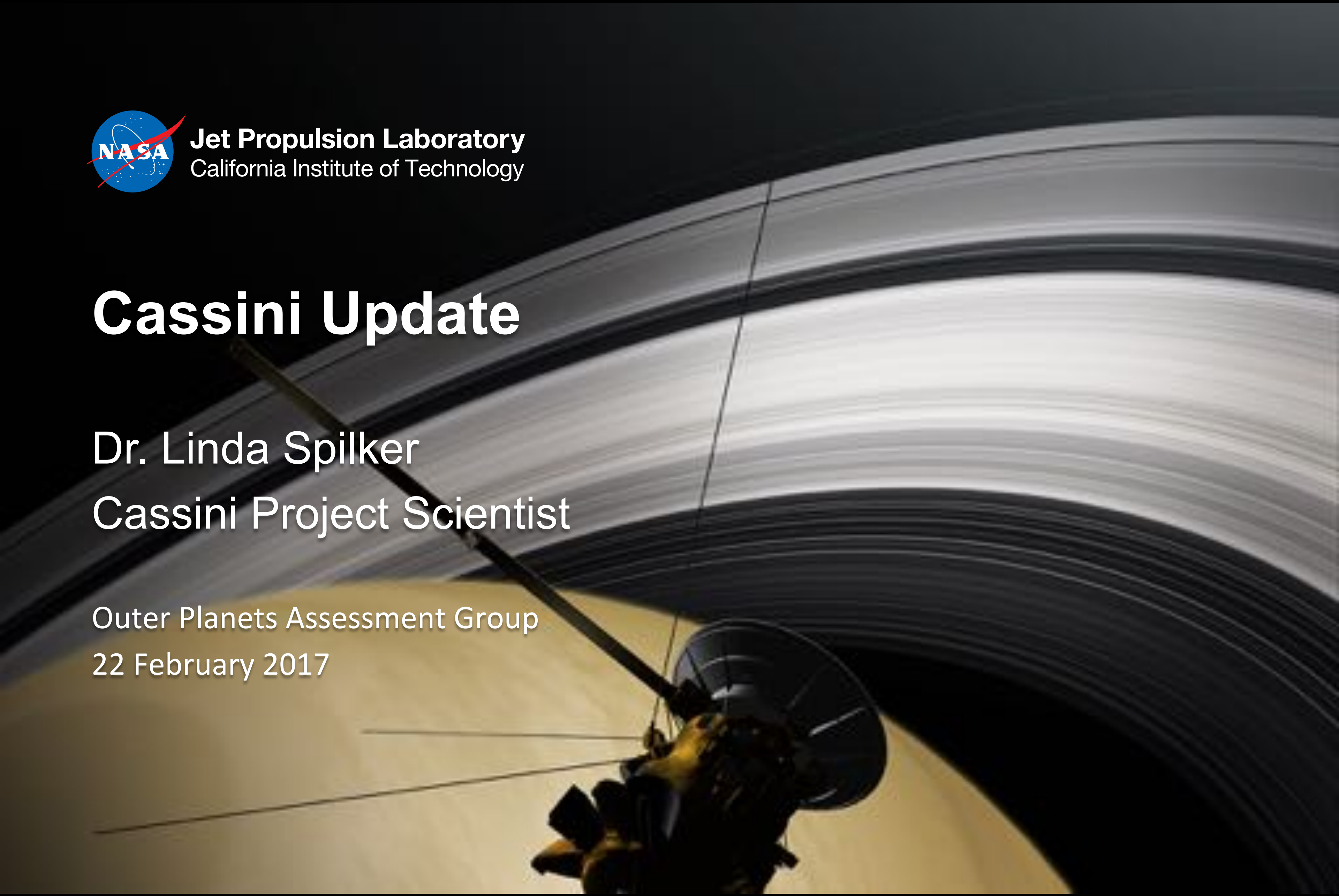
Jet Propulsion Laboratory
California Institute of Technology

Cassini Update

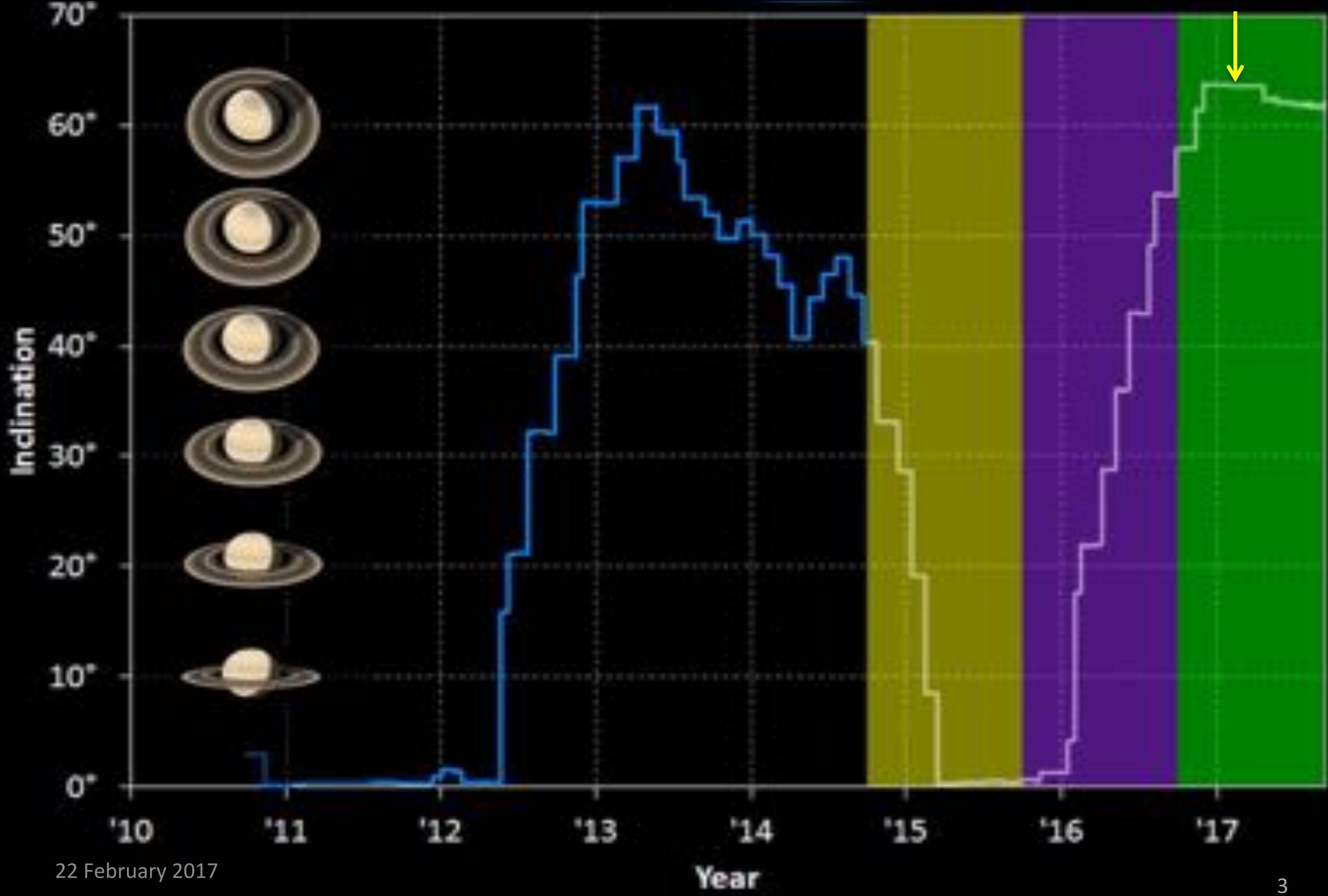
Dr. Linda Spilker
Cassini Project Scientist

Outer Planets Assessment Group
22 February 2017




Falling for You
Love,
Cassini

Solstice Mission Inclination Profile



Key Flybys Since Aug. 2016 OPAG

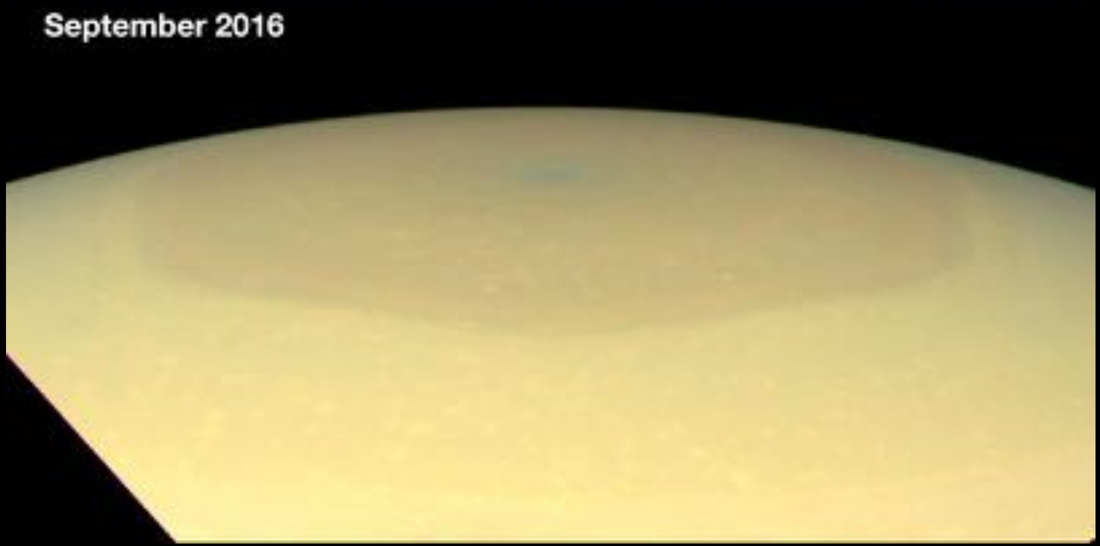
T124 – Titan flyby (1584 km)

- November 13, 2016
- **LAST Radio Science flyby**
- One of only two (cf. T106) ideal bistatic observations capturing Titan's Northern Seas
- First and only bistatic observation of Punga Mare
- Western Kraken Mare not explored by RSS before

T125 – Titan flyby (3158 km)

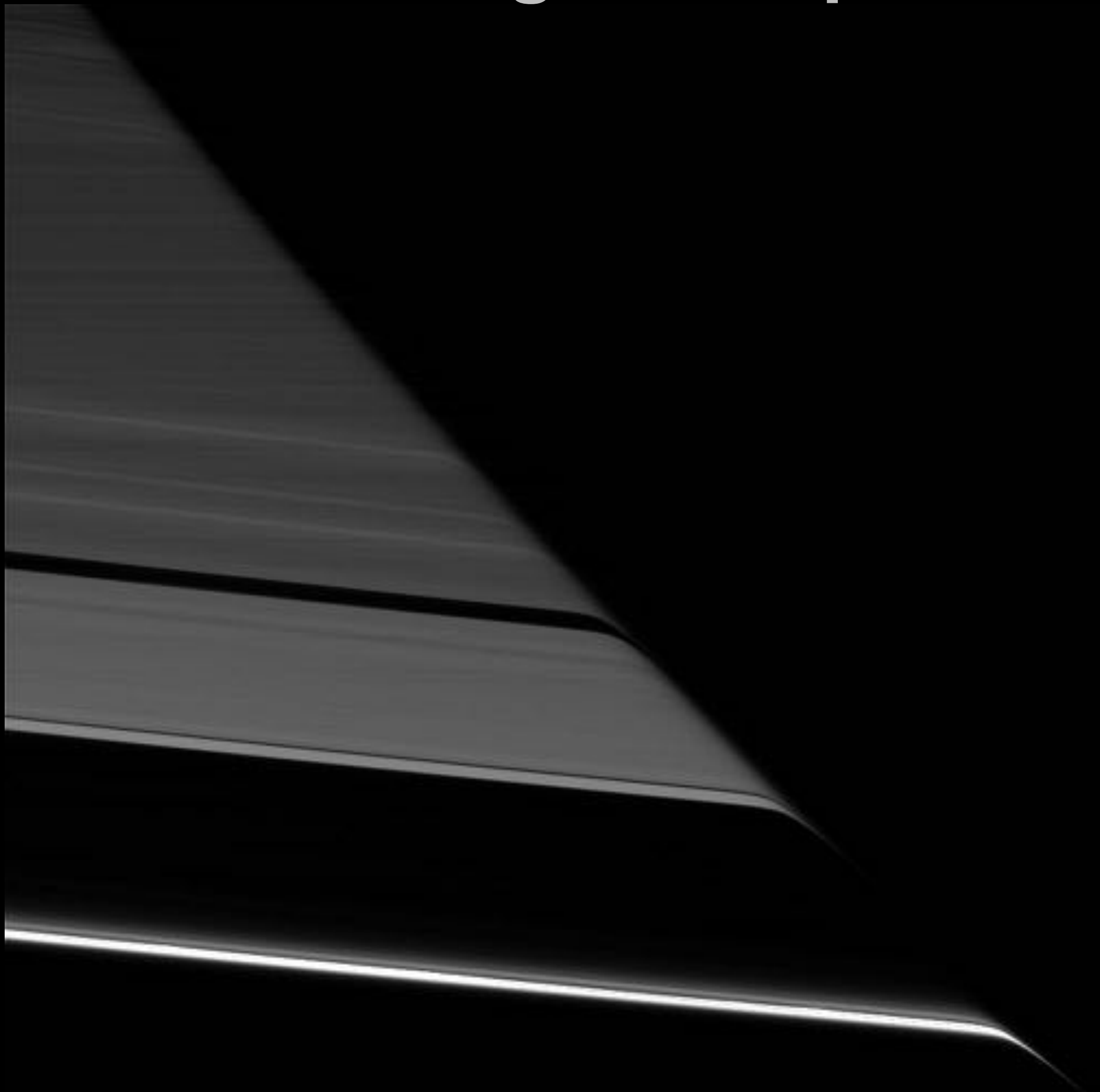
- November 29, 2016
- **LAST Optical Remote Sensing targeted flyby**
- VIMS high-resolution map of the North Pole looking for variations at and around the seas and lakes.
- CIRS last opportunity for vertical profile determination of gases (e.g. water, aerosols)
- UVIS limb viewing opportunity at the highest spatial resolution available outside of occultations

Interior of Hexagon Turning “Less Blue”



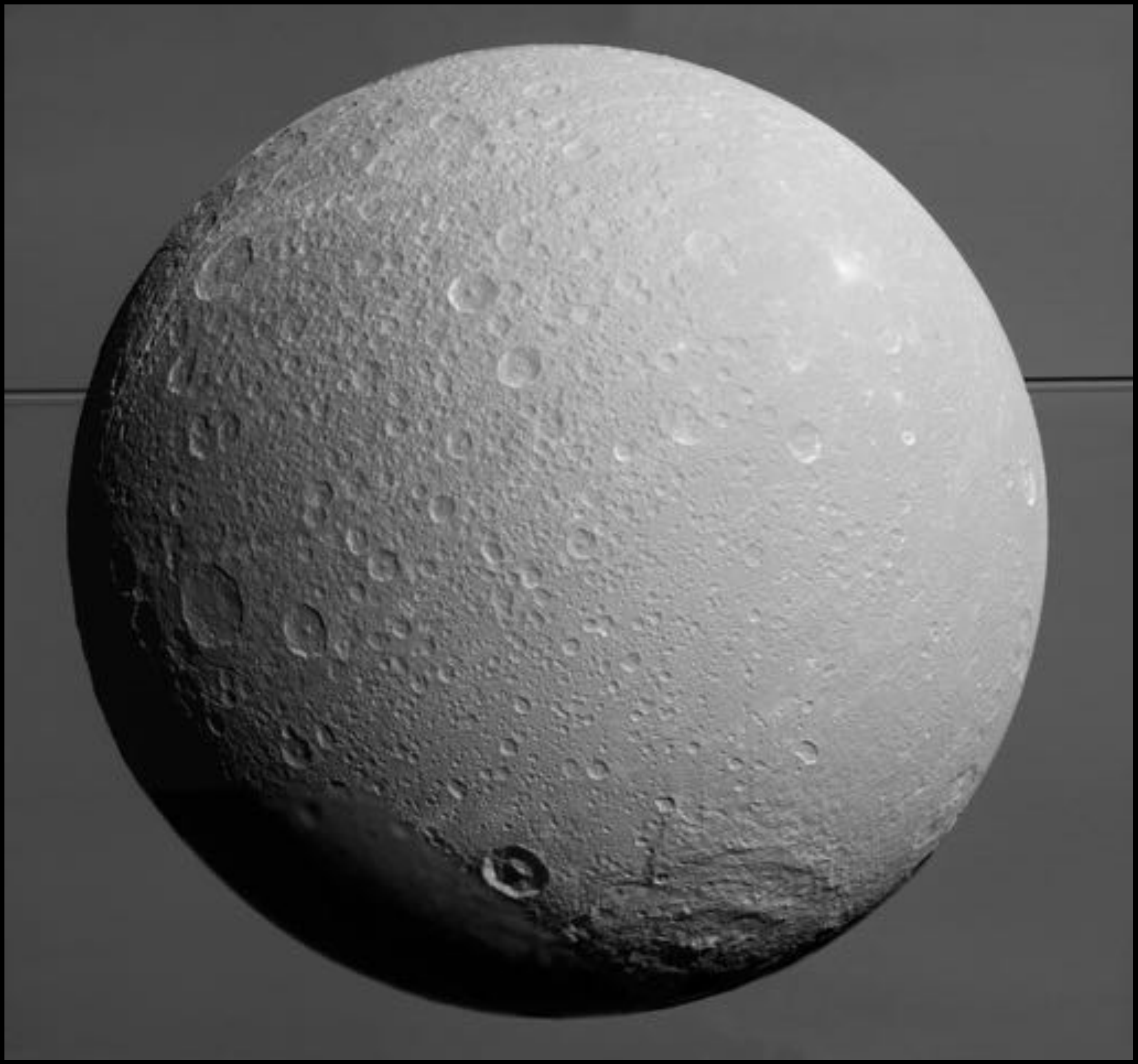
- Bluish to golden haze results from increased production of photochemical hazes as north pole approaches summer solstice.
- Hexagon acts as a barrier that prevents haze particles outside hexagon from migrating inward.

Refracting Atmosphere



Saturn's unlit rings appear to bend as they pass behind the planet's darkened limb due to refraction by Saturn's upper atmosphere. (Resolution 5 km/pixel)

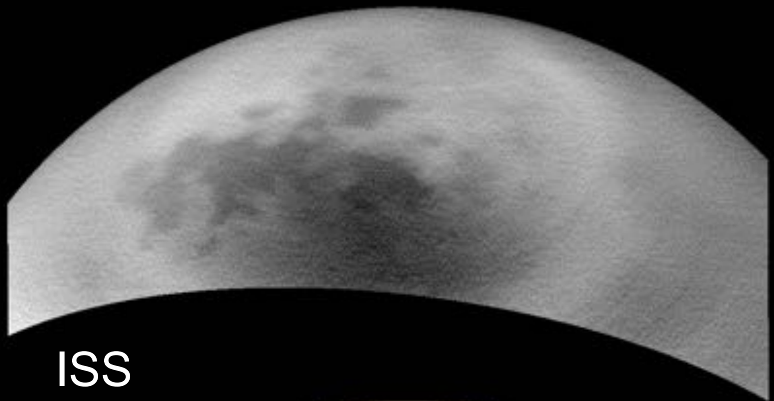
Dione Harbors A Subsurface Ocean



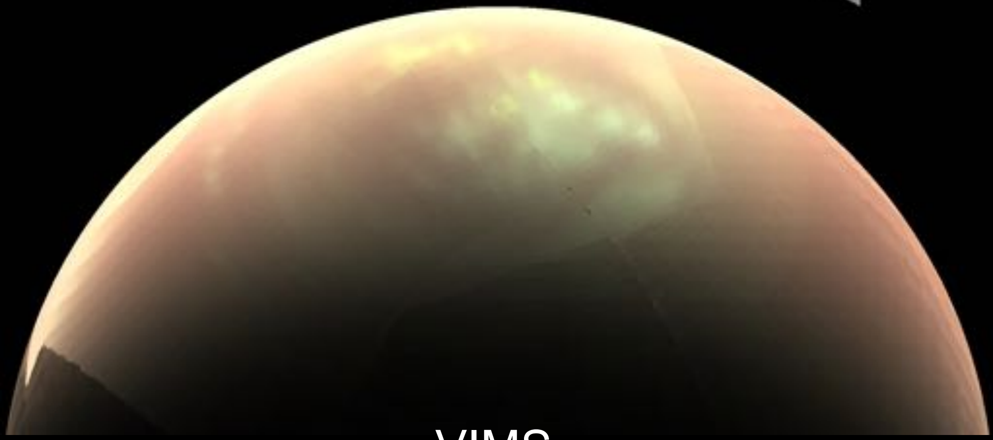
Researchers at the Royal Observatory of Belgium reanalyzed Cassini RSS gravity data of Dione and predict a crust 100 km thick with a global ocean 10's of km deep.

Titan's Summer Clouds Pose a Mystery

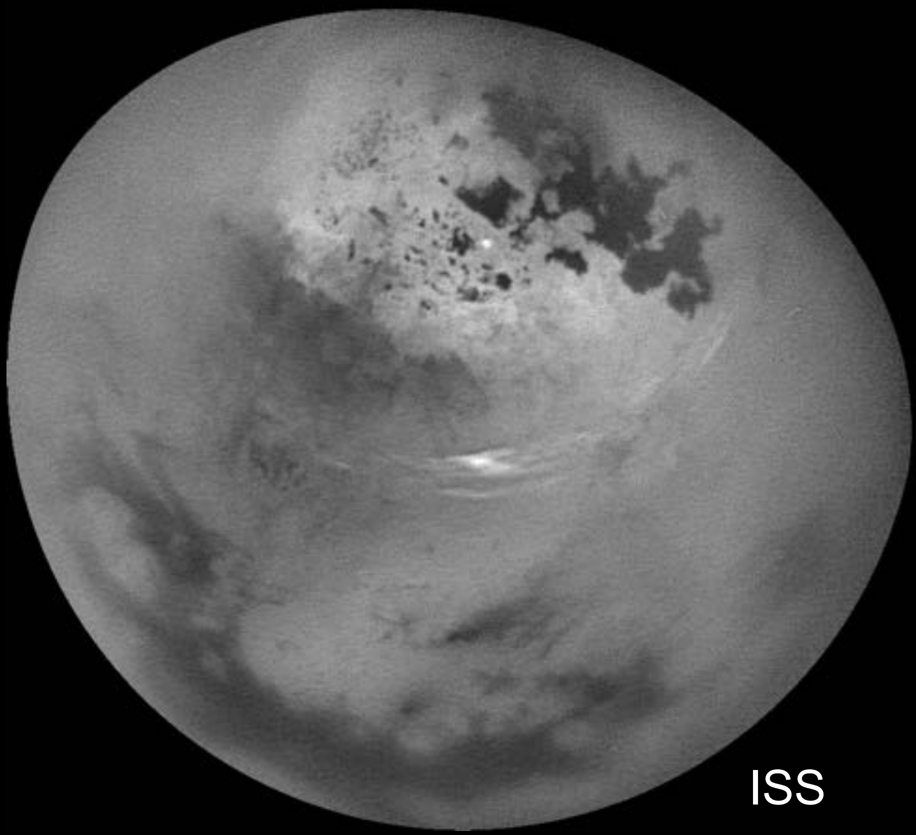
Why would clouds on Titan be visible in VIMS images, but not in ISS images?



ISS



VIMS

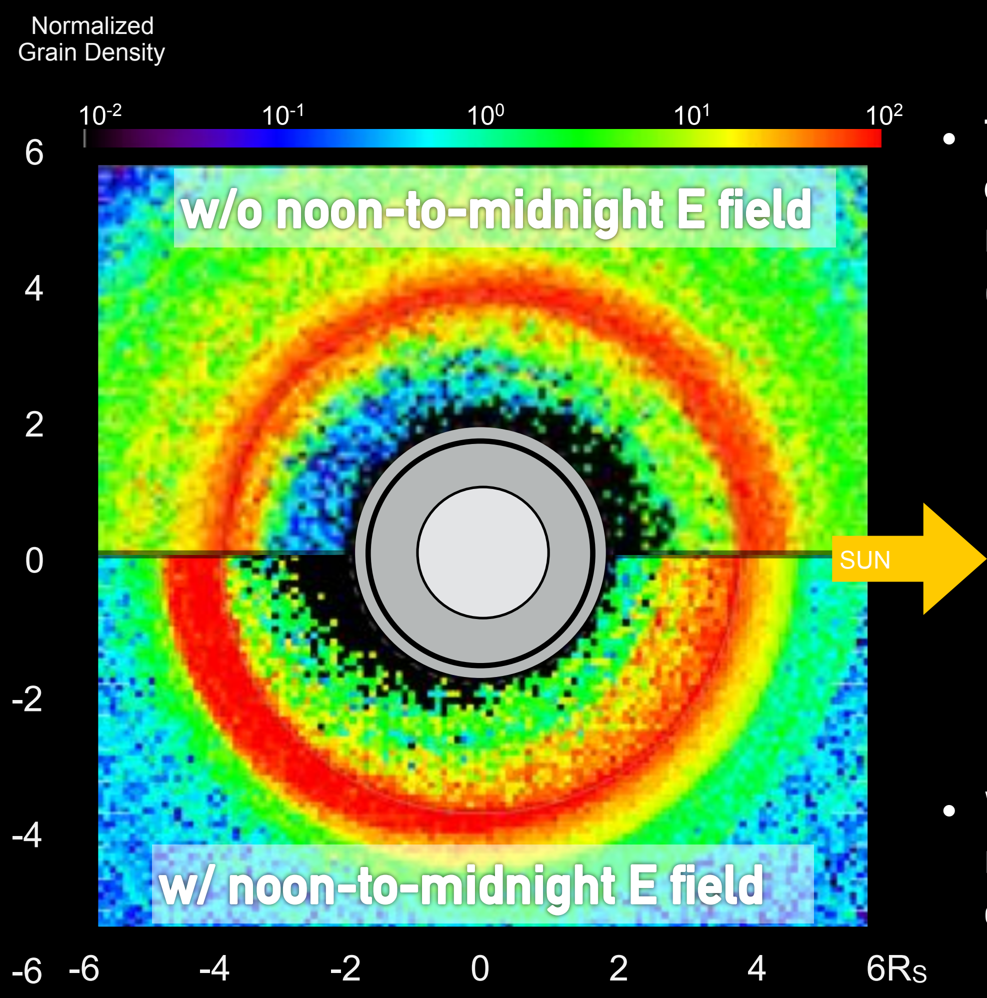


ISS

High, thin cirrus clouds that are optically thicker than Titan's atmospheric haze at longer VIMS wavelengths, but optically thinner than the haze at shorter ISS wavelengths, could be detected by VIMS while simultaneously lost in the haze to ISS.

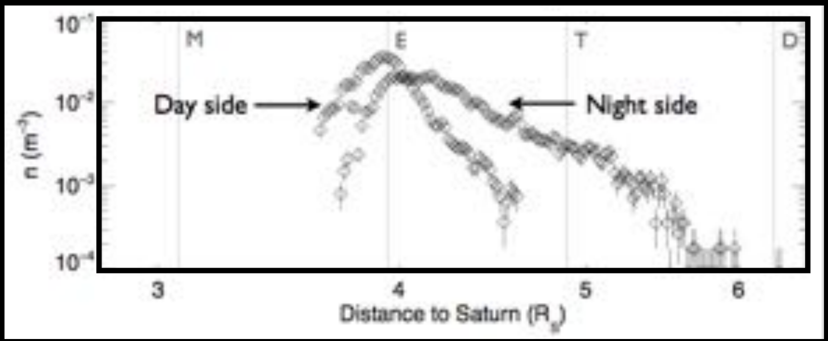
Day-Night Asymmetry of Saturn's E ring

Recently discovered noon-to-midnight electric field in magnetosphere main cause for observed day-night asymmetry of Saturn's E ring.



- The day-night asymmetry of Saturn's E ring was clear in both Cassini images and in situ measurements - a brighter, more compressed day-side and a fainter, more extended night-side.

Cosmic Dust Analyzer/HRD E ring profile



- Without the noon-to-midnight electric field, the modeled ring structure is the opposite of the observed profile.

62 Saturnian Moons -- 49 observed!

S/2009 S 1
Pan
Daphnis
Atlas
Prometheus
Pandora
Epimetheus
Janus
Aegaeon
Mimas
Methone
Anthe
Pallene
Enceladus

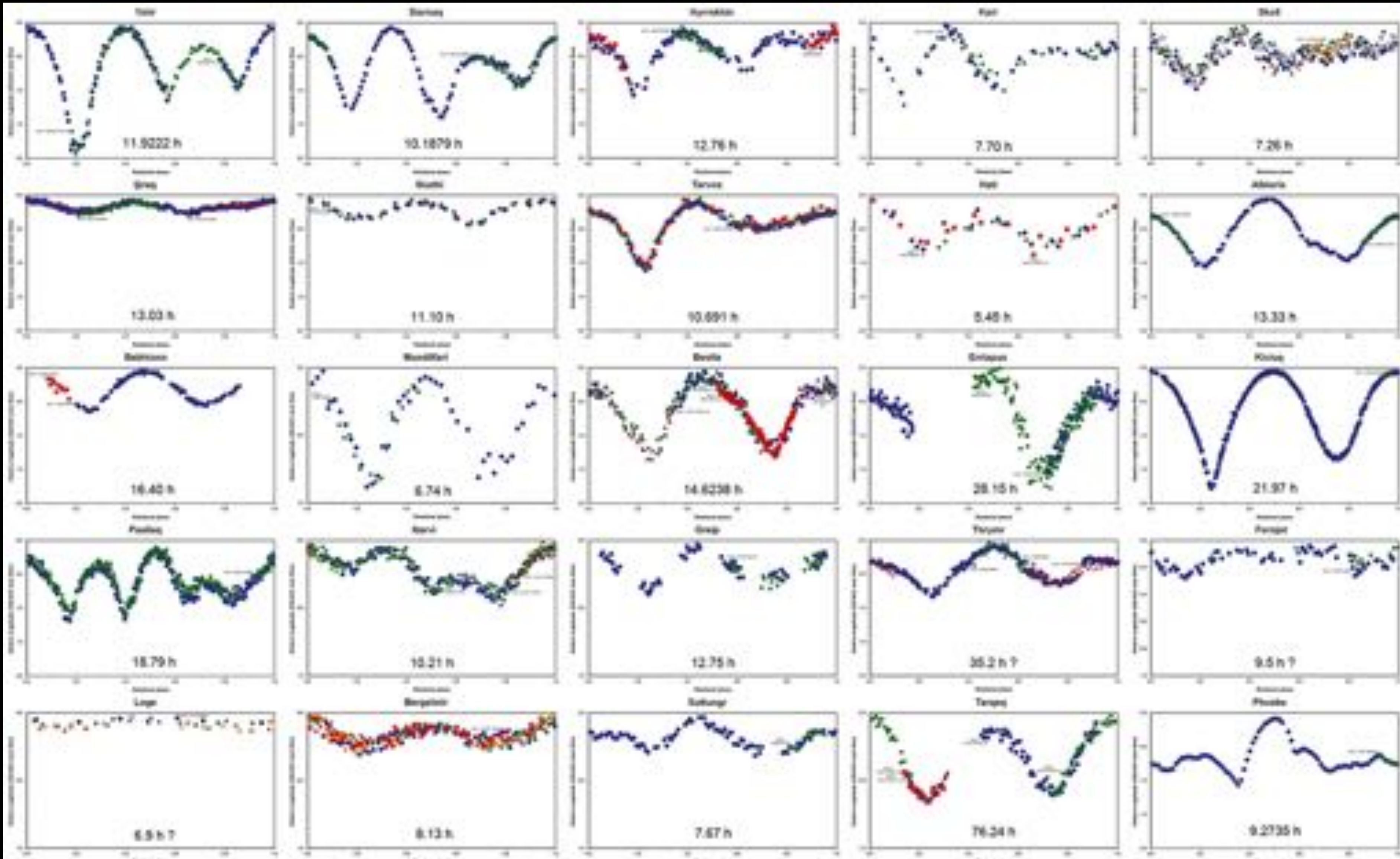
Telesto
Tethys
Calypso
Helene
Dione
Polydeuces
Rhea
TITAN
Hyperion
Iapetus

Kiviuq
Ijiraq
Phoebe

Paaliaq
Skathi
Albiorix
Bebhionn
Erriapus
Skoll
Tarqeq
Siarnaq
Tarvos
Hyrrokkin
Greip
Mundilfari
Bergelmir
Narvi

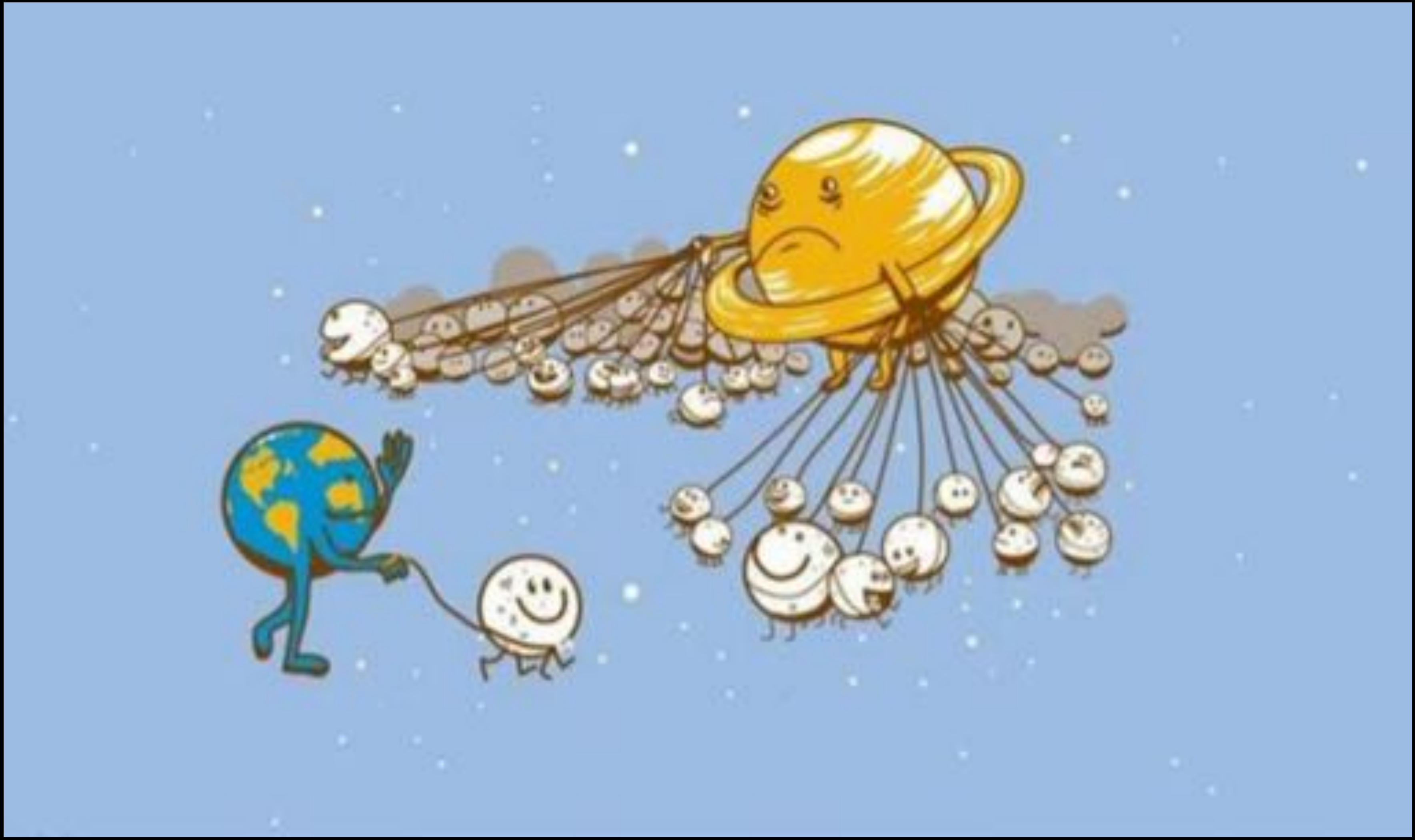
~~Jarnsaxa~~
Suttungr
Hati
Bestla
~~Farbauti~~
Thrymr
~~Aegir~~
Kari
~~Fenrir~~
~~Surtur~~
Loge
Ymir
Fornjot
~~+ 8 unnamed~~

25 irregulars – 25 lightcurves – 25 periods



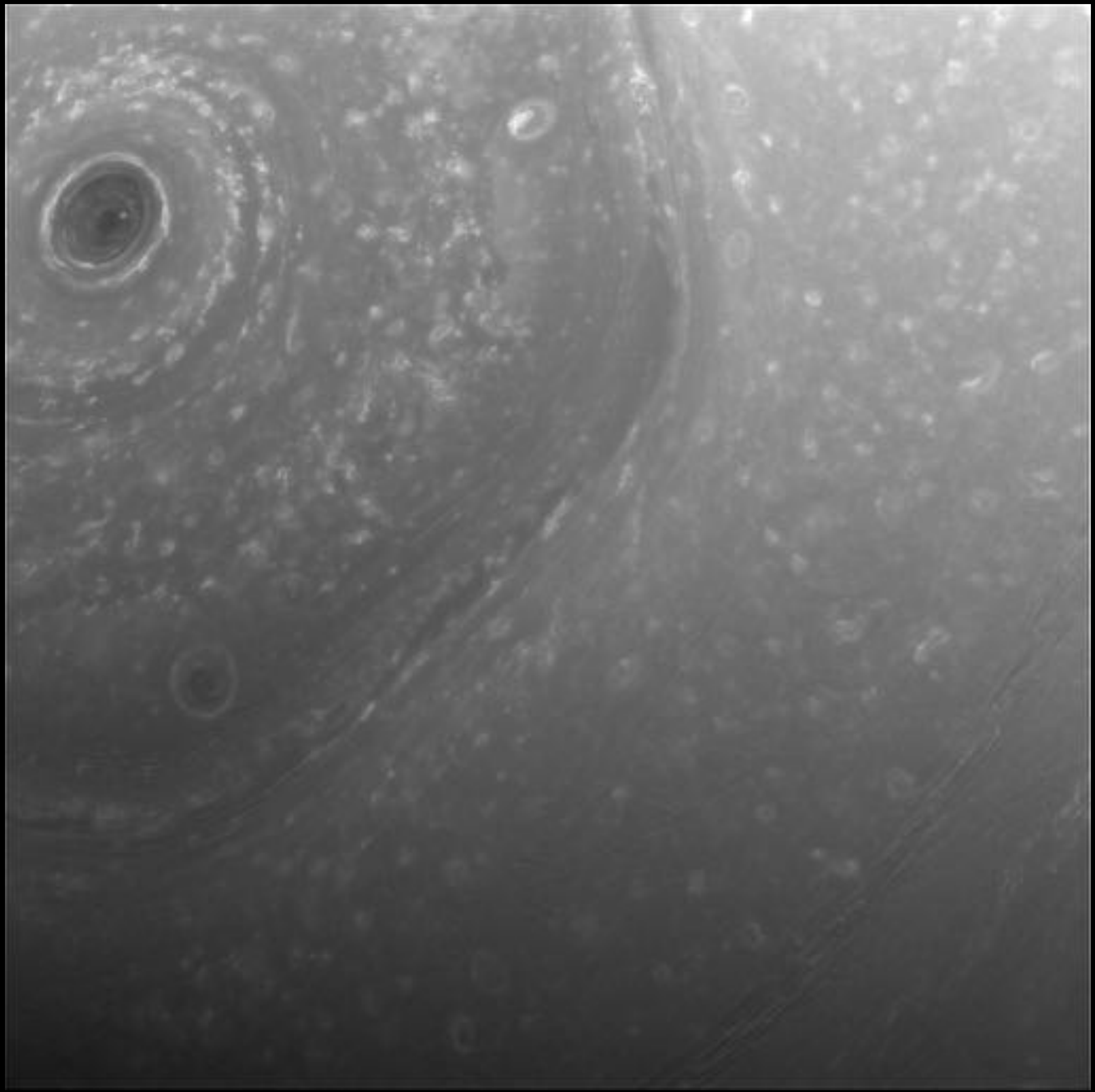
Denk and Mottola (2017a,b)

Saturn – irregular moons



http://www.slideshare.net/zelgandugh/saturns-moons

First Images from Ring-Grazing Orbit



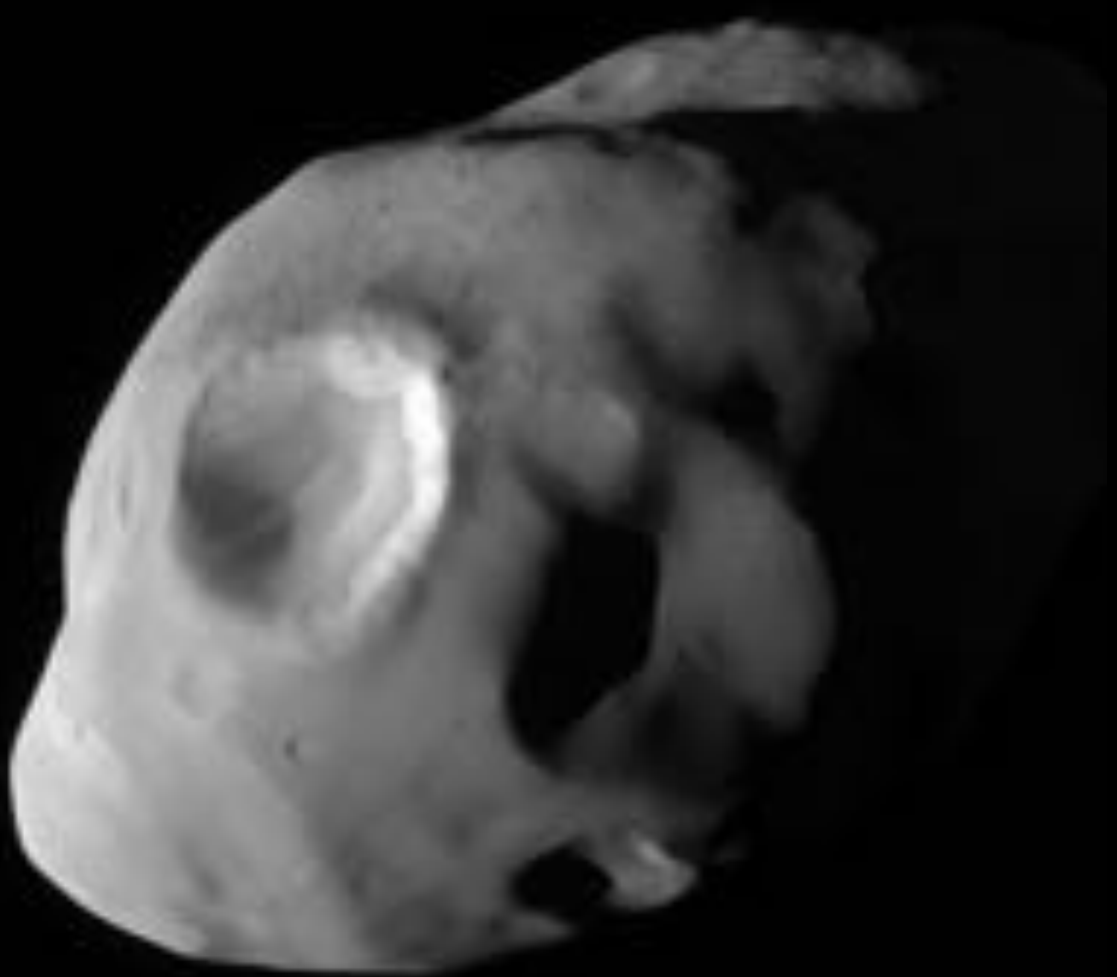
Close Flyby Opens Pandora's Box

Cassini's best close-up of the "shepherd moon" Pandora was taken on December 18, 2016. Pandora's size is 104 x 84 x 63 km and it orbits Saturn just outside the narrow F ring.

This potato-shaped moon has a fine coating of dust-size icy particles that softens its craters. Pandora is called a "shepherd moon" because its gravity constantly repositions particles in the F ring.

Interesting grooves and ridges are seen on the moon's surface.

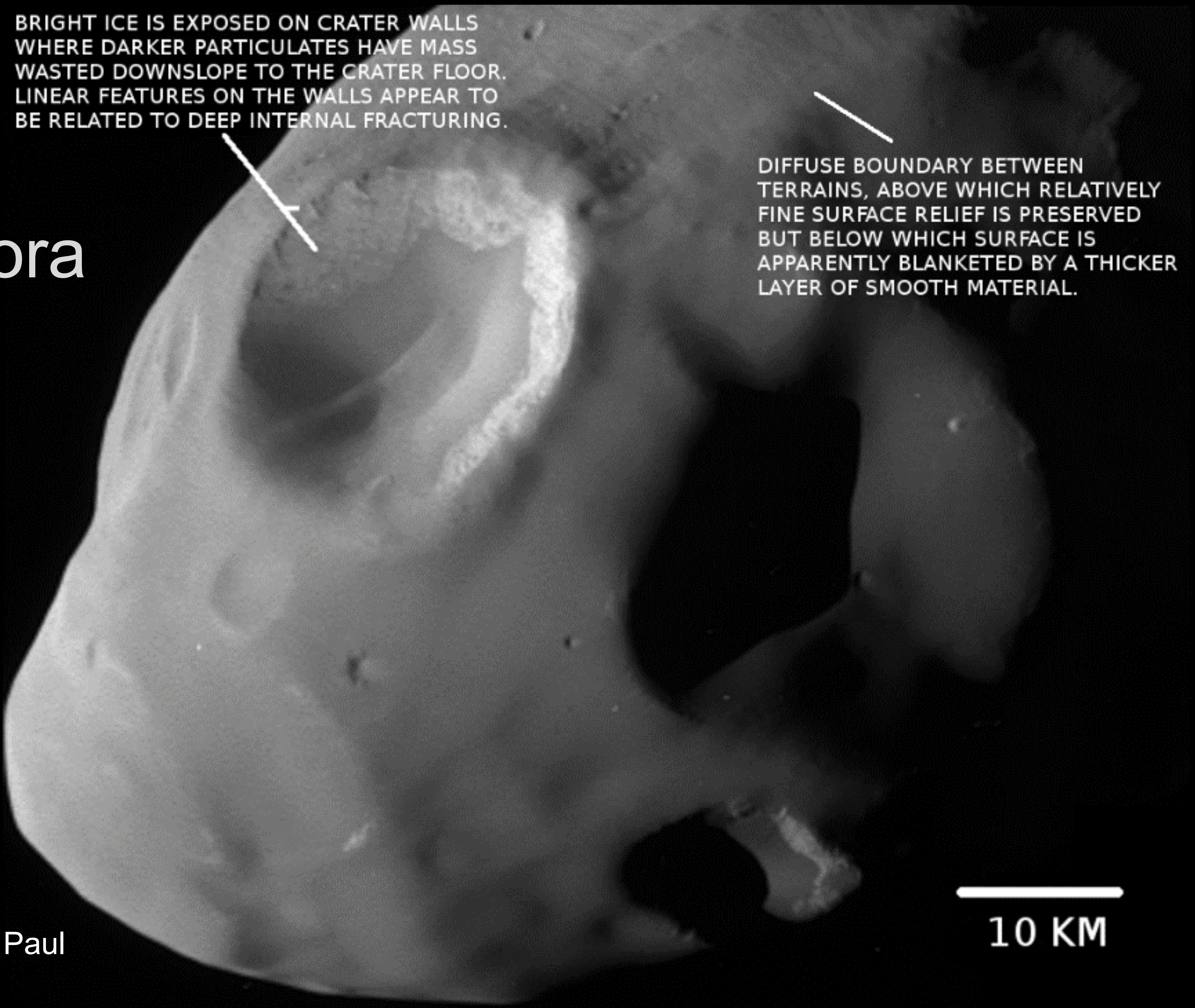
Image scale is 240 meters per pixel. This resolution is 3 times better than previous images of Pandora.



http://go.nasa.gov/2itNqJQ

240 m/pixel (787 feet/pixel)

Pandora



Courtesy of Paul Helfenstein

Closest Epimetheus Flyby

Cassini ‘s best close-up of Saturn’s co-orbital moon Epimetheus was taken on January 30, 2017.

Epimetheus is 130x115x106 km and it shares an orbit with Janus.

Tiny ice particles coat the surface and soften its craters.

Interesting fractures slice its surface.

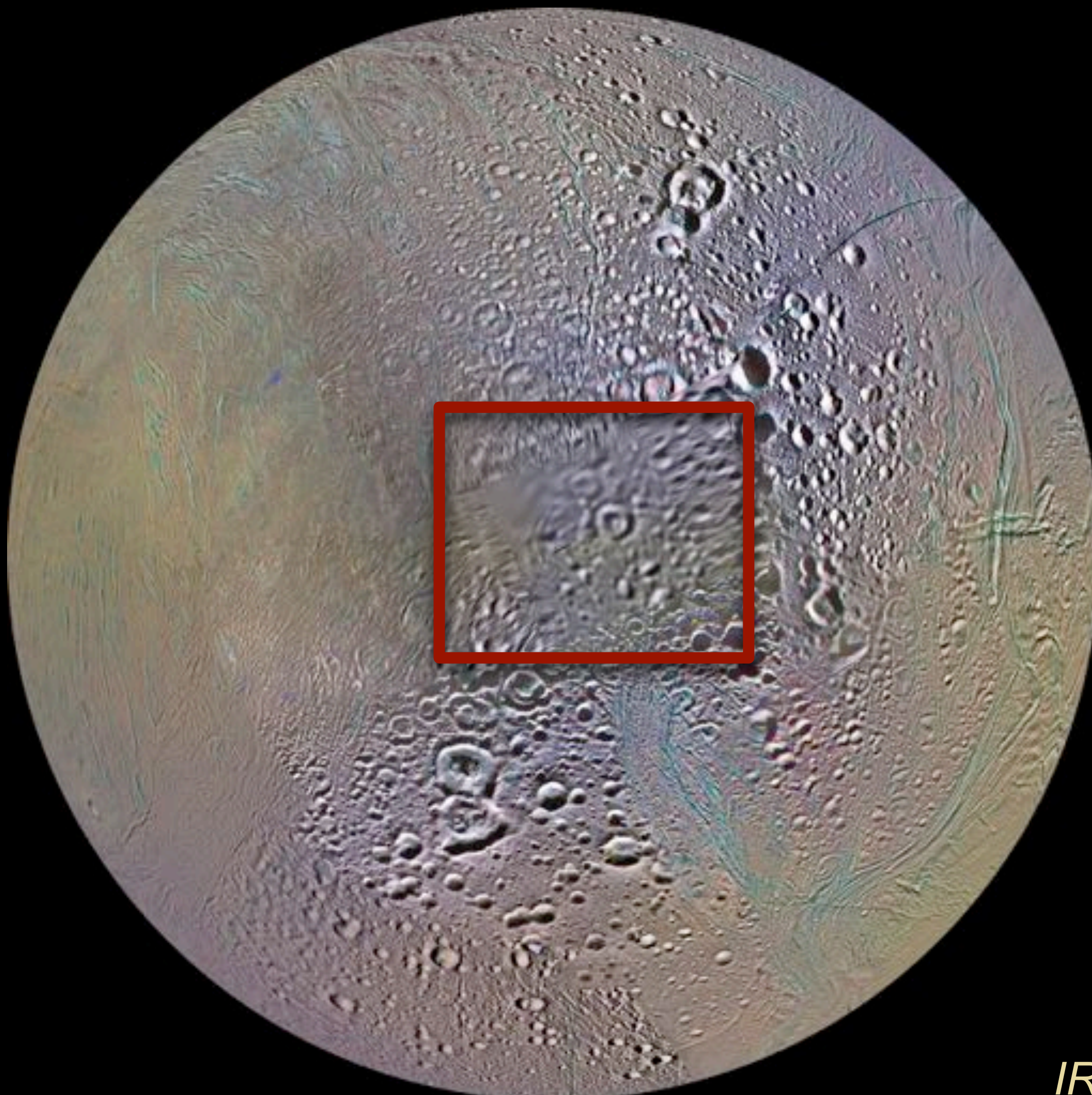
16

Epimetheus

Courtesy of Paul Helfenstein


5 km
Epimetheus

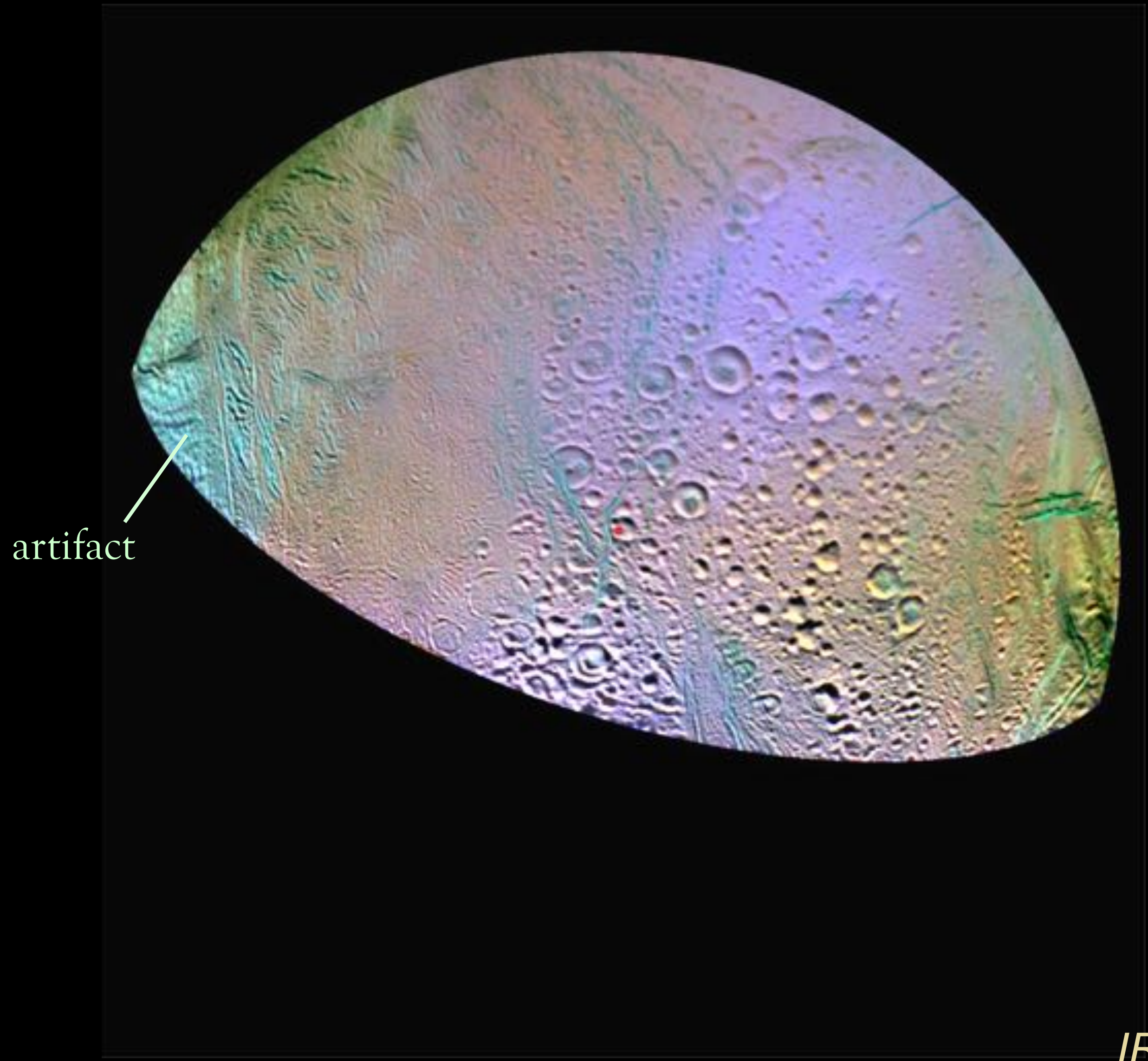
Enceladus North Polar Geology Different than South Pole



2014 mapping relied on Voyager (~1 km/pixel)

IR3 + Green + UV3

Enceladus North Polar Geology Different than South Pole

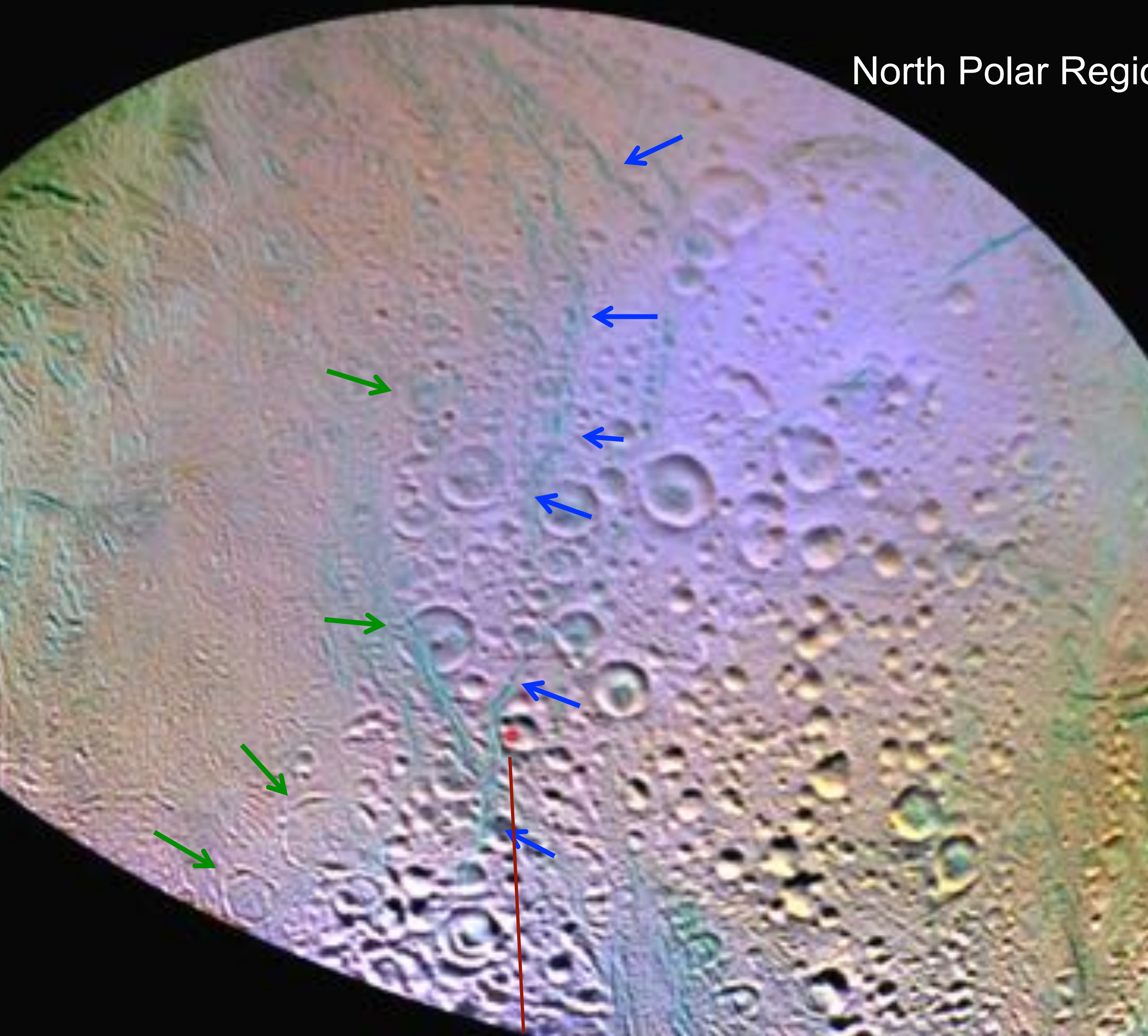


2016 mapping at 250 m/pixel fills NP gap!

Courtesy of Paul Schenk

IR3 + Green + UV3
Color saturated

North Polar Region Geology Revealed!



NP

- *Dominated by cratered terrains*
- *Relaxed craters within 50 km of Pole, some dilated (green arrows)*
- *Young fractures systems within km of Pole (blue arrows)*

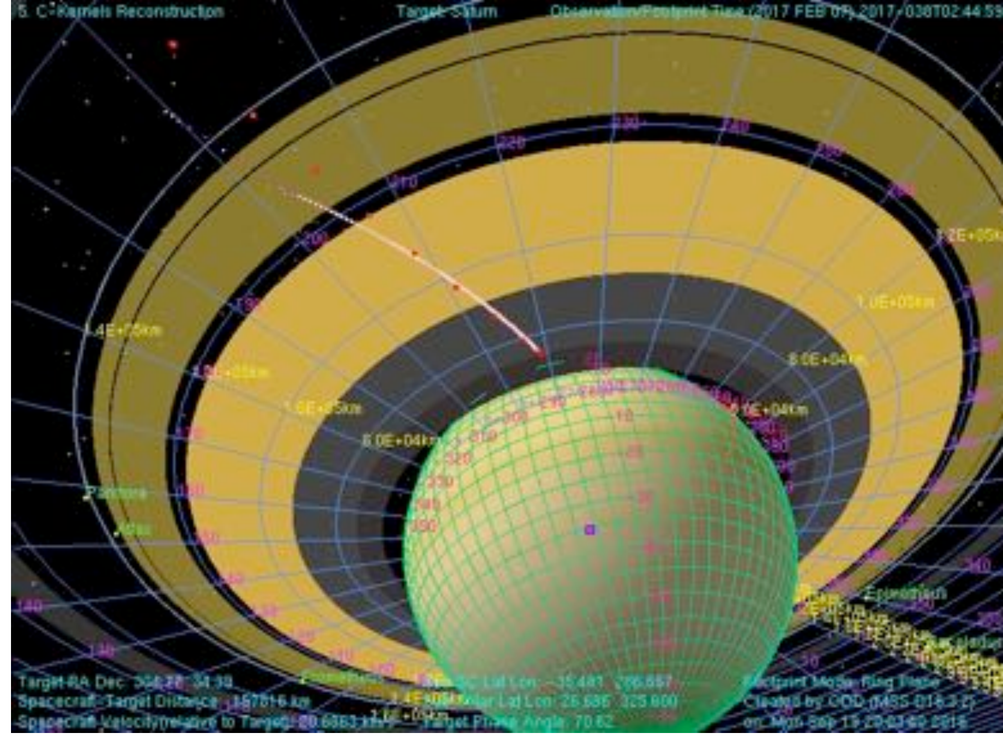
Courtesy of Paul Schenk

IR3 + Green + UV3

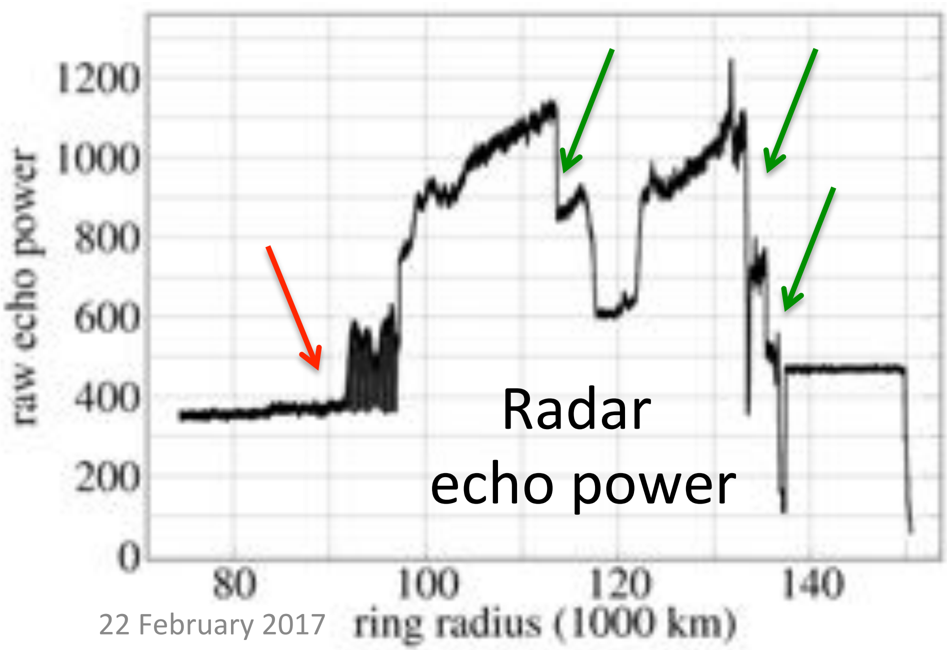
(color contrast enhanced)

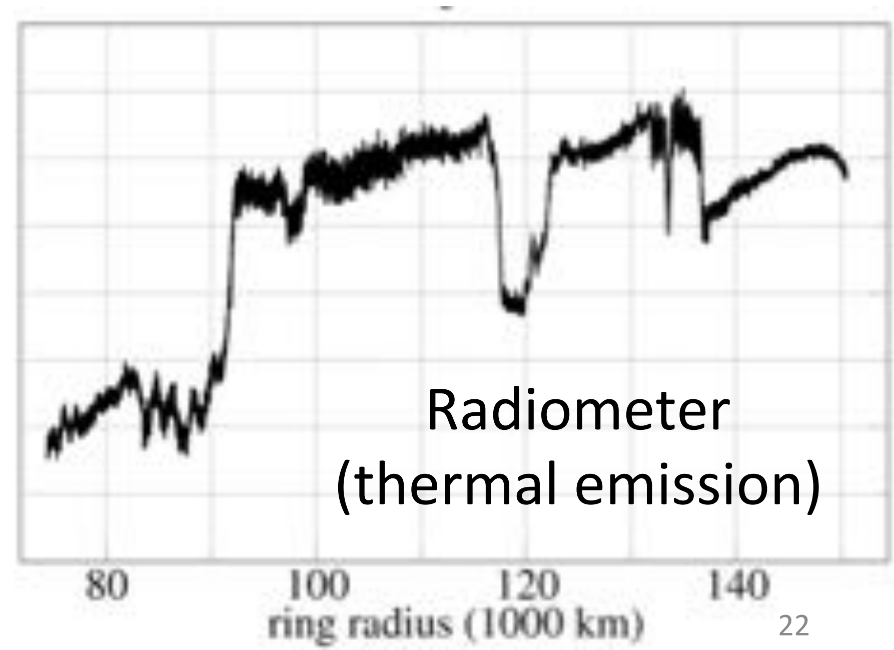
First full active Radar 1-D Imaging Scan

Richard West, Mike Janssen, Zhimeng Zhang



Raw Data:
Changing gain, bandwidth, mode…





First full active Radar 1-D Imaging Scan

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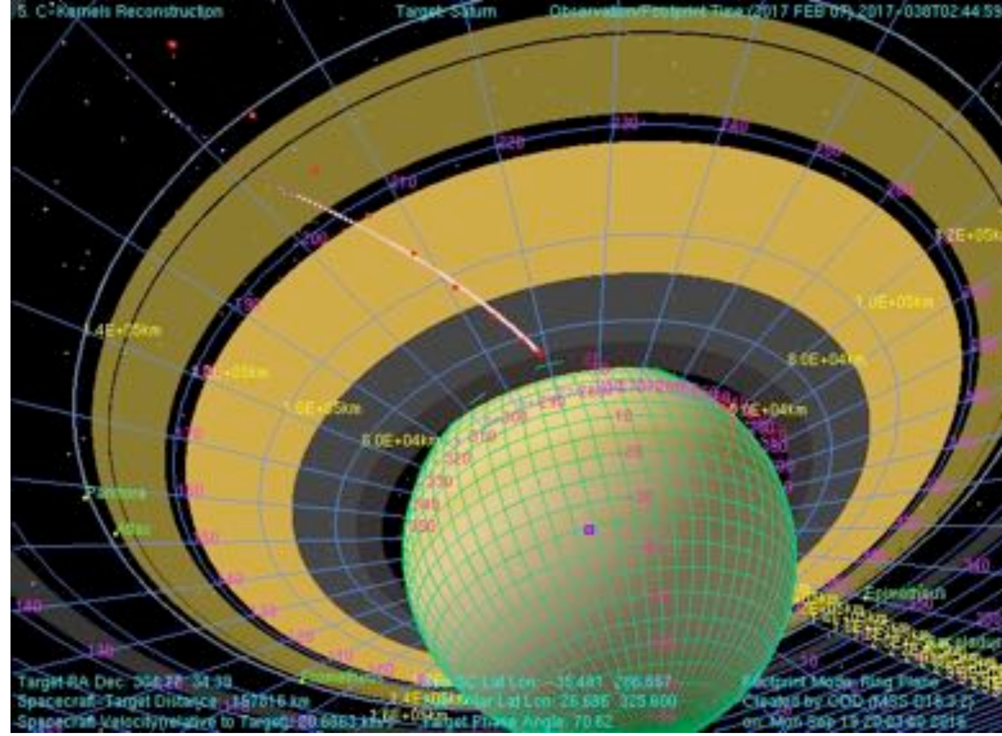
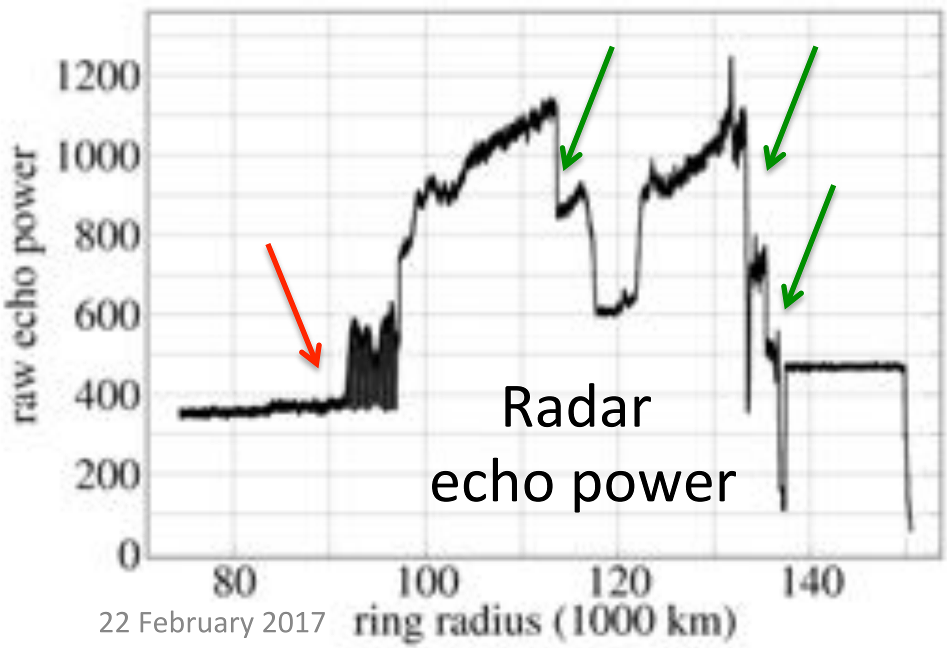


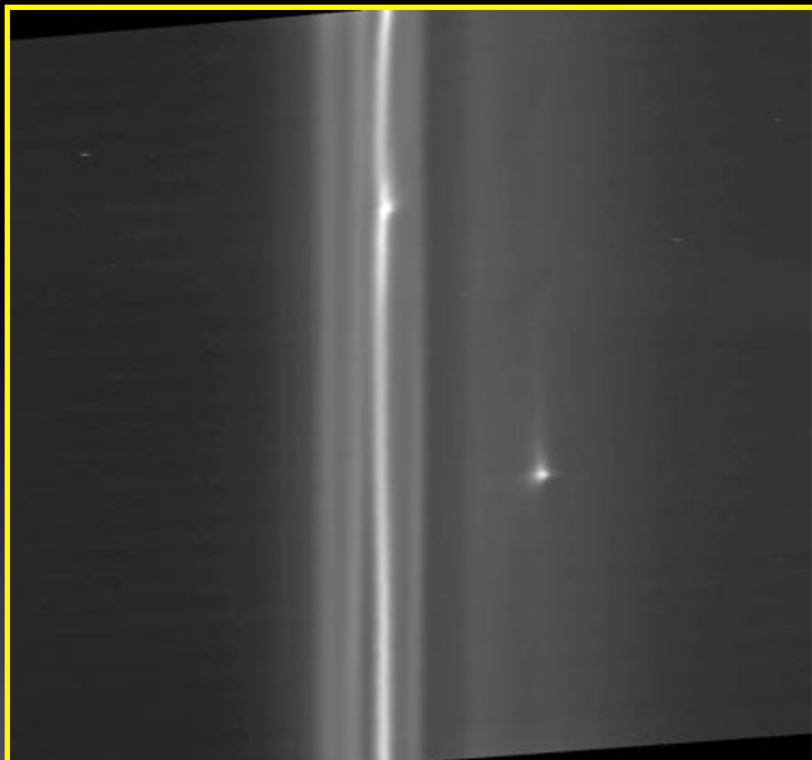
Raw Data:
Changing gain, bandwidth, mode…

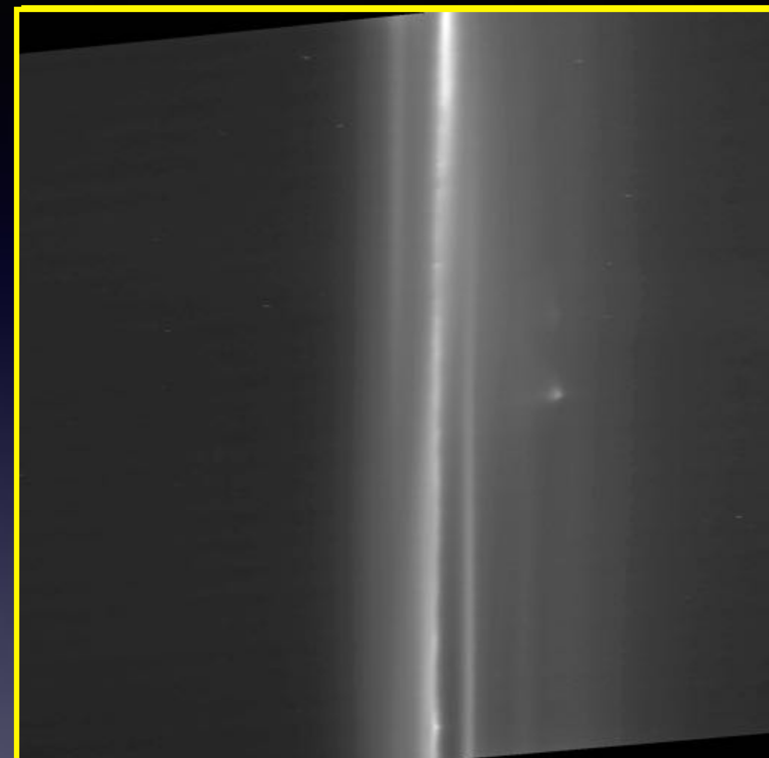


Expect 3-4 km resolution across the rings.
Sub-km resolution in parts of A and C Rings.
(Resolution comparable to best ISS images)

Tracking F ring Objects

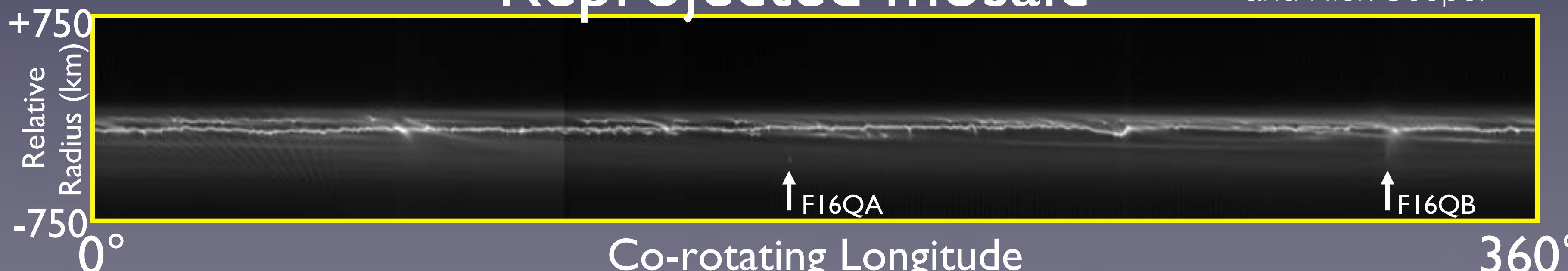
2017-036



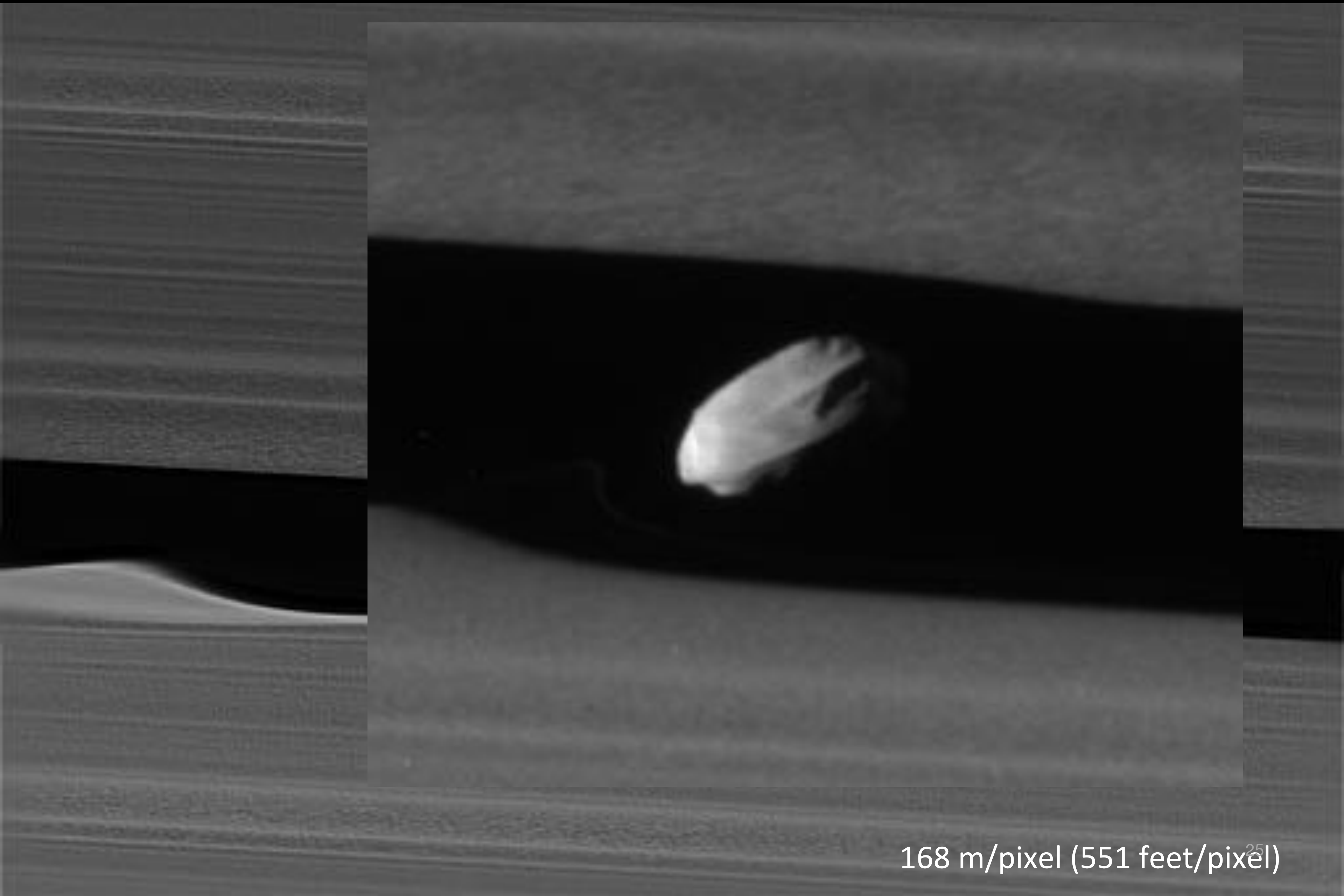


Courtesy of Carl Murray and Nick Cooper

Reprojected mosaic

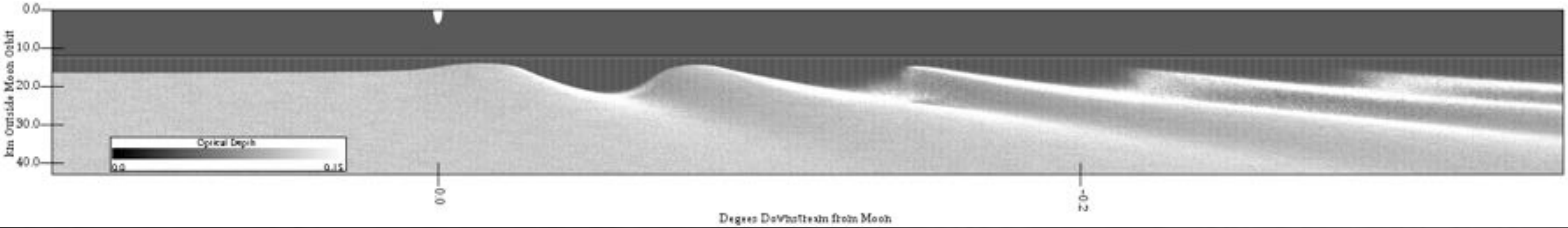


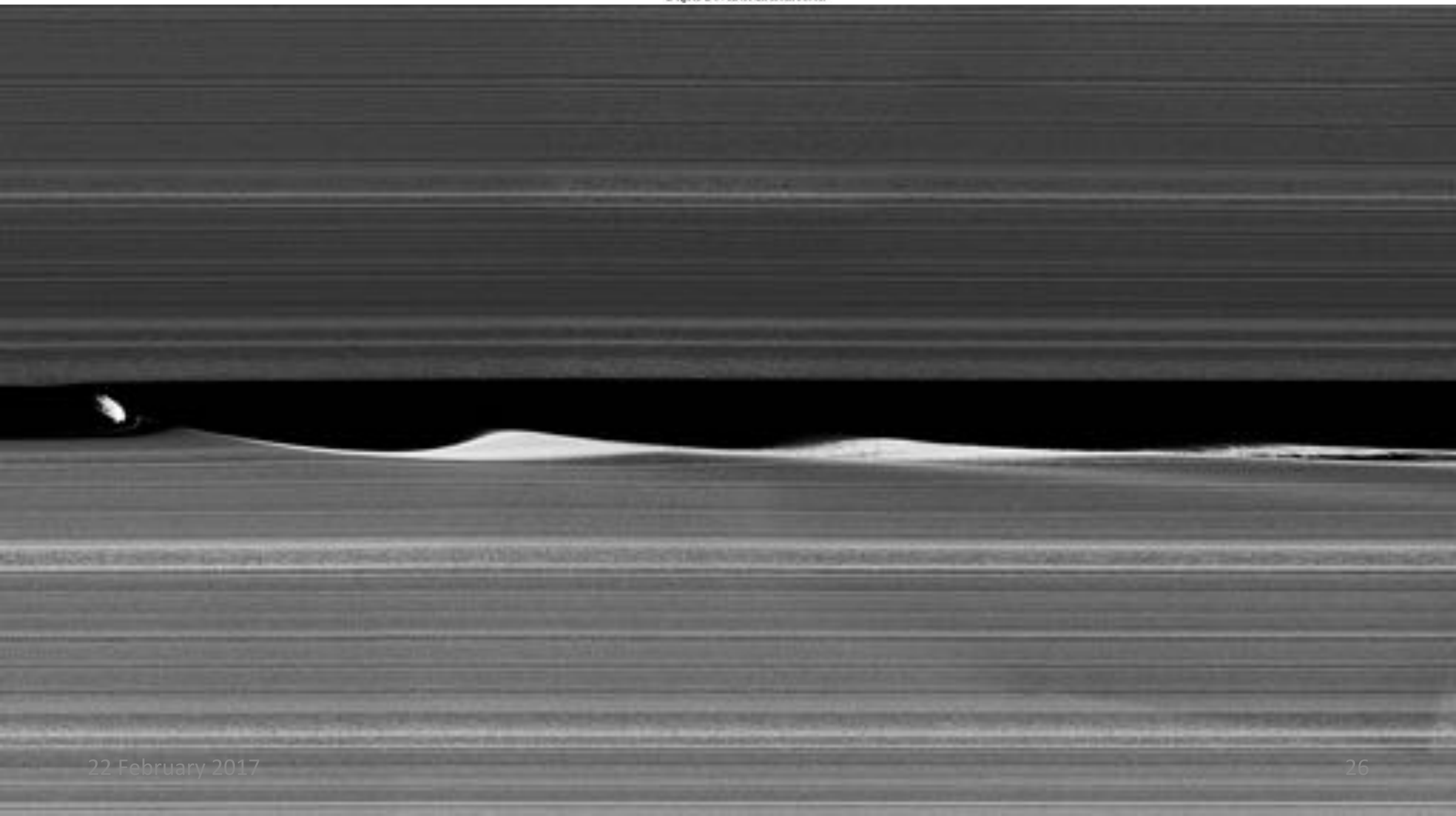
Tiny Daphnis Distorts Edge of Keeler Gap

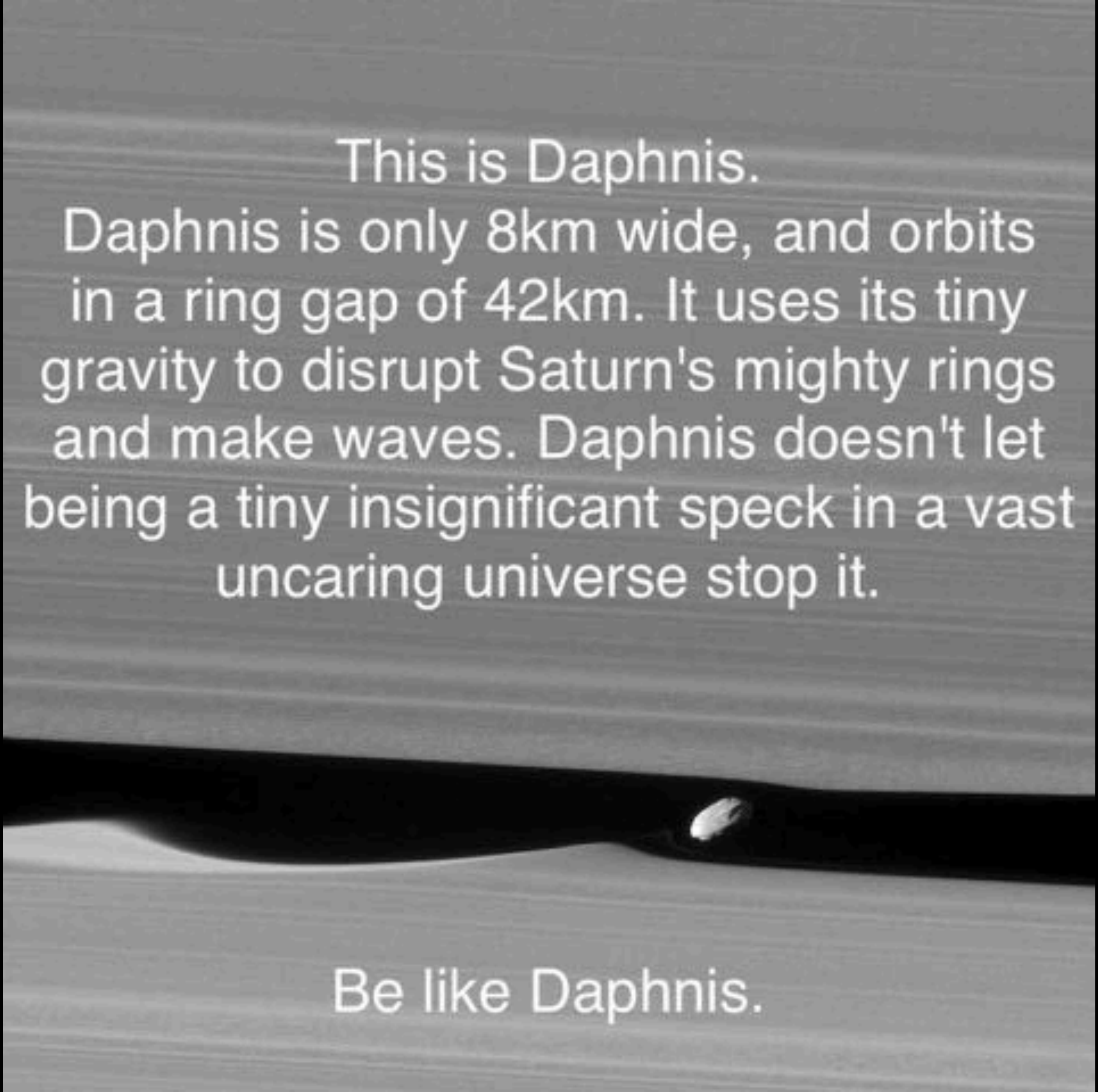


168 m/pixel (551 feet/pixel)

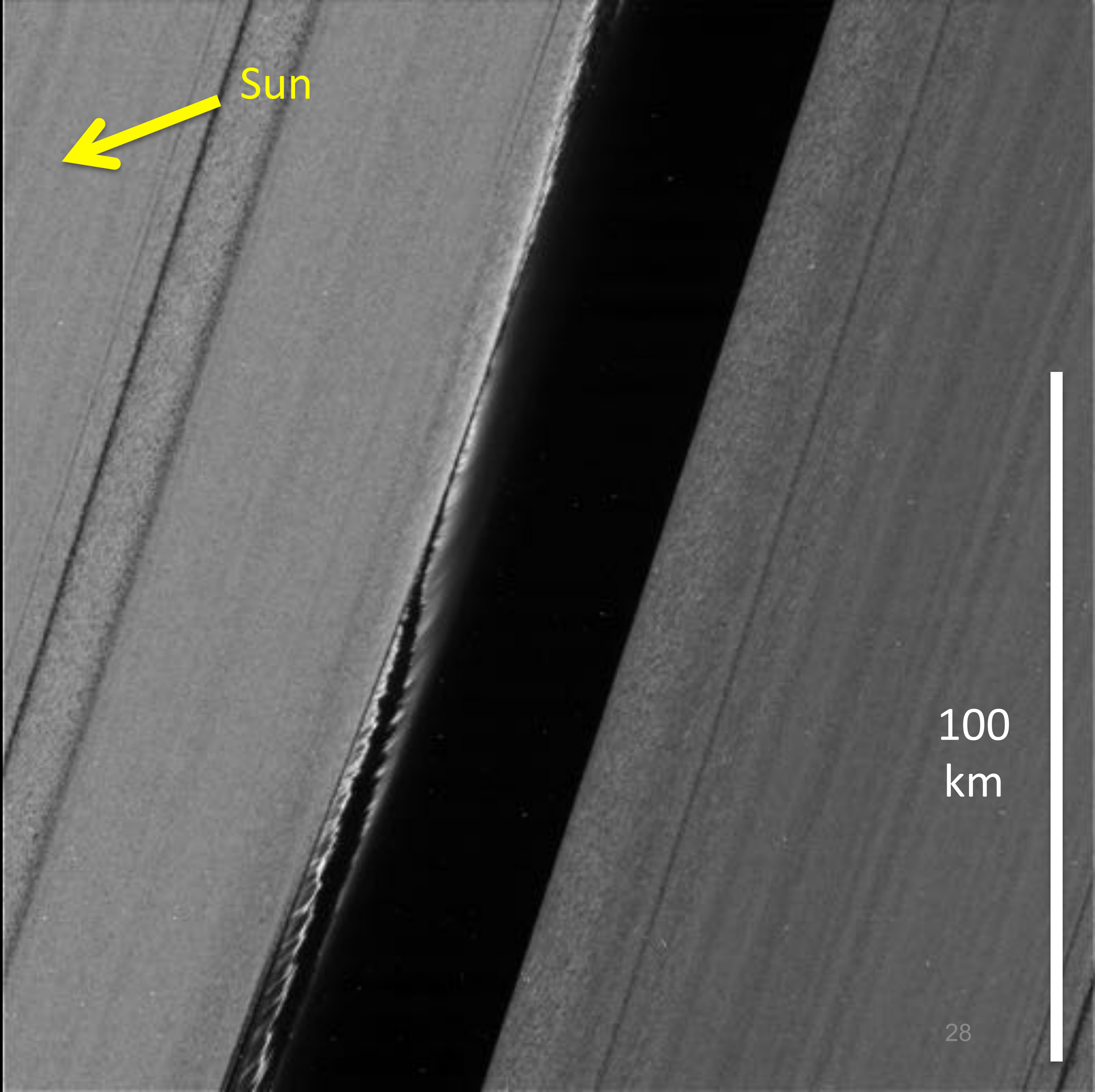
Numerical model with gravity (rotating wth Daphnis) by Mark Lewis (see OSM of Cuzzi et al 2010)





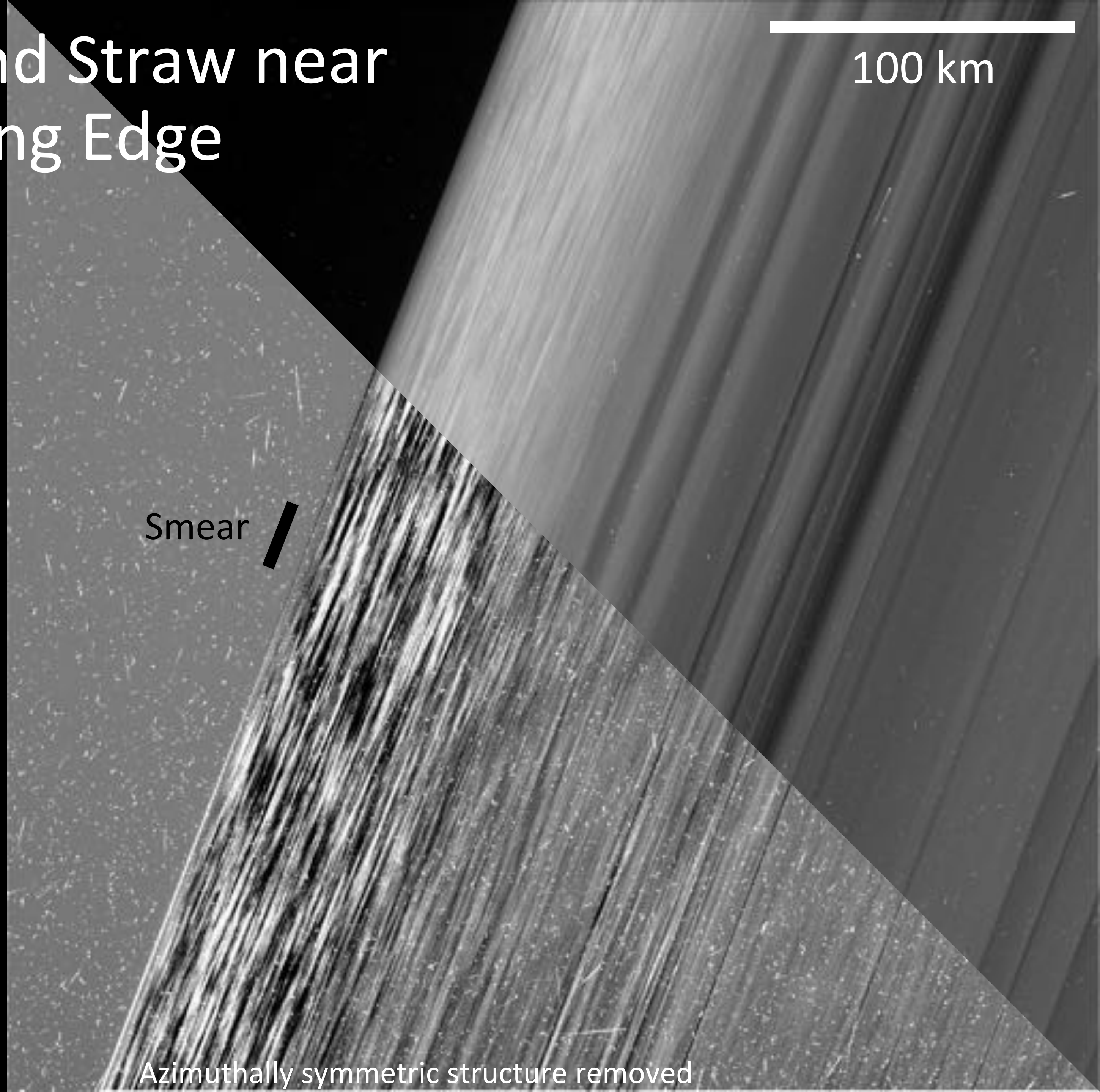

This is Daphnis.
Daphnis is only 8km wide, and orbits in a ring gap of 42km. It uses its tiny gravity to disrupt Saturn's mighty rings and make waves. Daphnis doesn't let being a tiny insignificant speck in a vast uncaring universe stop it.
Be like Daphnis.

Daphnis Making Waves

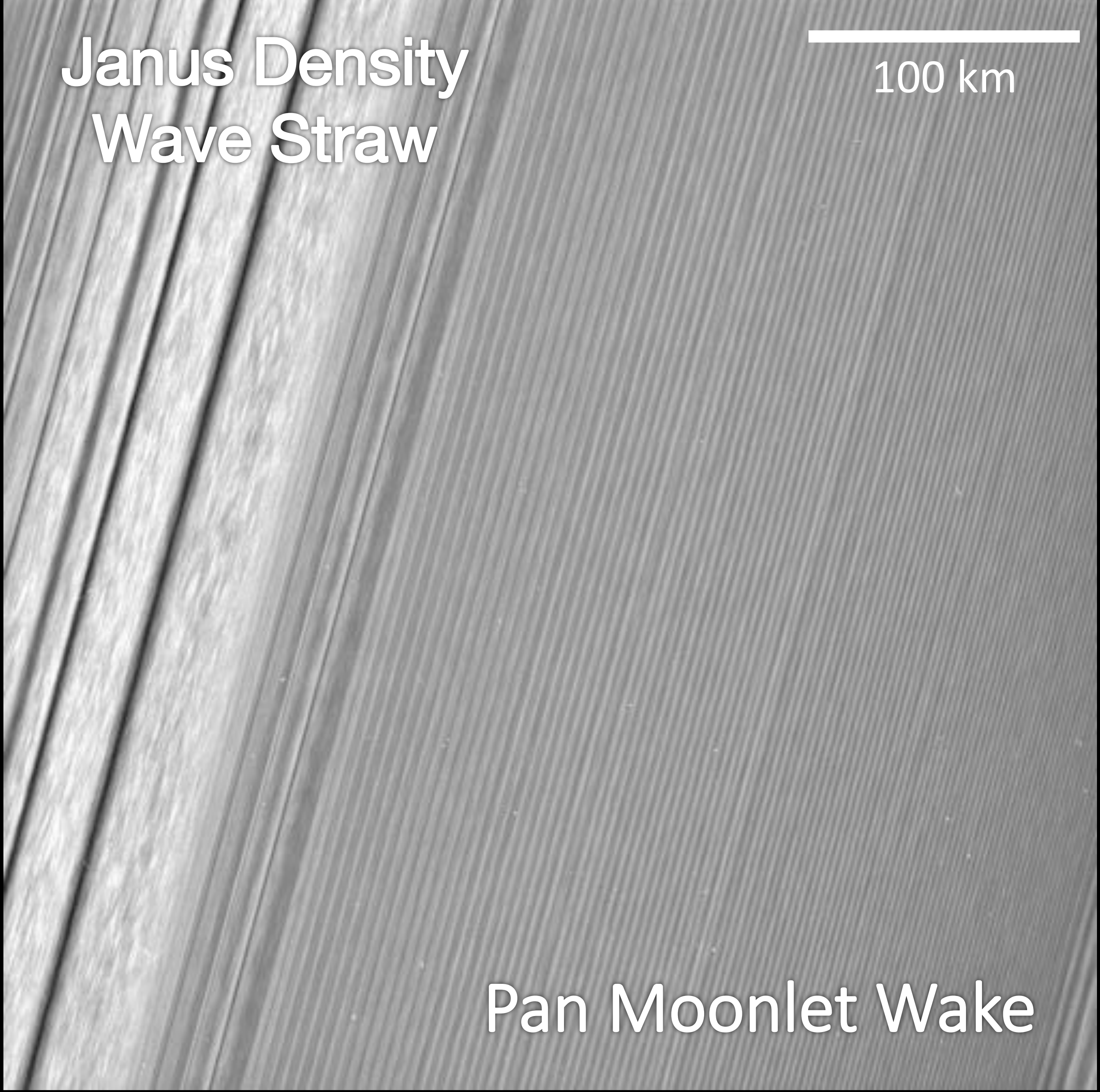


Clumps and Straw near Outer B ring Edge

Clumps and Straw near Outer B ring Edge



Courtesy of Matt Tiscareno


Janus Density Wave Straw
100 km
Pan Moonlet Wake

Going out in a Blaze of Glory: Cassini's Grand Finale

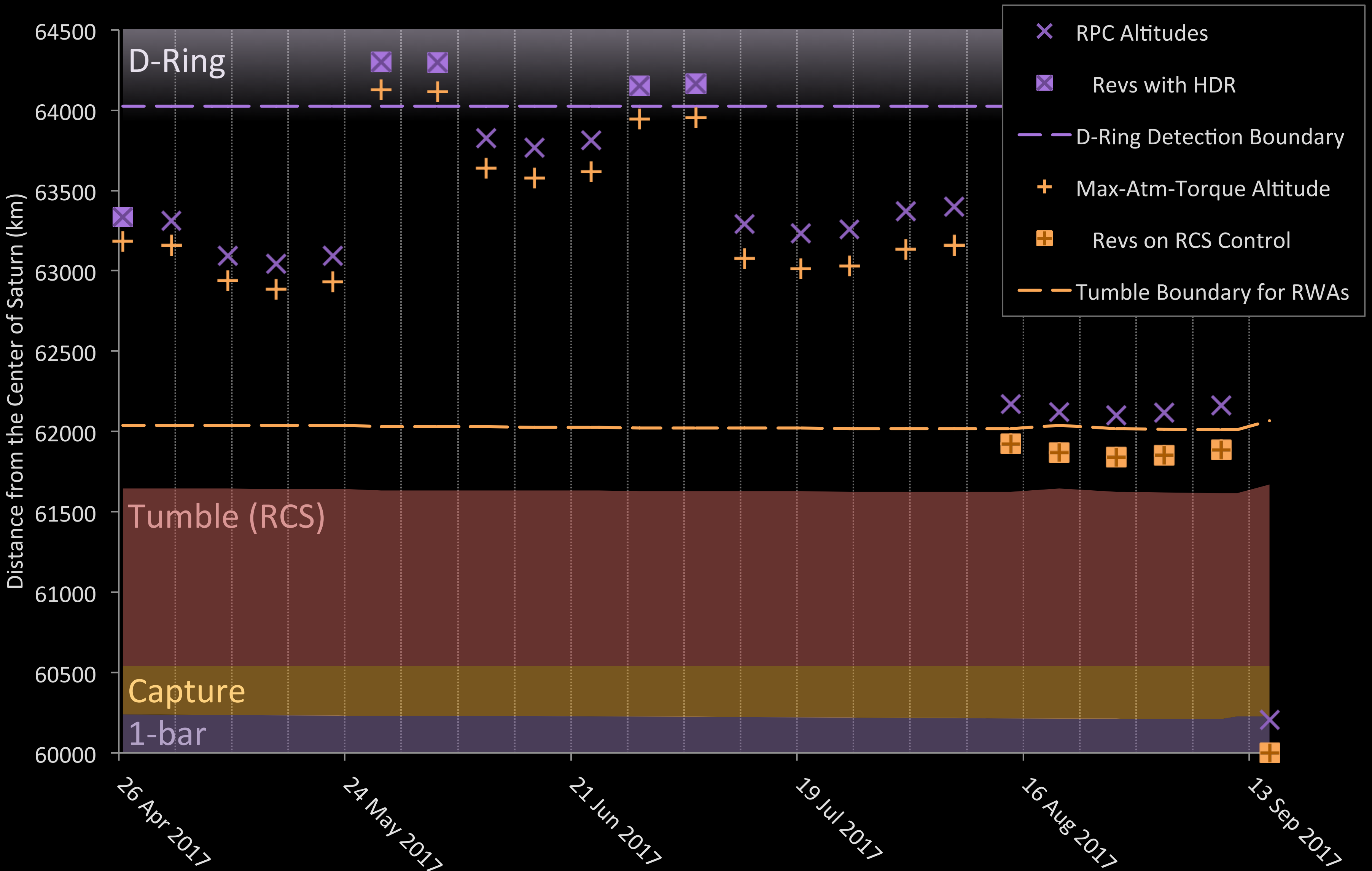
Solstice Mission Trajectory

Ring Grazing Orbits
November 2016 – April 2017

Grand Finale Orbits
April – September 2017

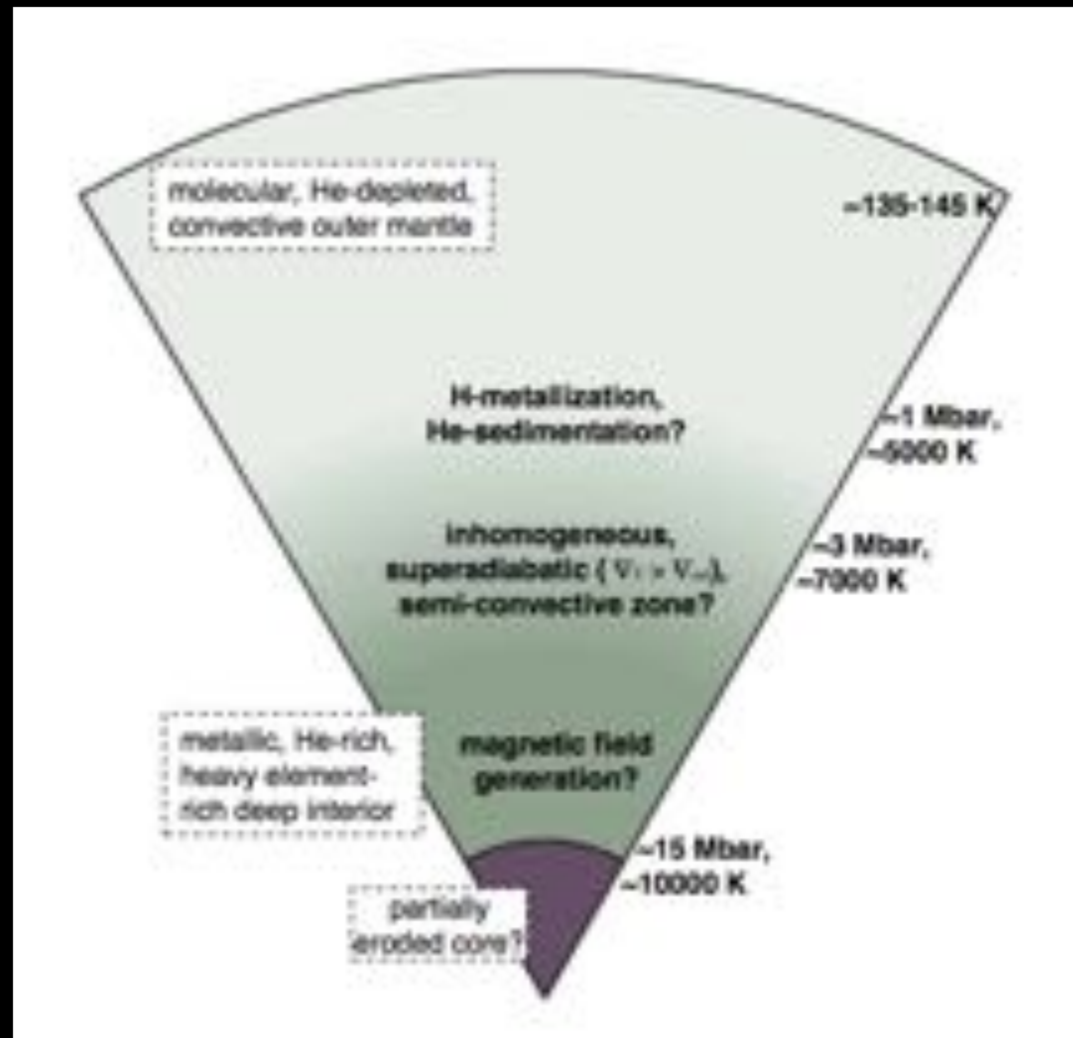
Grand Finale Orbits

Grand Finale Corridor



Probing Saturn’s Interior: Magnetic Dynamo Region and Rocky Core Size

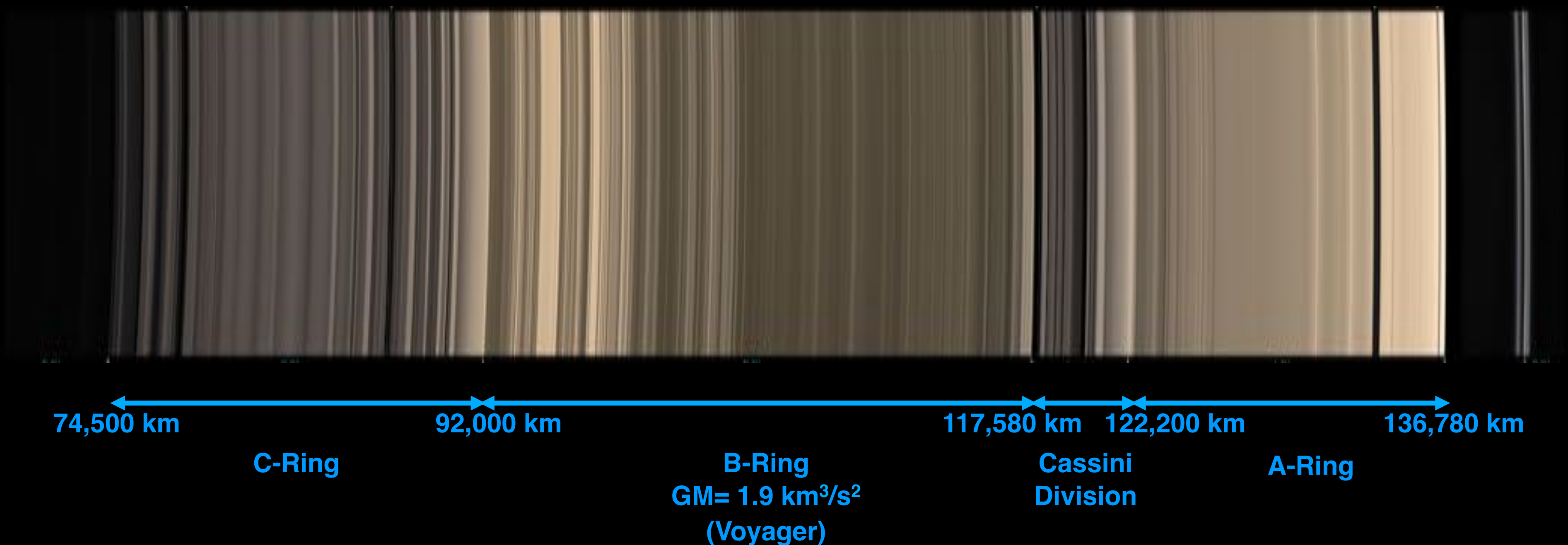
- Magnetic field measurements to probe magnetic dynamo region, why little or no axial tilt?
- Gravity field measurements (up to J10) to probe interior structure and estimate size of Saturn’s rocky core
- Rocky core is the seed that attracted all the gas as Saturn was forming



Probing Saturn’s Interior: Winds and Internal Rotation Rate

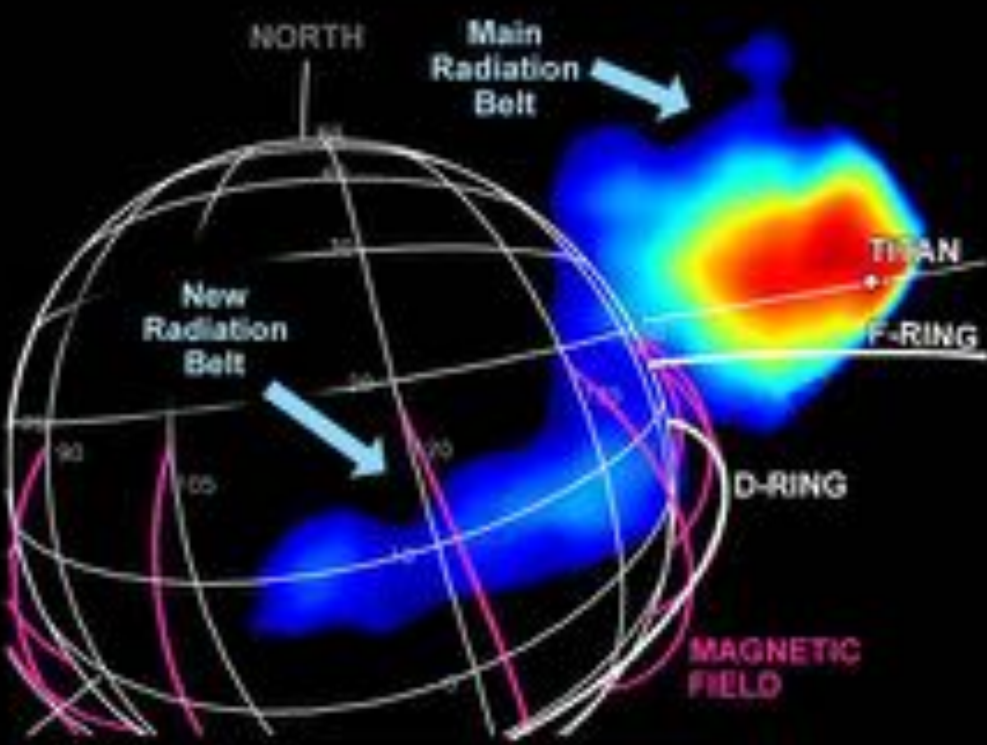
- Saturn’s internal rotation rate
  - Search for a wobble in the magnetic field
- Depth of Saturn’s winds
  - Measure depth of irregularities in the gravity field

Ring Mass: Constrain age of rings



- Current uncertainty in ring mass is 100% of nominal value
- 6 gravity passes to measure total ring mass will reduce uncertainty to about 5%
- Less massive: young rings; more massive: old rings

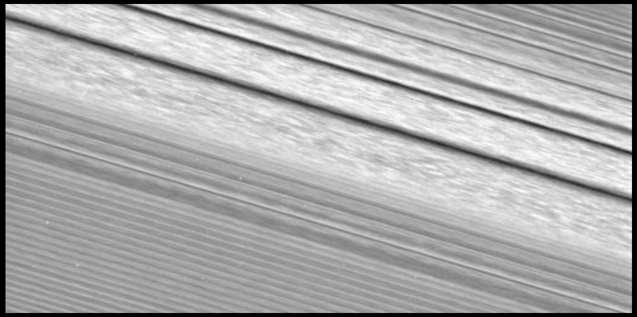
First *In Situ* Measurements of Ionosphere and Innermost Radiation Belts



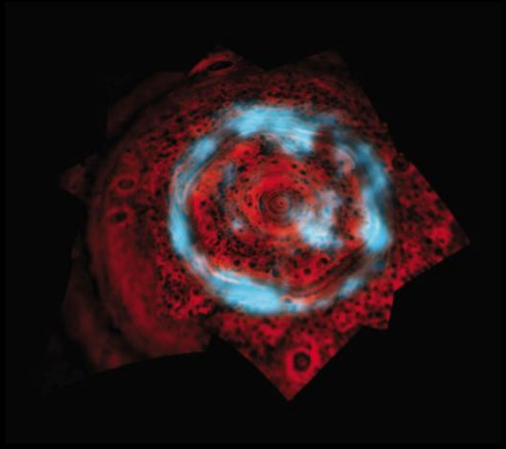
- Strength of innermost radiation belt
- Plasma composition

Final Orbits Science: Unique Observations

- First ever direct measurements of ring particle composition



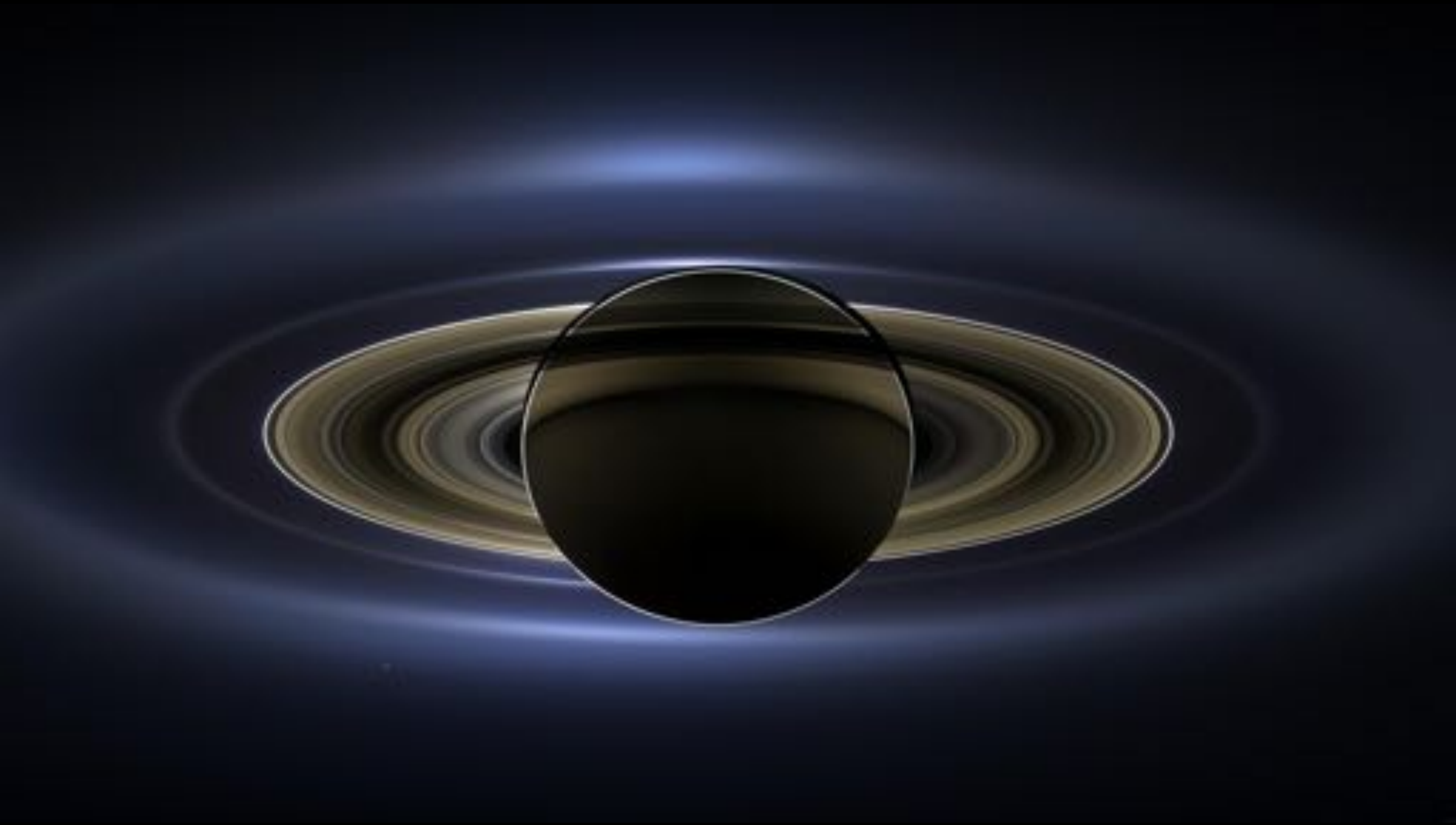
- Highest resolution main ring observations
  - Radio occultation, imaging
  - First active Radar



- Highest resolution Saturn polar observations and aurora

Direct Sampling of Saturn's Atmosphere

Questions?



Backup

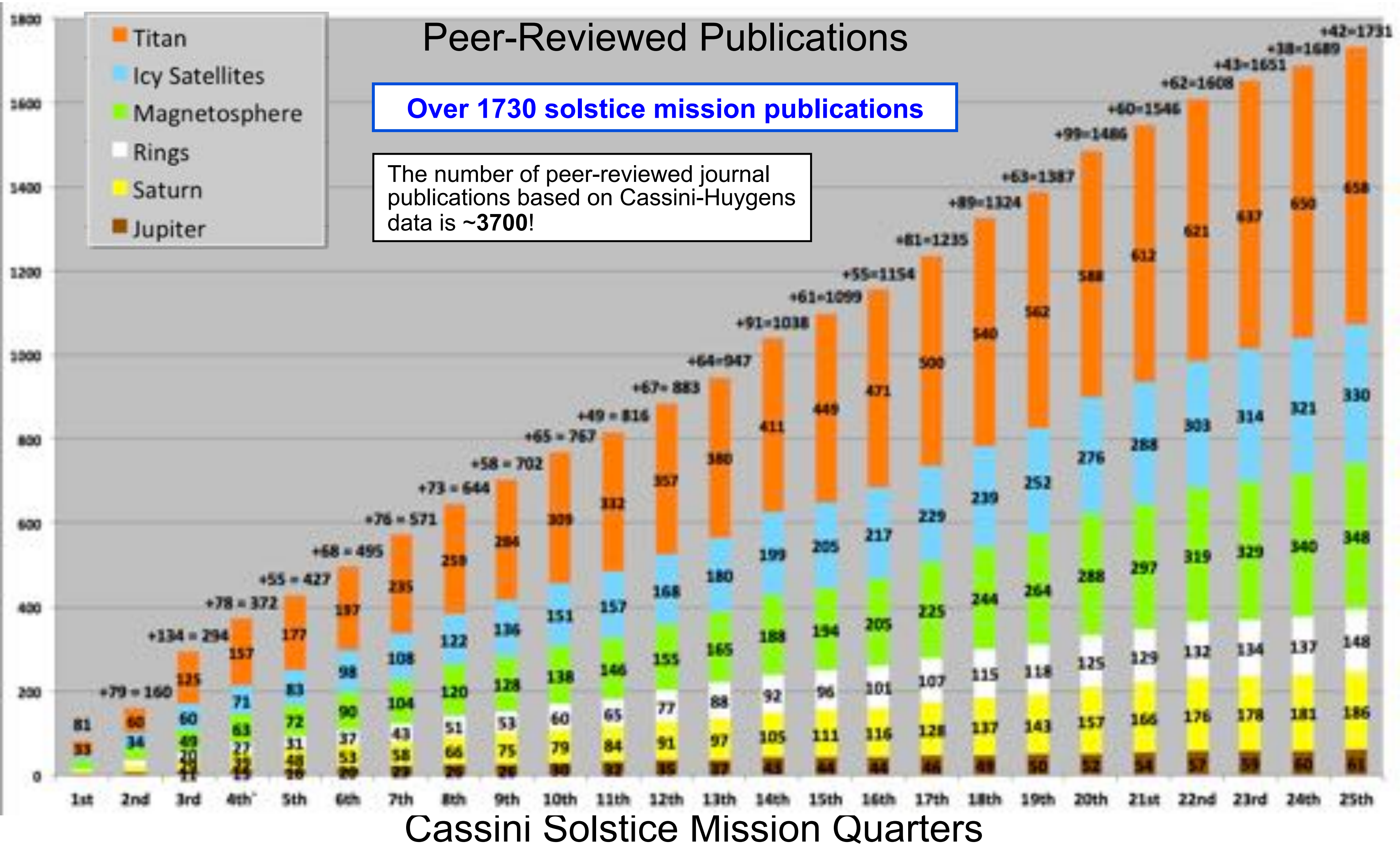
Upcoming Bests/Lasts

First of the Best Main ring close-up images	Dec-Apr 2016-2017	At very close range, Cassini will target points of special interest in the main rings, taking images whose combination of resolution and signal-to-noise will make them the best ever.
First of the Best Propeller close-up images	Feb-Apr	Cassini will target known propellers Santos-Dumont (262, both lit and unlit sides), Earhart (266), and Bleriot (269) at better than 1 km/pixel, revealing new details of propeller structure.
Last Epimetheus	February 21	Third closest
Best Pan (22K)	March 7	
Last Images to search for impact clouds	March 8	While in Saturn's shadow, Cassini will look at the rings with the Sun almost directly behind, in the hopes of catching impact ejecta clouds with their dust brightened in the backlit geometry.
Last Tethys (Red Tethys)	March 14	
Best Atlas (11k)	April 12	
Best High-phase mosaic	April 13	The closest opportunity for ISS to obtain a complete WAC mosaic of the rings at phase angles above 165 deg, during a solar eclipse period. Approx 60 frames will be required.
Last inner satellite orbit (satellorb)	April 18	
Last Targeted Titan flyby	April 22	
Last Taste of the atmosphere	April 23	
Last RADAR pass over the seas	April 23	
Best Timespan looking for lake changes	April 23	
Last Look (or not) at Magic Island	April 23	
First Look at the elevation of small lakes (possibly depth/composition)	April 23	
Last High-phase mosaic	April 26	The last opportunity for VIMS and ISS to observe the D, F and G rings at phase angles above 165 deg, during a solar eclipse period.
Best look at Saturn's North Pole with CIRS & VIMS	April 26	Highest resolution of the mission by a factor of 4.
First of the Best Remote Sensing views of Saturn	April 26	Also revs 281 (June 29), 291 (TBC)
Last Rhea	May 1	CIRS global composition
First of the Best Good look at Saturn Gravity	May 8	10x improvement over previous Also rev 284 (July 18)
Last South Polar Gas/Temperature Map	May 24	
Last Iapetus	May 30	
Best Orion's Belt Photo Op + Tethys Occultations (spectacular!)	June 6	
Last Periodic Engineering Maintenance	June	
Last Reaction Wheel Assembly	June	
Last Solar occultation	June 17	This is the last of a series of solar occultations carried out by VIMS and UVIS to determine particle sizes and transmission spectra for the rings.
Last AACS default update	June 27	
Last & Best Highest resolution ISS imaging of Saturn	June 29	Last of 2 ISS "noodles" - Continuous hi-res WAC imaging from pole to pole.
Last RSS ring occultation	July 6	The final standalone radio occultation of the rings to be observed by RSS, to complete the longitude coverage provided by the occultations obtained during the 6 gravity passes.
Best/Last Highest resolution ultraviolet image of the C ring	July 6	First and last opportunity for UVIS to resolve plateaus in the C ring.

Upcoming Bests/Lasts

Last Planned AACS sun sensor checkout and last one requiring a turn commanded by AACS	July 7	
Last Background sequence goes active on the spacecraft	July 10	
Last High-res images of the main rings	July 12	The final part of the Grand Finale's multi-rev radial scan of the main rings will likely be the last images able to resolve spiral density waves etc.
Last Main engine cover opening (unless we do a popdown maneuver)	July 14	
Last planned maneuver	July 15	
Last Saturn Gravity Pass	July 18-19	Last of 6 Gravity passes of the proximal orbits.
Last Enceladus thermal observation	August 1	
Last Dione	August 3	Plume search
Last Observation of another non-Saturn planet (Neptune)	August 10	Possibility of another Neptune obs on rev 288
First of the Best Saturn Radar swaths	August 14	Also revs 290 (Aug. 27), 292 (Sept 8)
Best Particle tracking occultation in B ring	August 15	Particle tracking occ with 3 m resolution in the particle frame in the B ring.
Best Particle tracking occultation in C ring	August 16	Particle tracking occ with 6 m resolution in the particle frame in the inner C ring.
Best look at Saturn's South Pole with CIRS & VIMS	August 20	Highest resolution of the mission by a factor of 4. Cooler outbound temperature will provide for the best SNR for highest spatial resolution.
Best VIMS Southern Aurora	August 20	H_3^+ mapping
Best RADAR mapping of Saturn	August 27	Best resolution of the mission by an order of magnitude.
First active radar measurement of Saturn	August 27	
Last Enceladus plume observation	August 28	
Last Particle tracking ring occultation	August 29	
Final Ring Plane crossing	September	
Final auroral field line crossing	September	
Lowest Saturn altitude achieved	September	
Last irregular satellite observation	September 5	
Last propeller images	September 7	After tracking propeller orbits over the life of the mission, Cassini will do its final check-up on our friends Bleriot, Earhart, etc., one week before the mission ends.
Last full INMS Pass (Saturn)	September 8	Final INMS sampling of Saturn's atmosphere over several latitudes.
Last Titan North Polar Gas/Temperature Map (closest to solstice)	September 11	
Last Images of Saturn and the main rings	September 13	After the final Titan flyby, the 293 FAREWELL images will be the last before Cassini's final descent.
Last Look at Titan's north polar regions and seas	September 13	
Farewell to Titan	September 13	
Last Enceladus	September 13	
Last Switch from reaction wheels to thruster control X hours before final plunge	September 14	

Cassini Publications



Enceladus and the Icy Moons of Saturn

University of Arizona
Space Science Series book

P. Schenk, R. Clark, C. Howett, A. Verbiscer, J.H. Waite (editors)

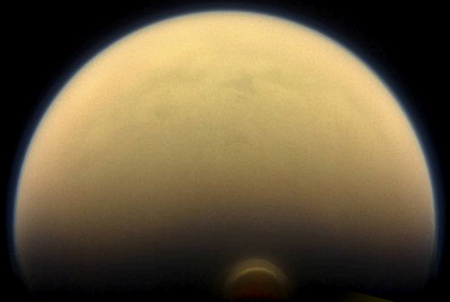
January 2018

Notional Title	Lead Author
ENCELADUS GEOPHYSICS GEOLOGY GEOCHEMISTRY	
History of Enceladus Discovery	**Dougherty**
Composition of Enceladus: Origin and Evolution	**McKinnon**
Interior of Enceladus	**Hemingway**
Geophysics/Tidal-Thermal Evolution	**Nimmo**
Geologic History & Tectonics of Enceladus	**Patterson**
ENCELADUS PLUMES and E-RING	
Plume and Surface Composition	**Postberg**
Enceladus Ocean Composition & Dynamics	**Glein**
Plume Vents and Dynamics	**Goldstein**
Plume Plumbing and Origins (Ocean to Surface)	**Spencer**
E-ring and its effects on Enceladus and the Saturn System	**Kempf**
Enceladus and Its Contribution to Saturn's Magnetosphere	**Smith**
SATURN'S ICY MOONS	
Geology of the Midsize Icy Moons	**Schenk**
Geophysics/Interiors and Thermal Evolution of the Midsize Icy Moons	**Castillo**
Surface Composition of Icy Moons	**Hendrix**
Icy Moon Atmospheres/Exospheres from Magnetospheric Interactions	**Teolis**
Ring/Magnetosphere Interactions with Satellite Surfaces	**Howett**
Surface Properties of Saturn's Icy Moons	**Verbiscer**
Cratering Histories in the Saturn System	**Kirchoff**
Saturn's Small Inner Icy Moons (and Hyperion)	**Thomas**
Phoebe and Saturn's Captured Outer Moons	**Denk**
ASTROBIOLOGY OF ENCELADUS	
Astrobiology Potential in Enceladus	**McKay**
Future Exploration of Enceladus and Saturn's Icy Moons	**Lunine**

11 Mission "Bests/Firsts" in Ring Grazing phase

Best Alpha Ori stellar ring occultations	August 21, 2016
Best Pandora (20k)	December 18, 2016
Best Daphnis (18k)	January 16, 2017
Best main ring radial scan	January through July 2017
Best/highest resolution UV image of A ring	February 6, 2017
Best propeller close-up images	February through April 2017
Best Pan (25K)	March 7, 2017
Best Atlas (13k)	April 12, 2017
Best ring high-phase mosaic	April 13, 2017
Longest Timespan looking for Titan lake changes	April 23, 2017
First look at the elevation of small lakes on Titan (possibly depth/composition)	April 23, 2017

‘Impossible’ Cloud on Titan Explained



Titan’s Icy Polar Clouds
The cloud at right contains HCN. Some other polar stratospheric clouds are made of dicyanoacetylene (C_4N_2) which is produced from sunlight-driven processes occurring on frozen organic particles. A similar process is seen in Earth’s stratosphere between gases and water ice particles.

Cloud crystals in the super-cold environment of Titan are revealing surprising solid-state chemical processes that illuminate similar chemistry occurring in Earth’s polar stratospheric clouds.

Titan’s spring brings polar ice clouds made of dicyanoacetylene (C_4N_2) molecules. The presence of these polar clouds seemed impossible, because Cassini infrared measurements showed there is not enough C_4N_2 in the stratosphere to form the observed ice clouds. So where does the C_4N_2 come from?

Cassini found that springtime sunshine kicks off an ‘on-site’ manufacturing process that produces the icy raw material for the C_4N_2 clouds. Photochemical reactions between hydrogen cyanide (HCN) and cyanoacetylene (HC_3N) in Titan’s stratosphere were found to produce C_4N_2. This unexpected photochemical effect on icy solids explains how these seemingly ‘impossible’ clouds form in Titan’s springtime polar stratosphere!

Something similar occurs in Earth’s polar stratosphere, where solid-state chemistry involving chlorine is at the heart of ozone loss in Earth’s atmosphere. Comparison of the atmospheres of Earth and Titan informs us on the fundamental processes that occur throughout nature.

Solid-state photochemistry as a formation mechanism for Titan's stratospheric C_4N_2 ice clouds. C. Anderson, R. Samuelson, Y. Yung and J. McLain, *Geophysical Research Letters*, **43**, 3088-3094, 2016.

Partly Clumpy with a Chance of Flurries

Strong Density Waves in Outer A Ring

'Snow storms' of icy debris from ring particle collisions have been detected in dynamic regions of Saturn's rings.

Gravitational tugs on ring particles by nearby moons produce **density waves** (highlighted in background image), where ring particles collide energetically and sometimes clump together. Cassini can detect the results of the mayhem occurring because puffs of snow-like debris are produced when particles as large as boulders collide.

Cassini scientists combined both ultraviolet and infrared observations to gain insight into this phenomenon. Within the density waves, the size of the smallest particles drops from about the size of large snowballs to small hailstones, indicating collisional breakup of icy ring particles.

Laboratory collision studies can help untangle the complexities surrounding the age of the rings, as well as giving insight into how solar systems evolve from their own clumpy disks.

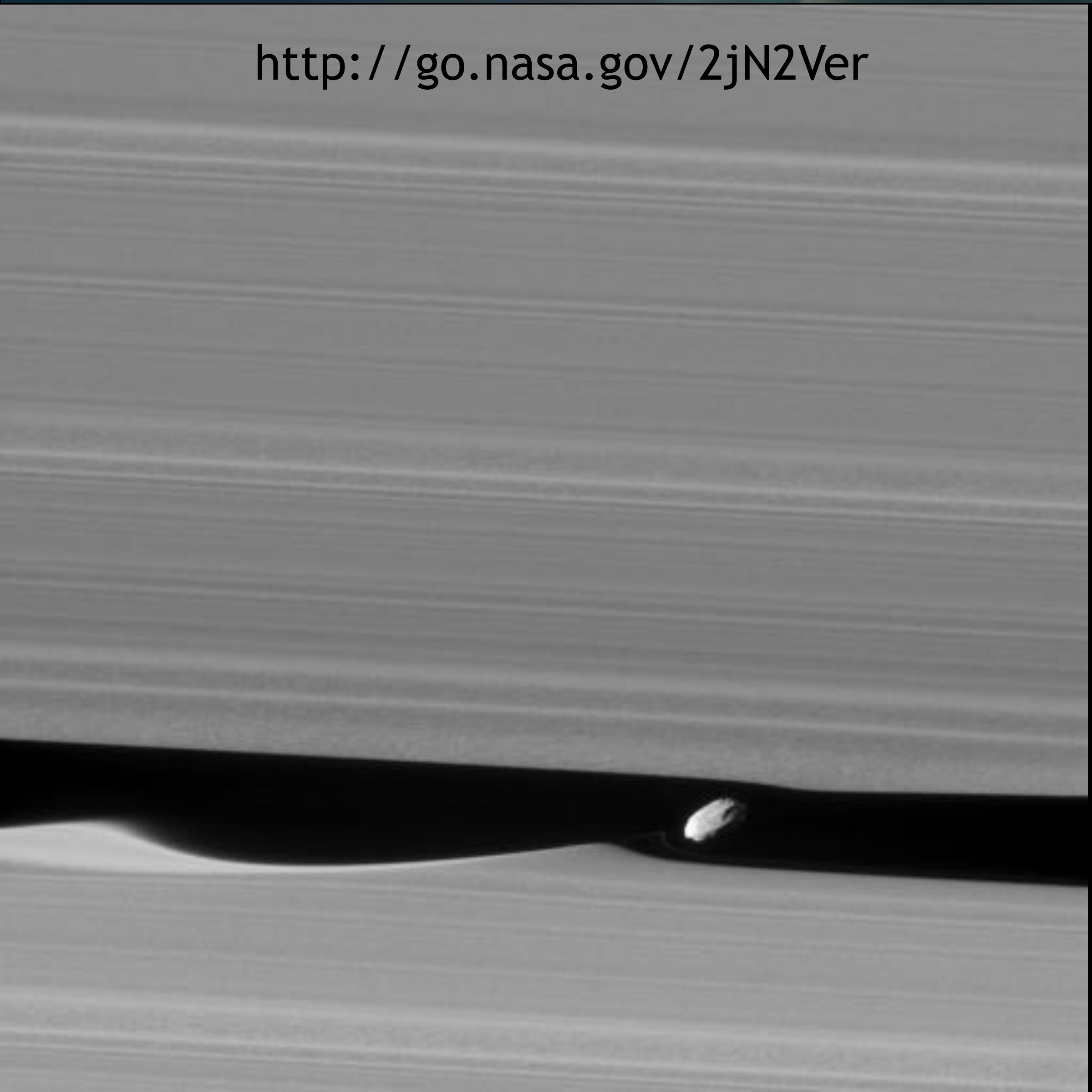
Simulated ring particles colliding at speeds comparable to those in the ring's density waves reveal a resulting spray of debris. Imagine millions of similar collisions occurring and sloughing off snow-like clouds.

Photo credit: University of Central Florida, Center for Microgravity Research

Colwell et al. *Particle sizes in Saturn's rings from UVIS stellar occultations 1, Variations with ring region.* Icarus, 2016, submitted.
Jerousek et al. *Small particles and self-gravity wakes in Saturn's rings from UVIS VIMS stellar occultations.* Icarus 279, 2015.

Daphnis Making Waves in HD

http://go.nasa.gov/2jN2Ver



Cassini's best close-up of the ring moon Daphnis was taken on January 16, 2017. Its average size is 5 miles (8 kilometers) across and is embedded in the 26 mile (42 kilometer) wide Keeler Gap in the A ring.

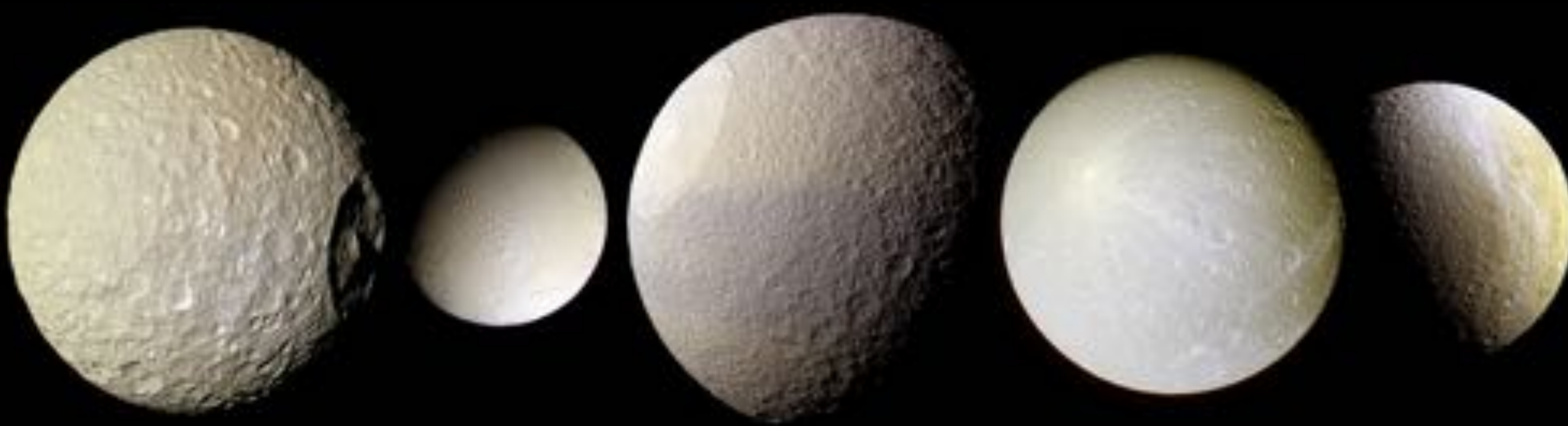
A narrow ridge around its equator and a fairly smooth mantle of material on its surface is likely an accumulation of fine ring particles. A few craters are obvious at this resolution. An additional runs parallel to the equatorial band.

The little moon's gravity raises waves in the edges of the gap in both the horizontal and vertical directions. A faint, narrow tendril of ring material follows just behind Daphnis (to its left). This may have resulted from a moment when Daphnis drew a packet of material out of the ring, and now that packet is spreading itself out.

Image scale is 551 feet (168 meters) per pixel.

Global Color North Polar Observations

All five mid-sized moons (inside Titan's orbit)



Mimas	Enceladus	Tethys	Dione	Rhea
1.0	2.4	2.5	3.3	5.5 km/pxl

200 pxl

A year on Saturn. 1 Saturnian **calendar** day = 29.47 Earth days. *Note: rotation-based Saturnia day is 10 Earth hours*

Prime Mission Titan Activity | Extended Mission Titan Activity | Voyager Birthdays | XXM

January

M	T	W	T	F	S	S
				1	2	3
4	5	6	7	8	9	10
11	12 SOI	13	14	15	16	17 TA
18 TB	19 TC	20 T3	21	22 T4&T5	23	24
25	26	27	28 T6&T7	29	30 T8	31

February

M	T	W	T	F	S	S
1 T9	2 T10	3 T11	4 T12	5	6 T13	7 T14
8 T15	9 T16	10	11 T17&T18	12 T19	13 T20	14 T21
15 T22&T23	16 T24	17 T25&T26	18 T27&T28	19	20 T29&T30	21 T31&T32
22 T33	23 T34	24 T35	25 T36	26	27 T37&T38	28 T39&T40

March

M	T	W	T	F	S	S
1	2 T41	3 T42	4	5	6 T43&T44	7 EOM
8 T45	9	10	11 T46	12 T47	13 T48&T49	14
15 T50	16 T51	17 T52	18 T53	19 T54&T55	20 T56&T57	21 Equinox T58&T59
22 T60&T61	23	24 T62	25	26 T63	27 T64&T65	28 T66
29 V1	30 T67	31 T68&T69				

April

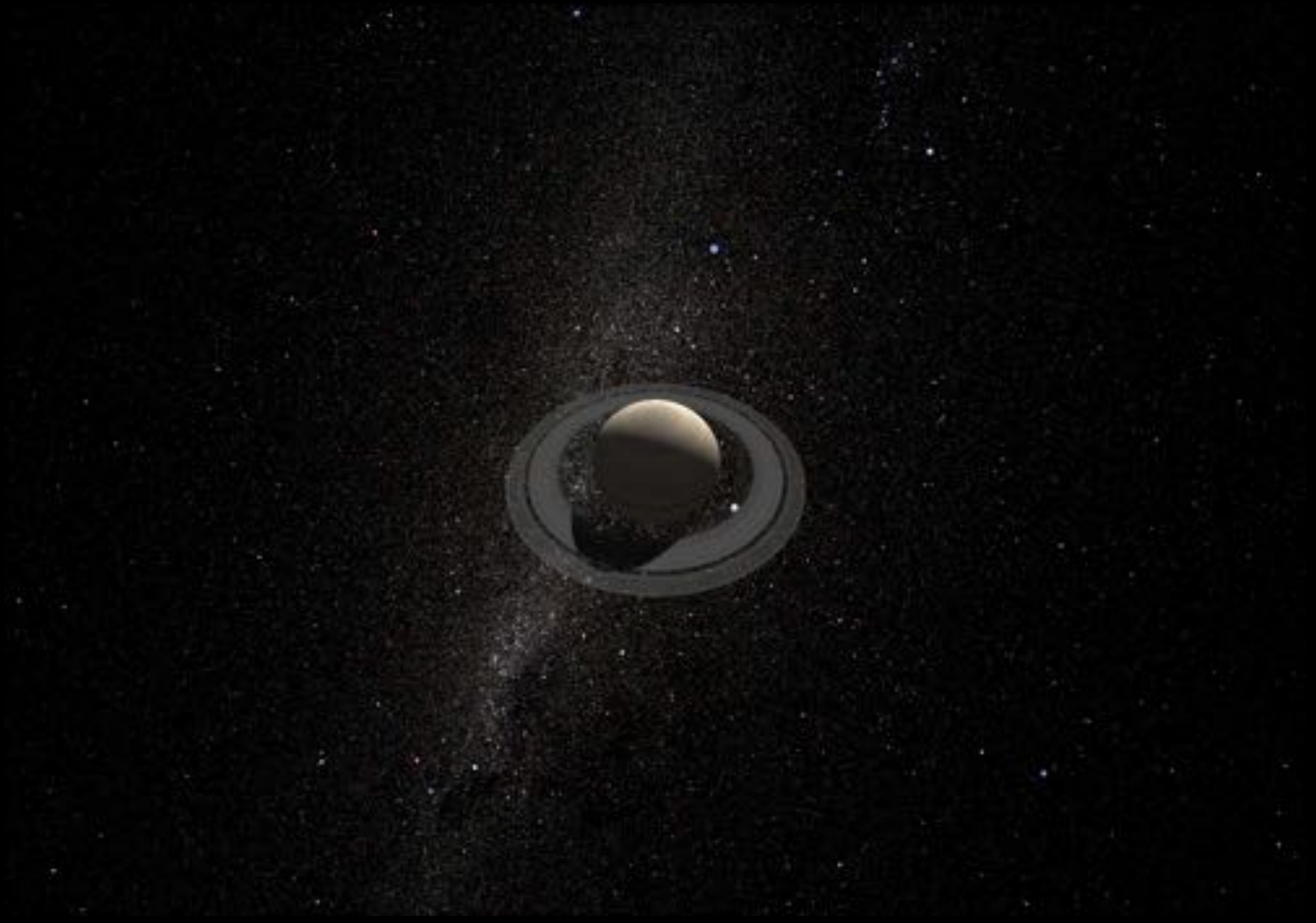
M	T	W	T	F	S	S
			1 T70 & 71	2	3	4 T72
5	6 T73	7	8 V2	9 T74	10	11 T75 & 76
12 T77	13	14	15 T78	16	17	18 T79
19 T80	20 T81&T82	21	22	23 T83	24 T84	25
26 T85	27	28 T86	29 T87	30 T88		

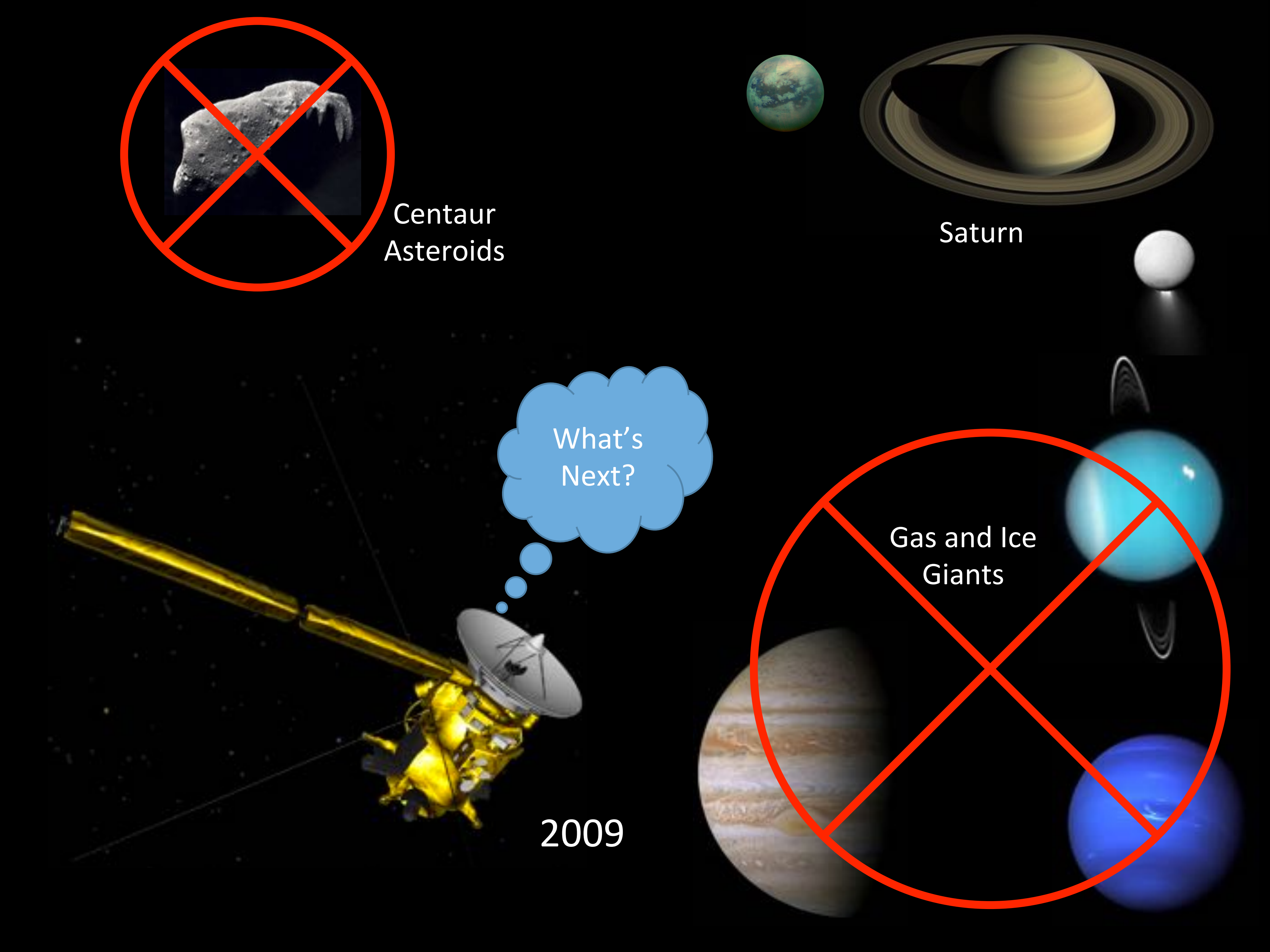
May

M	T	W	T	F	S	S
					1	2
3 T89 & 90	4	5 T91	6	7 T92&T93	8	9 T94
10 T95	11 T96	12 T97	13	14 T98	15 T99	16 T100
17 T101	18 T102	19 T103	20 T104	21 T105 & 106	22	23 T107
24 T108	25 T109	26 T110	27	28 T111	29	30 T112
31						

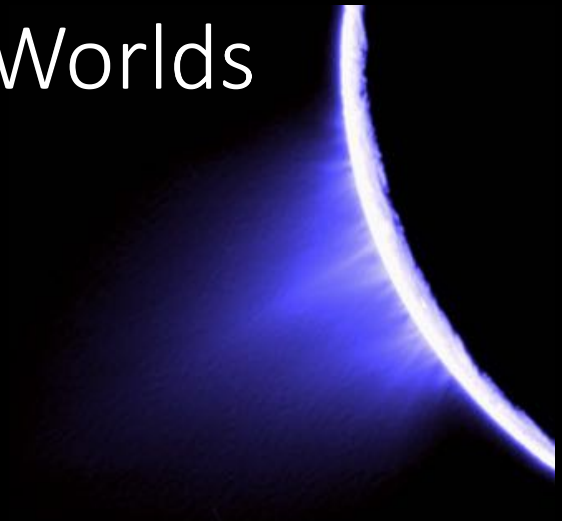
June

M	T	W	T	F	S	S
	1	2 T113	3	4 T114	5	6 T115&116
7 T117 &118	8	9 T119	10 T120	11 T121	12 T122	13 T123
14	15 T124	16 T125, nT253	17 nT255	18 nT259,261	19 nT264	20 T126
21 Solstice nT273,275	22 nT278	23 nT283,285	24 nT288	25 EOM nT292	26	27
28	29	30				




Centaur
Asteroids
Saturn
What's
Next?
Gas and Ice
Giants
2009

Protecting Saturn's Ocean Worlds



You don't have to leave Saturn
but you can't impact Enceladus