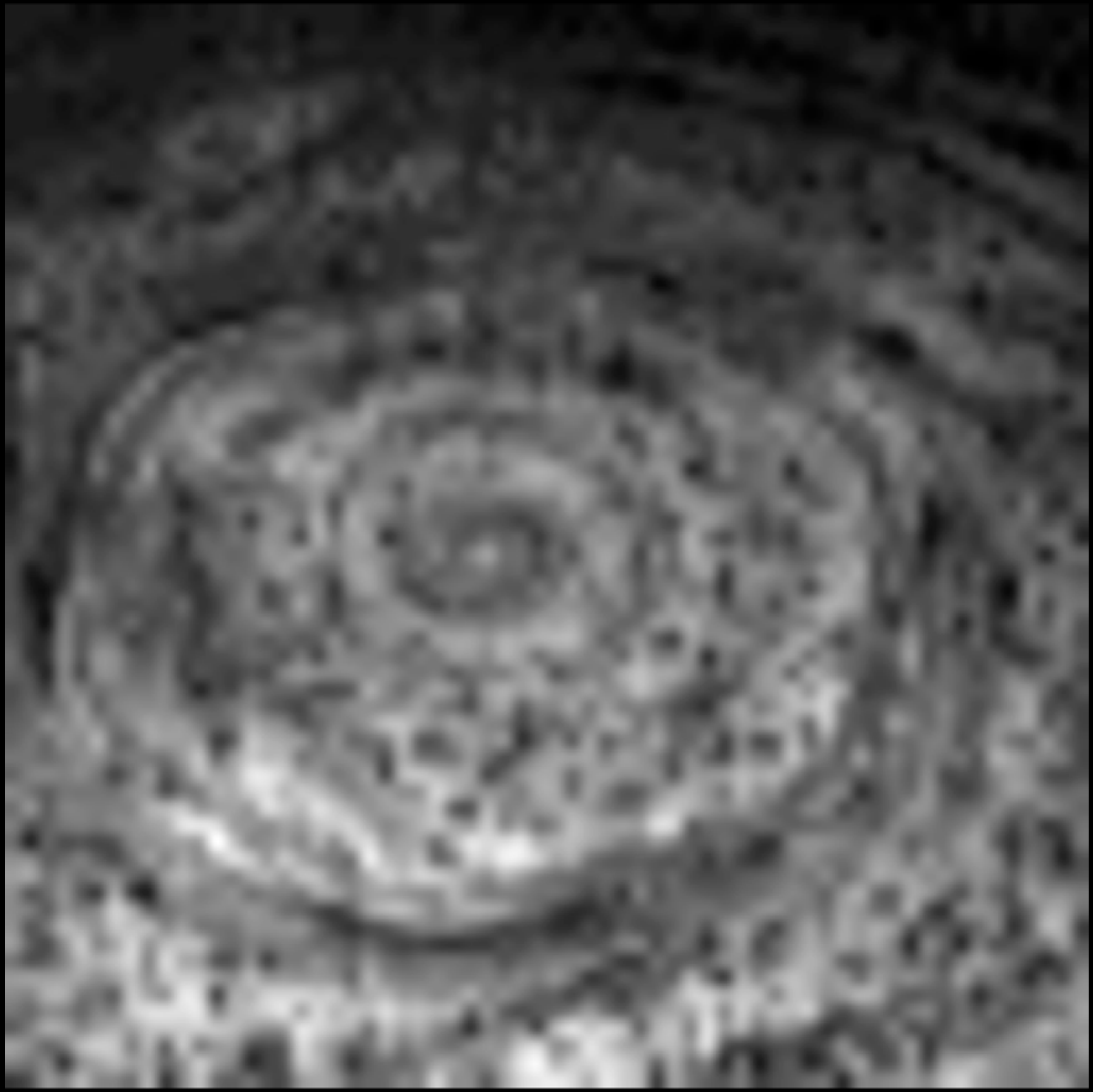
Red= 5.0-µm thermal glow from Saturn's interior

Clouds are dark, as they block the glow

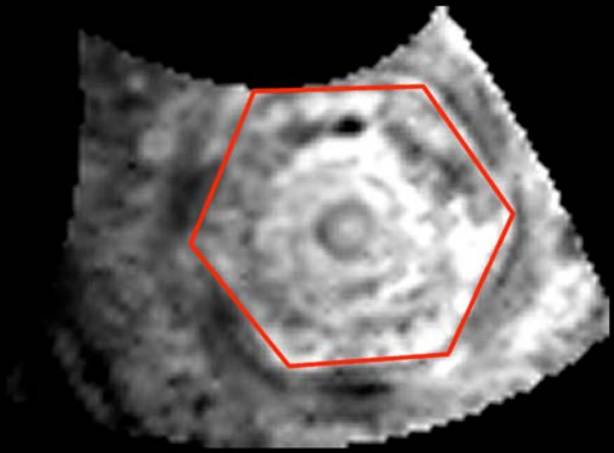
Clearings in clouds are bright

Aqua = 1.3 µm reflected sunlight seen on distant horizon

North Polar Hexagon Movie:
Saturn Spinning under Cassini

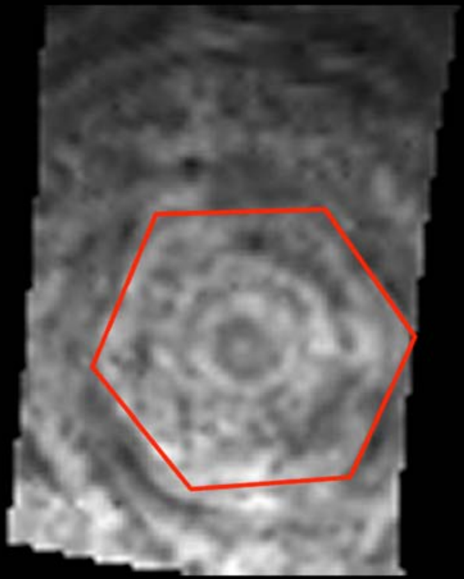


Hexagon Rotates at Rotation Rate of Saturn Seen by Voyager



29 October 2006

Range to Cloudtops: 908551 km



10 November 2006

Range to Cloudtops: 1035363 km

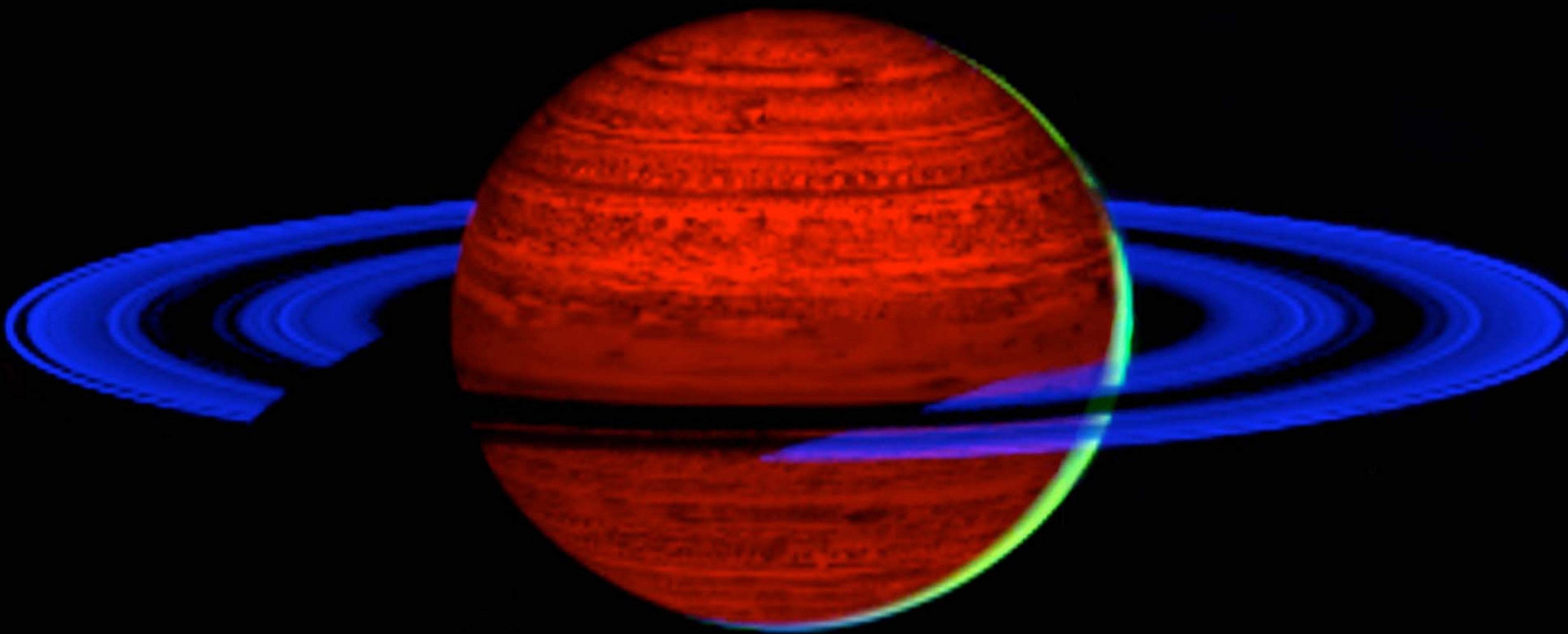
Rotation Period: Equals Nominal Voyager SKR period to 0.1 ± 7.0 seconds

Over 12 days, vertices stay at constant longitude to 0.02 ± 1.65 degrees

Voyager Radio Period: 10 hr 39 min 24±7s   Cassini Radio Period: 10 hr 45 min 45 ± 36s

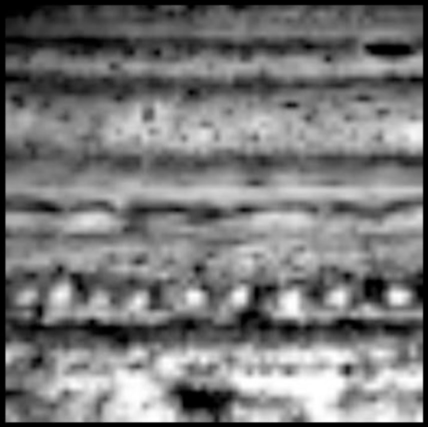
(Gurnett *et al.*, 2005, *Science* **307**, 1255-1259)

Saturn: A Night-time Equatorial View

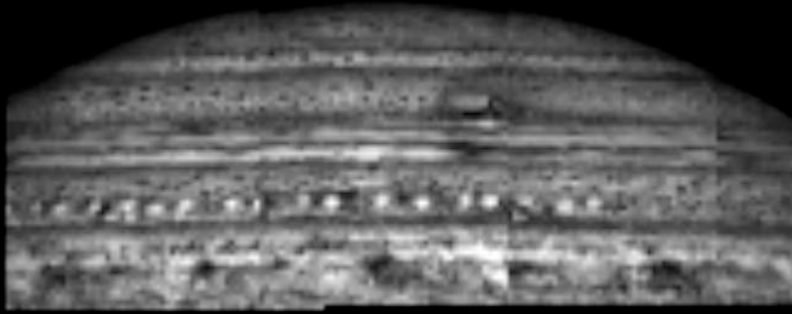


Red= 5.0-µm thermal glow
Green = 3.0-µm reflected sunlight
Blue = 2.3 -µm reflected sunlight

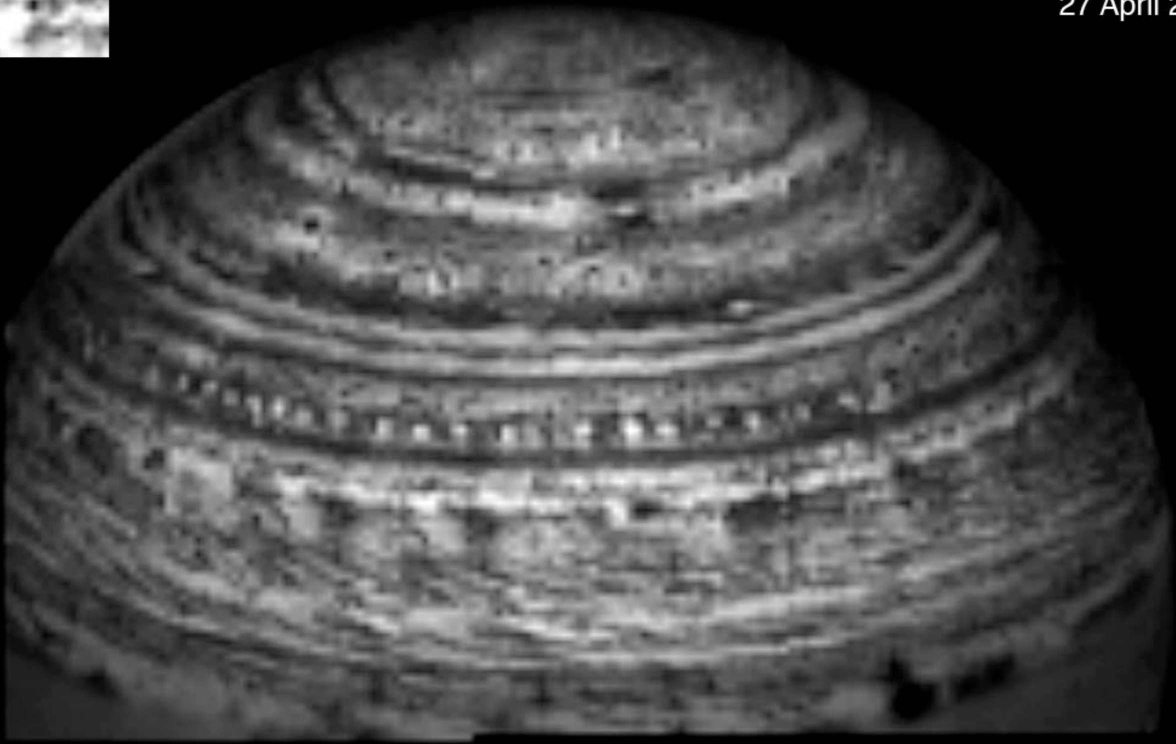
Saturn “String of Pearls” Feature



16 July 2005

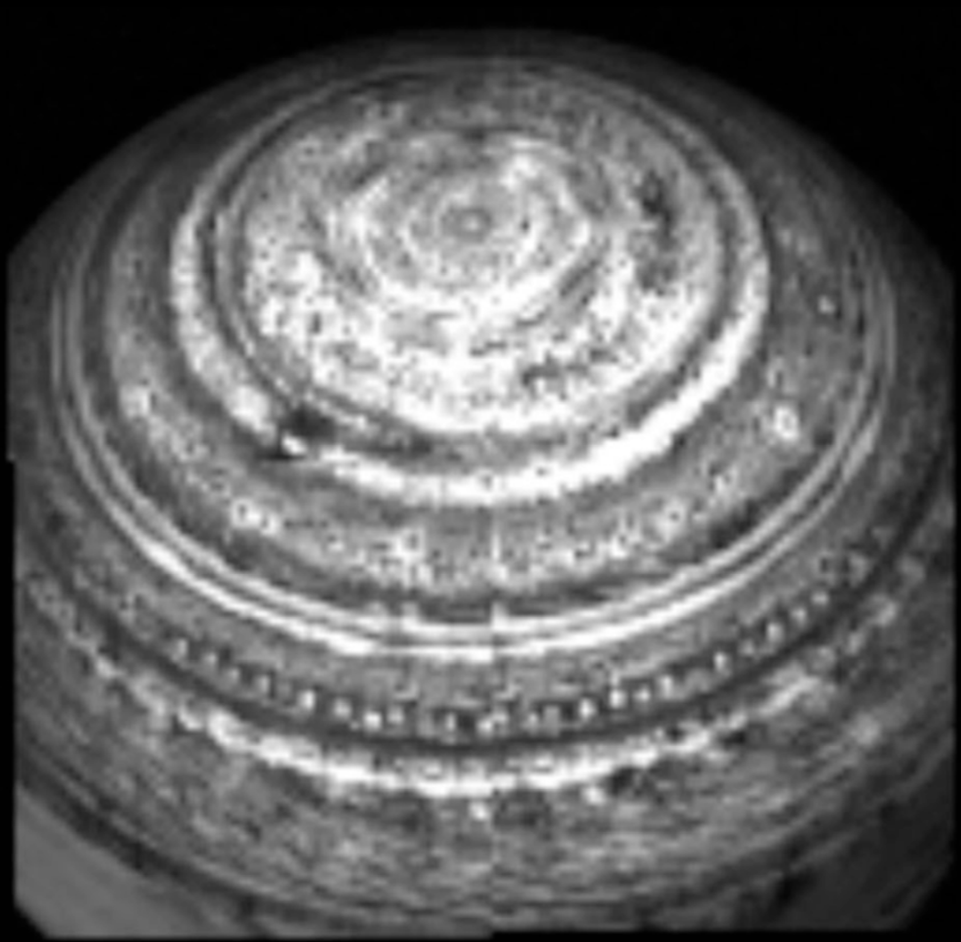


27 April 2006



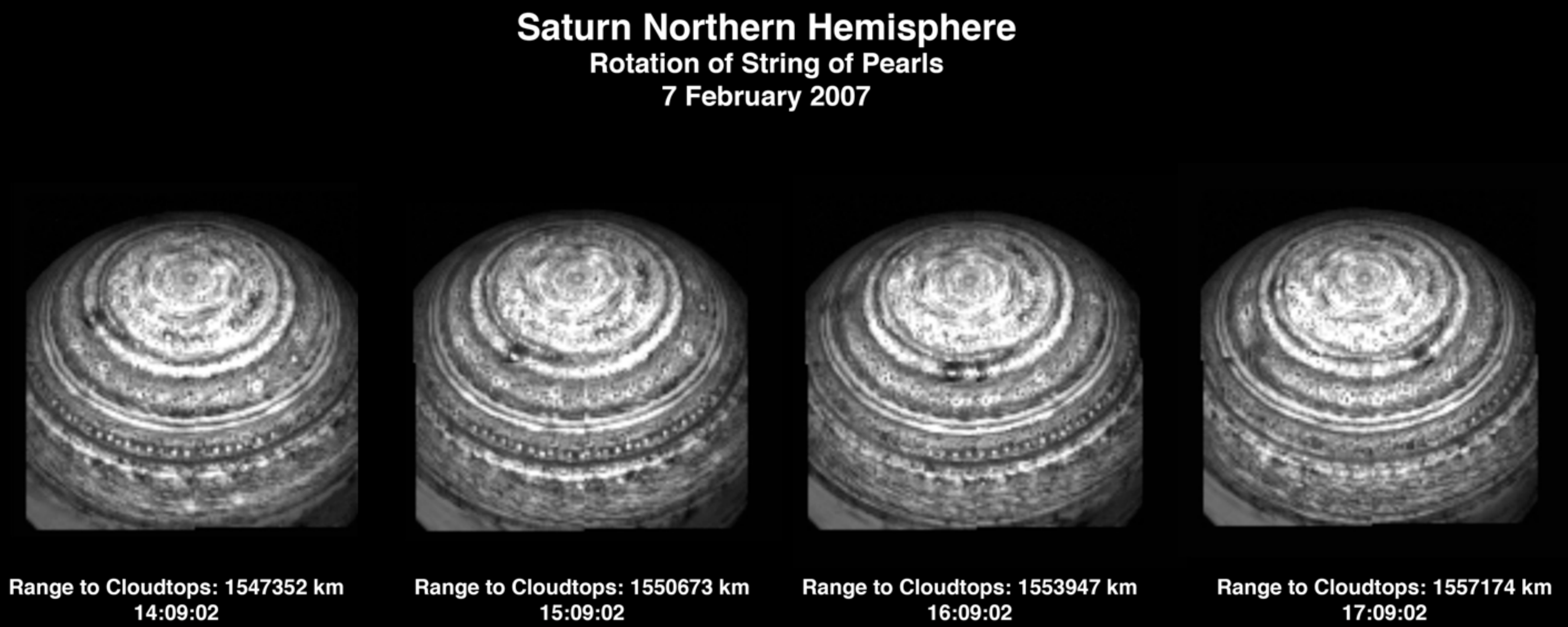
11 September 2006

7 February 2007



Range to Cloudtops: 1550673 km

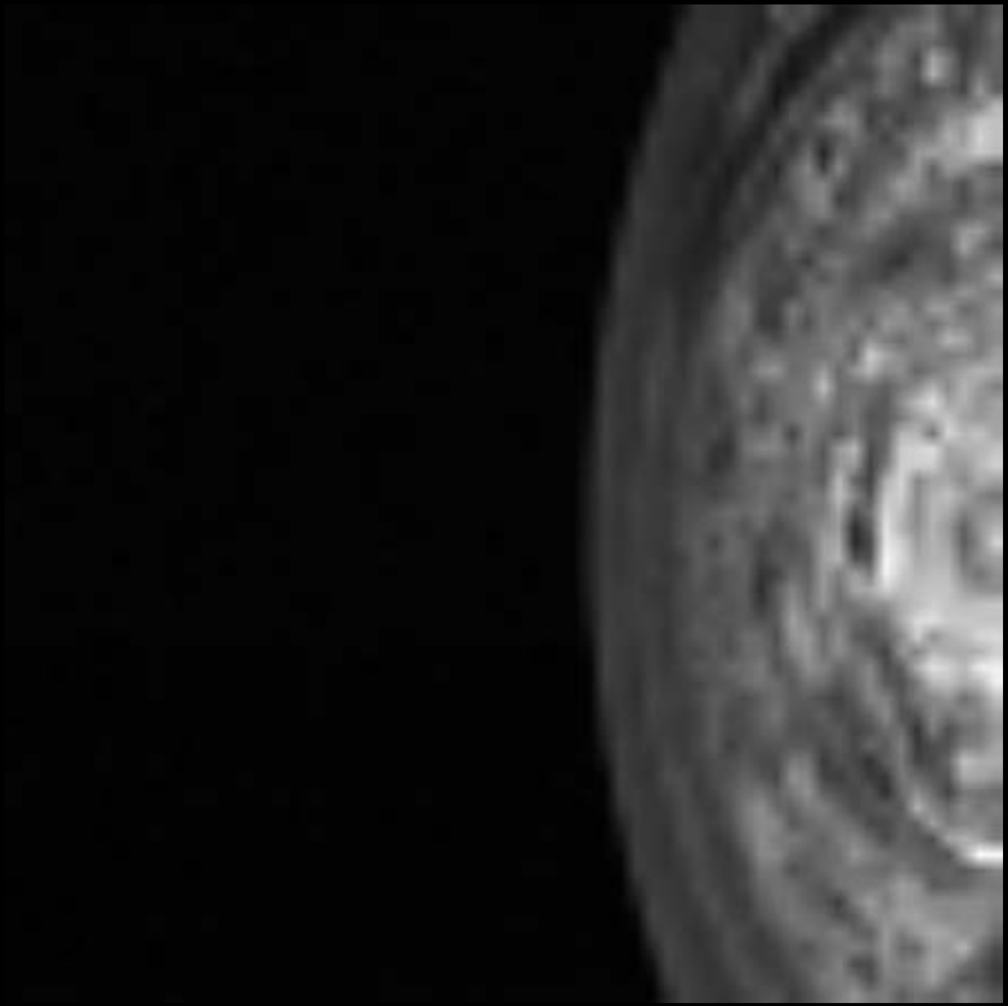
15:09:02



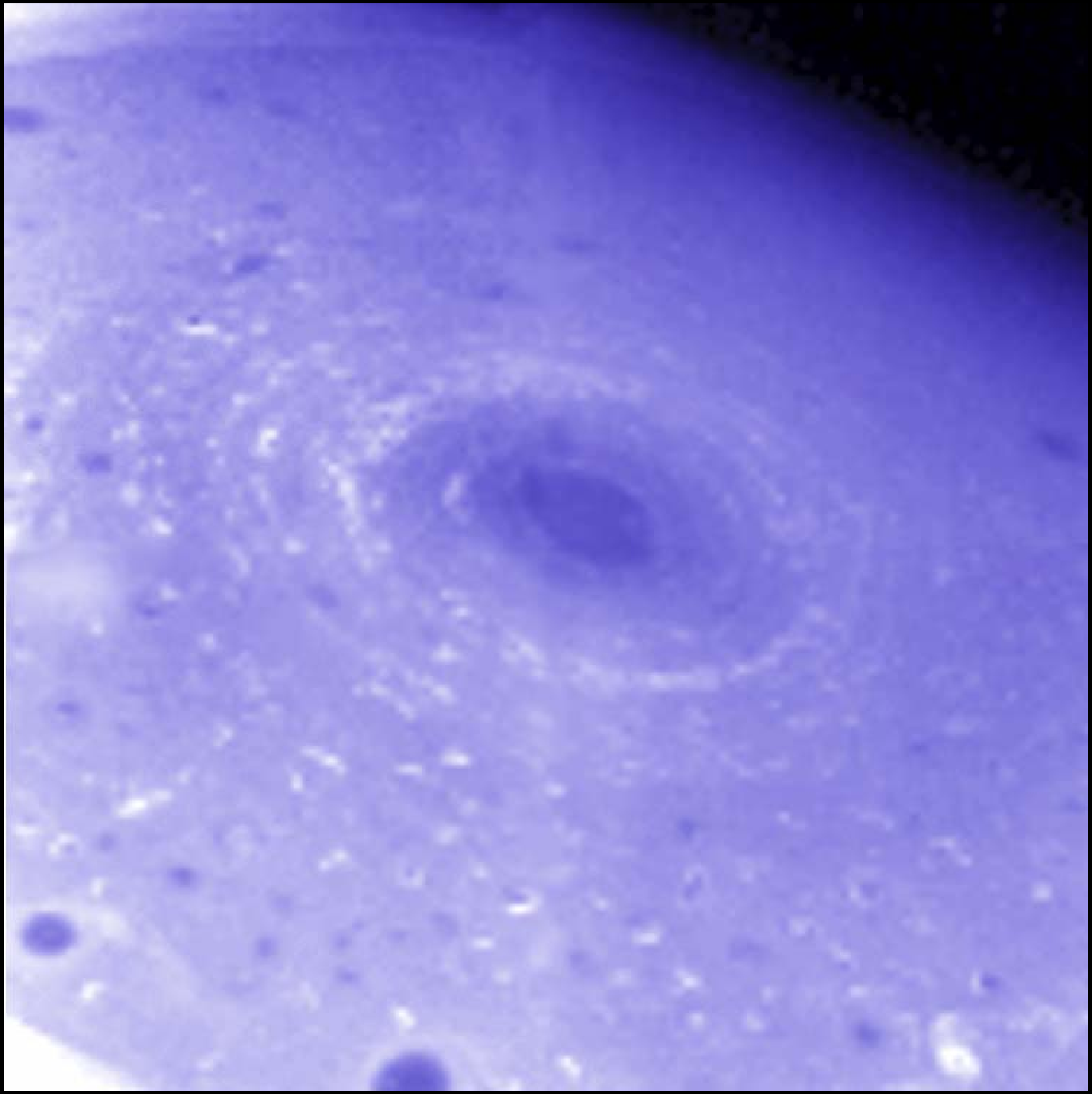
"String of Pearls" at 40^{o} N. latitude spans about 90 degress of longitude.
Spacing of bright pearls (clearings in clouds) is about 3^{o} of longitude (2100 km).
Each pearl is about 800 km across.

“Rolling Saturn”

A One-Saturn-Day Tour from the North Pole through the Equator



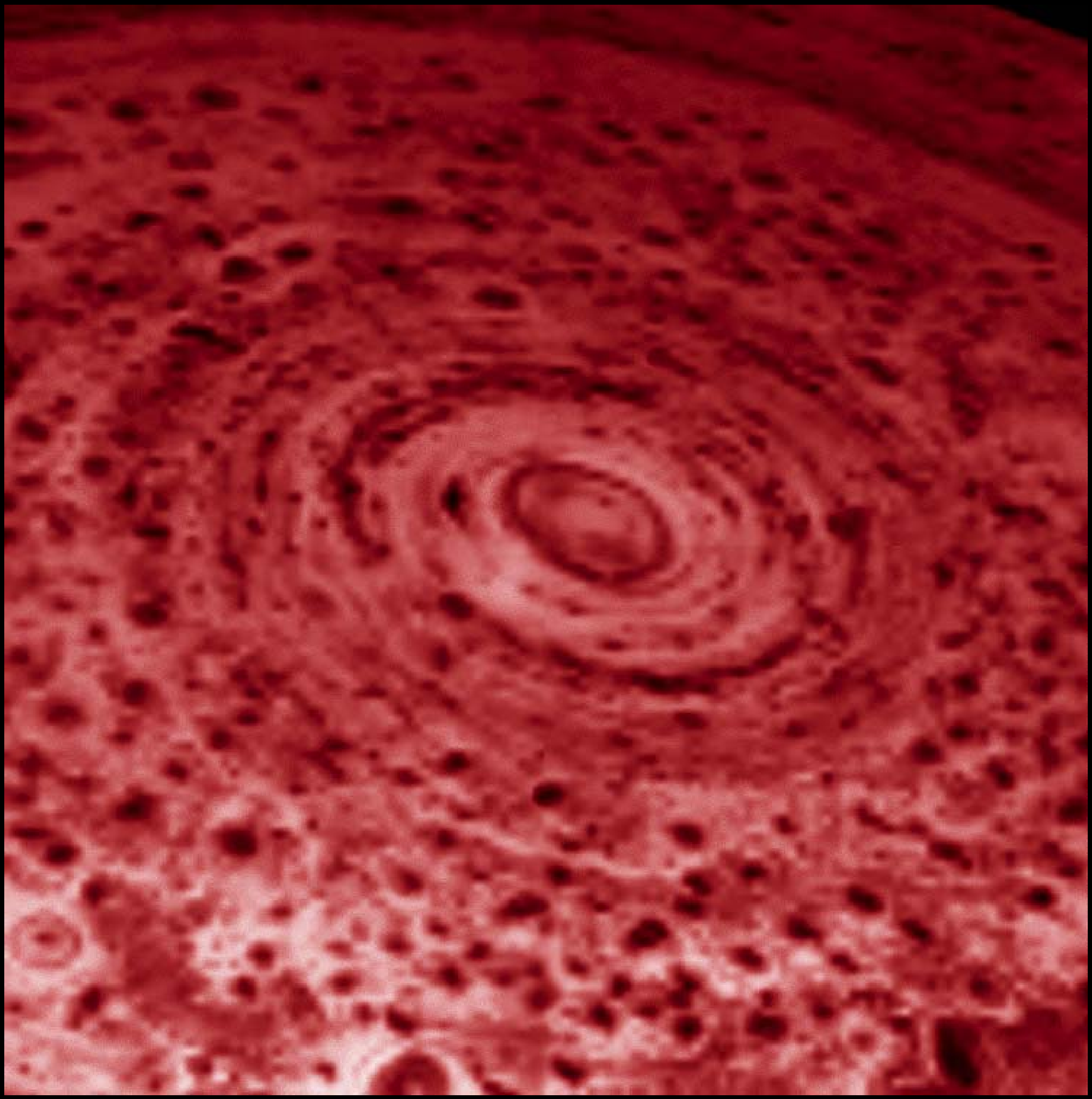
Saturn's South Pole
Hurricane-Like Feature



1.3 μm Reflected Sunlight

- Dark Center implies clear, deep clouds
- Bright rings of clouds give way to numerousdistinct cloud "cells"
- Both bright and surprisingly dark ("cooked"?) clouds seen
- Implies powerful vertical transport processes and perhaps thermochemistry

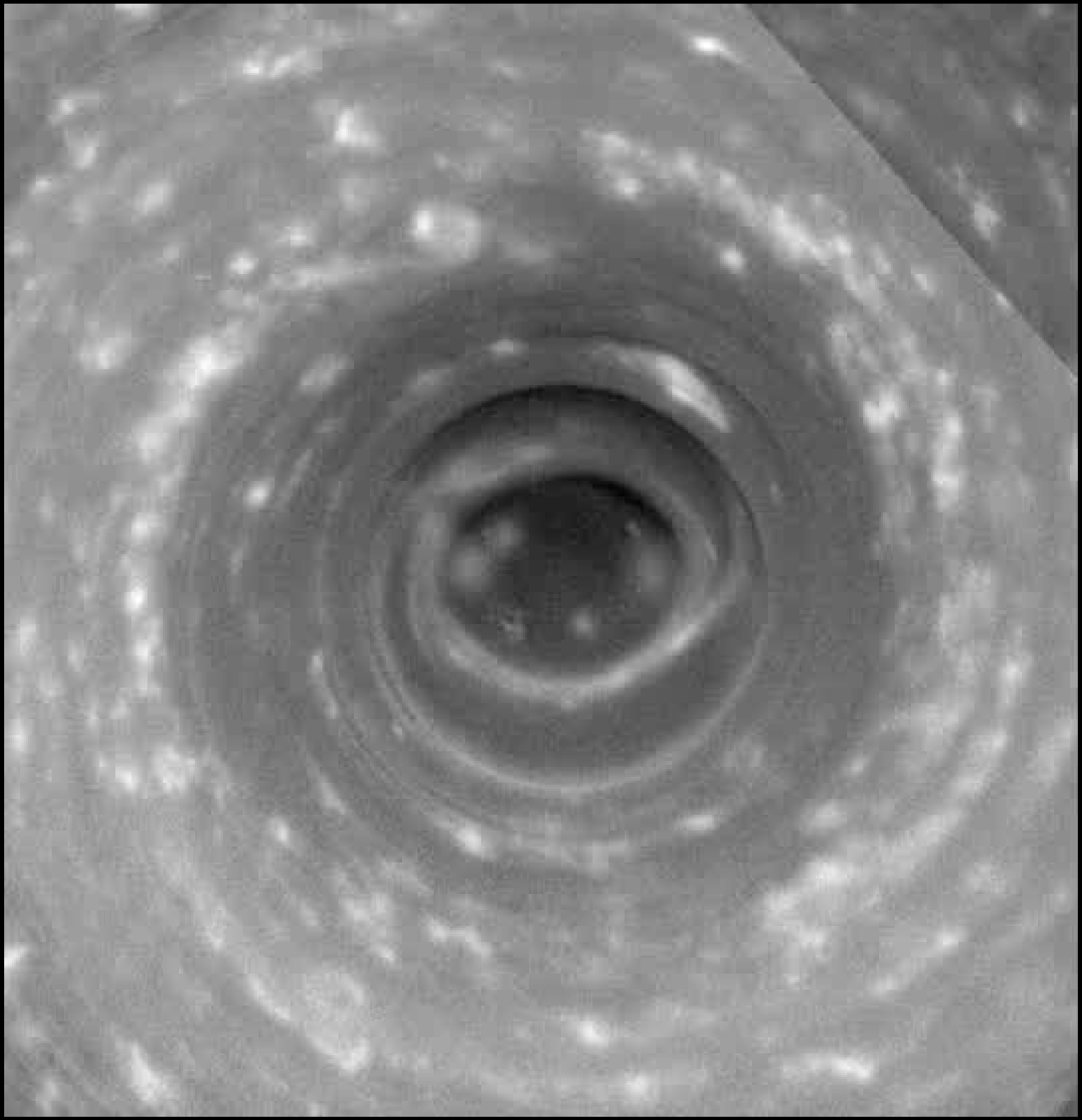
Saturn’s South Pole
Hurricane-Like Feature



5.0 μm Thermal Glow

- Warm, clear, deep center
- Rings of dark clouds and clearings
- Multitude of distinct, discrete cloud features, reaching deep into Saturn
- Implies strong vertical dynamics throughout polar region

South Polar Atmospheric Rotation Movie



Movie shows cloud movements in longitude-fixed system

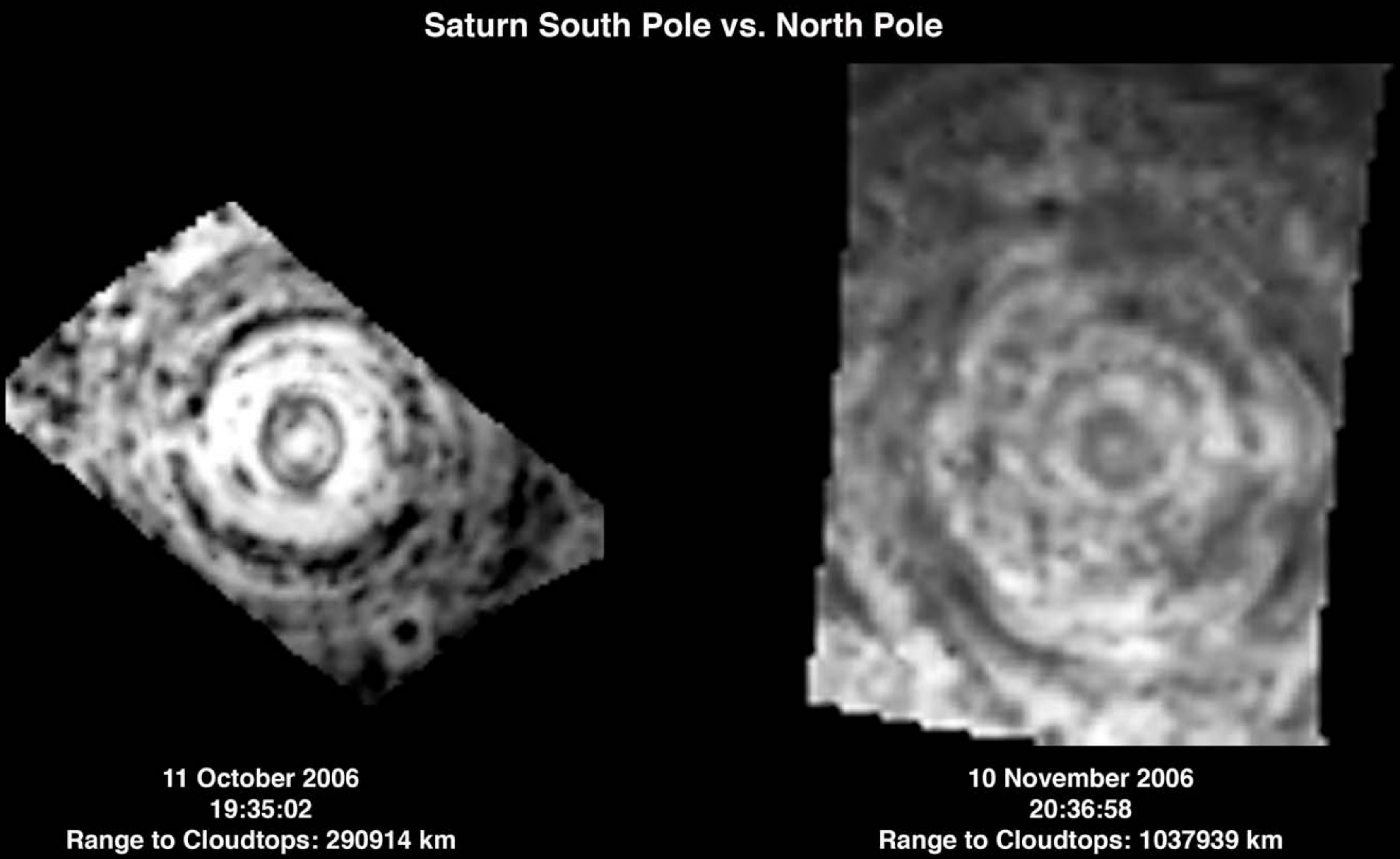
360 degrees W Longitude at top.
180 degrees W. Longitude at bottom

Hurricane-like winds of Saturn move faster near center of vortex, progressively slows at larger distances from center. Agrees with conservation of momentum ("spinning ice-skater" model)

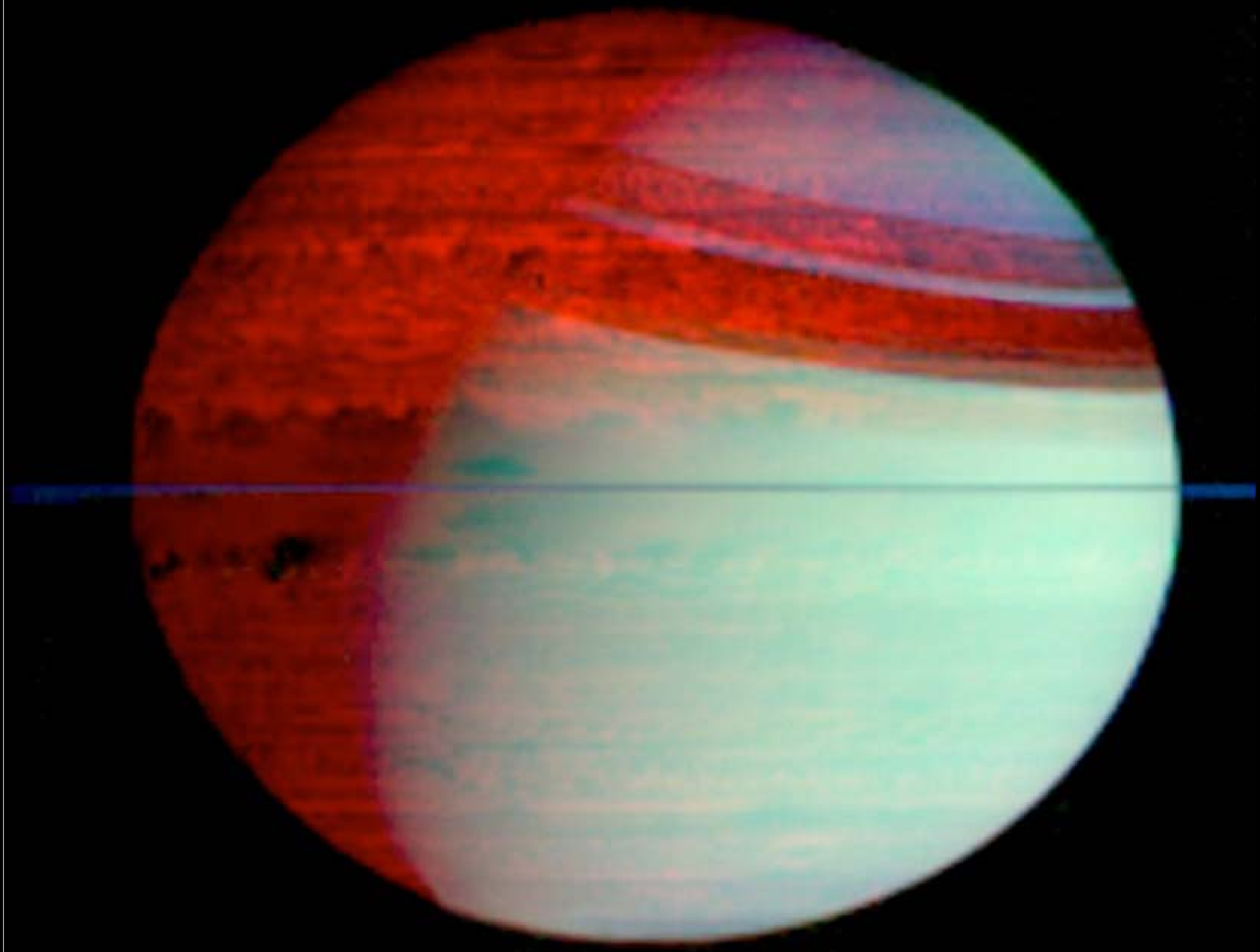
Two Towering walls of clouds revealed by shadows (Note shadows rotate counter-clockwise as the day progresses in this movie)

Cloud Walls tower 50 km (30 miles) above neighboring clouds

North Pole vs South Pole in Saturn’s 5-μm Glow



Saturn's Hemispherical Asymmetry

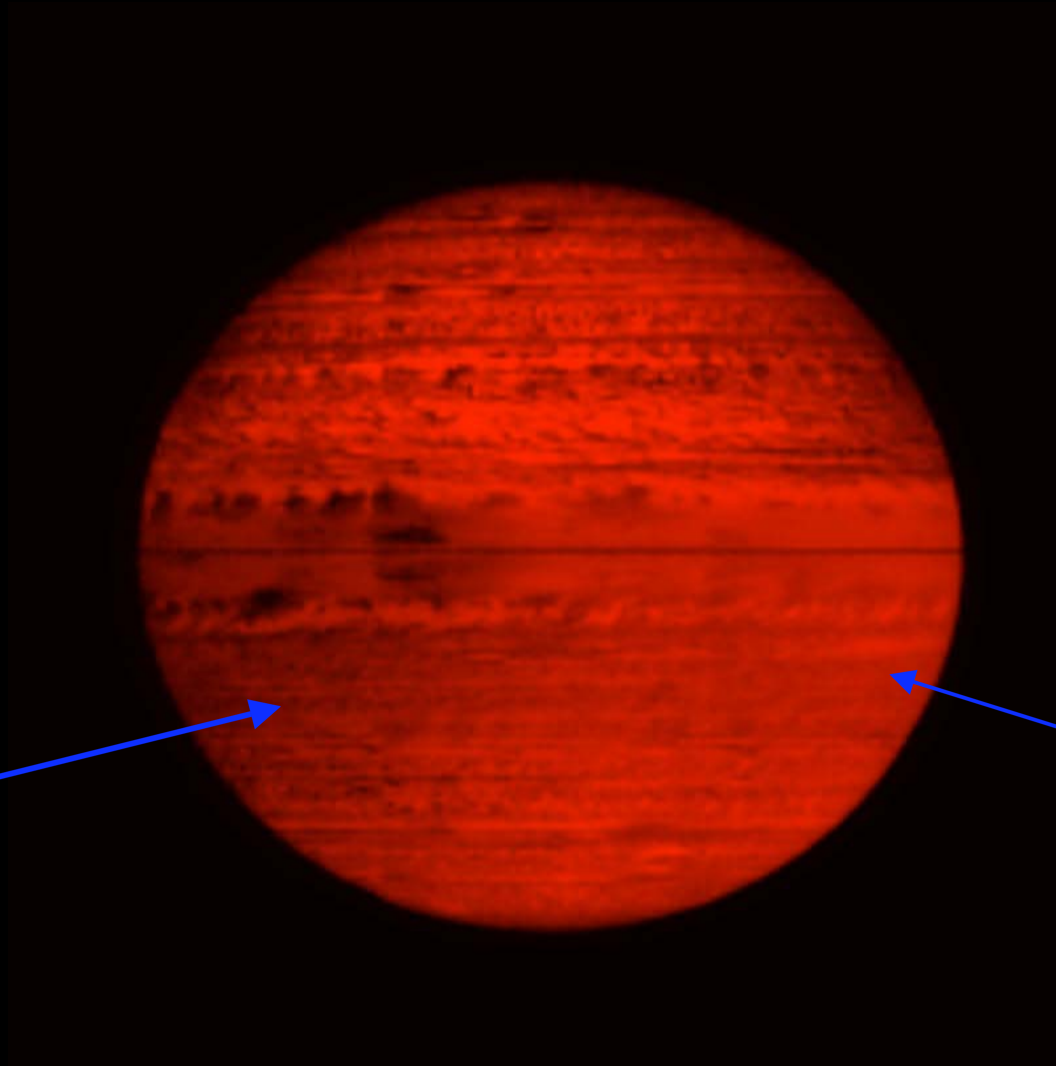


Northern and southern hemispheres have different brightnesses

Seen in both reflected sunlight and in thermal glow

In reflected sunlight: South brighter than north

Saturn at 5 um
Night vs Day



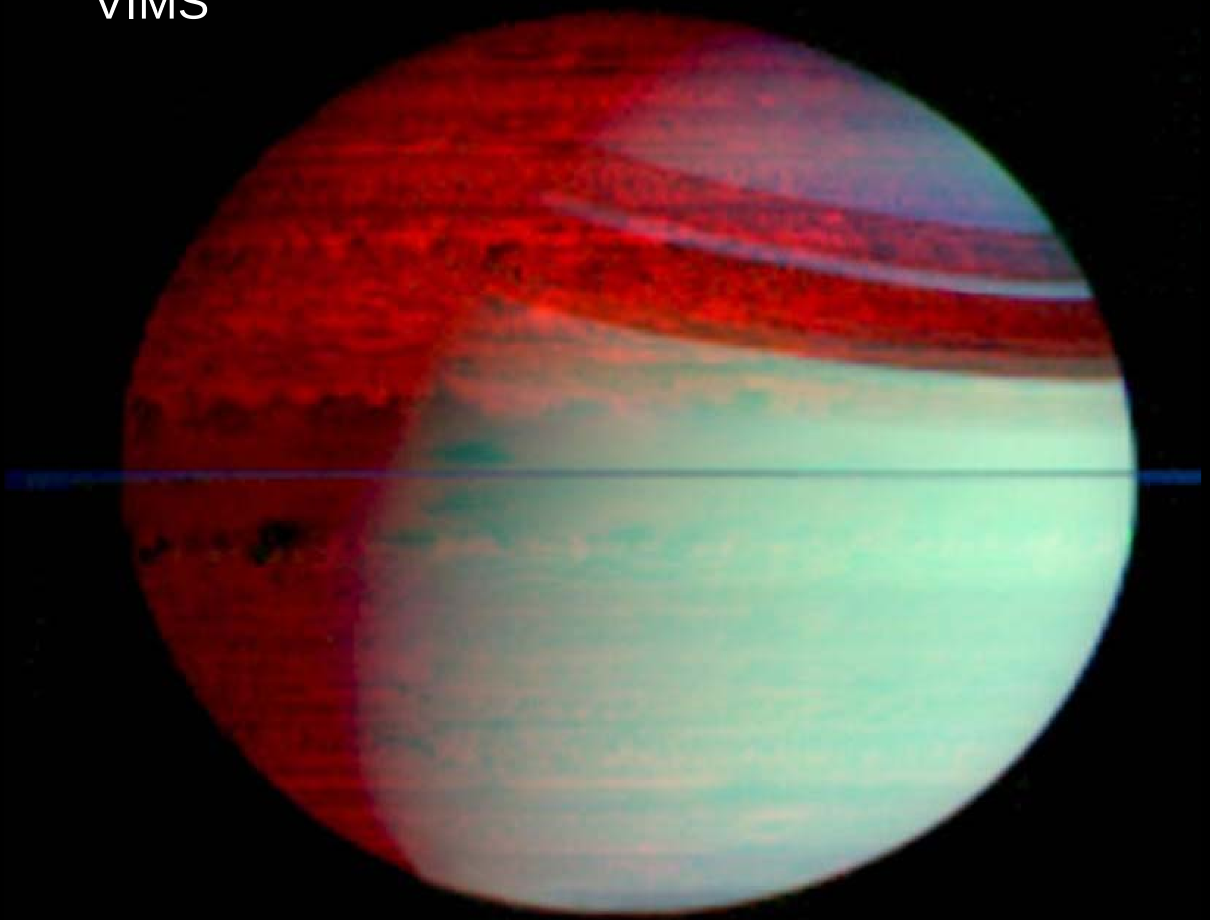
In thermal:
South brighter than
North in daylight,
dimmer in night glo

Nightside
Darker
Than North

Dayside
Brighter
Than North

Saturn's Hemispherical Asymmetry

VIMS



Explanation:

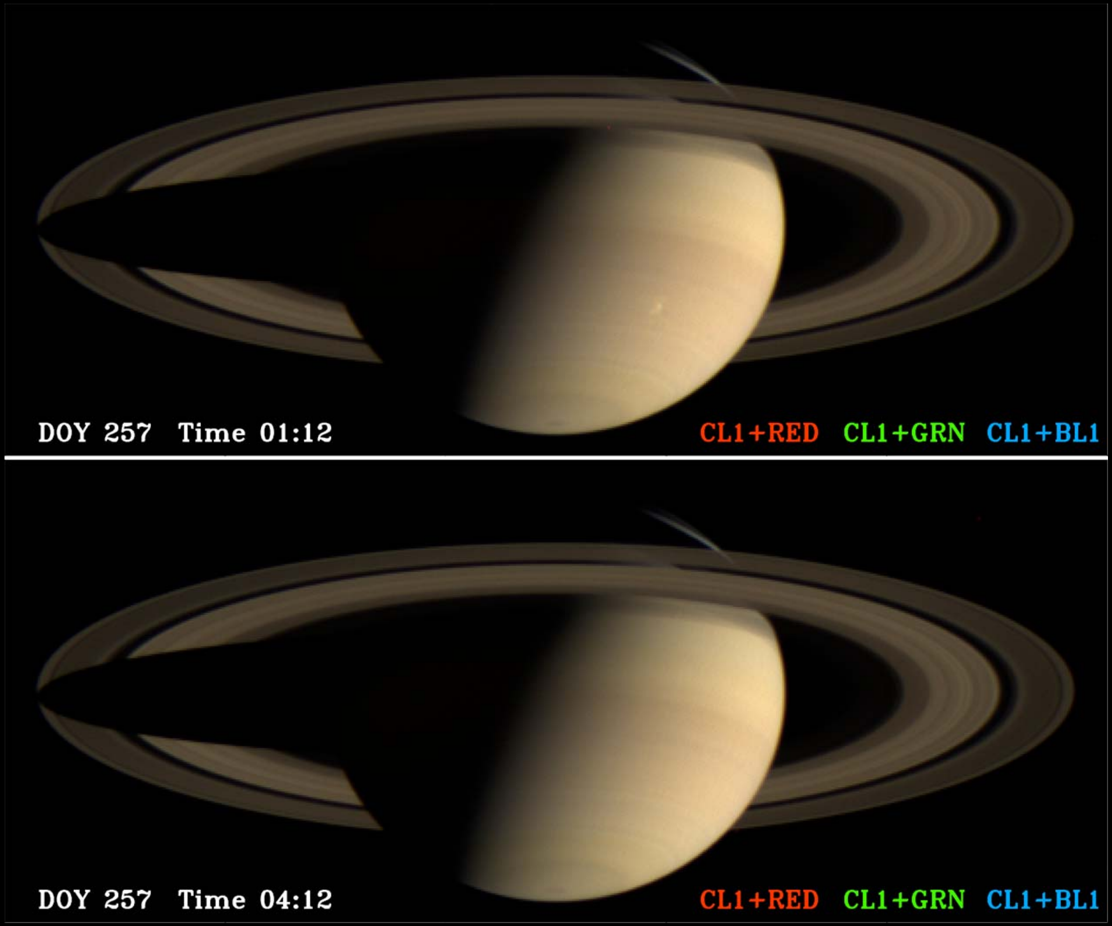
Upper tropospheric haze layer is about twice as thickin the south than in the north

Thicker haze layer reflects more sunlight, and
Also more effectively blocks Saturn's 5-µm glow.

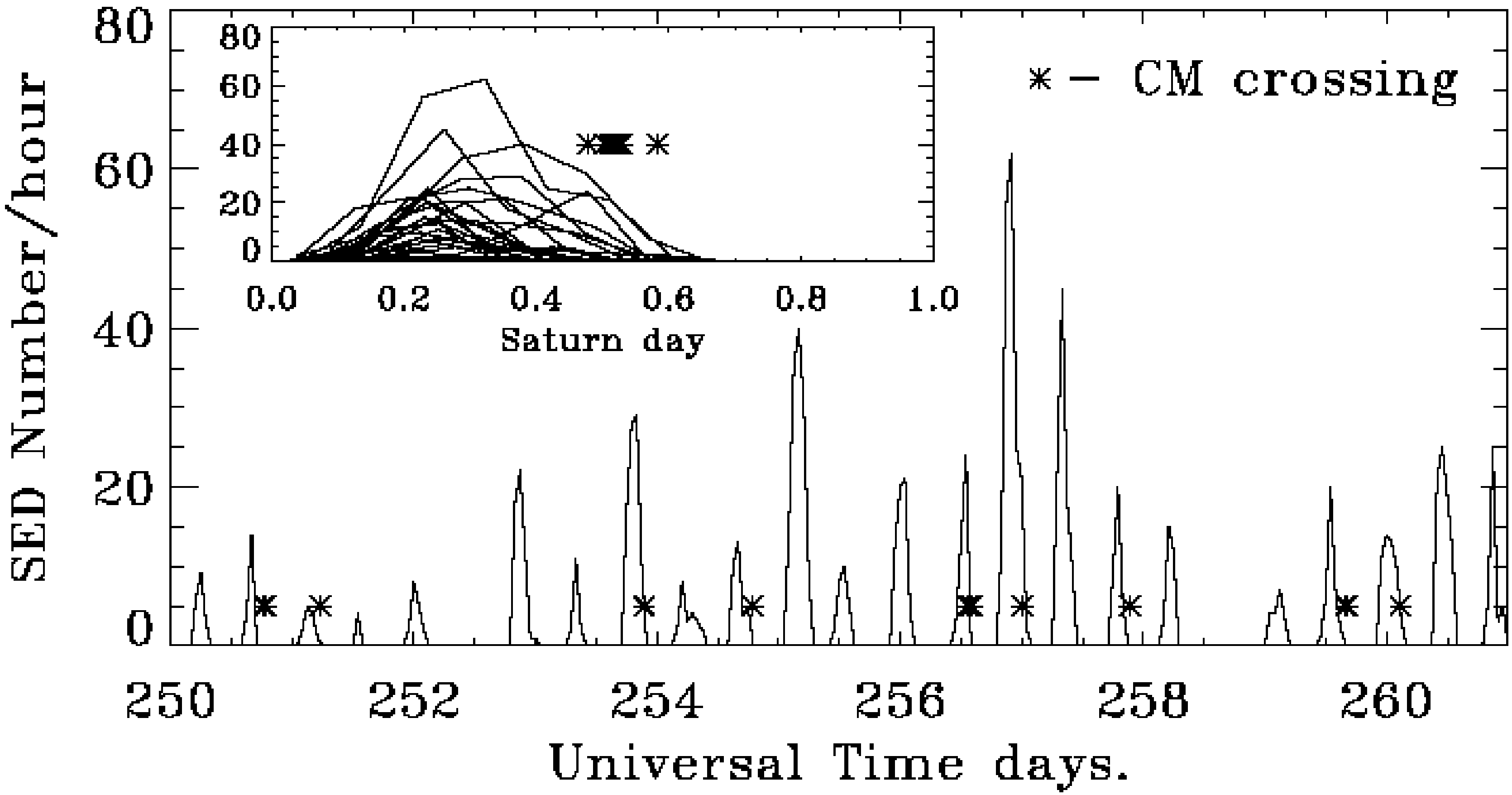
Haze particles are bigger in the south

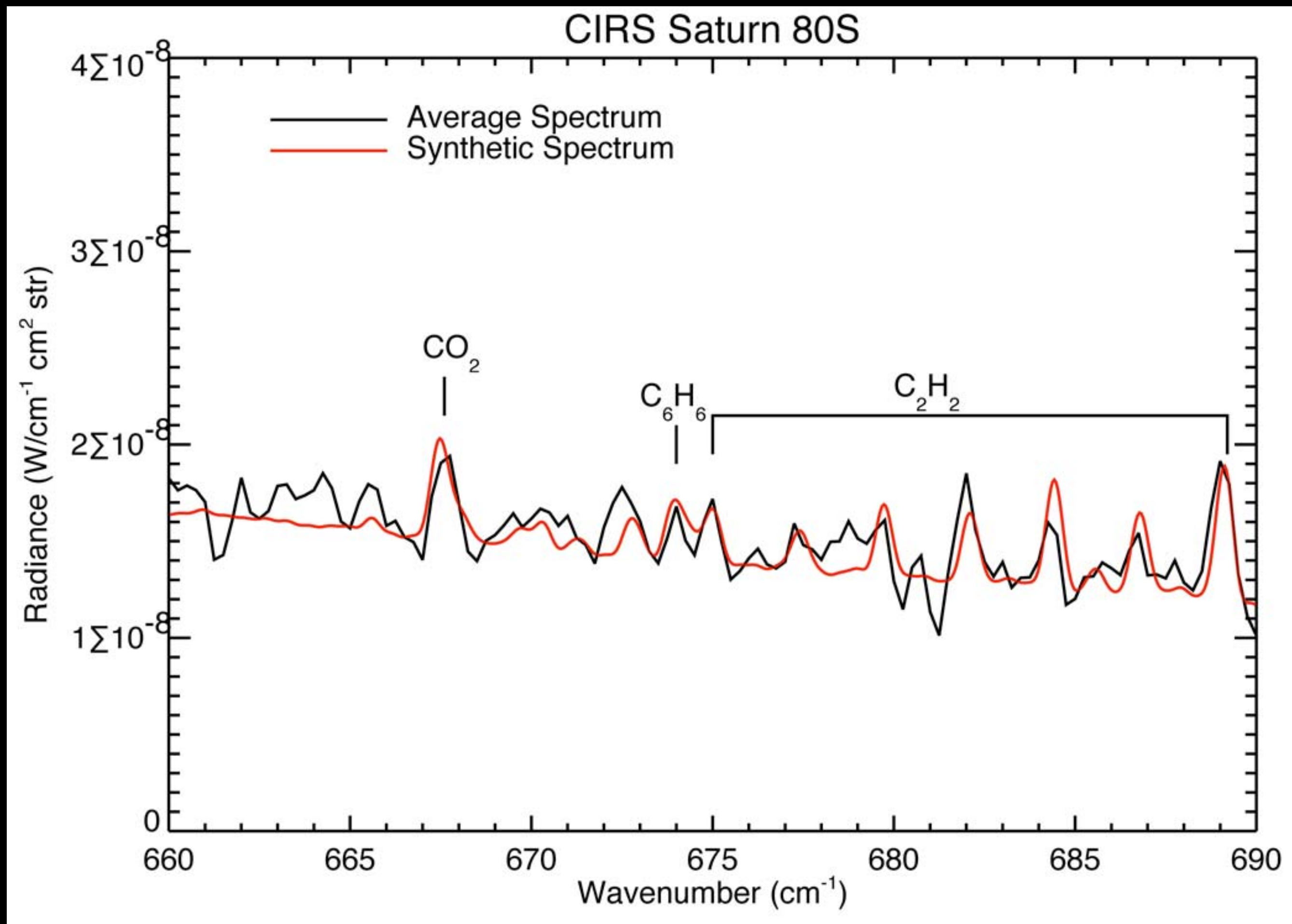
Seasonal effect?
Increased convective activity in summer?
Increased photochemical haze production in summer?

Lightning on Saturn observed by Cassini ISS and RPWS during 2004-2006.

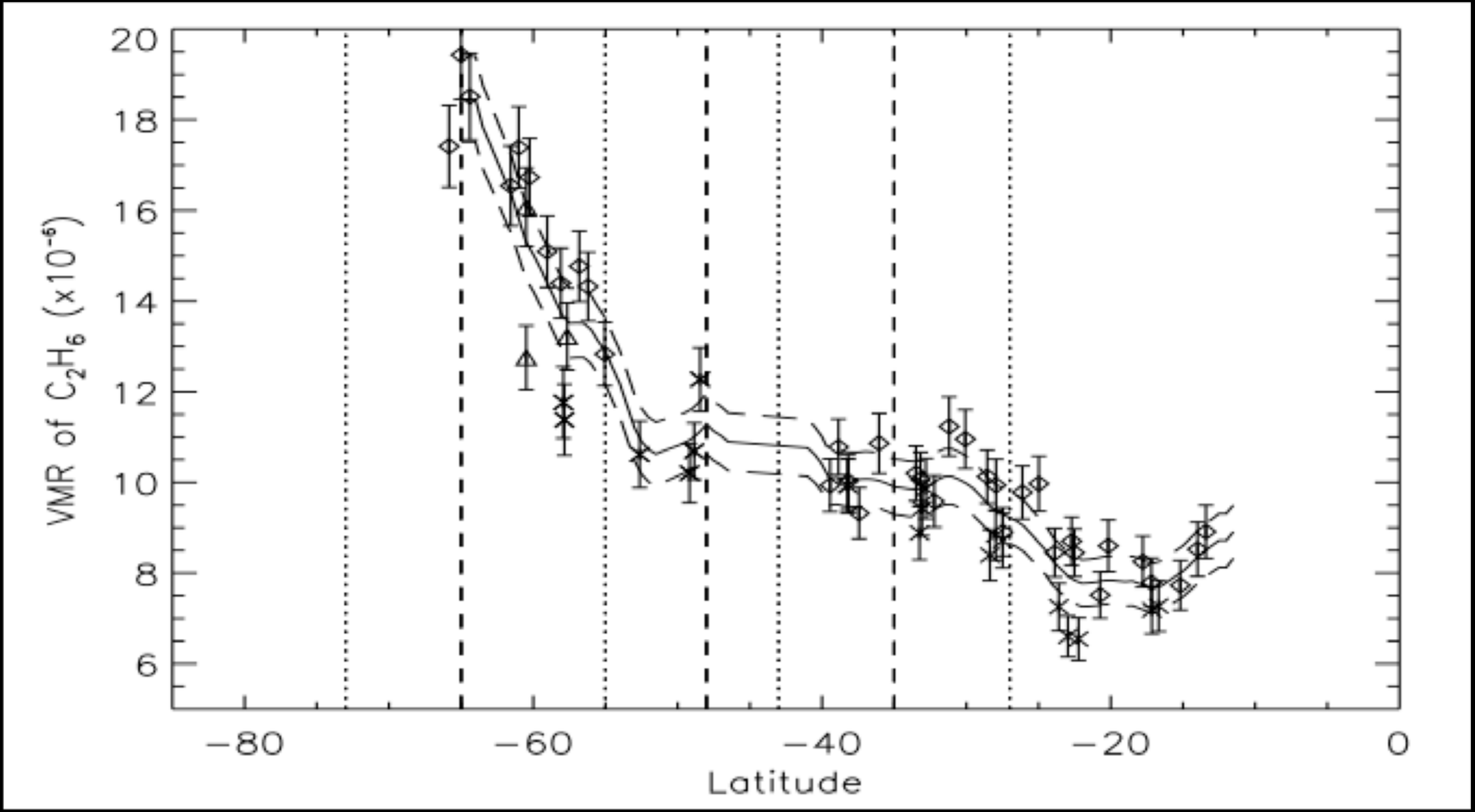


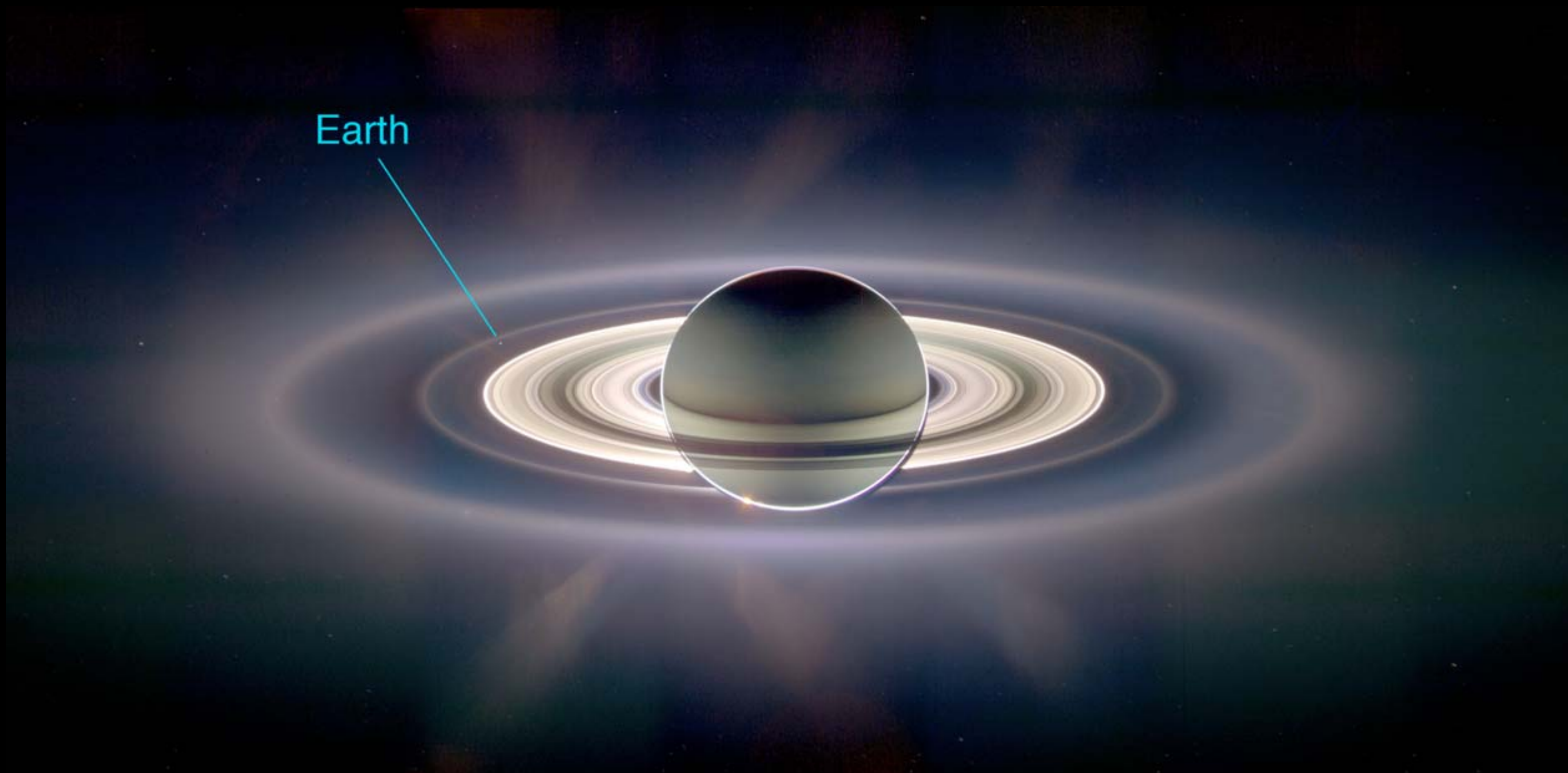
RPWS & ISS: Electrostatic discharges & storms




CIRS Saturn 80S
Average Spectrum
Synthetic Spectrum
CO_2
C_6H_6
C_2H_2
Radiance (W/cm^{-1} cm^2 str)
$4\Sigma 10^{-8}$
$3\Sigma 10^{-8}$
$2\Sigma 10^{-8}$
$1\Sigma 10^{-8}$
0
660
665
670
675
680
685
690
Wavenumber (cm^{-1})

Latitudinal Variation of Ethane




Earth

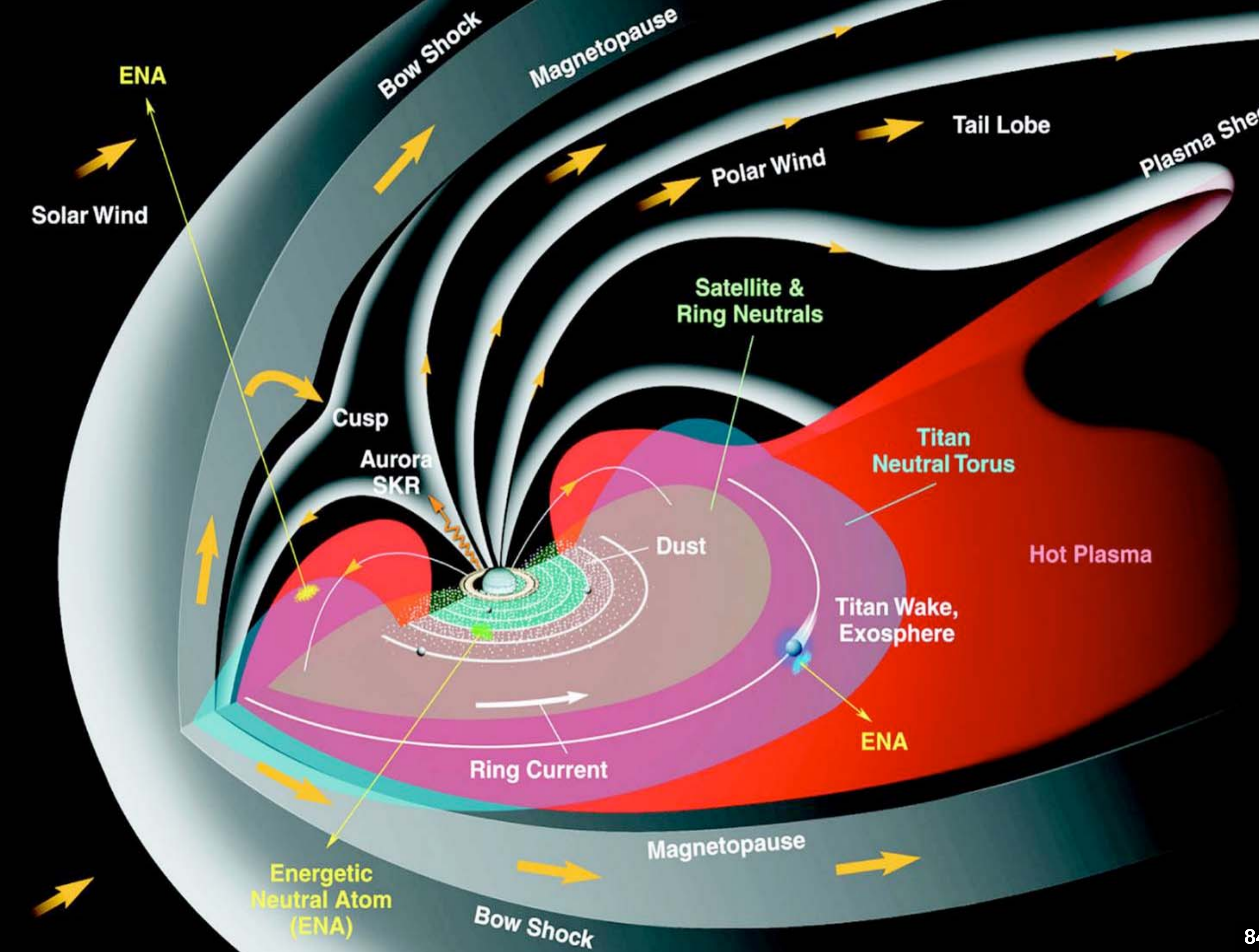
Magnetosphere

- The Magnetosphere is a giant magnetic bubble surrounding the planet Saturn.
- The source of the magnetic field is a highly conductive material (metallic hydrogen) inside the planet rotating very quickly (once every 10.8 hours).
- There is a very complex interaction between the icy satellites and rings of Saturn, the plasma trapped in the magnetic field, the neutral gases in the bubble, and the solar wind (a stream of ionized particles flowing from the Sun, which blows the magnetosphere into a blunt-nosed, long-tailed windsock).
- The icy moon Enceladus, with its strong emission of water into the magnetosphere at 4Rs, dominates the neutral and ionized gas populating the magnetosphere inside 10Rs, while Saturn's atmosphere and ionosphere also contribute in the outer regions.
- Typical constituents found in the system are O, H_2, H, OH, CH_4 , in both neutral and charged states, and from the solar wind, He^{++}.

Some Basic Facts

	Earth	Jupiter	Saturn
Radius	1 R_E=6378 km	1 R_J = 11.2 R_E	1 R_S = 9.45 R_E
Magnetic moment	M_E= 7.84×10^{15} T m^3	M_J = 20,000 M_E	M_S = 580 M_E
Equatorial surface field	B_E = 0.3 Gauss	B_J = 14.3 B_E	B_S = 0.7 B_E
Subsolar magnetopause distance	~ 10 R_E	~ 120 R_J ≈ 1350 R_E	~25 R_S ≈ 235 R_E
Rotation period	T_E ≈ 24 h	T_J ≈ 9.925 h	T_S ≈ 10.5 h
$a_{centrifugal}$/g @equator	3×10^{-3}	1.04	1.74
Ionospheric mass source rate	~2 kg/s	~10 kg/s	~10 kg/s
Satellite/ring mass source rate	~ 0 kg/s	~1,000 kg/s (Io)	~30 kg/s (rings) ~100 kg/s (Enceladus) ~20 kg/s (Titan)

Earth: Solar wind control, slow rotator
Jupiter: Io mass loading control, fast rotator
Saturn: Interplay between rotational control and multiple mass loading sources, fast rotator

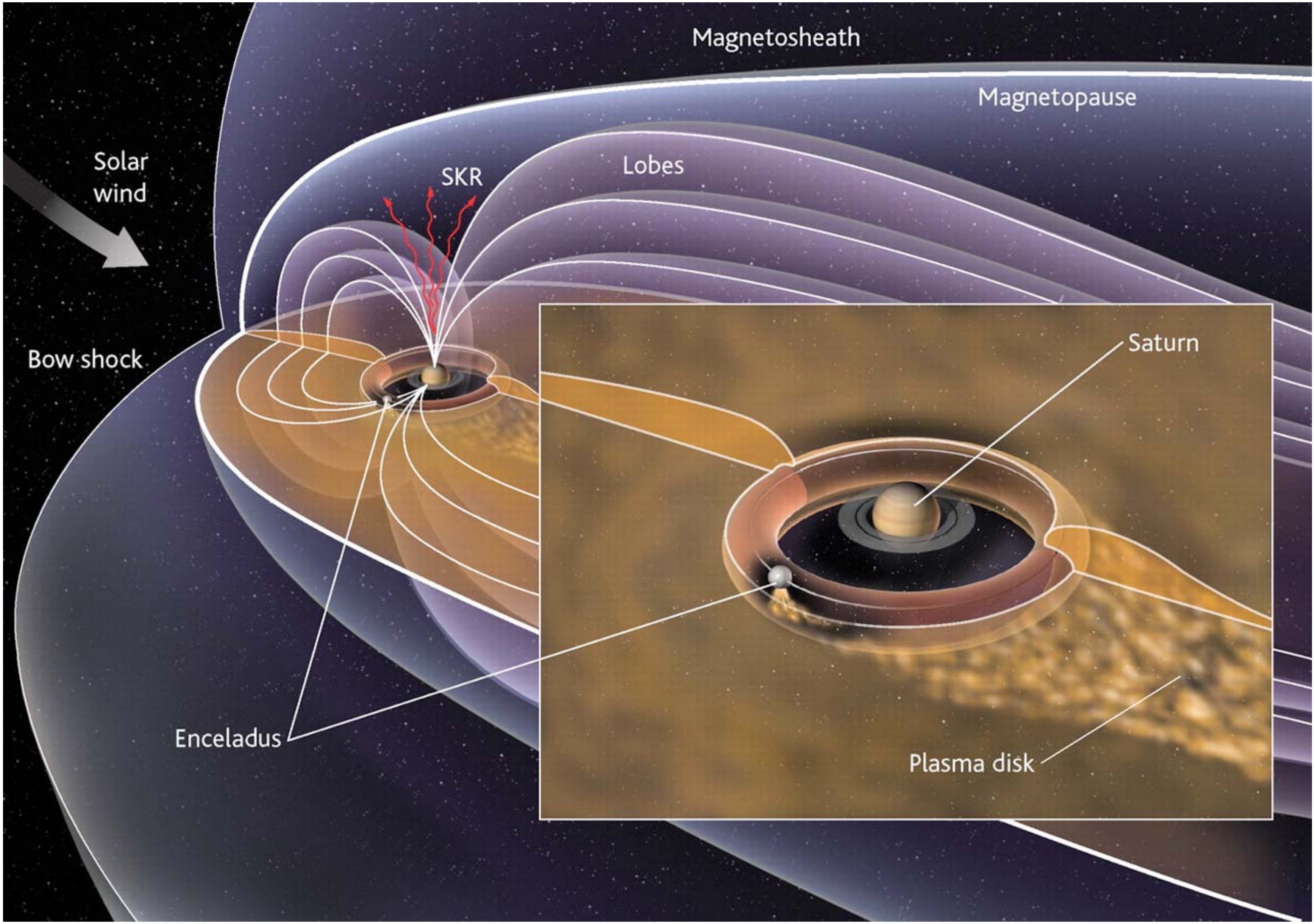

ENA
Bow Shock
Magnetopause
Tail Lobe
Plasma Sheet
Polar Wind
Solar Wind
Satellite &
Ring Neutrals
Cusp
Aurora
SKR
Titan
Neutral Torus
Dust
Hot Plasma
Titan Wake,
Exosphere
ENA
Ring Current
Magnetopause
Energetic
Neutral Atom
(ENA)
Bow Shock

Selected 3rd Year Discoveries

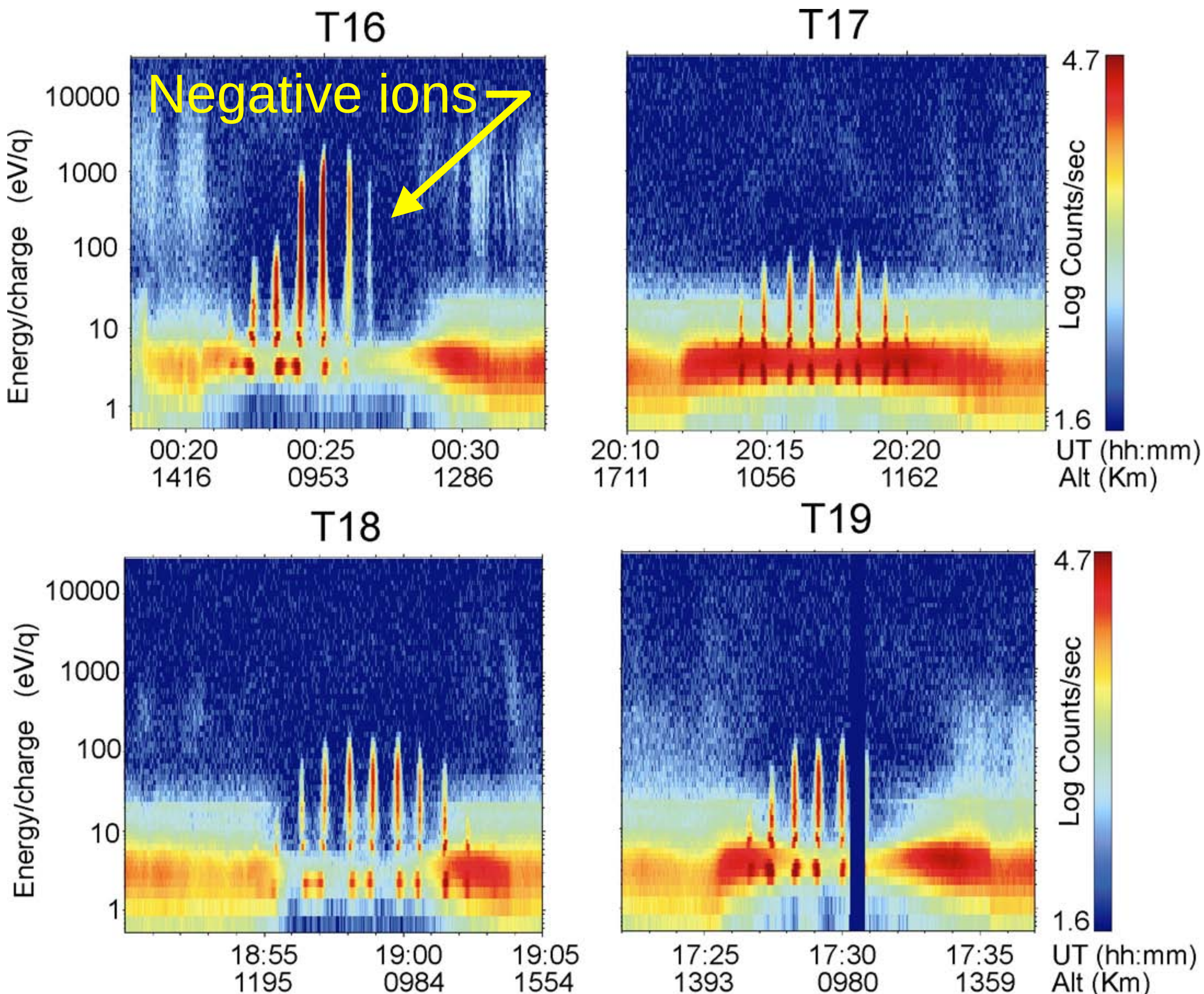
- Water/ice geysers on Enceladus fill the magnetosphere with dust and neutrals, mass-loading the inner plasma sheet with water group ions, making it unstable to the interchange instability
- Positive and negative heavy ions were discovered in Titan's upper atmosphere, just below the homopause
- Field-aligned flows were discovered along auroral magnetic field lines
- The heavily loaded inner plasma sheet slows the rotation of the magnetic field by a variable amount resulting in a variable radio rotation rate

Magnetospheric Plasma Sources and Sinks

- Enceladus is the primary source
  - First clues from deflection in the magnetic field
  - In situ measurements of plume
    - INMS (mostly water vapor)
    - CDA (micron-sized dust particles)
  - Charge exchange appears to be the primary ionization mechanism; rates are slow enough that pickup occurs throughout neutral torus.
- Nitrogen from Titan is a minor constituent – likely removed by proximity to magnetopause and convection down the tail
- Certainly, there are other plasma sources
  - Other icy satellites
  - Rings
  - Saturn’s Ionosphere
- Primary loss mechanism is by interchange instability; heavily-loaded flux tubes move to the outer magnetosphere by centrifugal force and lost down the magnetotail.

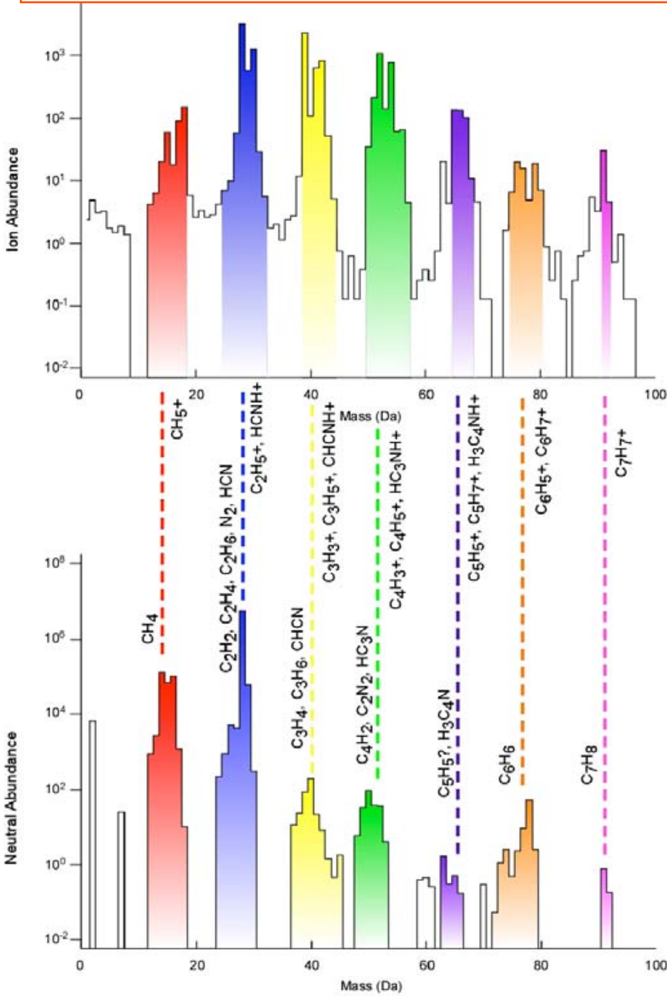

Magnetosheath
Magnetopause
Solar wind
SKR
Lobes
Saturn
Bow shock
Enceladus
Plasma disk

CAPS/ELS Discovered Heavy Negative Ions Below Titan's Homopause

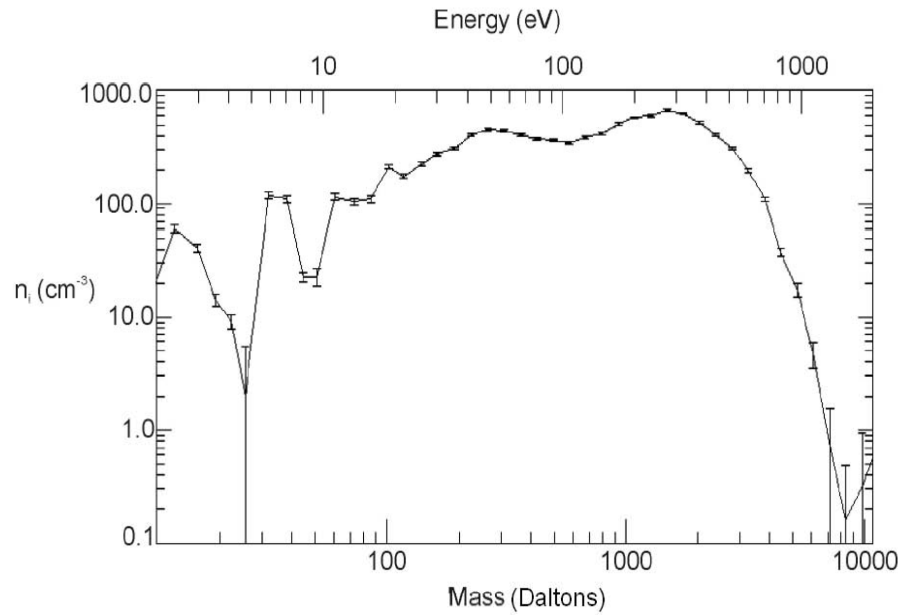


INMS & CAPS Discovered Complex Heavy Neutrals and Ions

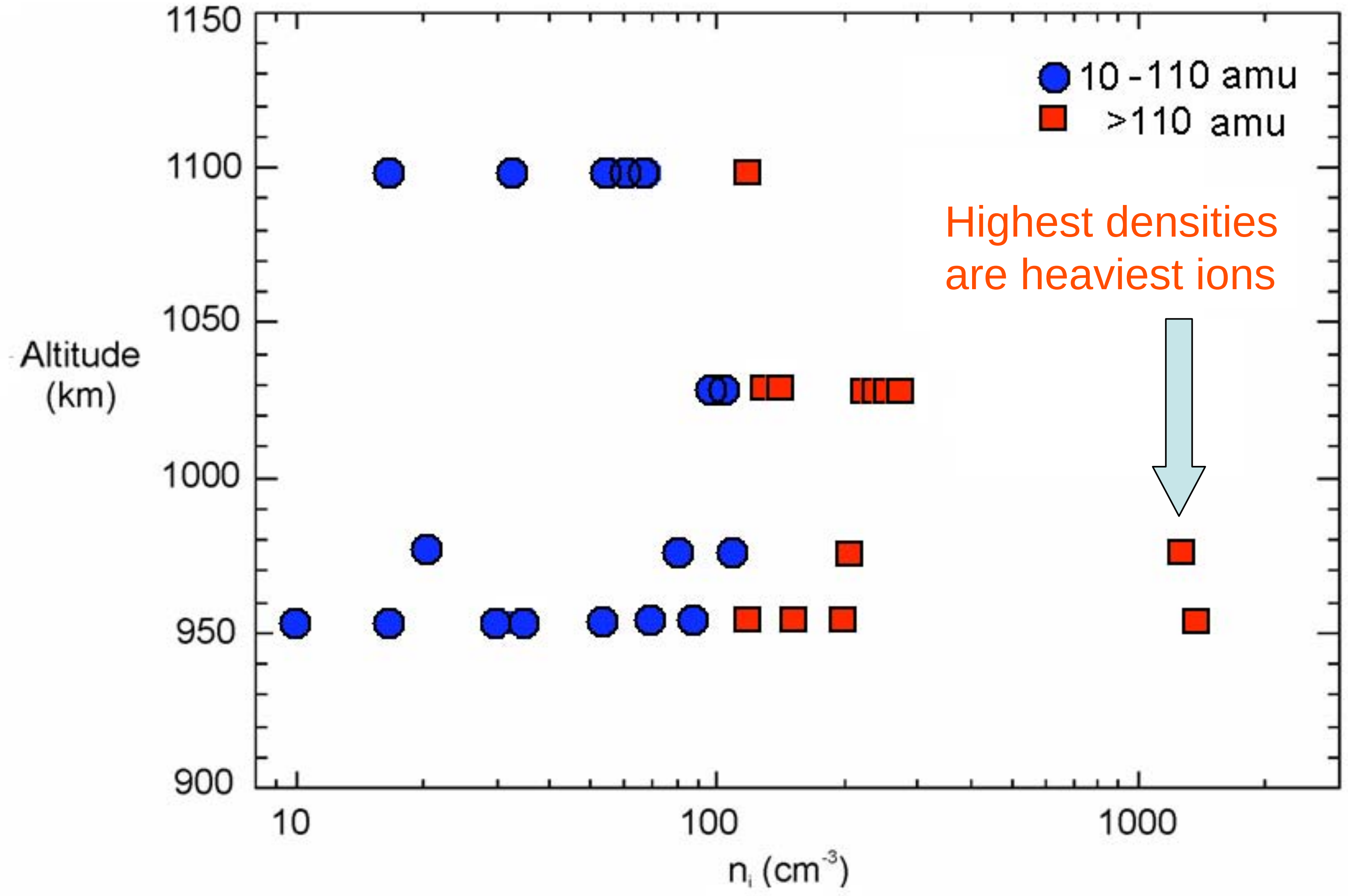
Ion-neutral organic chemistry builds heavy positive ions



Heavy negative ions are the result



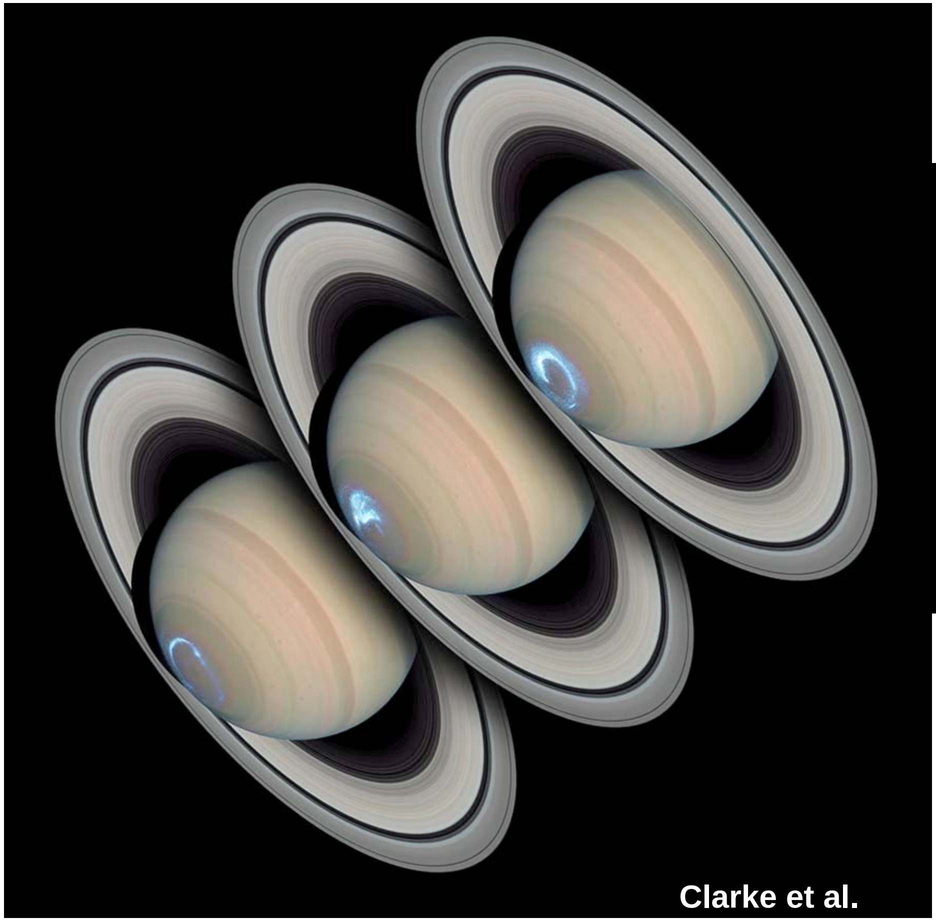
What Holds Up the Heavy Ions at ~1000 km?

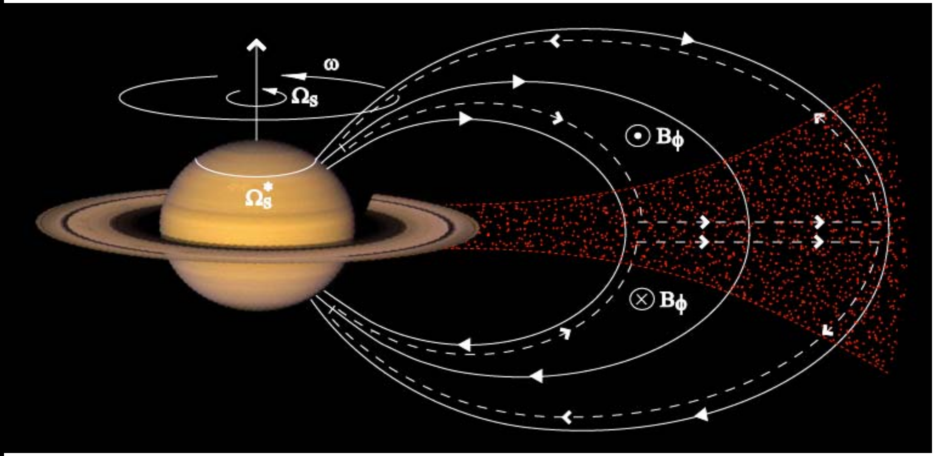


Negative Ions—Open Questions

- How do we make negative ions?
- What keeps them “afloat” in the atmosphere?
- What are the current carriers when the negative charges are heavy ions?
- Where do the ions go?—Do they contribute to Titan’s haze layers?

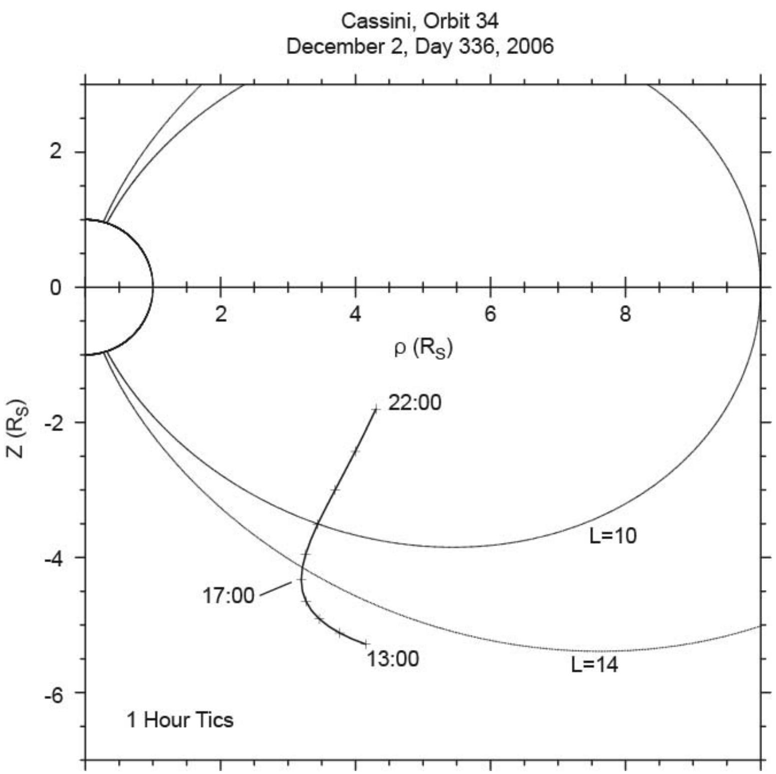
Aurora

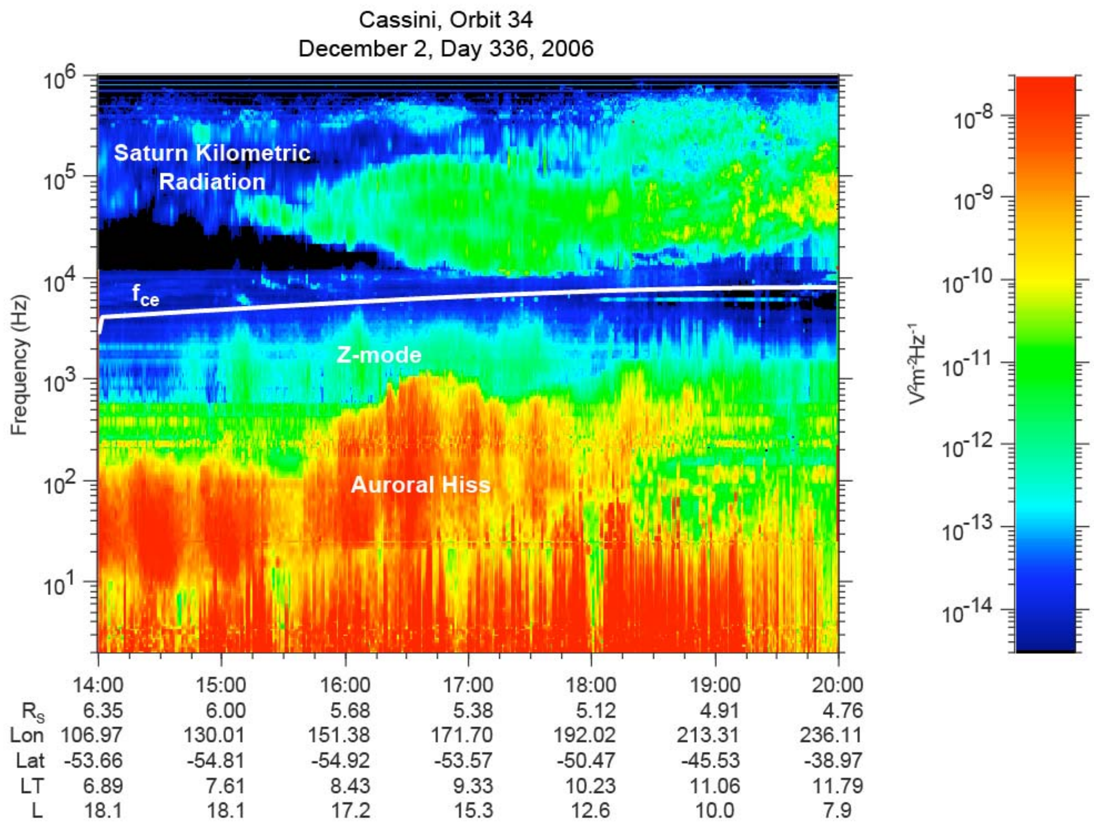




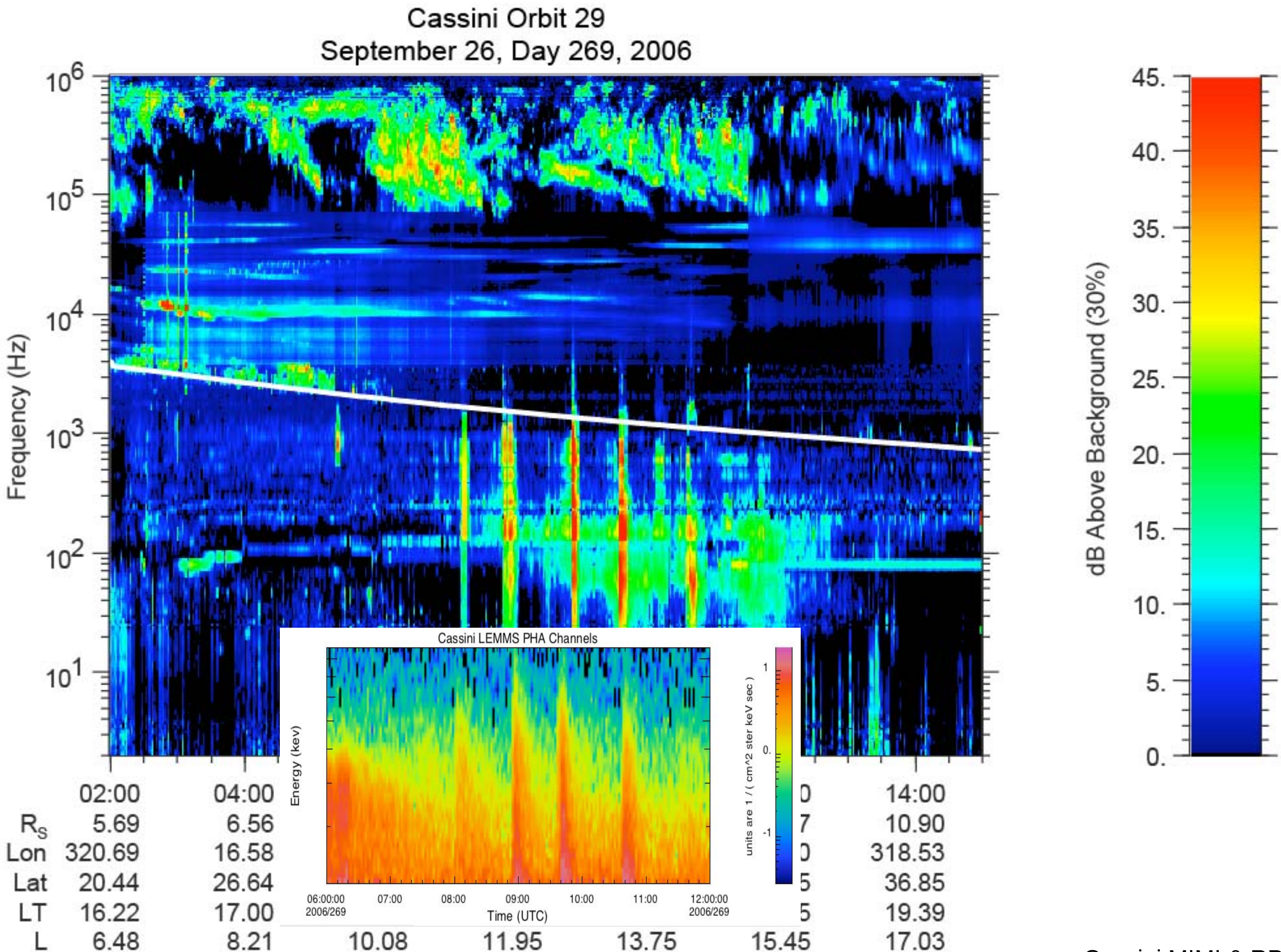
Field-aligned currents associated with precipitating particle fluxes are responsible for the aurora.
The MAPS instruments (CAPS, MAG, MIMI, RPWS) did find these precipitating beams.

Auroral Field Lines



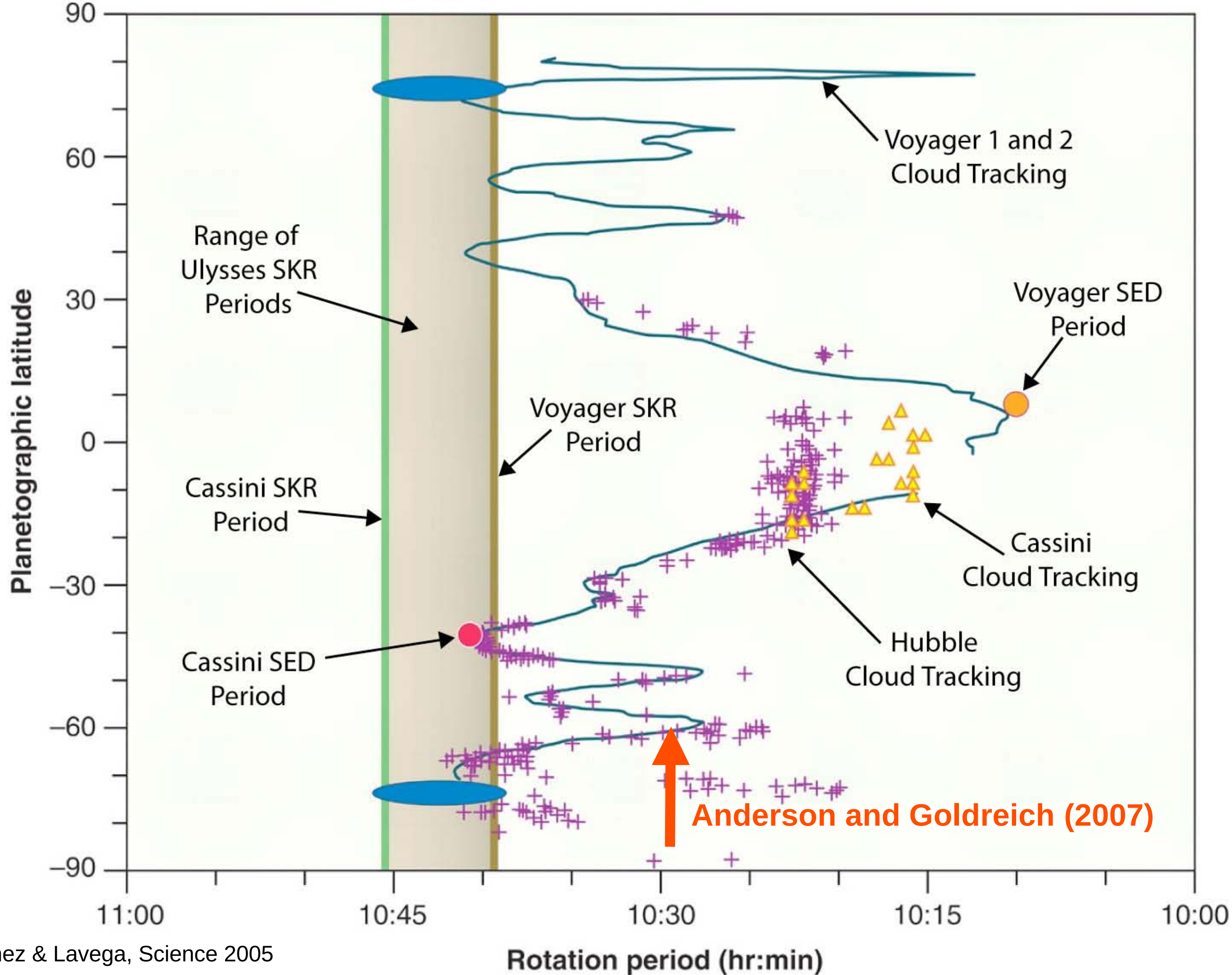


Cassini RPWS



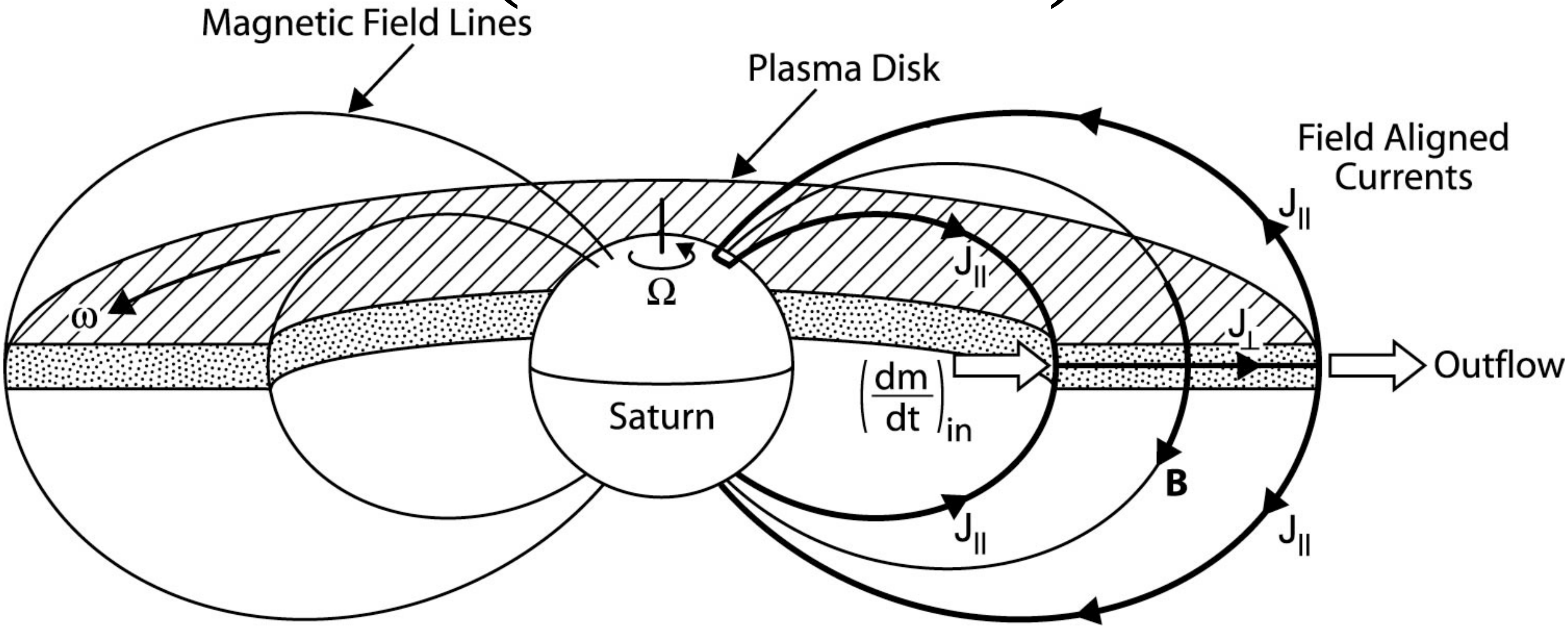
Cassini MIMI & RPWS

Various Measurements of Saturn's Rotation Period



after Sanchez & Lavega, Science 2005

The Rotational Slippage Model (Gurnett et al.)

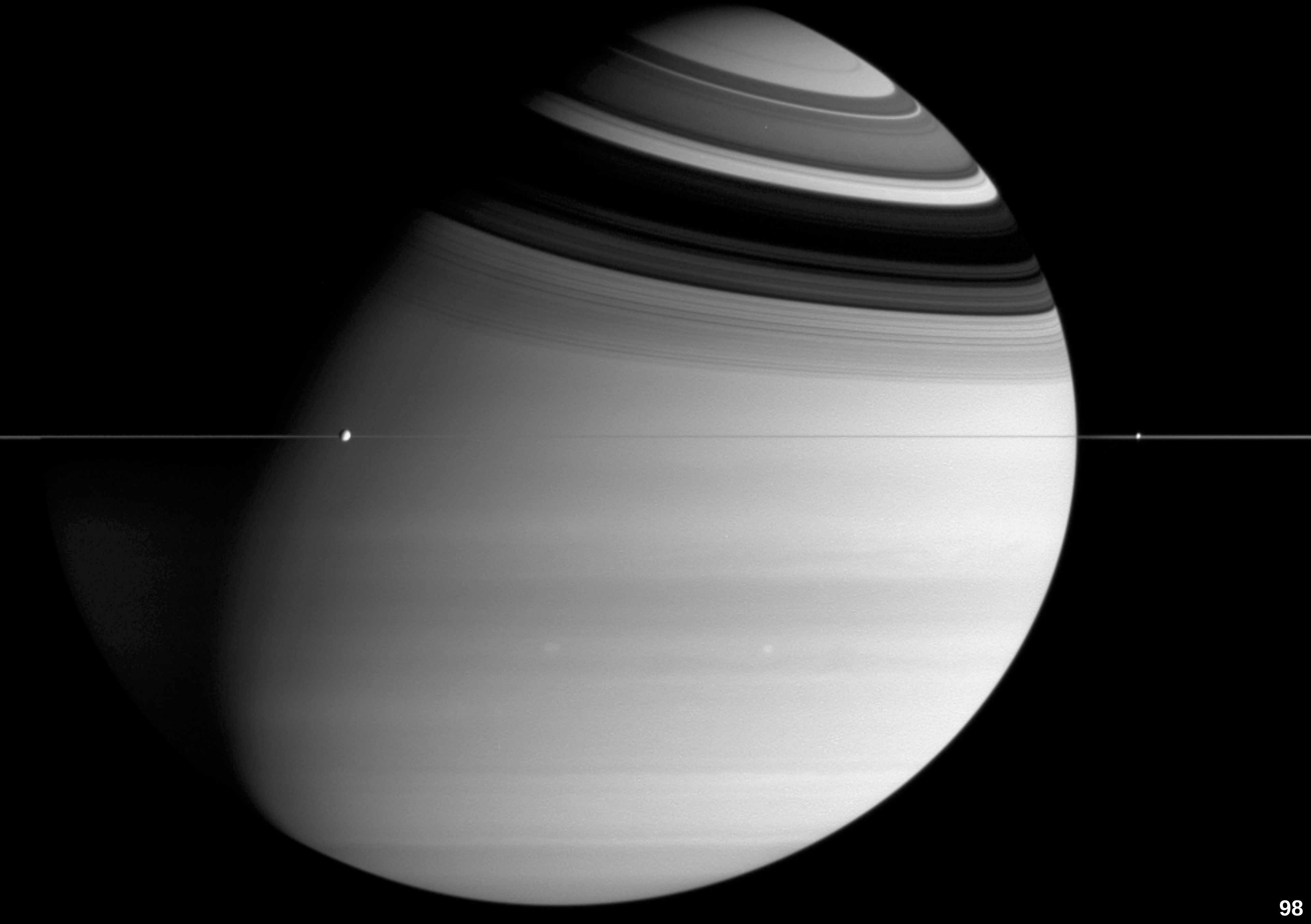


- Hypothesis: the SKR rotation period is determined by a variable slippage of the magnetosphere relative to Saturn's upper atmosphere.
- Possible reason: mass loading from the Enceladus gas torus.

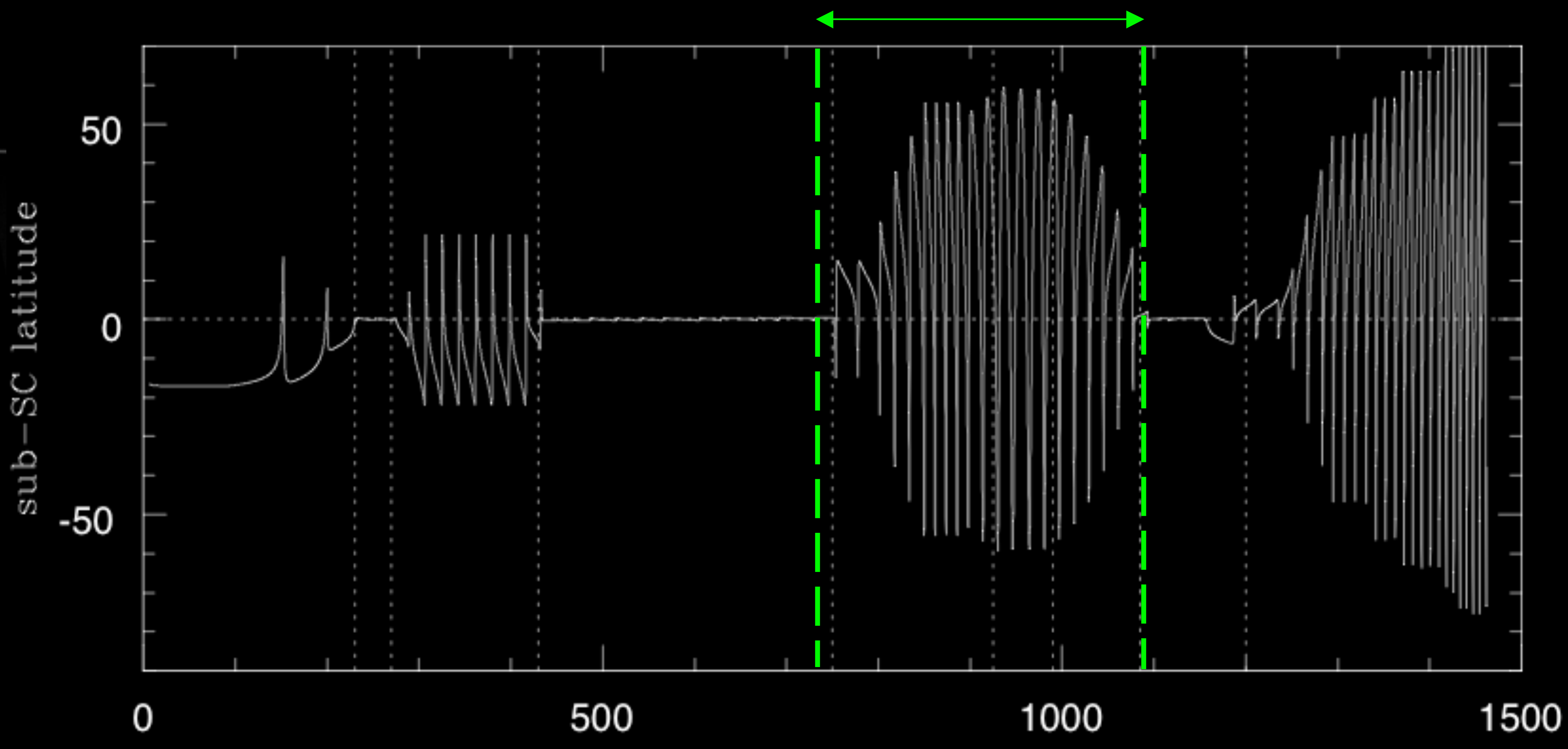
Rings

- The rings of Saturn consist of billions and billions (☺) of tiny ring particles all orbiting Saturn separately.
- The particles closer to Saturn orbit faster (like on a race track).
- Ring particles have sizes between cm and 10 meters (or so).
- The rings consist largely of water ice mixed with smaller amounts of rocky material.
- The macro structure of the rings is dominated by the interactions of the ring particles with the icy satellites and embedded moons.

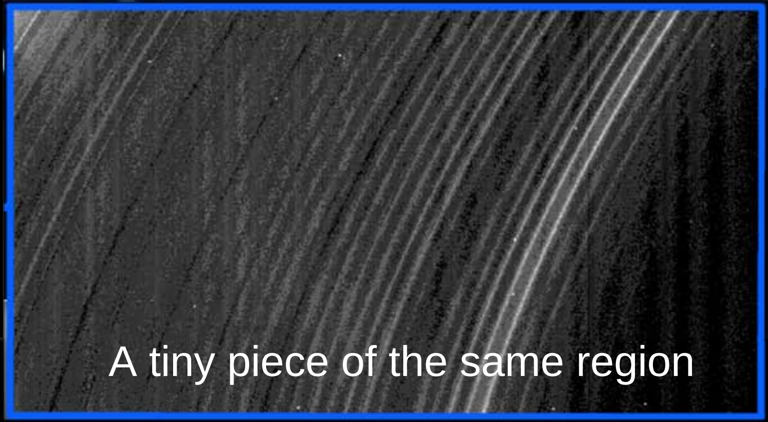
Cassini's view of the rings in year 2



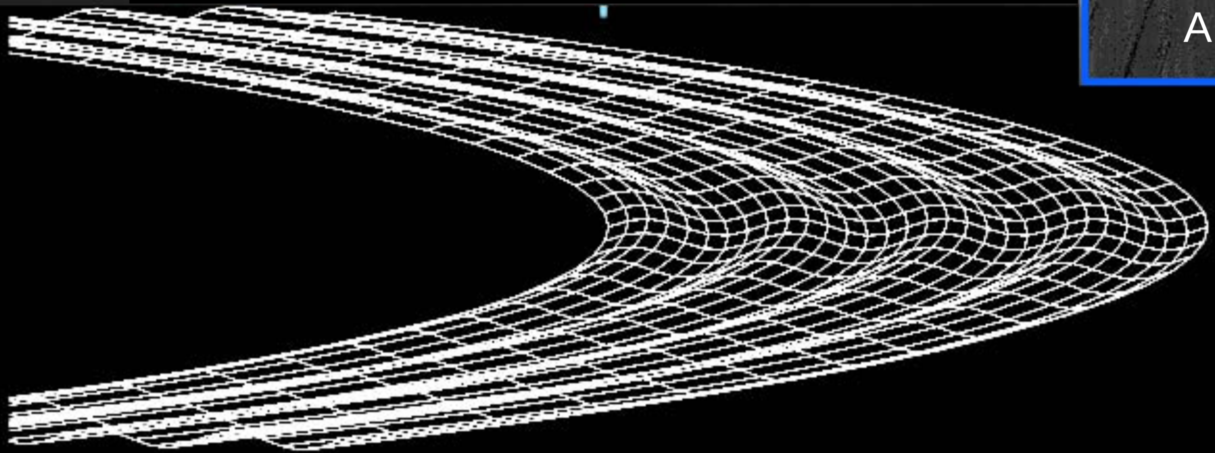
Doing better in year 3!



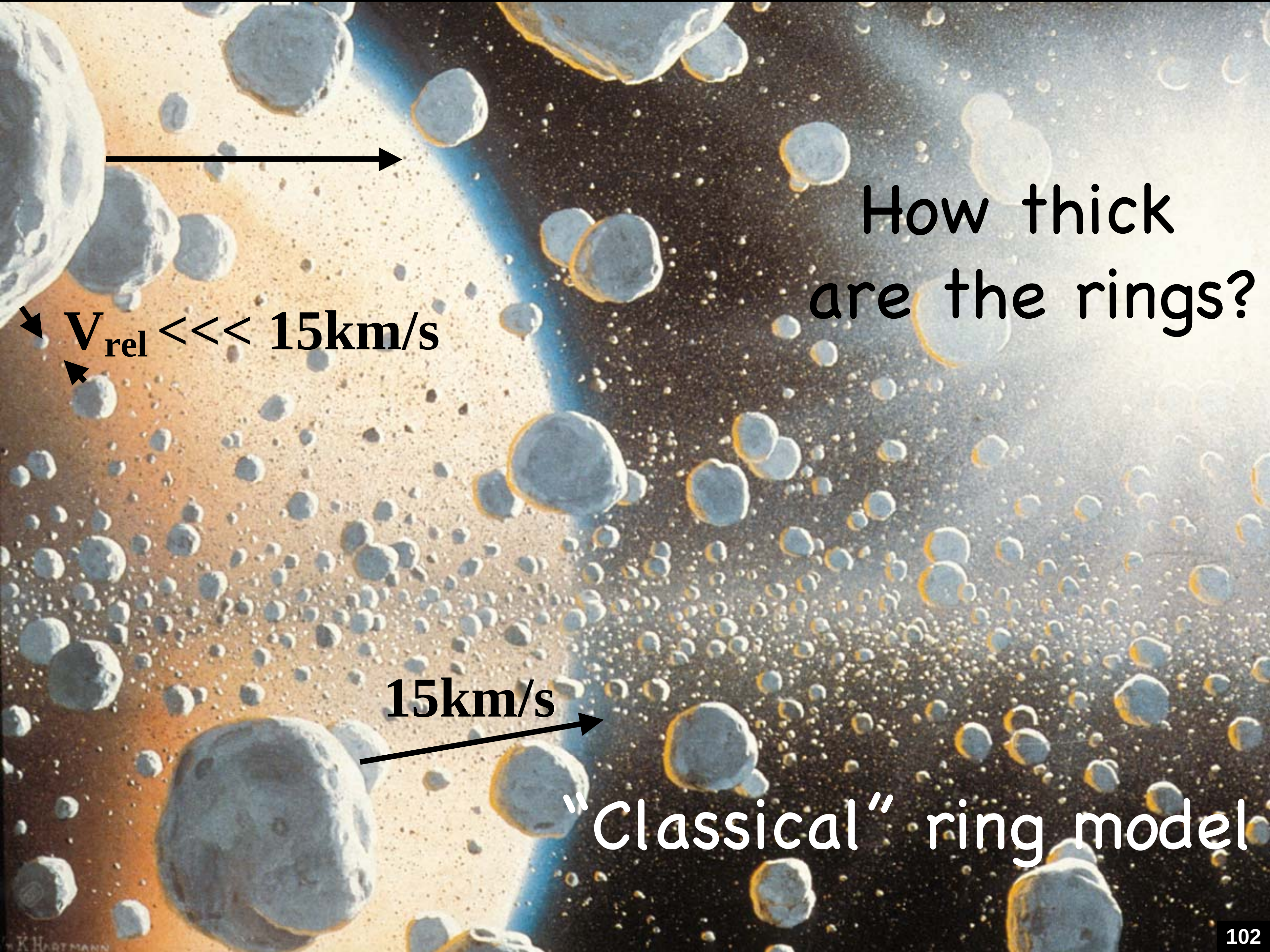
The warped D ring: recent impact?



A tiny piece of the same region

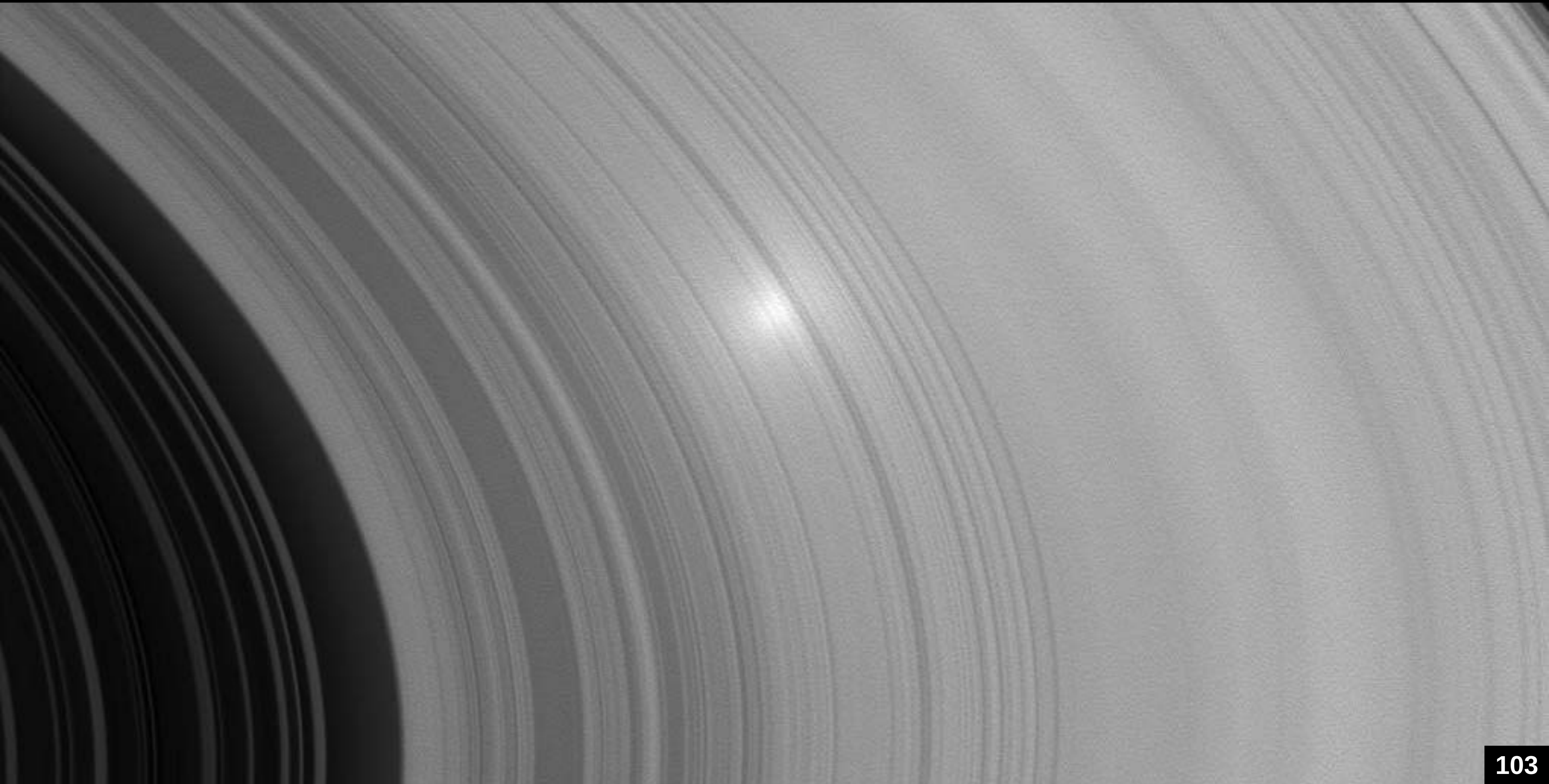


The ISS team released a dramatic movie showing the rings as they appeared to Cassini while it sped from south to north, rapidly crossing the ring plane. The rings are only tens of meters thick locally, nearly vanishing when Cassini is exactly in the ring plane.



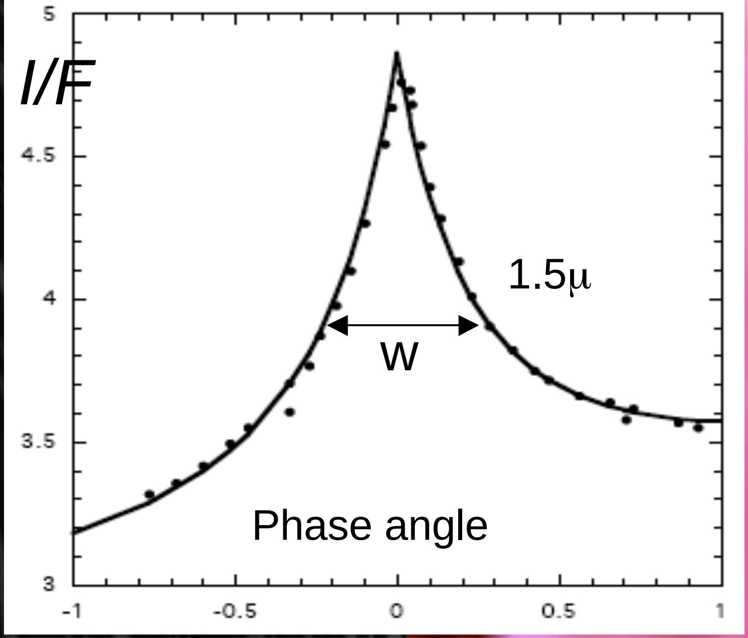
V_{rel} <<< 15km/s
How thick
are the rings?
15km/s
"Classical" ring model

The Opposition Effect:
Intense backscatter from shadow hiding or from particle surfaces ???

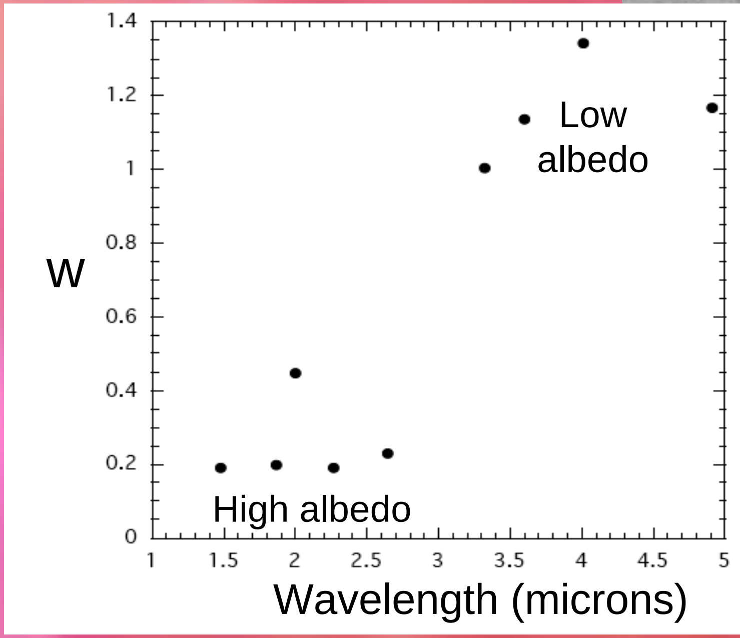


The Opposition Effect:
Coherent backscatter from particle surfaces;
No support for a many-particle thick layer

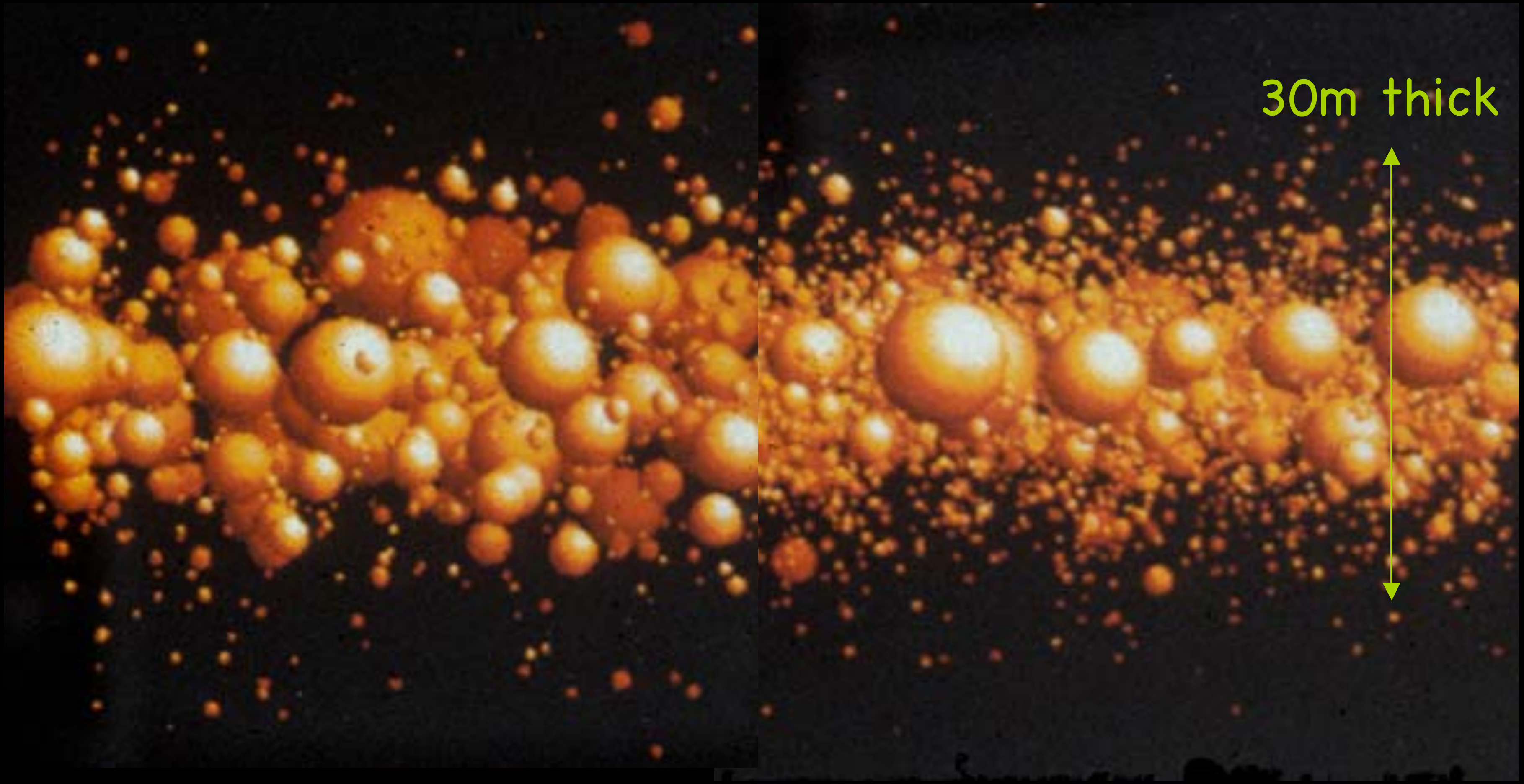
VIMS data and analysis



Nelson et al 2006;
Hapke et al 2006 LPSC

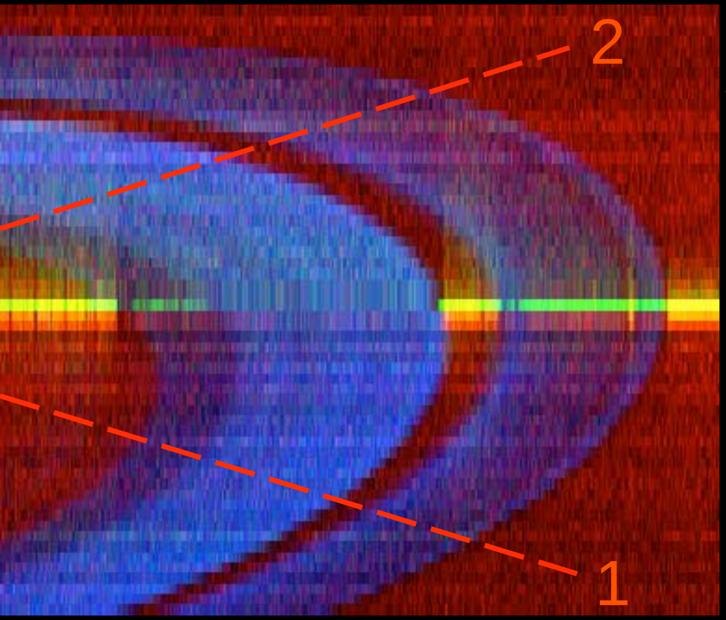


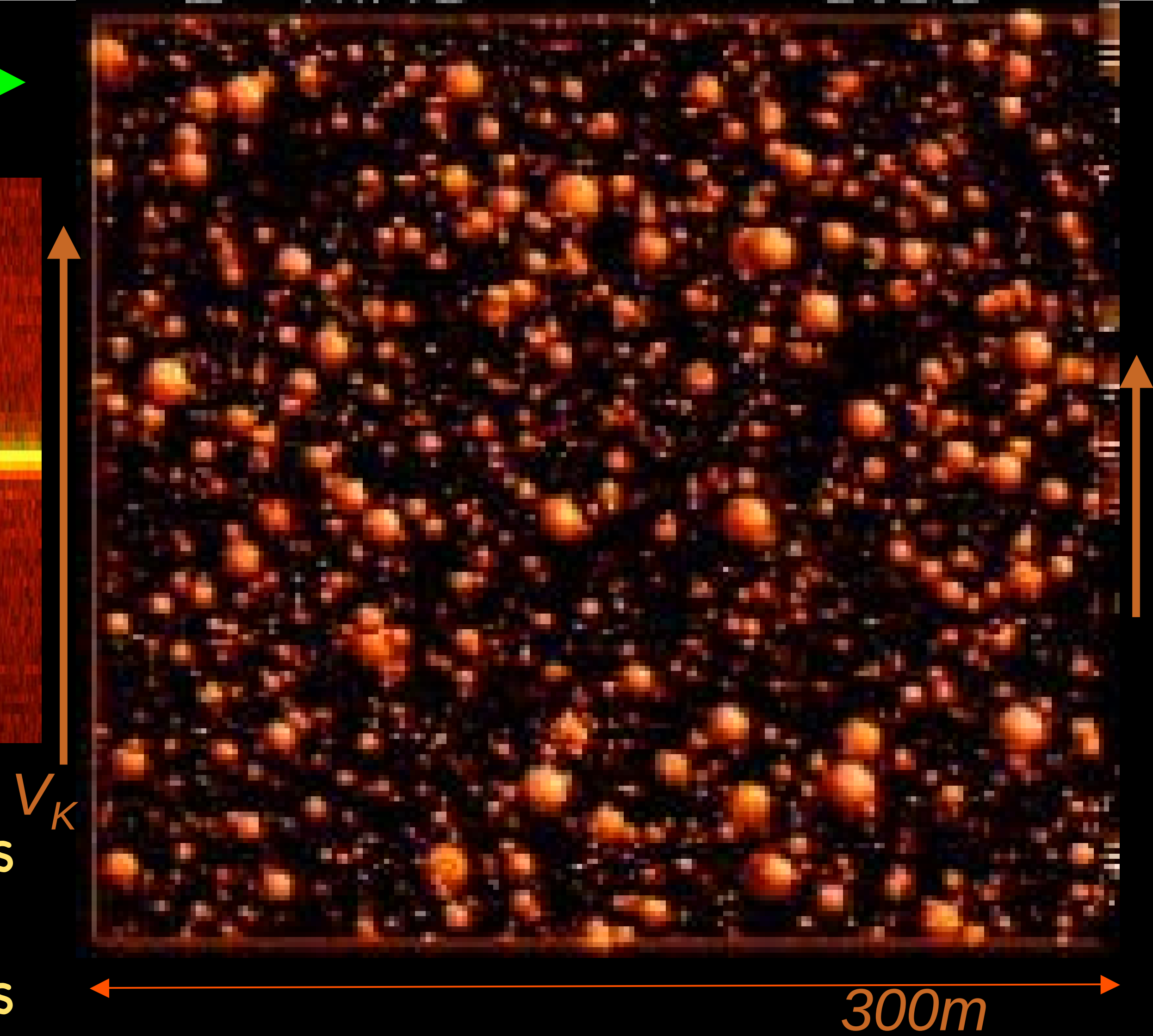
A preferred, more densely packed ring model



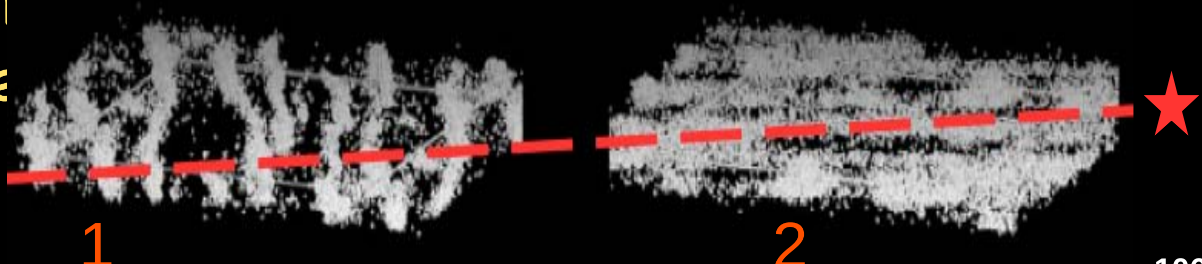
Gentle collisions & weak gravity between particles give the rings the quality of a viscous fluid

Self-gravity wakes →

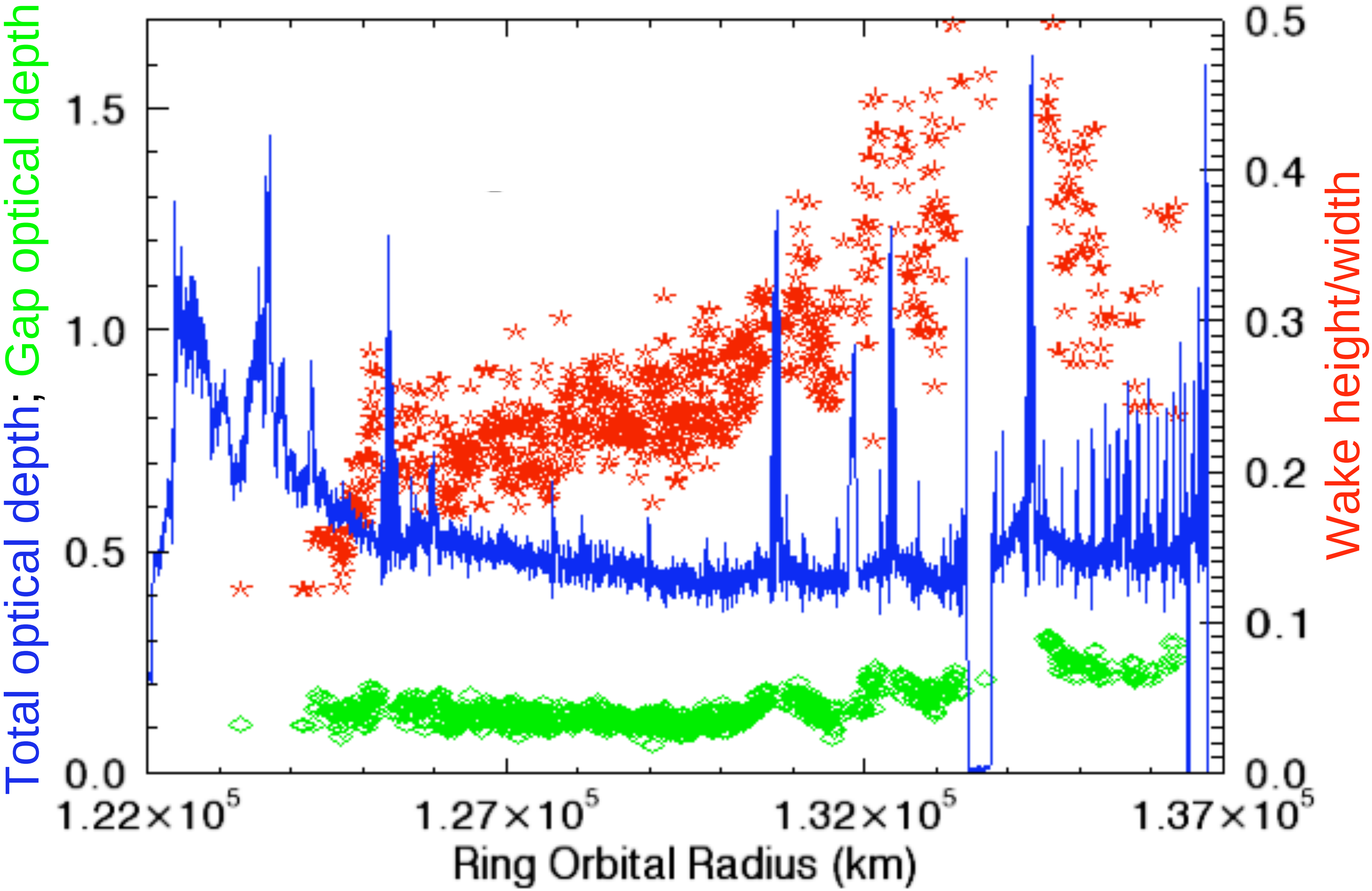




Occultations of stars by the rings: different view angles provide a 3D "CAT-scan" of ring micro-structure

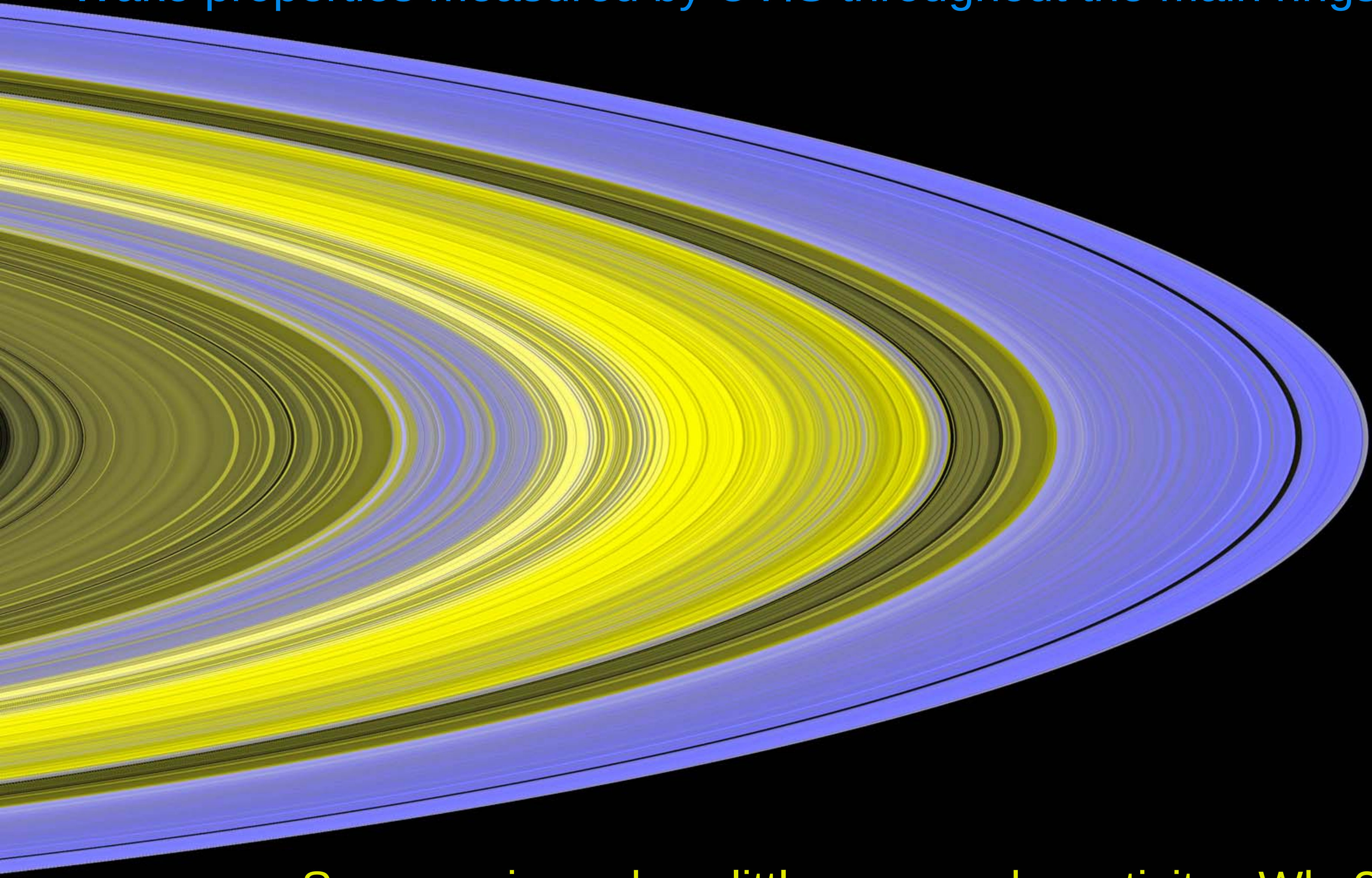


Self-Gravity Wake Properties in A Ring



Colwell et al GRL 2006

Wake properties measured by UVIS throughout the main rings

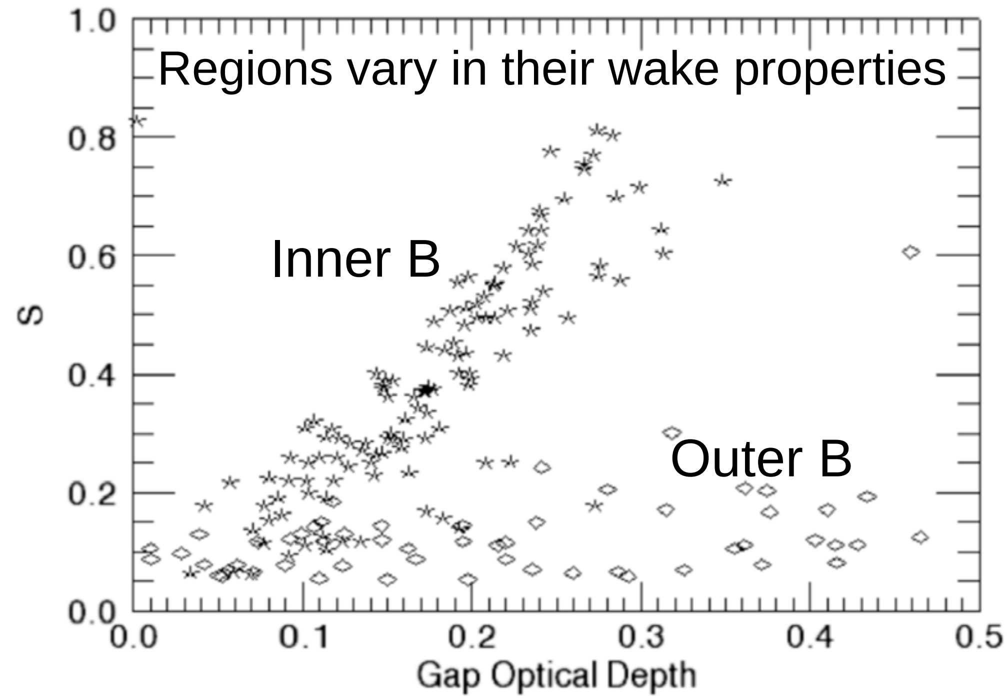


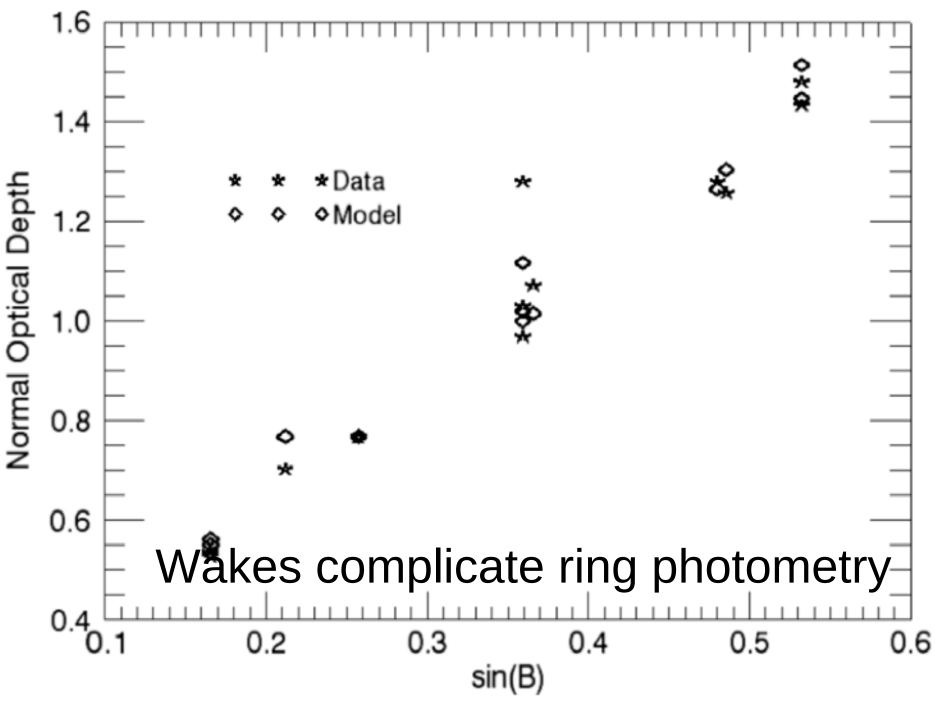
Some regions show little or no wake activity.. Why?

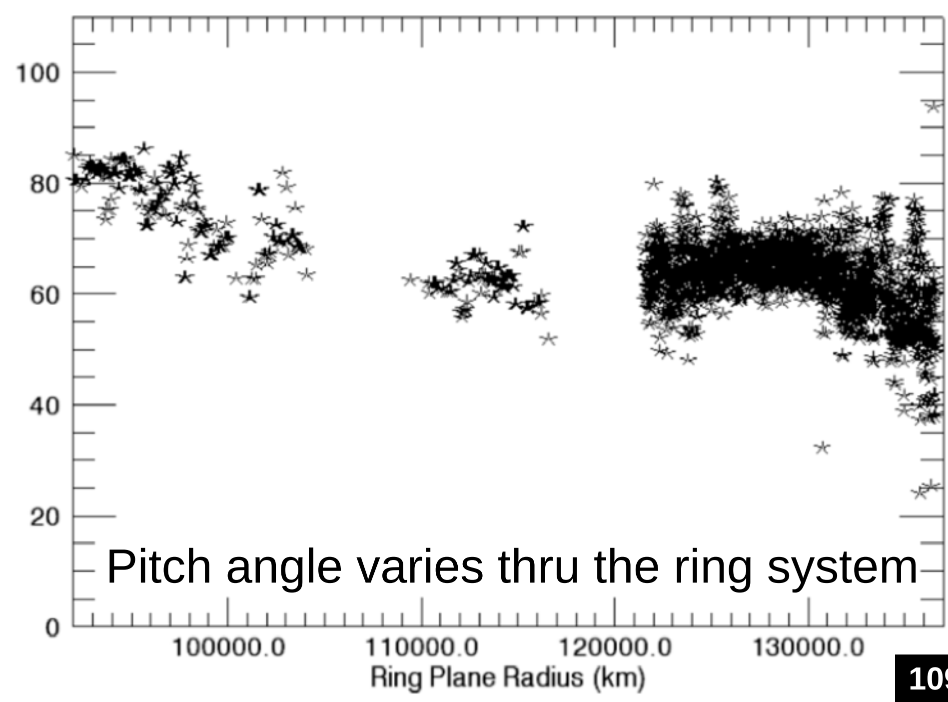
Self-gravity wakes.. Or what?
Fine scale structure everywere, with properties that vary from region to region.

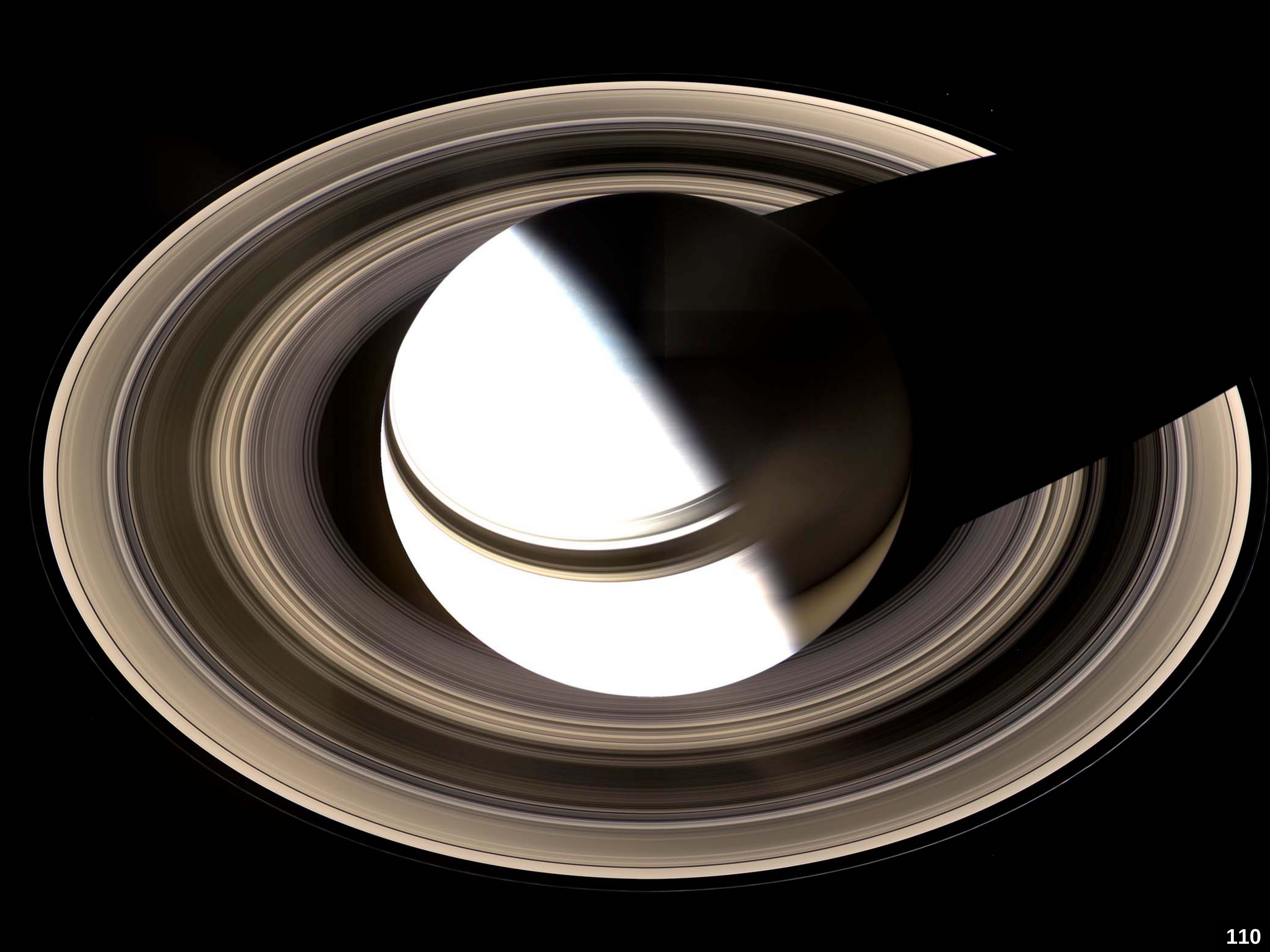
“Ring optical depth” varies with elevation angle (unresolved mix of dense and near-empty regions)

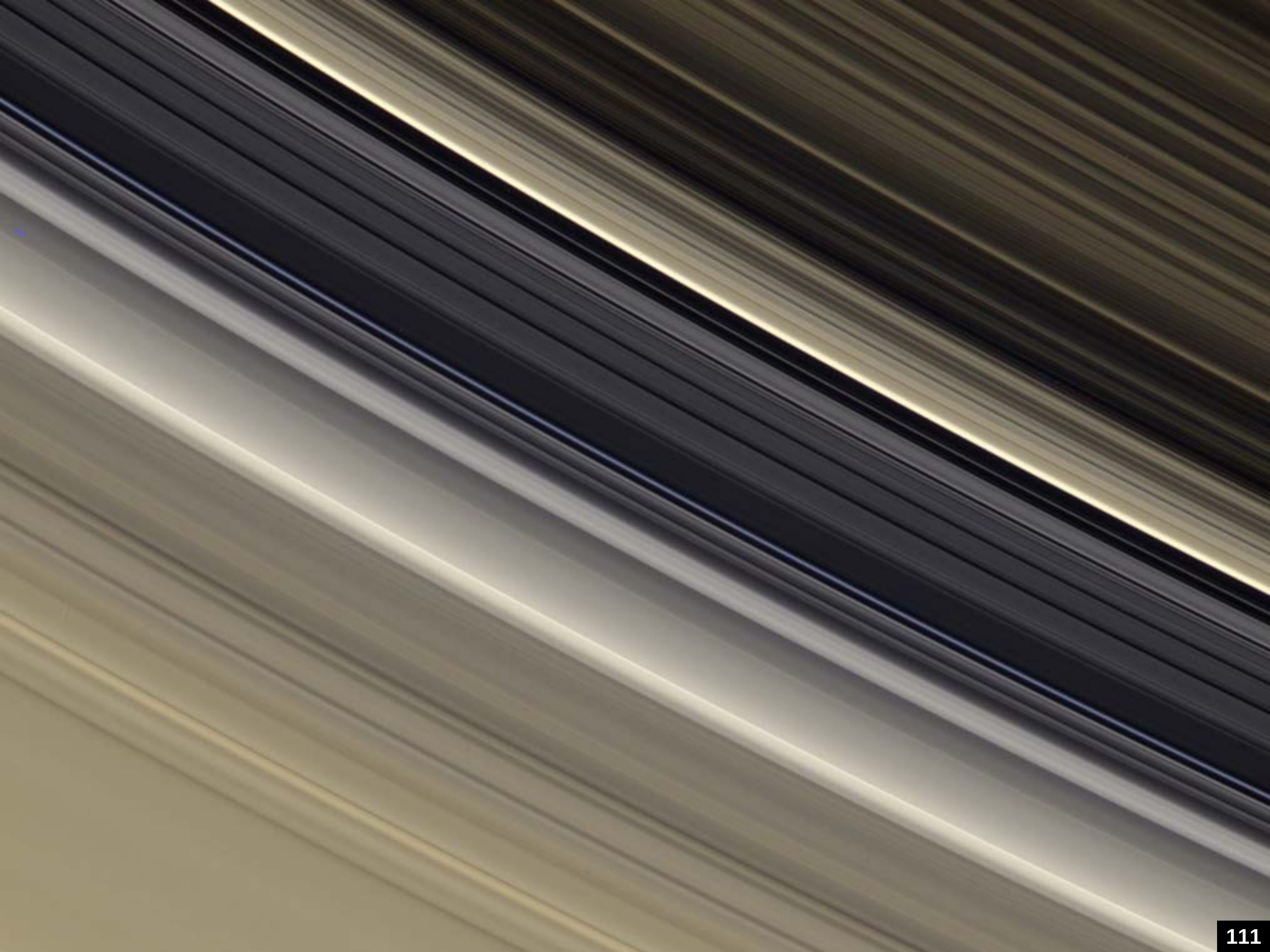
(Colwell et al, UVIS)



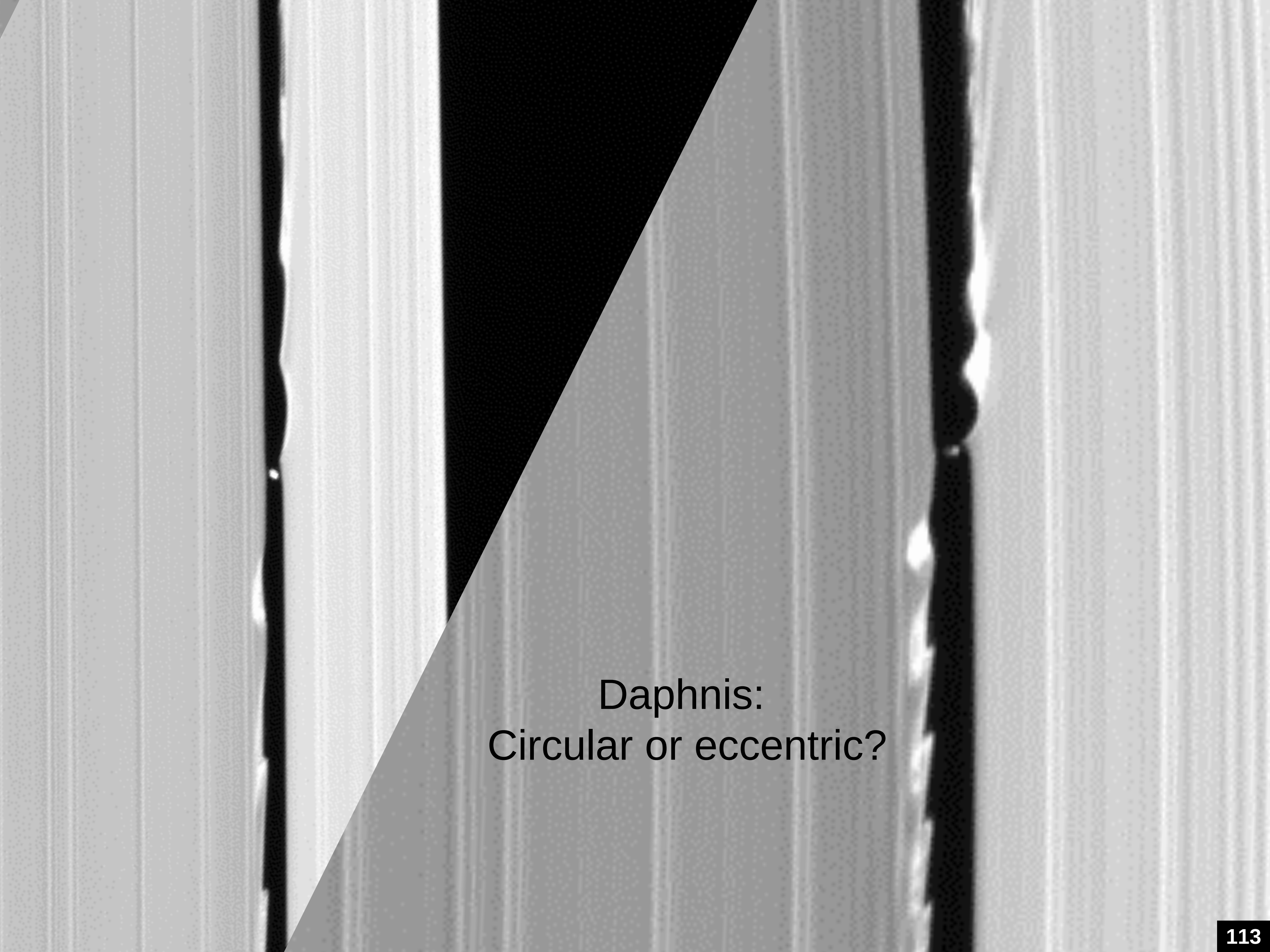


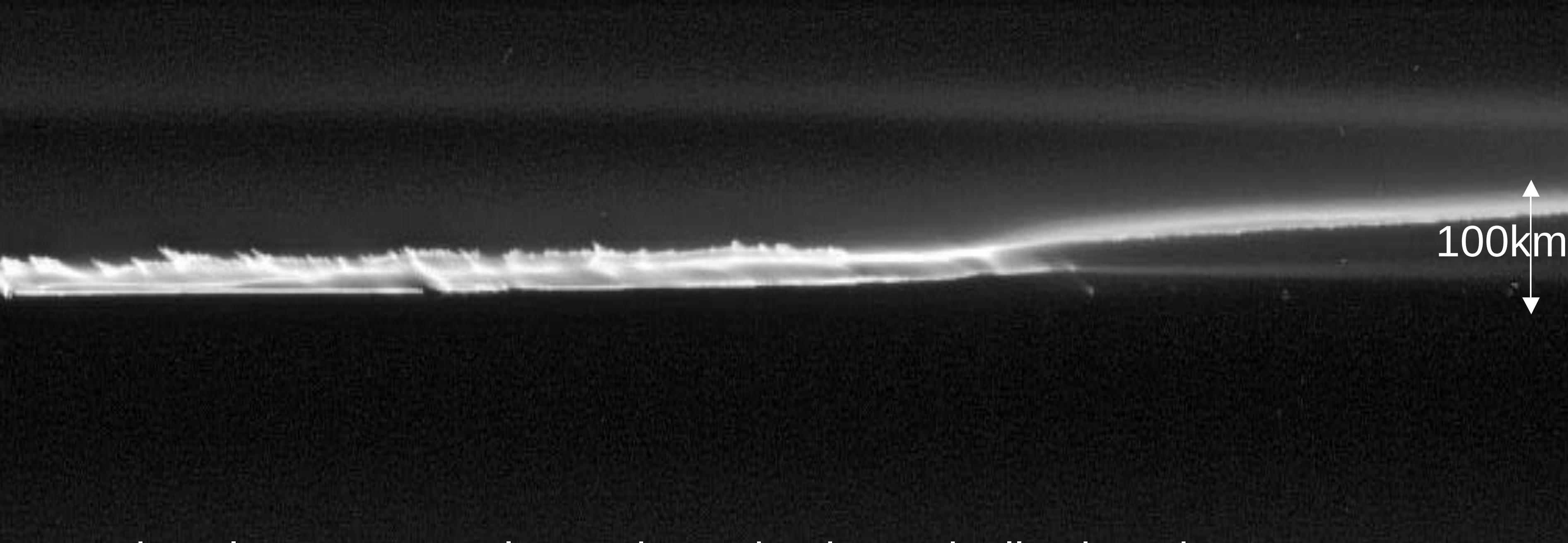




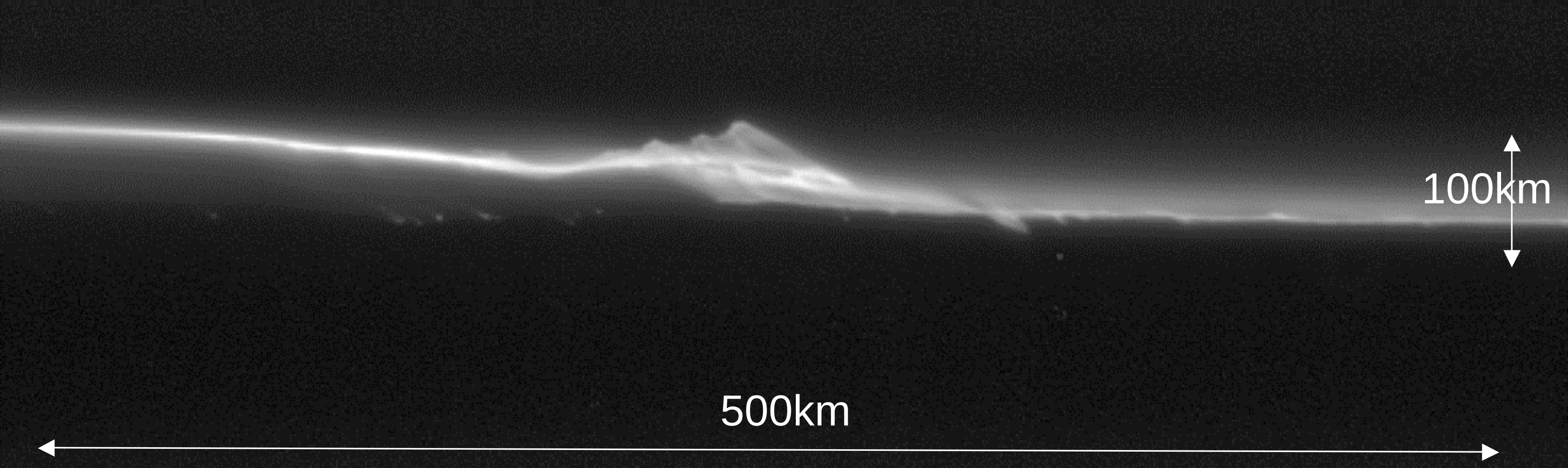



New Encke gap ringlets

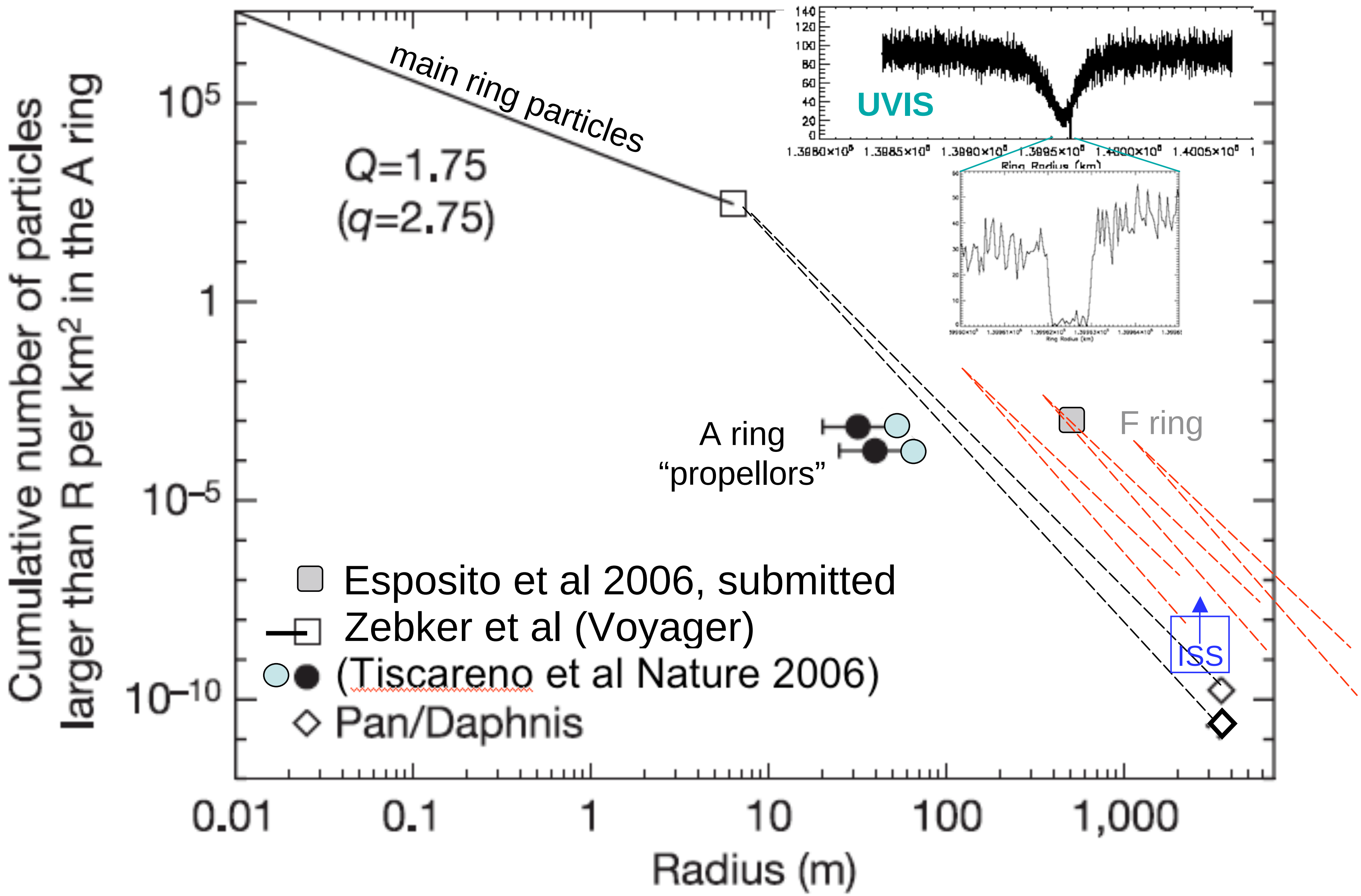

Daphnis:
Circular or eccentric?

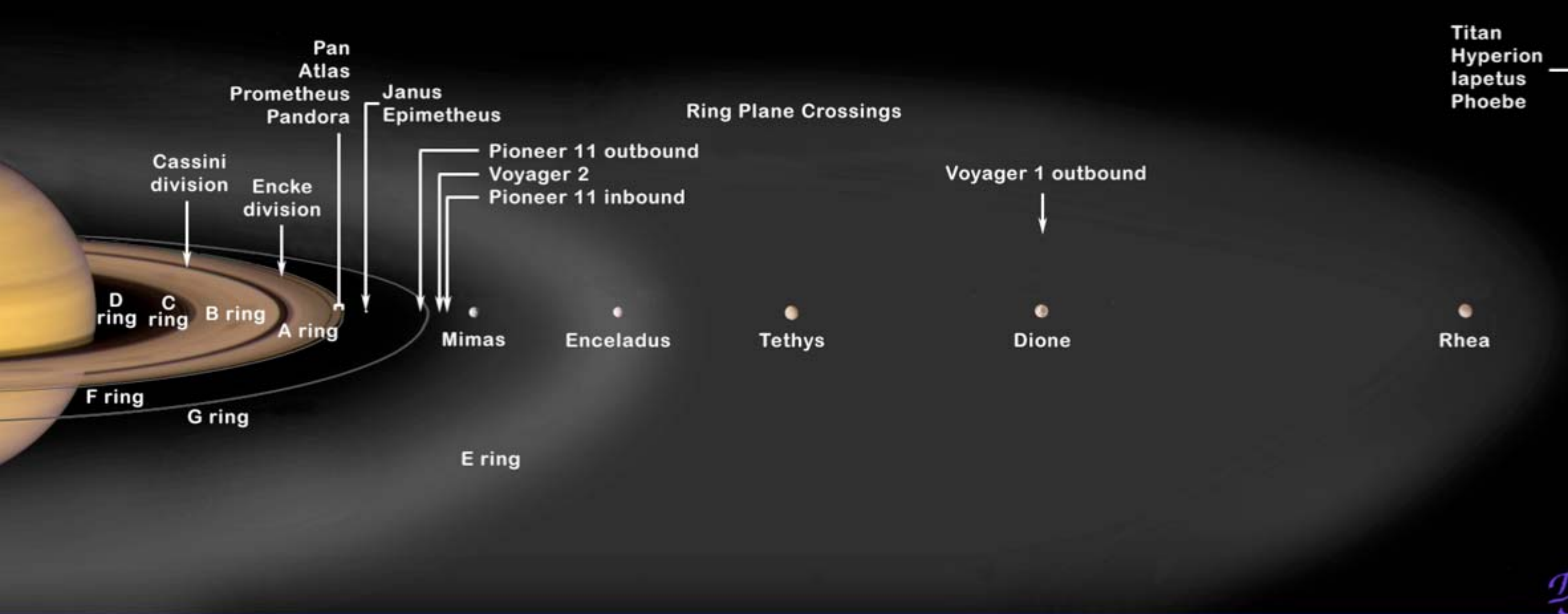


F ring closeups reveal very dynamic, dramatically changing core structure
with probably transient clumps less than a mile across

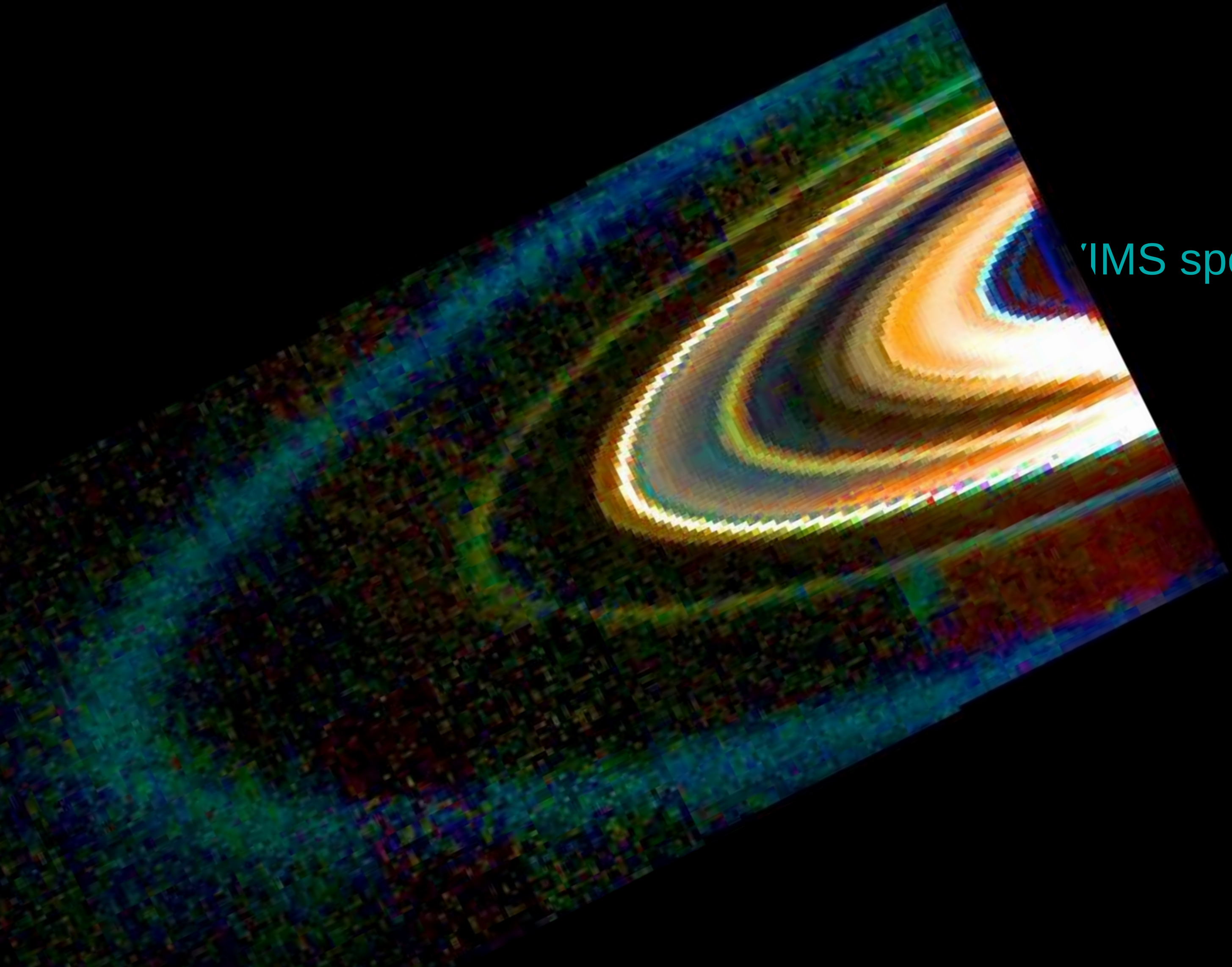


F ring moonlet belt ? (10^{20}-10^{21}g)

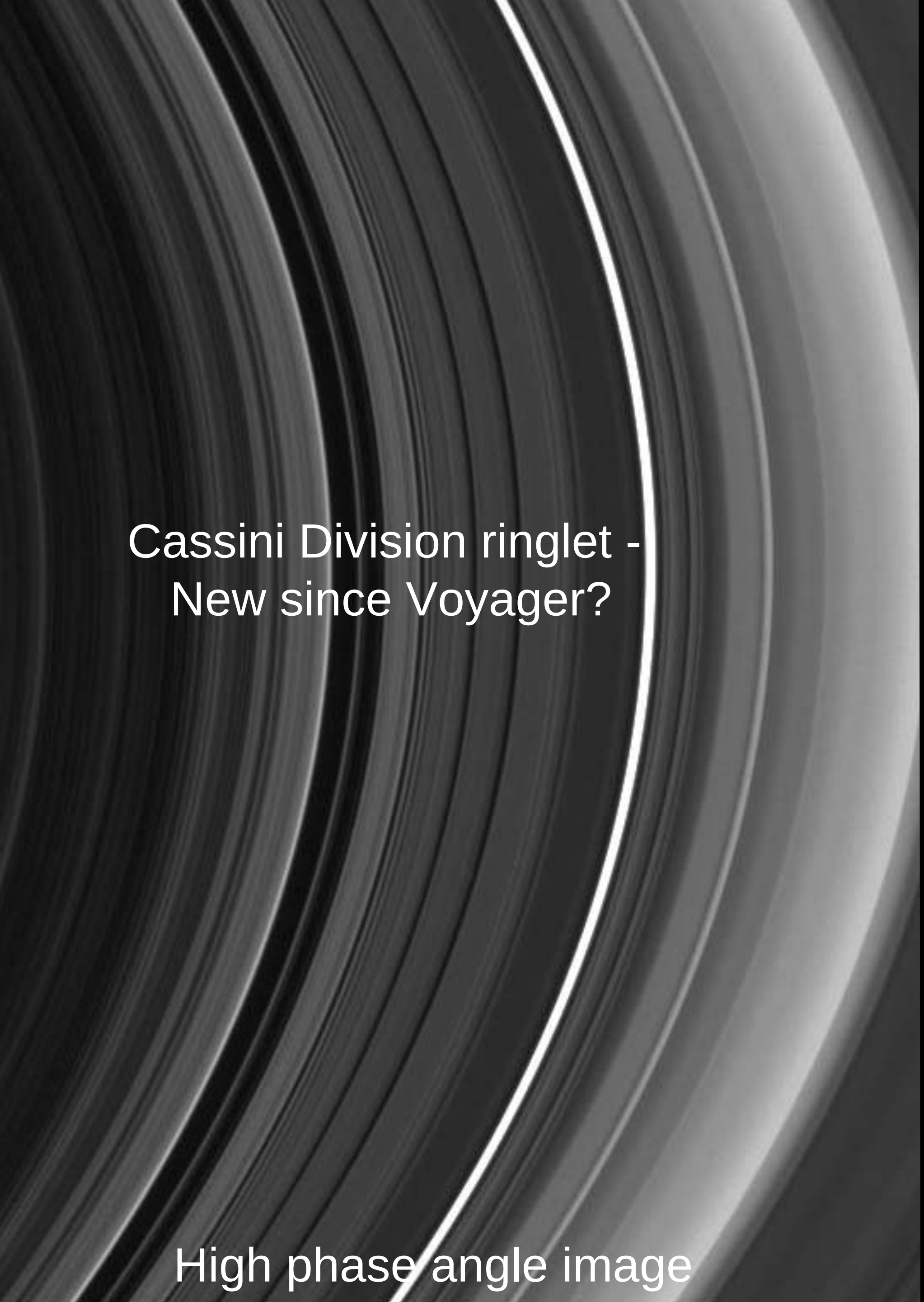



Pan
Atlas
Prometheus
Pandora
Janus
Epimetheus
Ring Plane Crossings
Titan
Hyperion
Iapetus
Phoebe
Cassini division
Encke division
Pioneer 11 outbound
Voyager 2
Pioneer 11 inbound
Voyager 1 outbound
D ring
C ring
B ring
A ring
F ring
G ring
E ring
Mimas
Enceladus
Tethys
Dione
Rhea

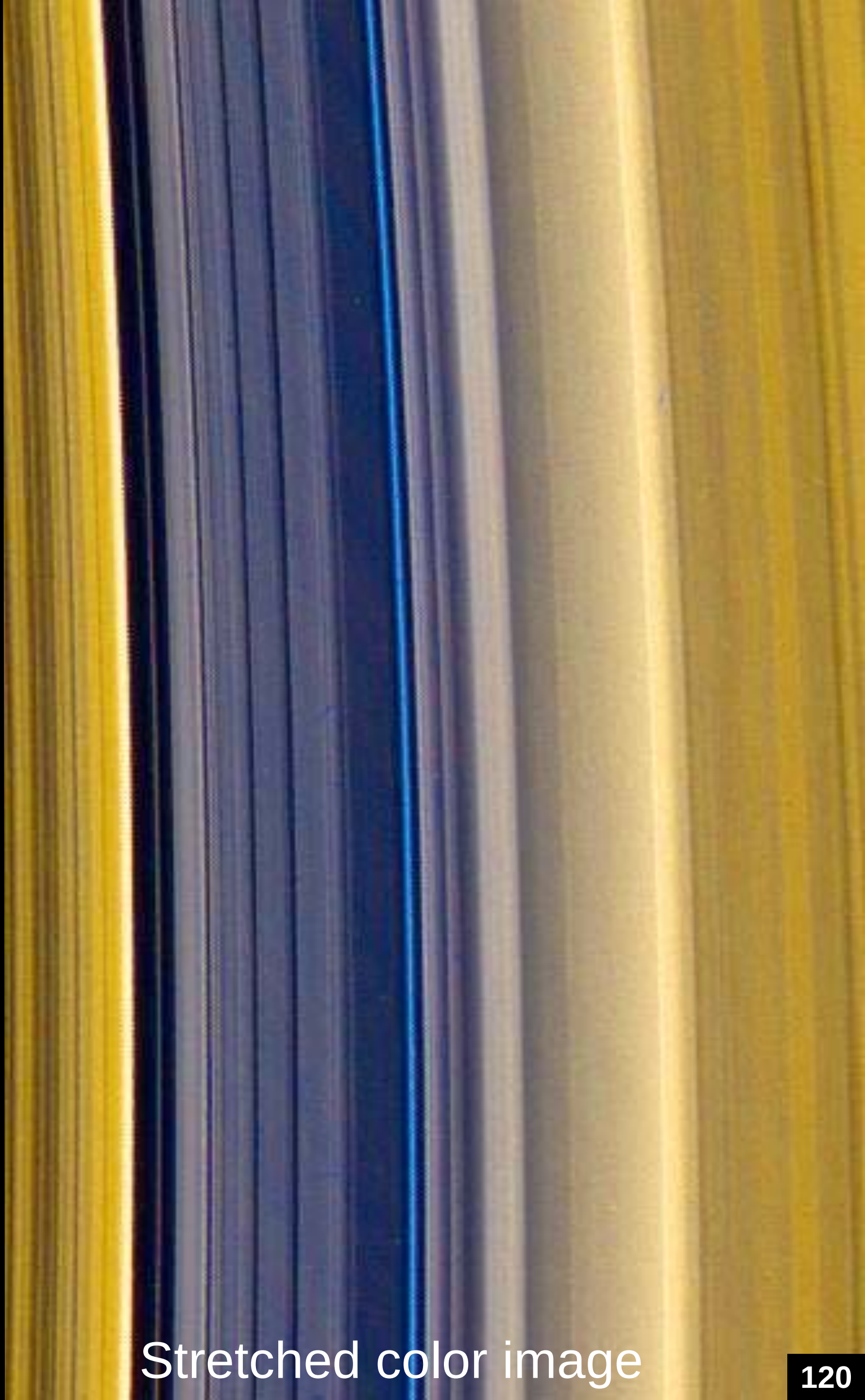

G ring arc

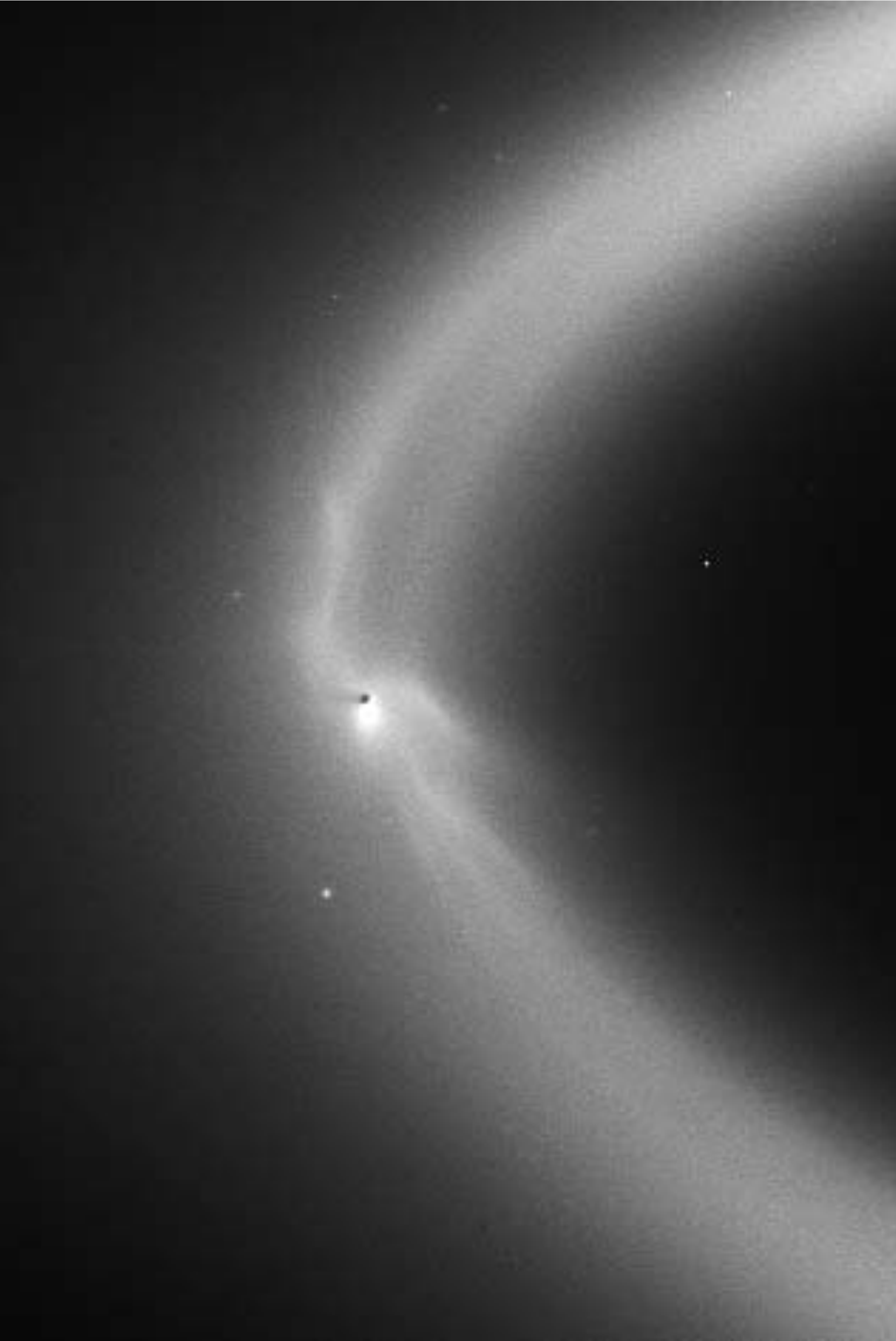


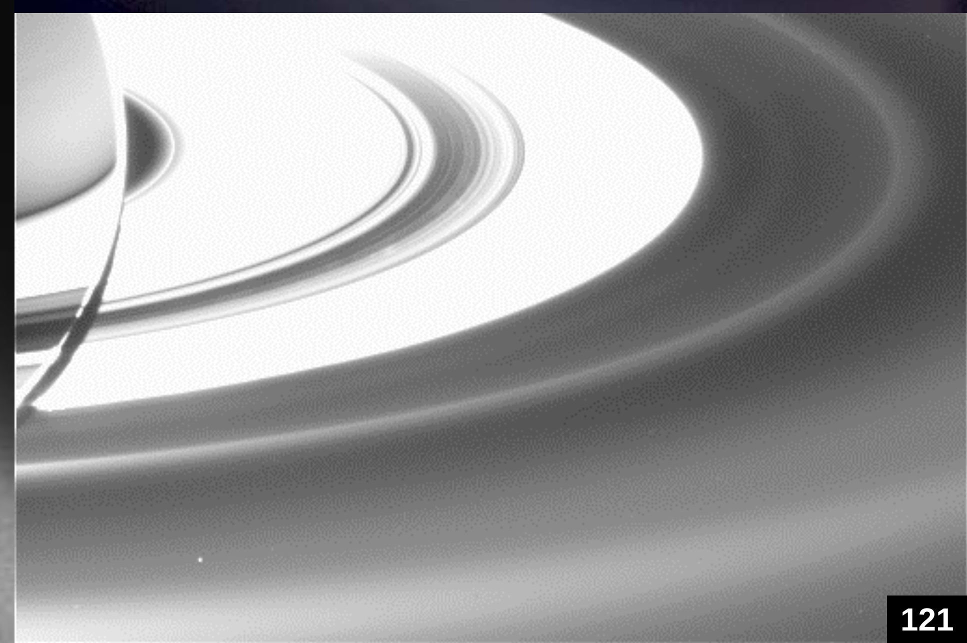
IMS spectral map



High phase angle image


Stretched color image





Spokes (bright hazy features) are increasingly common. Spokes are thought to be increasingly visible because solar photocharging of the rings decreases as the seasons change, permitting levitated dust to survive longer above the rings. The image also shows patchy, azimuthally variable structure at various places, that is not understood.

Peculiar, nonaxisymmetric, wispy structure

Year 3 was a big year for rings:

(Previous year was spent nearly all in the ring plane)

This year:

Highest-ever elevation viewing of lit and unlit rings
Many new or best-in-tour observations obtained
Ultra-high phase angle images revealed new rings and ringlets
Self gravity wakes (and related structure) found in the B ring
Wispy, azimuthally irregular structure is common in the B ring
Dynamic F ring region (and moonlet belt?)
Warped D ring region: a recent impact
Spoke activity on the rise

And,

Many new observations are not even analyzed yet


C
B
C D
A
F
ISS approach color composite

Some fun facts
and
What to expect in year 4!

Gee Whiz Cool Facts

- How many orbits, sequences, and commands?

  ~22 orbits (Rev 25-Rev 47); ~10 sequences (S21-S30); ~350,000 commands

- Which instrument has returned the most data from the S/C in the last year? Which instrument the least?

Inst	First Year		Second Year		Third Year
RPWS	16.5 (Gbytes)		17.6 (Gbytes)		20.6 (Gbytes)
CAPS	9.8		10.8		12.1
ISS	9.7		10.6		11.3
CIRS	2.8	4.0	3.5	4.2	4.8
MAG	4.5		4.9		4.8
VIMS	1.8		3.2		4.5
MIMI	3.1				
UVIS	2.7		2.2		3.1
RADAR	0.7		0.8		1.3
CDA	0.7		1.3	68.0	1.0
INMS	0.3		0.3		0.5
RSS - S/C	0.0		0.0		0.0
Total	52.6		59.2		
(RSS - DSN	220		277		364)

Gee Whiz Cool Facts (cont)

- How many Orbit Trim Maneuvers (OTMs)

  Planned=54, Executed=39, Cancelled=14, Deleted=1

- How many miles has Cassini traveled? What is our miles per gallon rating?

  First Year: 100 million km (63 million miles)
  Second Year: 117 million km (73 million miles)
  Third Year: 143 million km (89 million miles)

  First Year :879.0 kg of NTO, 528.9 kg of MMH, and 7.6 kg of N2H4 [325 gallons]
  Second Year: 47.1 kg of NTO, 28.3 kg of MMH, and 7.5 kg of N2H4 [19 gallons]
  Third Year: 48.2 kg of NTO, 29.5 kg of MMH, and 10.9 kg of N2H4 [21 gallons]

  First Year: Miles/gallon=194,000 miles/gallon (includes SOI)
  Second Year: Miles/gallon= 3.7 million miles/gallon
  Third Year: Miles/gallon= 3.5 million miles/gallon

What to Expect in Year 4!

- ~27 orbits to complete, ~10 sequences, 13 targeted flybys, 74 non-targeted icy satellite (120,000 km or less) opportunities
- In the 4th year of the Cassini tour we start with equatorial orbits and we get our only targeted Iapetus flyby (September 2007) of the mission - a big highlight!
- We have two very low (<10,000 km) non-targeted flybys, one of Rhea (Aug 30, 2007) and one of Epimetheus (Dec 03, 2007).
- The last targeted Enceladus flyby of the prime mission (Mar 12, 2008).
- For most of the 4th year, we are increasing the inclination to near polar (over 70 degrees) orbits to look down on Saturn and its rings, this is the highest inclination of the prime and extended missions.
- The project is also doing the integration for XM9 starting in January of 2008 and delivering one months worth of spacecraft activities every 10 weeks.
- The scientists and tour designers begin the post 2010 tour design.

Mission Summary Chart

Targeted Iapetus **High Inclination**

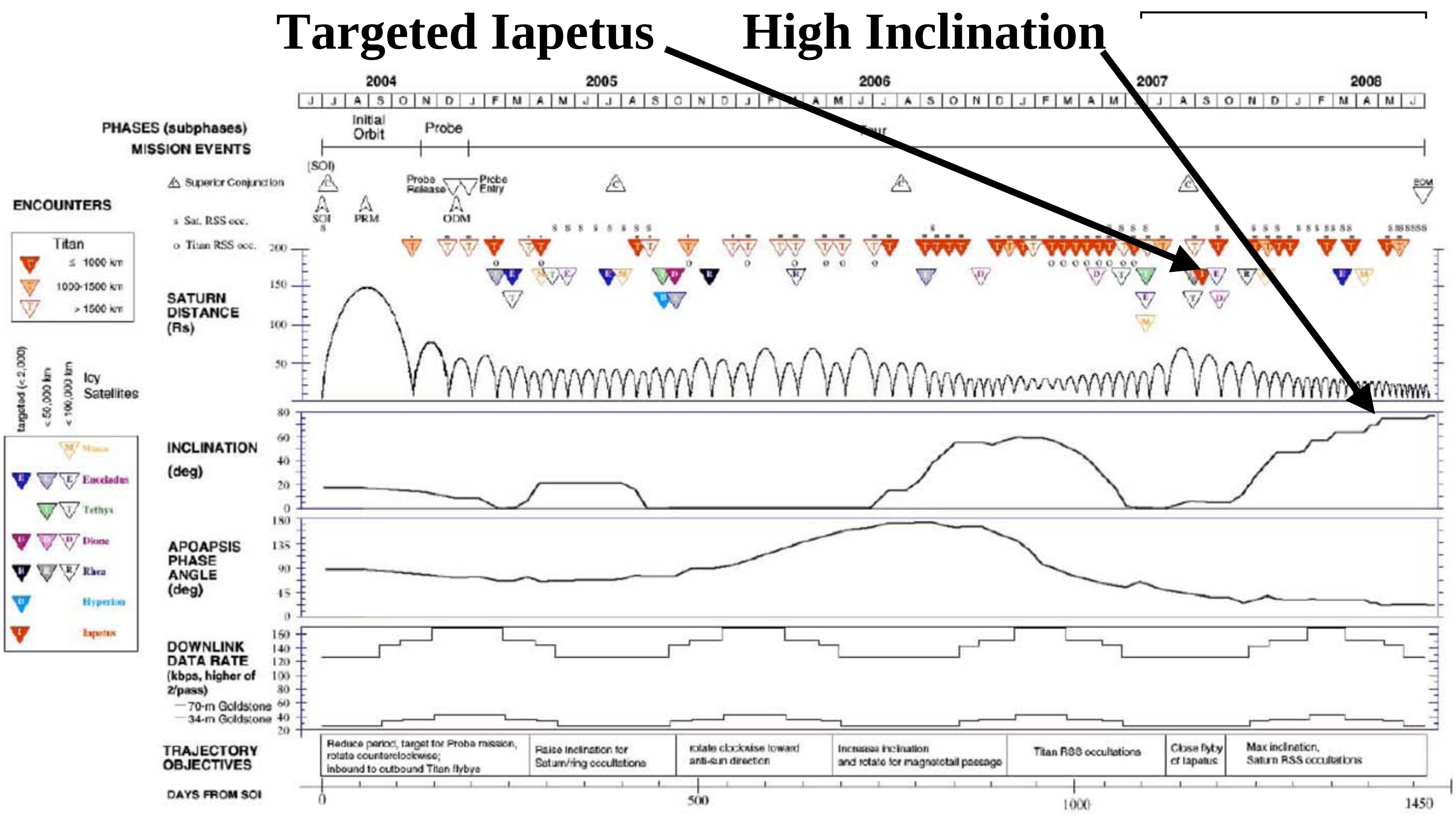


Figure 2.2 Cassini Tour Segment Timeline (2002-01)

Targeted Flyby Summary - 4th year

Seq	Rev	Name		Event	Epoch (SCET)	Date
S32	48	48TI (t)	[T34]	TITAN	2007-200T01:11	Jul-19
S33	49	49TI (t)	[T35]	TITAN	2007-243T06:33	Aug-31
S33	49	49IA (t)	[I1]	IAPETUS	2007-253T14:16	Sep-10
S34	50	50TI (t)	[T36]	TITAN	2007-275T04:43	Oct-02
S35	52	52TI (t)	[T37]	TITAN	2007-323T00:47	Nov-19
S35	53	53TI (t)	[T38]	TITAN	2007-339T00:07	Dec-05
S36	54	54TI (t)	[T39]	TITAN	2007-354T22:58	Dec-20
S36	55	55TI (t)	[T40]	TITAN	2008-005T21:30	Jan-05
S38	59	59TI (t)	[T41]	TITAN	2008-053T17:32	Feb-22
S38	61	61EN (t)	[E3]	ENCELADUS	2008-072T19:06	Mar-12
S39	62	62TI (t)	[T42]	TITAN	2008-085T14:28	Mar-25
S40	67	67TI (t)	[T43]	TITAN	2008-133T10:02	May-12
S40	69	69TI (t)	[T44]	TITAN	2008-149T08:24	May-28

Come join us! http://saturn.jpl.nasa.gov