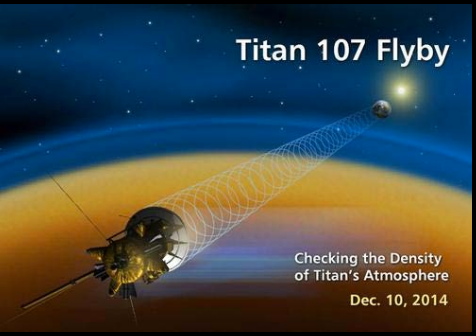
Jet Propulsion Laboratory
California Institute of Technology

Cassini Solstice Mission

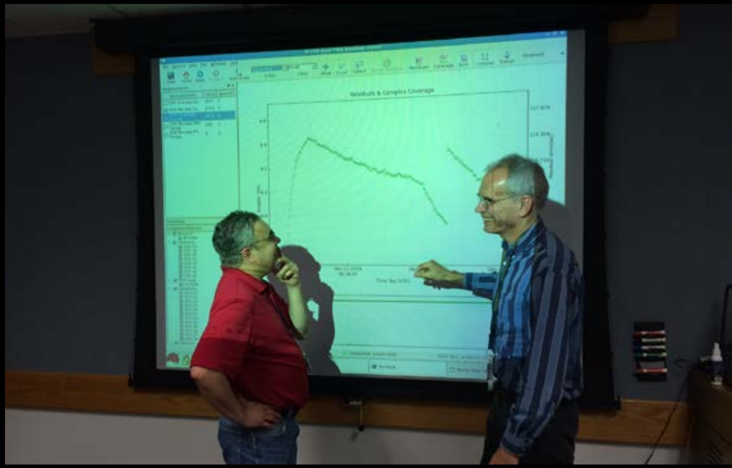
2015: A Year in Nuggets

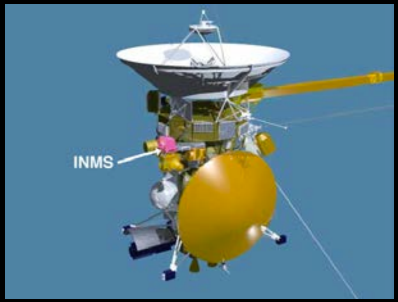
Cassini Project Science

Three Ways of Measuring Titan's Atmosphere (For the Price of One Flyby)



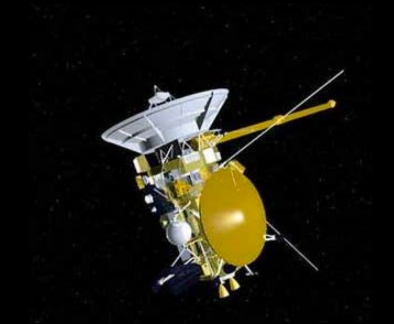
- How dense is Titan's atmosphere? Cassini has three ways to find out
- Important to fully understand Titan's atmospheric structure and and how it changes over time
- T107 is the last flyby where all three methods are used simultaneously





- The Ion and Neutral Mass Spectrometer directly samples atmospheric density

- The Navigation team tracks Cassini's radio signal and determines the atmospheric drag



- The Attitude and Articulation System uses accelerometer and thruster telemetry to estimate drag

Note that any data presented here are unpublished, minimally processed, and undergoing refinement and analysis

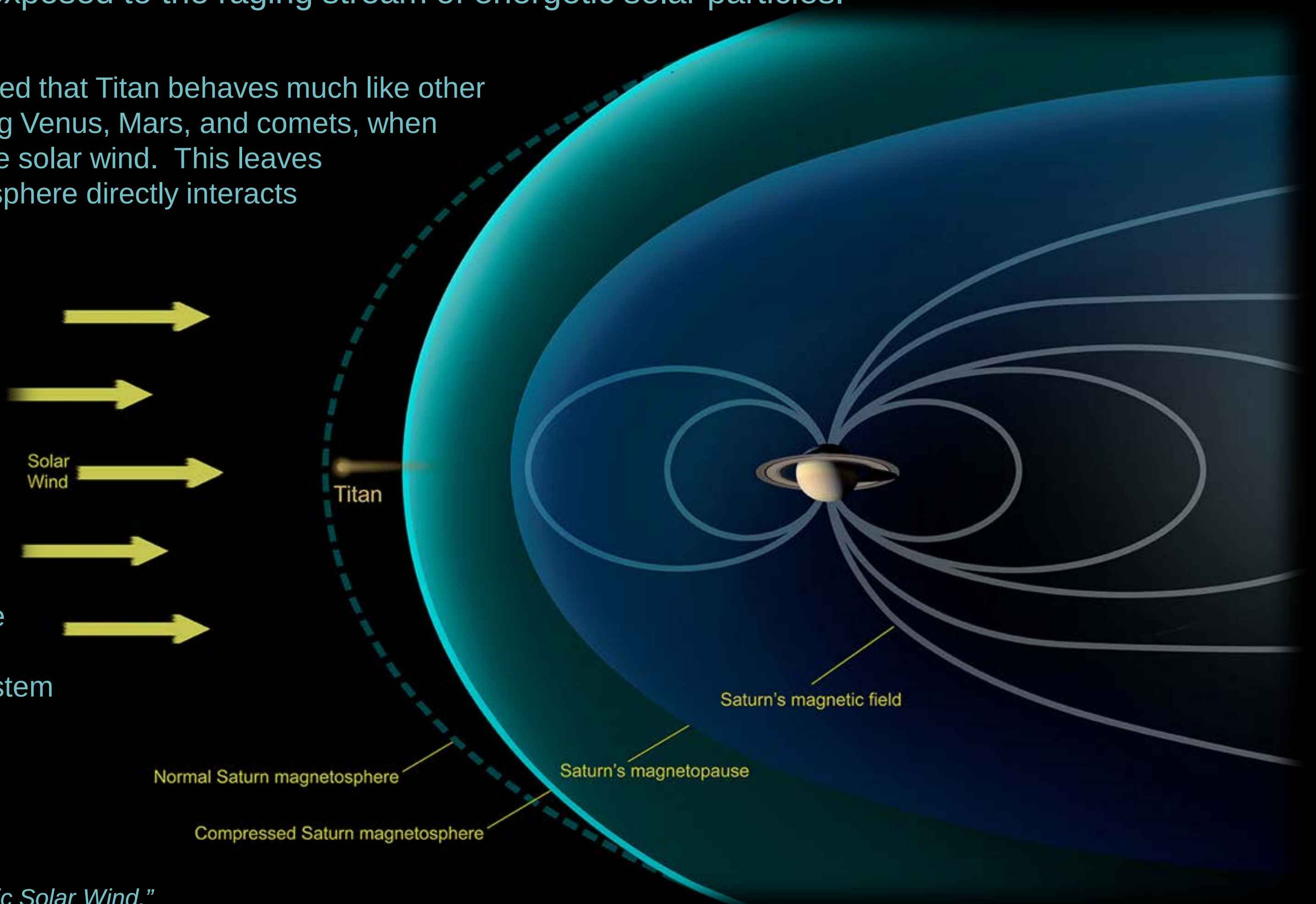
Cassini Catches Titan Naked in the Solar Wind

Titan is nearly always within Saturn's magnetosphere, the vast bubble created by the giant planet's magnetic field. Cassini caught Titan outside that protective magnetic bubble during a flyby on December 1, 2013. A strong surge in solar activity had blown back the sun-facing side of Saturn's magnetosphere, leaving the un-magnetized body of Titan exposed to the raging stream of energetic solar particles.

Cassini scientists have concluded that Titan behaves much like other un-magnetized bodies, including Venus, Mars, and comets, when exposed to the raw power of the solar wind. This leaves Titan unprotected and its atmosphere directly interacts with the undiluted solar wind.

This is not the case at Earth, where the powerful magnetic field acts as a first line of defense against the solar wind, helping to protect our atmosphere from being stripped away.

The finding adds significantly to our understanding of how the sun interacts with magnetized versus un-magnetized solar system bodies.

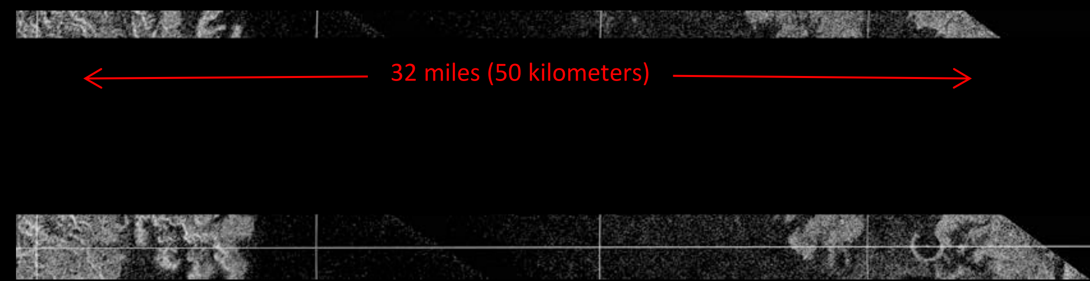


"Titan's Interaction with the Supersonic Solar Wind,"
Bertucci, et al., Geophysical Research Letters, 42, 2015, DOI: 10.1002/2014GL062106

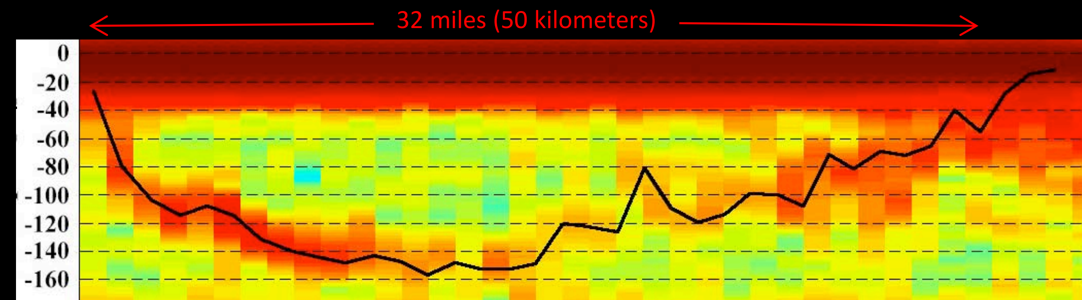
Measuring the Depth of an Alien Sea

For the first time, scientists have plumbed the depths of a sea on another body in the solar system.

- On Saturn's moon, Titan, Cassini's radar obtained bathymetric (lake depth) measurements of Ligeia Mare, a sea larger than Lake Superior.
- The observation revealed that Ligeia Mare is up to about 560 feet (170 meters) deep and exceptionally transparent to radar. Normally, the radar maps surface characteristics. Its new use for bathymetry has opened the way for similar measurements of other Titan seas by Cassini.
- The measurement was possible because the methane-ethane lake is very pure, which allowed the radar signal to easily pass through, bounce off the seafloor and return to the radar instrument on Cassini.
- Analysis indicates that this liquid, somewhat similar to liquid natural gas on Earth, exists in Ligeia Mare at quantities about 40 times greater than the proven oil reserves on Earth.



Cassini successfully measured the bathymetry (lake depth) of this 50-kilometer track (red lines) across Titan's Ligeia Mare. Latitude and longitude lines from a larger map appear in white.



Colors of each point in the graph show the strength of the radar's return signal, red being the strongest. The position of each point indicates the timing of the signal's return, which corresponds to depth (indicated in meters at left). Top layers of the lake reflected much of the signal (as seen by the deep red at top), while remaining radar pulses passed through and returned off the seafloor.

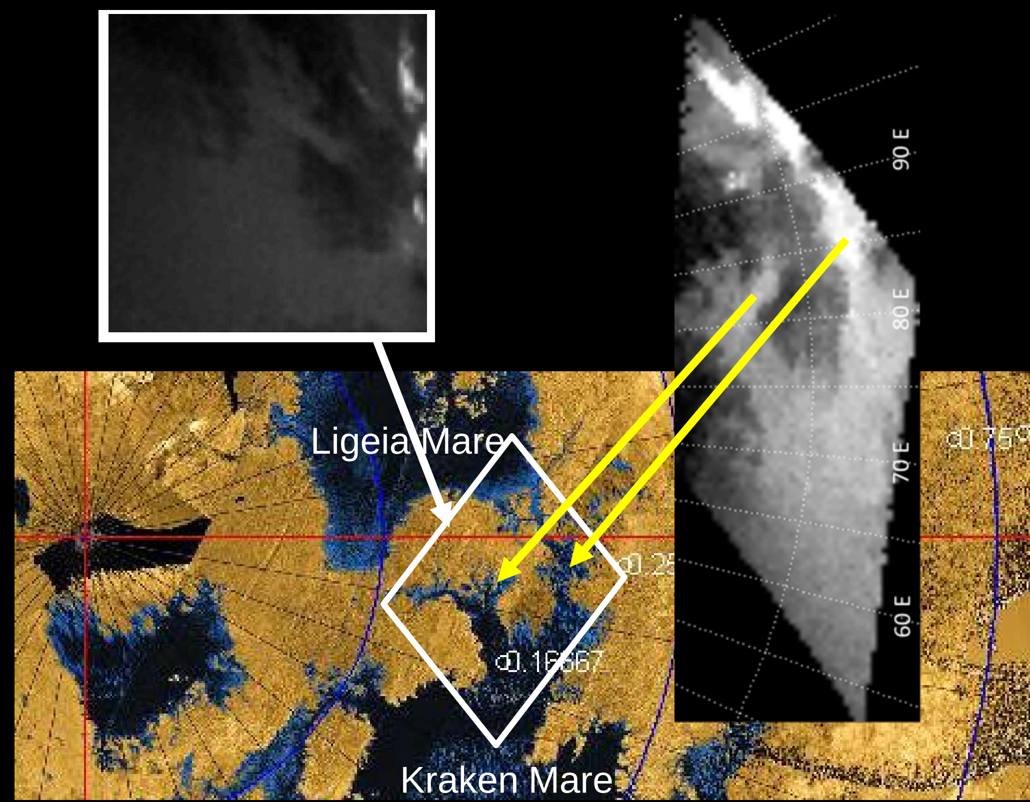
"The Bathymetry of a Titan Sea", M. Mastrogiuseppe, et al., Geophysical Research Letters,41, 1432-1437, 2014.

Liquid Strait Connects Two Titanian Seas

Cassini observed reflections on the strait between Titan's seas Ligeia and Kraken (below), demonstrating that the strait is filled with liquid. 5-µm images, almost free of scattered light, display specular reflection on smooth surfaces such as liquids.

5-µm

reprojected 5-µm image

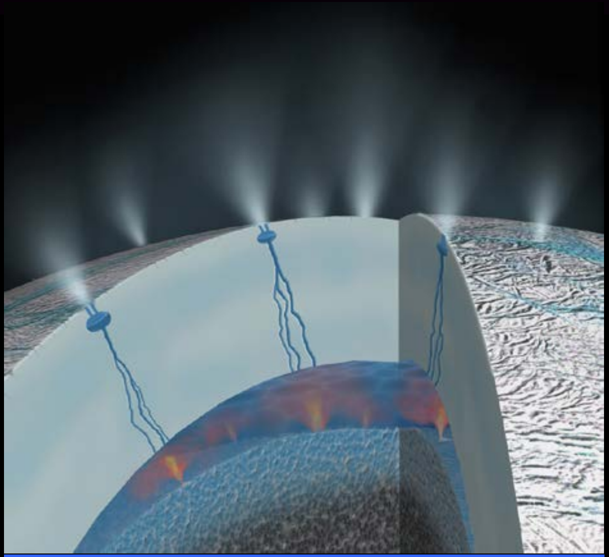


- Cassini's visual and infrared mapping spectrometer acquired a long, high resolution swath between the equator and the North Pole (not yet processed).
- Despite challenging observing geometry, a specular reflection is observed at 5-µm, confirming the liquid nature of the strait named Trevize Fretum.

Note that any data presented here are unpublished, minimally processed, and undergoing refinement and analysis

Telltale Geyser Dust from Enceladus Seafloor Vents

Cassini discovers the first evidence for ongoing seafloor hydrothermal activity on a body other than Earth. Hydrothermal activity occurs when seawater infiltrates and reacts with a rocky core, emerging as a heated, mineral-laden liquid. This new finding opens the possibility for prebiotic or even biotic chemical mixtures to “slow-cook” inside Saturn’s moon Enceladus, where the ocean meets hot rock.



There is a strong possibility that hot water rises from seafloor vents on Enceladus. This raises the potential for habitable environments beneath the ice crust of this small, active moon.

- Silica nanoparticles were captured by Cassini’s cosmic dust analyzer. Analysis revealed these particles came from Enceladus’ seafloor.

- Laboratory experiments indicate that these dust particles must have formed on the seafloor at temperatures above 90° C (194° F). This is a much hotter environment than scientists thought existed inside the icy moon, suggesting that seafloor hydrothermal activity is occurring.

- Similar activity is observed around mid-Atlantic seafloor vents, where some extreme life forms reside.

- This result shows that Enceladus’ plume activity is an eruptive process that begins in its core and is not limited to the near-surface.

“Ongoing hydrothermal activities within Enceladus,” Hsu *et al.*, *Nature,* March 12, 2015.

Methane in Enceladus Geysers Likely Originates from Seafloor Vents

Cassini has found the first evidence of active seafloor hydrothermal vents, where seawater and the rocky core meet to form warm mineral-laden liquid, on Saturn's moon Enceladus. This new finding provides additional evidence for Enceladus' ocean as a possible habitat for life.

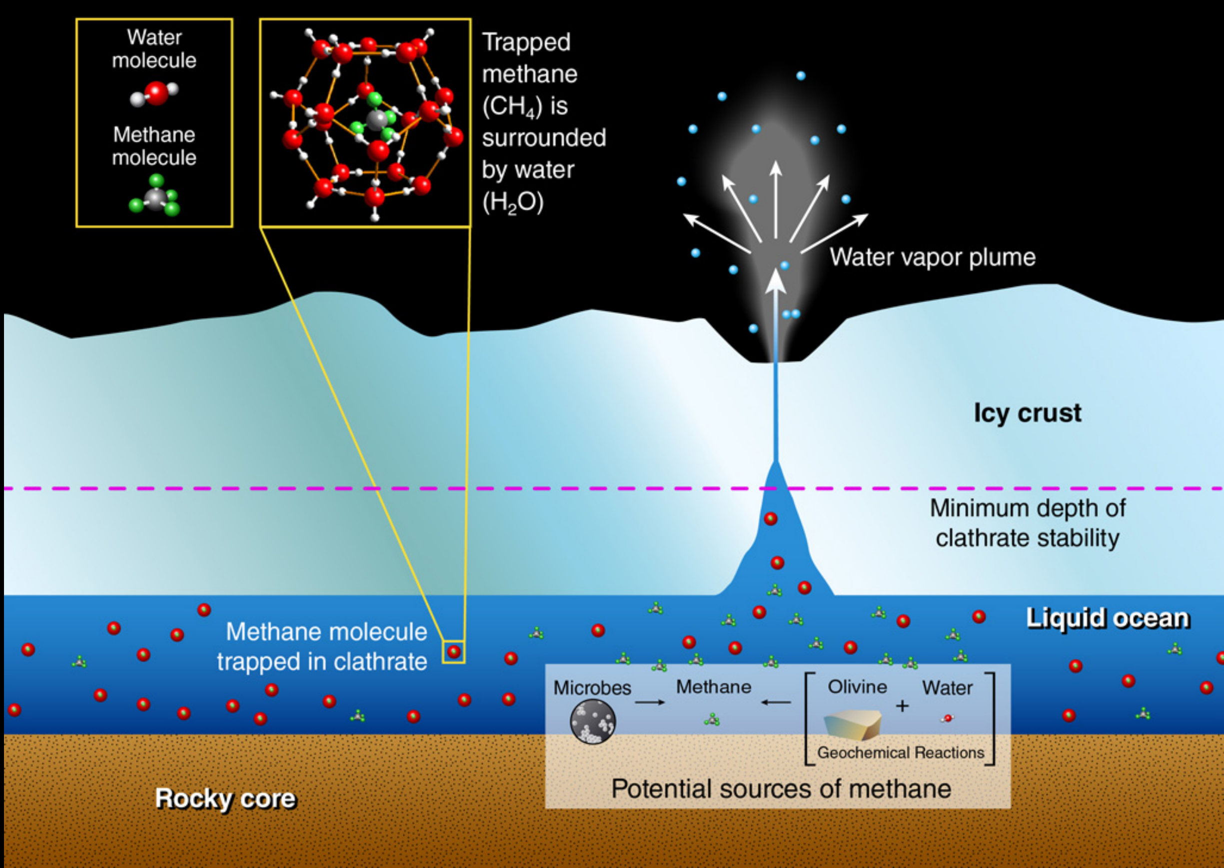
- Cassini's mass spectrometer found abundant methane in Enceladus' vapor plumes. Those plumes are thought to originate within the moon's internal ocean.

- Ocean models show that methane molecules are trapped in ice "cages", called clathrates. So methane should *not* be abundant in the plumes – unless some source is rapidly adding methane in the ocean, faster than it is trapped into clathrates.

- Chemical reactions near warm hydrothermal vents are the most likely candidate for producing additional methane.

"Possible evidence for a methane source in Enceladus' ocean ," Bouquet *et al.*, *Geophysical Research Letters,* March 12, 2015.

Trapping of Methane in Enceladus' Ocean



Sunburn Colors Jupiter's Red Spot

Just like a human who spends too long in the sun, Jupiter's Great Red Spot gets its ruddy color from overexposure to ultraviolet light from the sun, according to new laboratory analysis by Cassini researchers.

- Ultraviolet light breaks down ammonia and acetylene, producing the Great Red Spot's characteristic hue. Analysis suggests that beneath the sunburned top of the storm are bland, pale clouds of ammonia and hydrocarbons still unexposed to sunlight.
- These new results contradict the other leading theory for the origin of the spot's striking color – that reddish chemicals are churned up from beneath Jupiter's clouds. If upwelling of reddish chemicals were the cause, the red spot would be even redder.
- Determining the chemistry responsible for Jupiter's colorful clouds provides insights into the composition of the giant planet and clues to the original ingredients that made up our solar system.

"Why is the Great Red Spot Red? The Exogenic, Photolytic Origin of the UV/Blue-Absorbing Chromophores of Jupiter's Great Red Spot as Determined by Spectral Analysis of Cassini/VIMS Observations using New Laboratory Optical Coefficients," K.H. Baines, R.W. Carson, T. W. Momary, American Astronomical Society, DPS meeting #46, #511.05, 2014

Press Release - http://go.nasa.gov/1DVgMFM

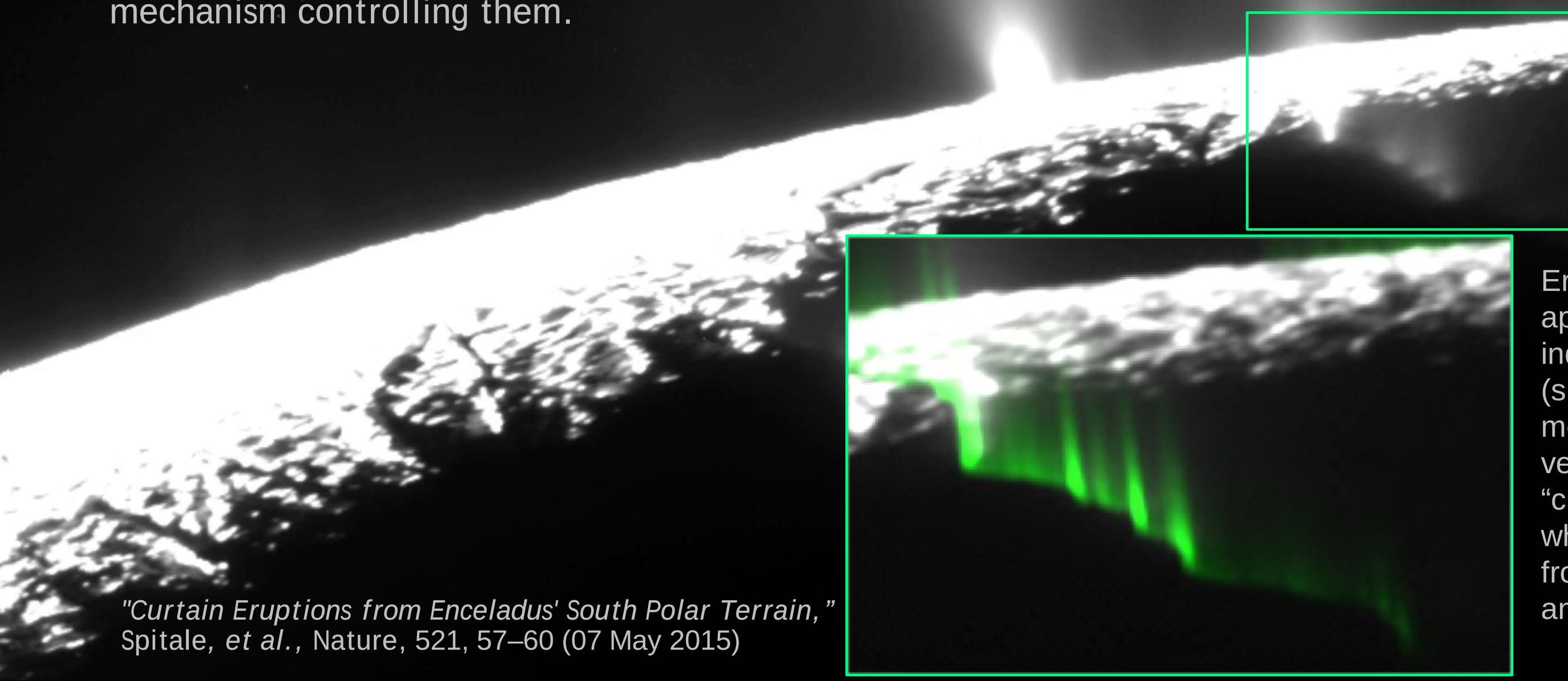
Lifting the Curtain on Enceladus' Jets

Eruptions at Enceladus' south pole may actually be continuous curtains of ice and gas emerging along the entire length of surface fractures called "Tiger Stripes."

New analysis of Cassini images indicates that what appear to be individual jets may be an optical illusion due to viewing angle and lighting conditions along the curtain. An animation can be found here: http://go.nasa.gov/1JSY6ts

Activity along these fractures may be akin to eruption of "curtain lava" from volcanic fractures on Earth.

Understanding the spatial distribution of these eruptions is crucial to evaluating theories for the mechanism controlling them.



Eruptions that appear to be individual jets (small box) look more like an icy version of "curtain lava" when viewed from a different angle (large box).

"Curtain Eruptions from Enceladus' South Polar Terrain," Spitale, *et al.*, Nature, 521, 57–60 (07 May 2015)

Returning to the Icy Water Worlds of Saturn

After nearly three years in an inclined orbit, Cassini has returned to Saturn’s equatorial plane for fresh views of Enceladus, Rhea, Dione, Mimas, Hyperion, and Tethys. Some of these satellites may host liquid water oceans beneath their icy crusts.

Cassini took these images of Rhea on February 9, 2015 from a distance of about 30,000 to 50,000 miles (50,000 to 80,000 kilometers). http://go.nasa.gov/1eLpRYd

Mimas: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of Cassini observations.

http://go.nasa.gov/12pq7FH

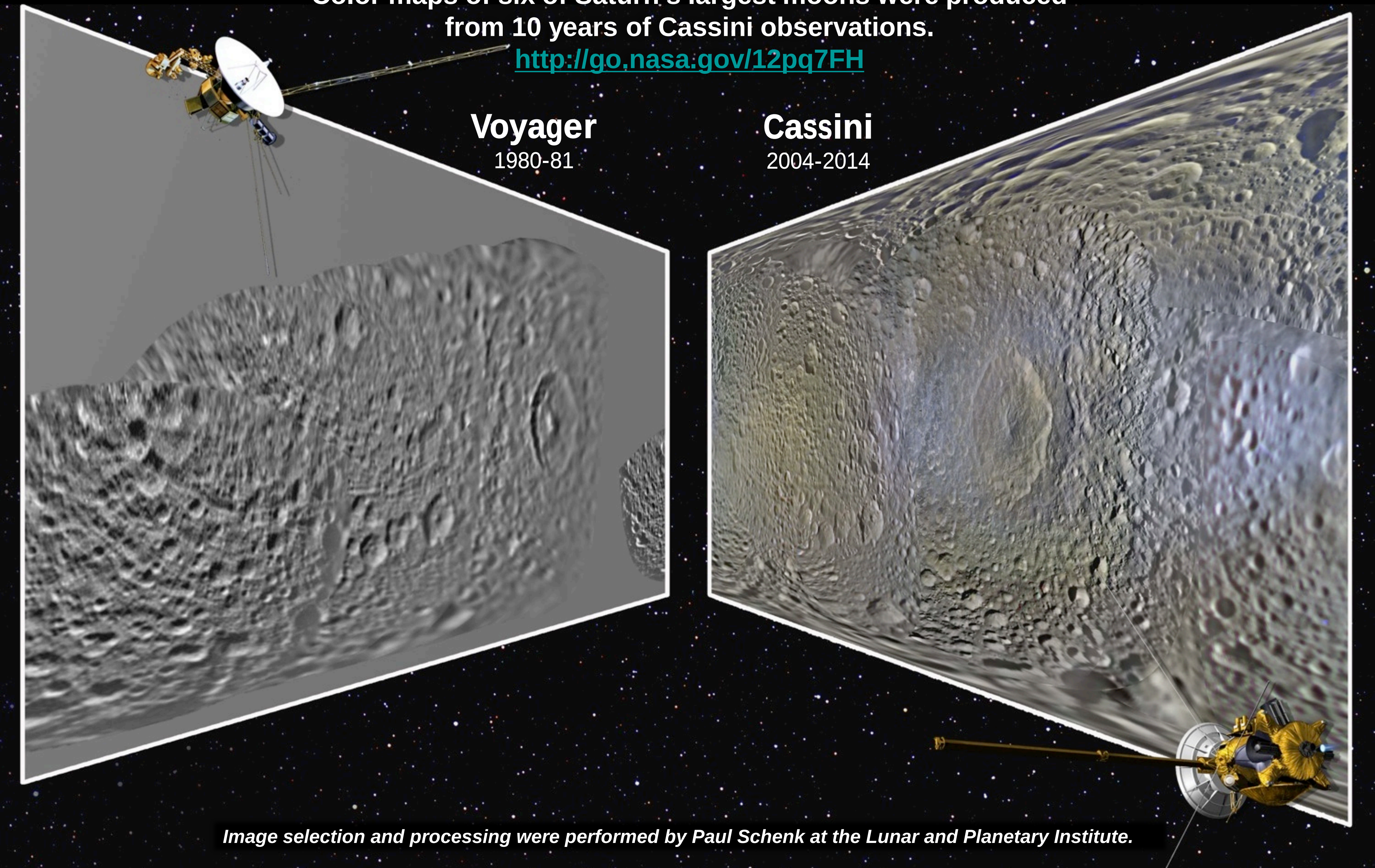
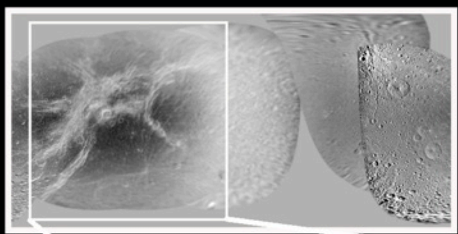
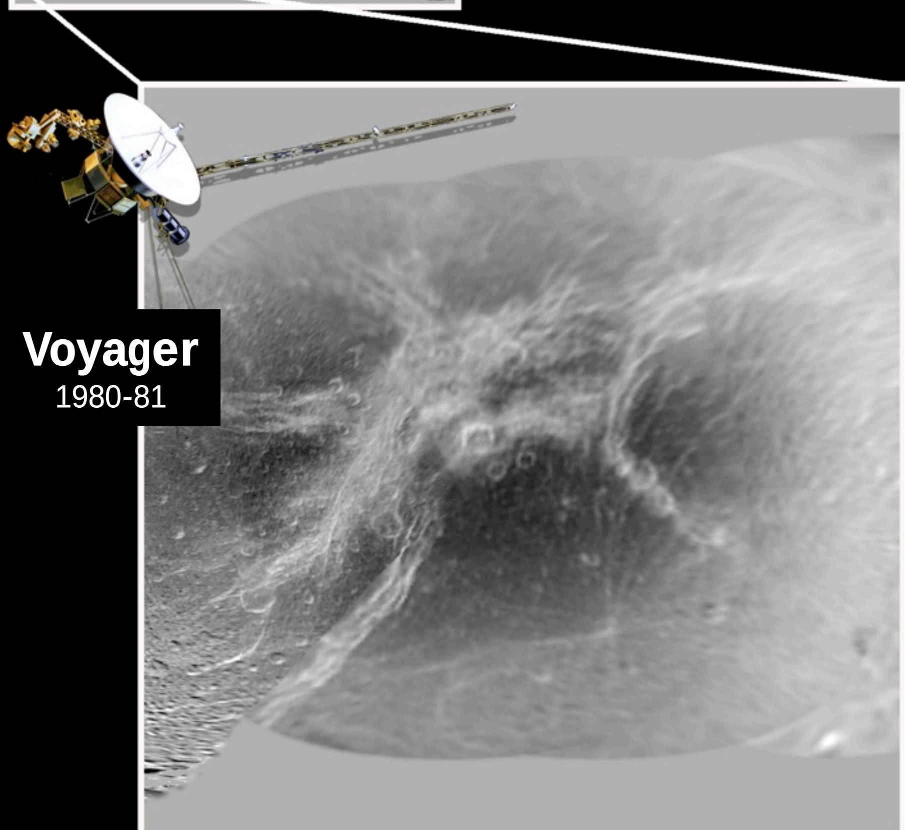


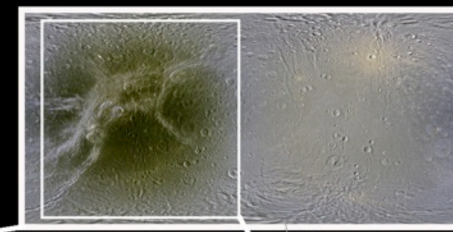
Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

Dione: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of observations by Cassini.
http://go.nasa.gov/12pq7FH







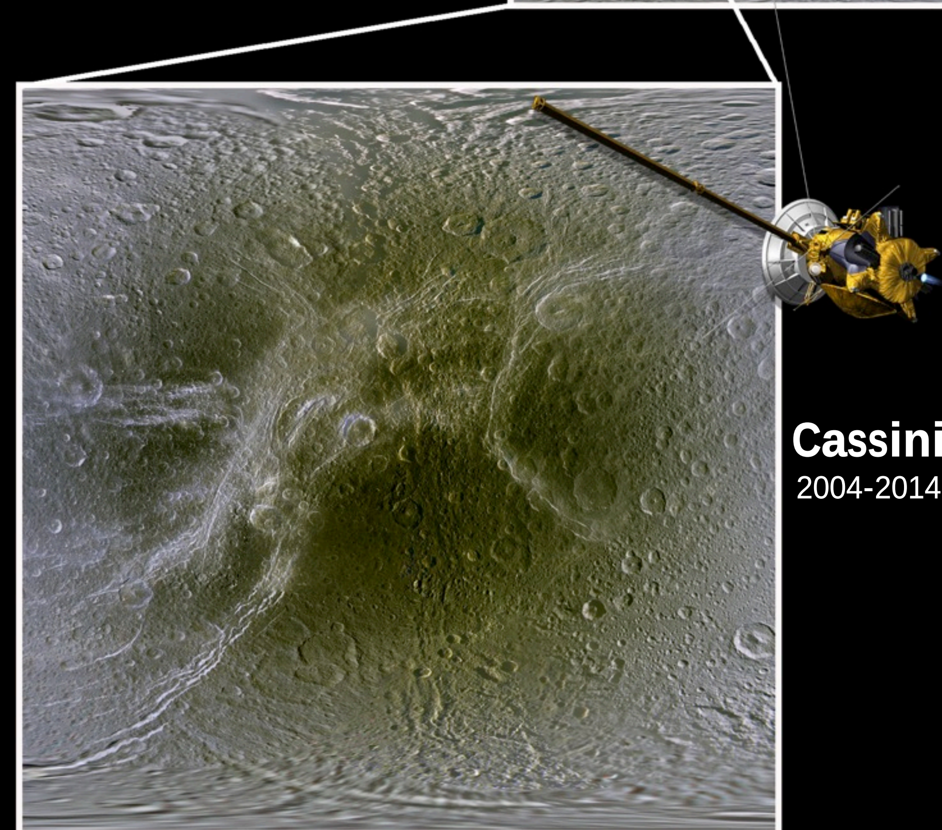


Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

Enceladus: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of observations by Cassini.
http://go.nasa.gov/12pq7FH

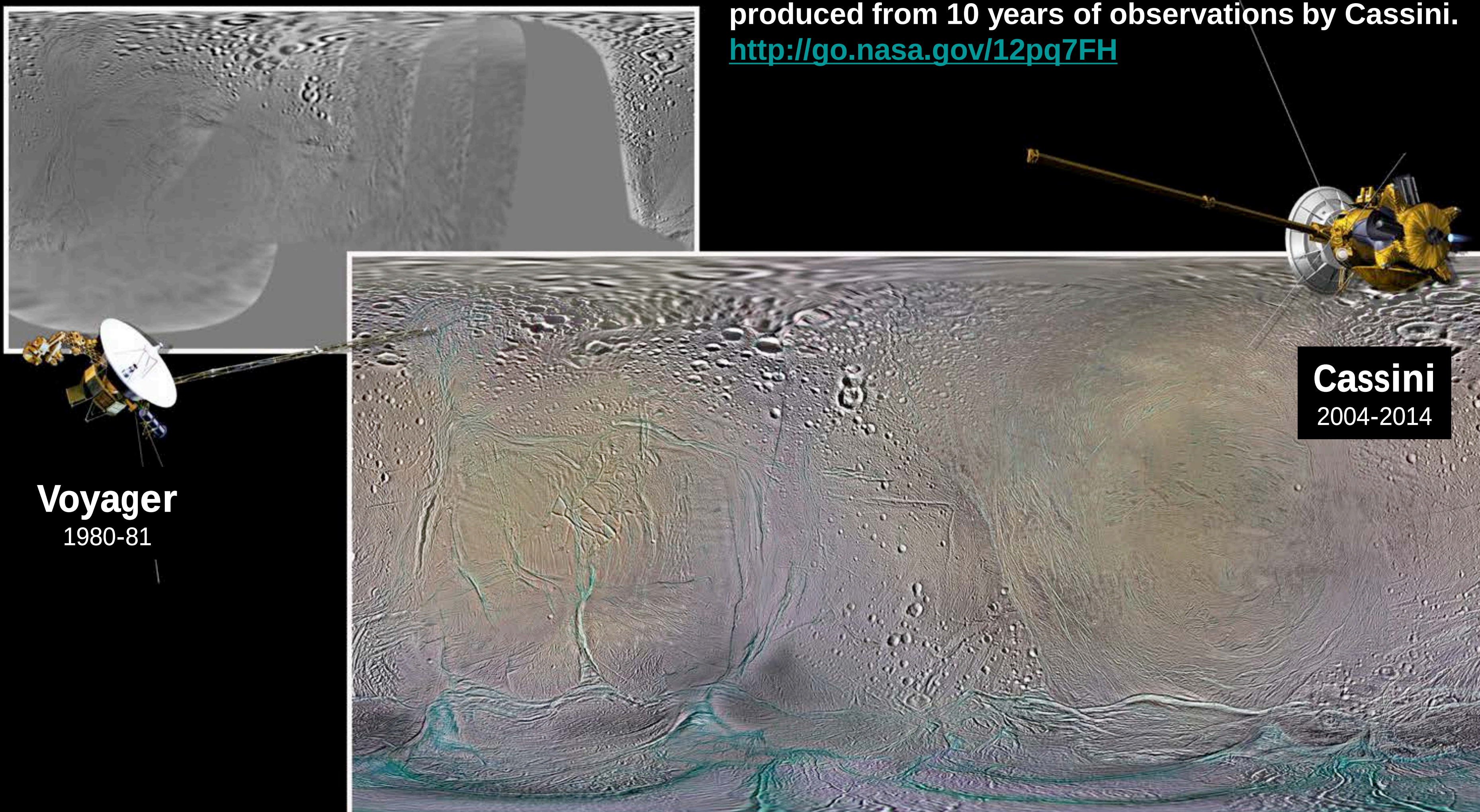


Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

Rhea: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of observations by Cassini.
http://go.nasa.gov/12pq7FH

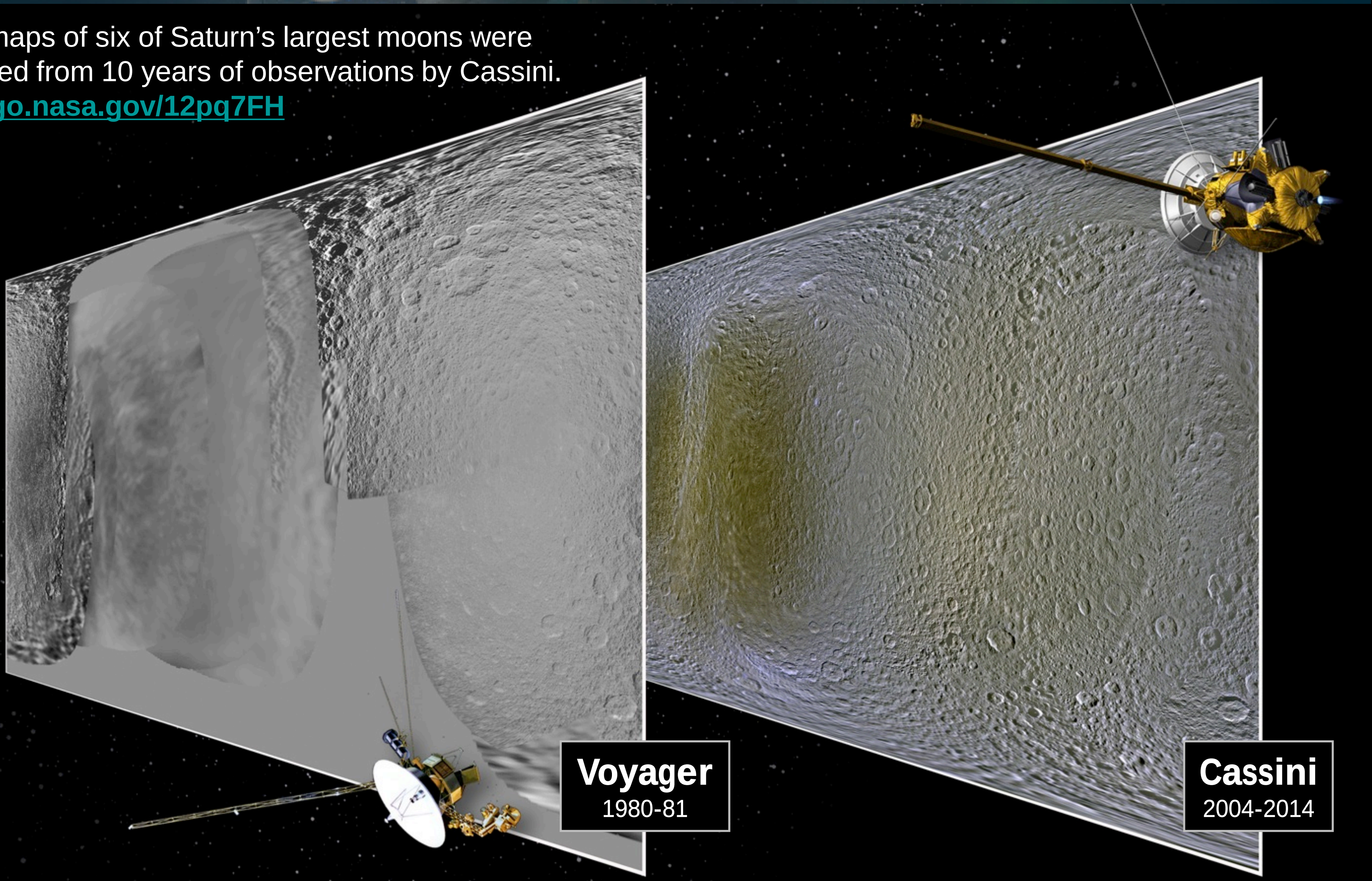


Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

Iapetus: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of observations by Cassini.
http://go.nasa.gov/12pq7FH

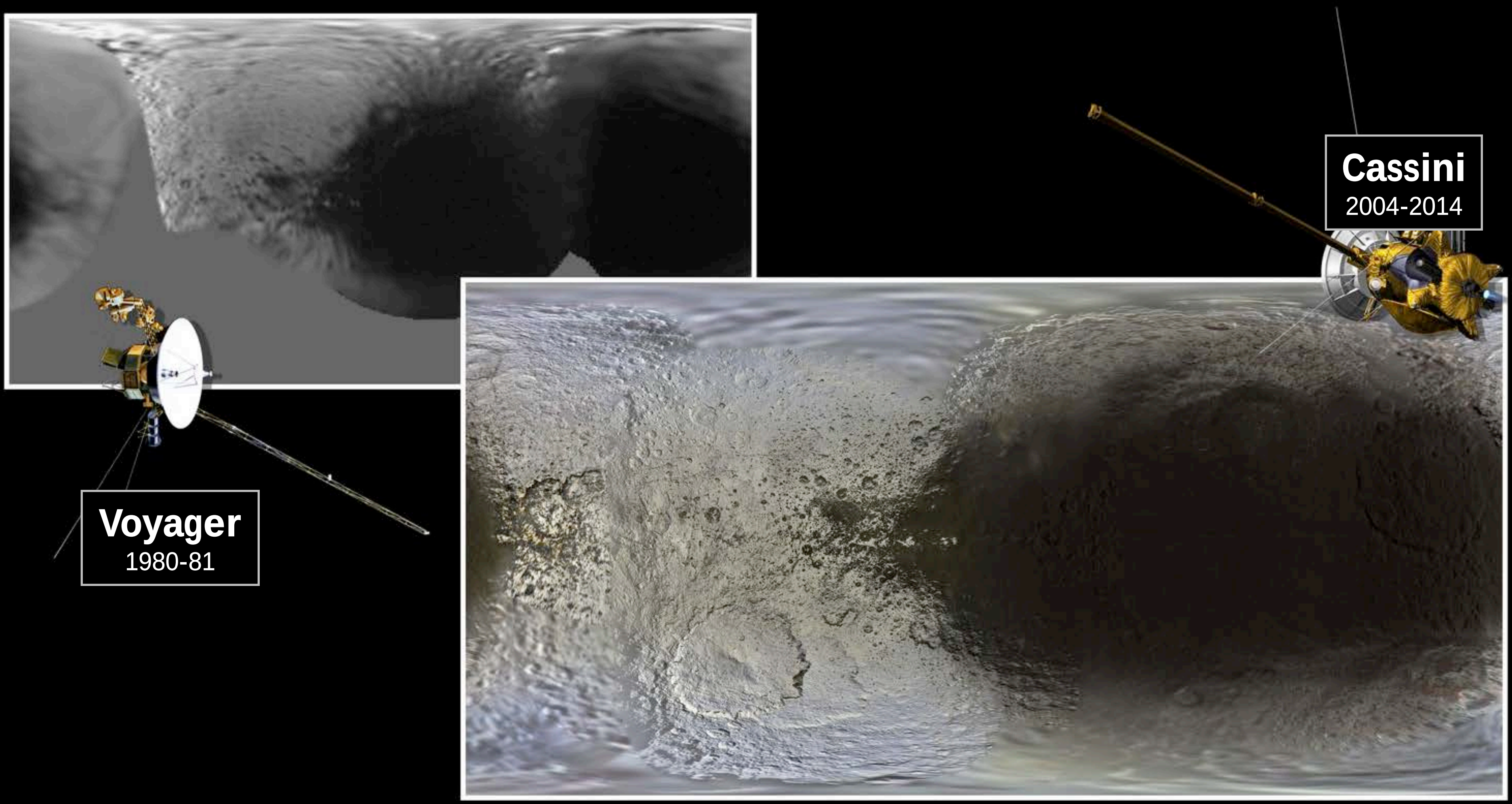


Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

Tethys: Before and After Cassini

Color maps of six of Saturn's largest moons were produced from 10 years of observations by Cassini.
http://go.nasa.gov/12pq7FH

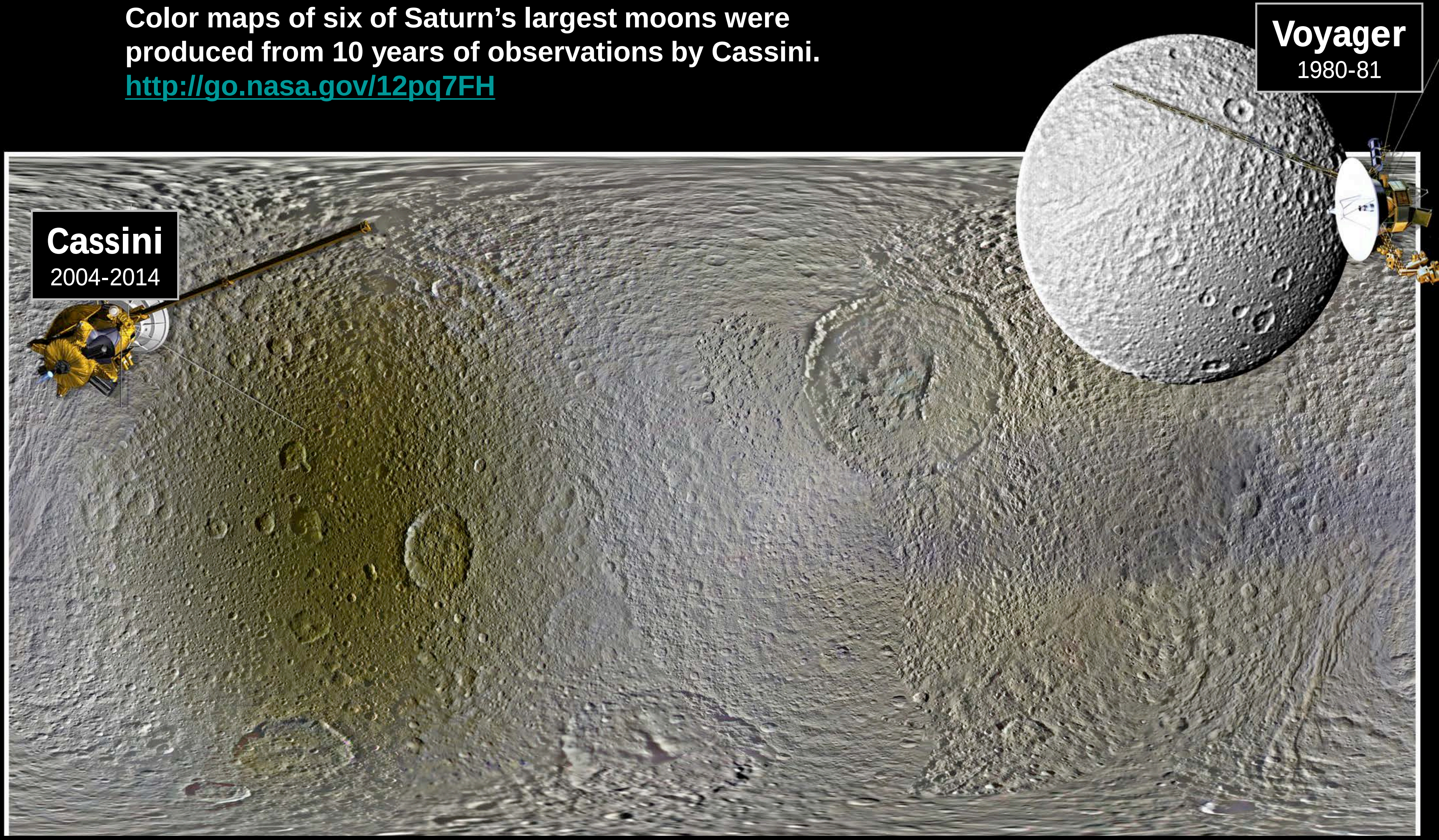
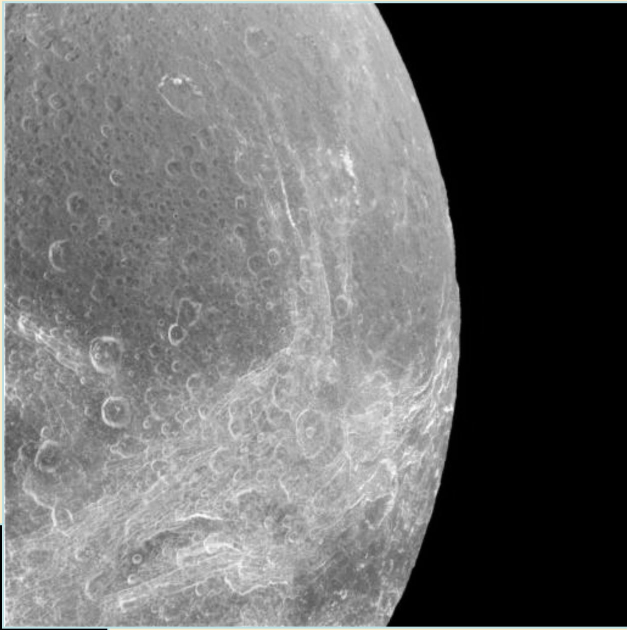


Image selection and processing were performed by Paul Schenk at the Lunar and Planetary Institute.

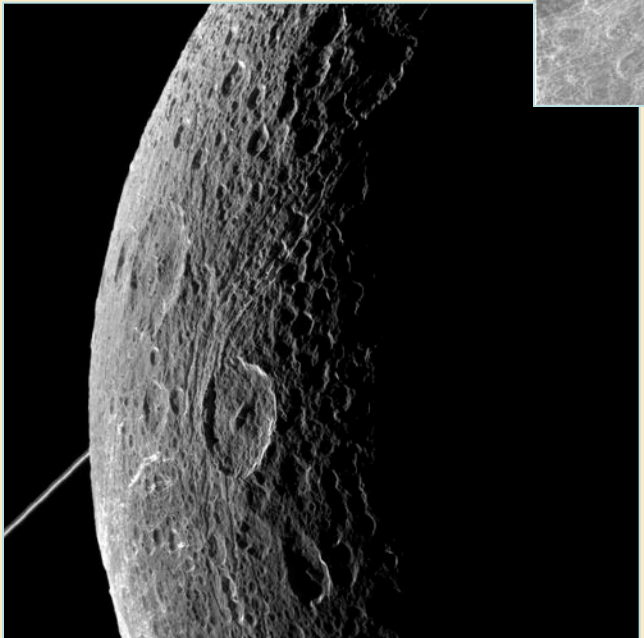
Cassini's Penultimate Dione Flyby

Cassini made its next-to-last close flyby of Dione on June 16, 2015. With one more flyby on August 17, 2015, scientists hope to understand if Dione is currently active, and how that activity might relate to its interior structure.



The goals of this flyby were to:

- Understand Dione's shape, interior structure, and rigidity of its outer ice shell.
- Detect and determine the composition of fine particles possibly being emitted from Dione, an indication of geologic activity at a low level.
- Obtain a better view of the tectonically deformed terrain named "Eurotas Chasmata" on the moon's trailing side.
- Map the dark side to understand how Dione's surface loses heat.

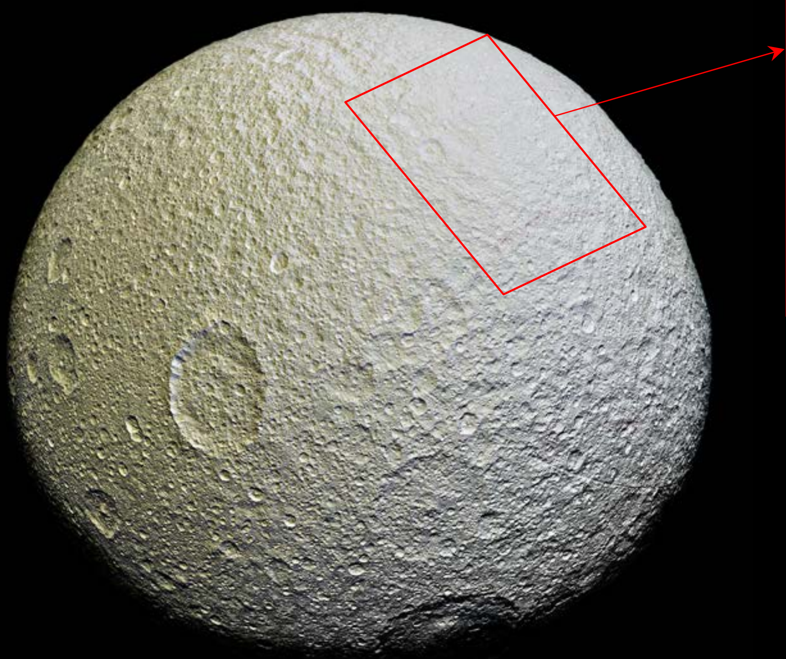


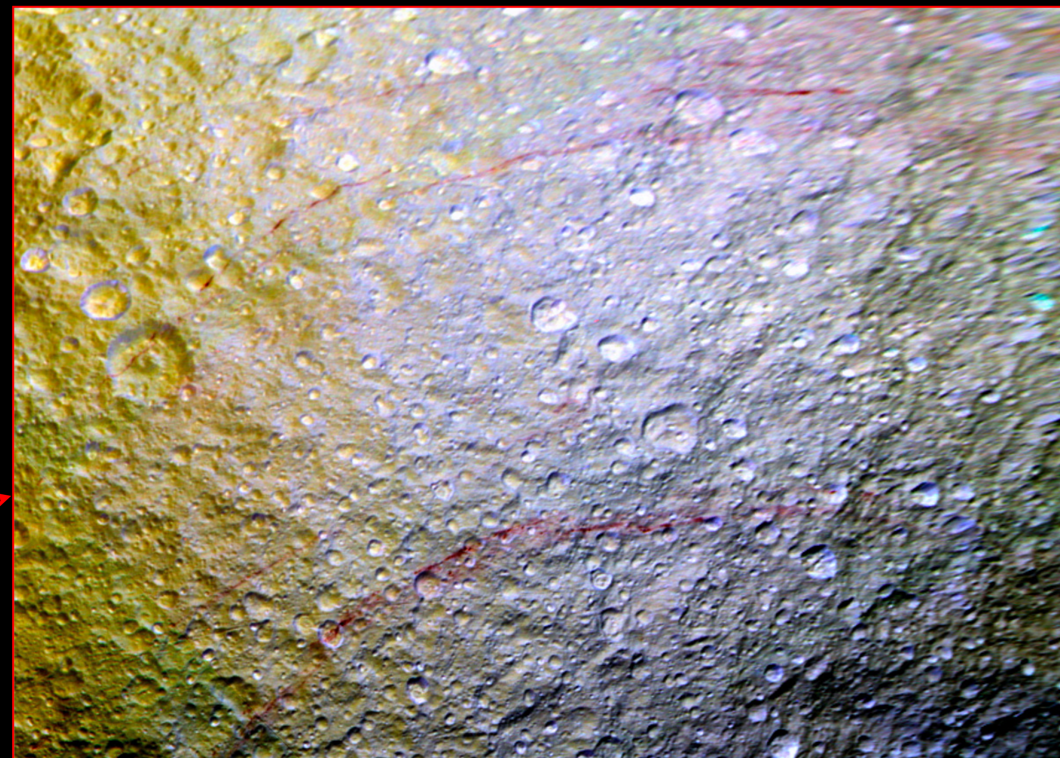
Above: An image of the complex tectonic features on Dione's trailing side.

Left: The crescent of Dione showing cratered surface. Saturn's bright rings can be seen on edge in the lower left background.

Graffiti on Tethys

Newly discovered red arcs on Saturn's moon Tethys are mystifying because they are not linked to any obvious geologic features. The graffiti-like arcs were found in enhanced-color images taken by Cassini April 11, 2015. Their presence on the hemisphere coated by recent water-ice grains from Saturn's E ring suggests that the features are young or reddish material is being resupplied. The next opportunity to observe them even closer will be November 11, 2015 during a 8,300 km flyby.





Reddish arcs are illustrated in this magnified, infrared-enhanced color image (above). The origin and composition of the red arcs are currently unknown, but there may be an analogy with reddish-tinted bands observed on Jupiter's water world, Europa.

Enhanced-color image (left) shows one hemisphere is stained by Saturn's radiation belts while the other is spray-painted white by water ice particles orbiting the planet.

Press Release - http://go.nasa.gov/1D98I5Y

Seasonal Extremes at Saturn's Poles

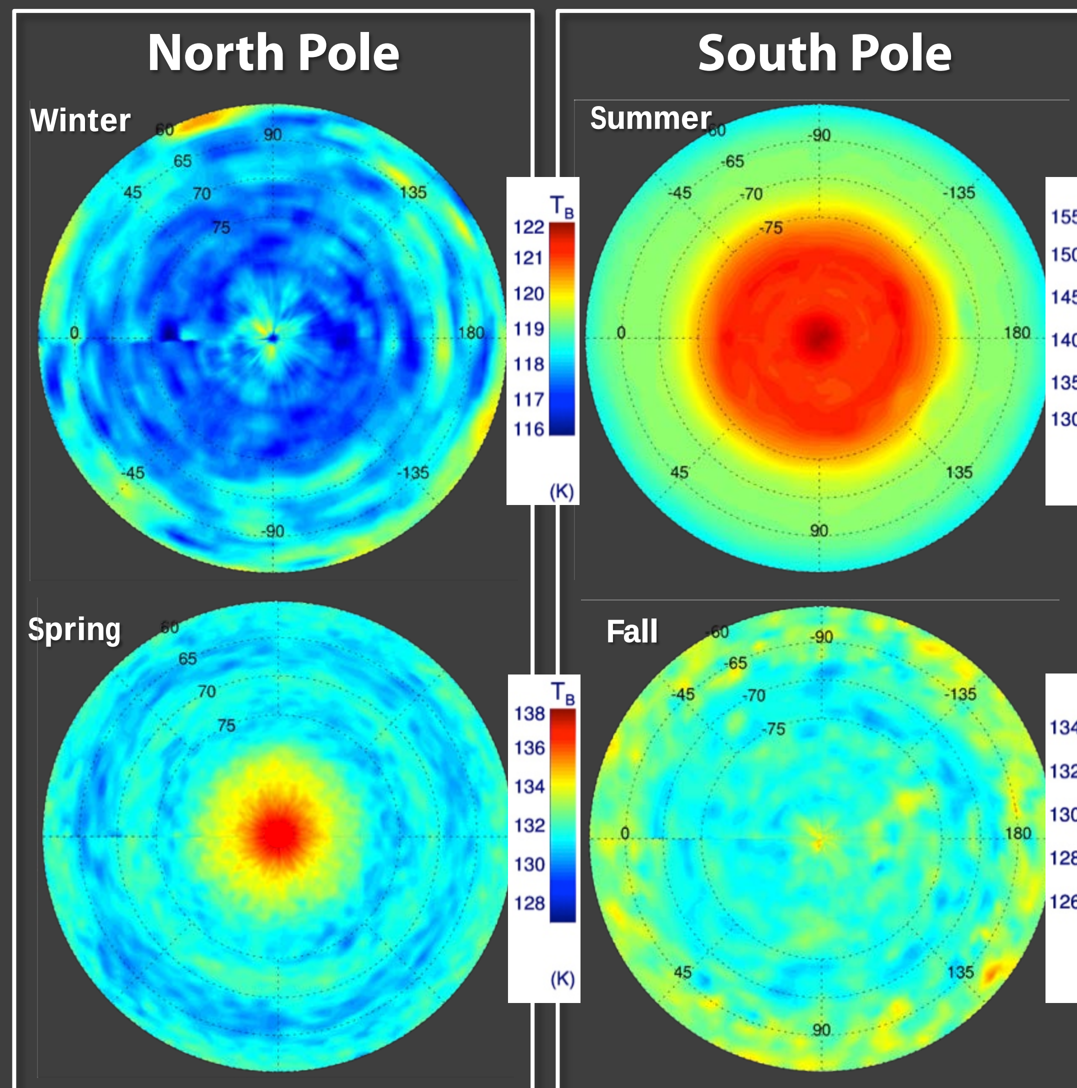
Saturn's polar regions have displayed extreme seasonal changes during Cassini's decade-long watch:

- Saturn's polar stratosphere features large warm vortices (a polar hood) during the summer that change substantially over last decade;
- The North Pole warmed by about 36 degrees F (20 kelvins) during spring. Cassini is still waiting for emergence of a seasonal vortex expected to appear before end of mission;
- The South Pole cooled by about 63 degrees F (35 kelvins) during its fall;
- Shifting temperatures depend not only on sunlight, but also enormous circulation patterns.

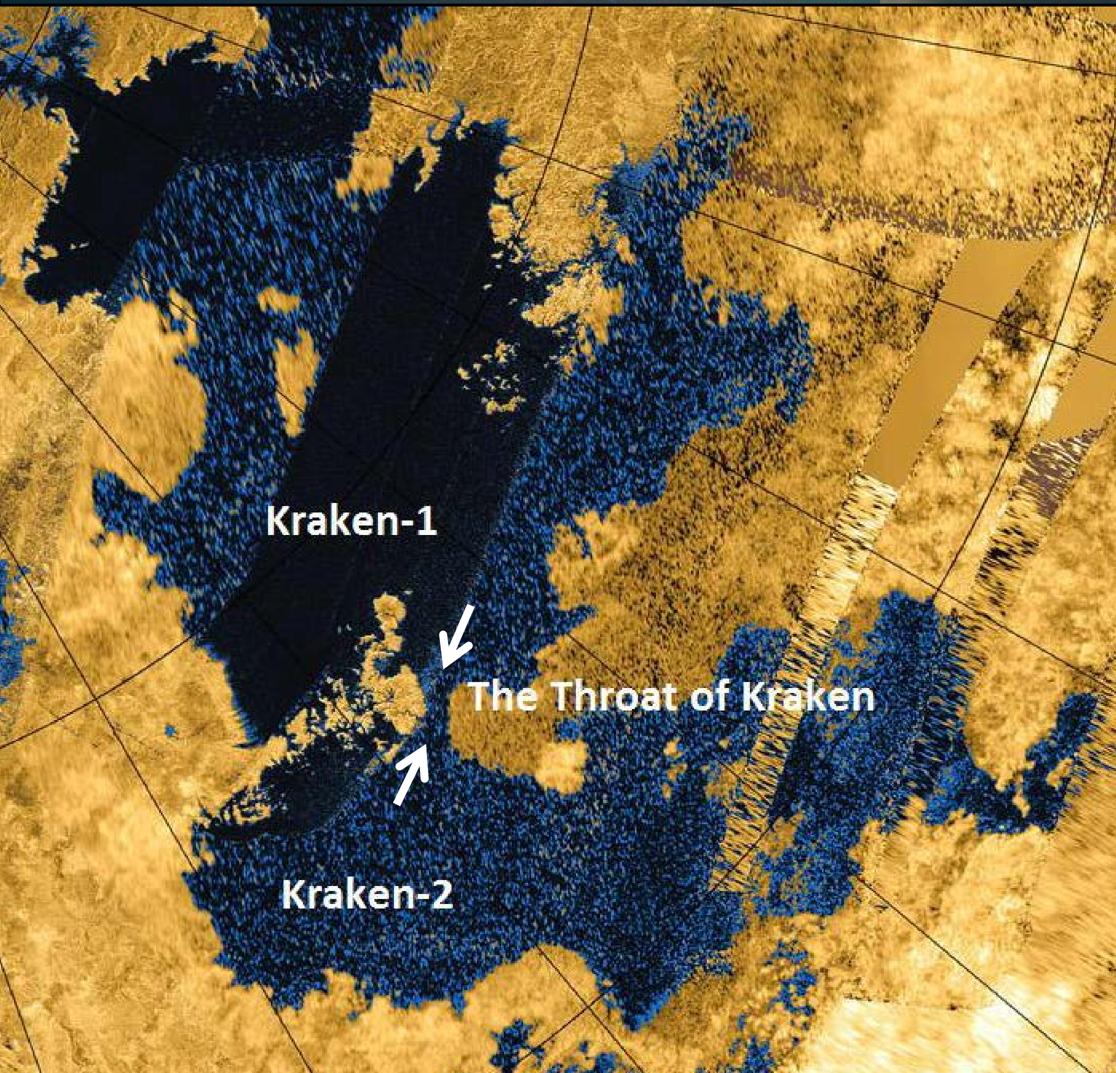
Cassini is providing the most comprehensive view ever obtained of seasonal change on a giant planet. Long-term observations are filling significant gaps in our knowledge of fundamental meteorology and chemistry of giant planet atmospheres.

L.N. Fletcher, et al. (2015). Seasonal evolution of Saturn's polar temperatures and composition, Icarus 250, p131–153.

Stratospheric Temperature Maps of the Poles



Whirlpools May Form in Titan's "Throat of Kraken" Strait



"A radar map of Titan Seas: Tidal dissipation and ocean mixing through the Throat of Kraken," R.D. Lorenz, et al., Icarus, 237, 9-15, 2014.

Whirlpools and rough seas may exist in a narrow, shallow strait that links two basins of Titan's "Sea of Kraken."

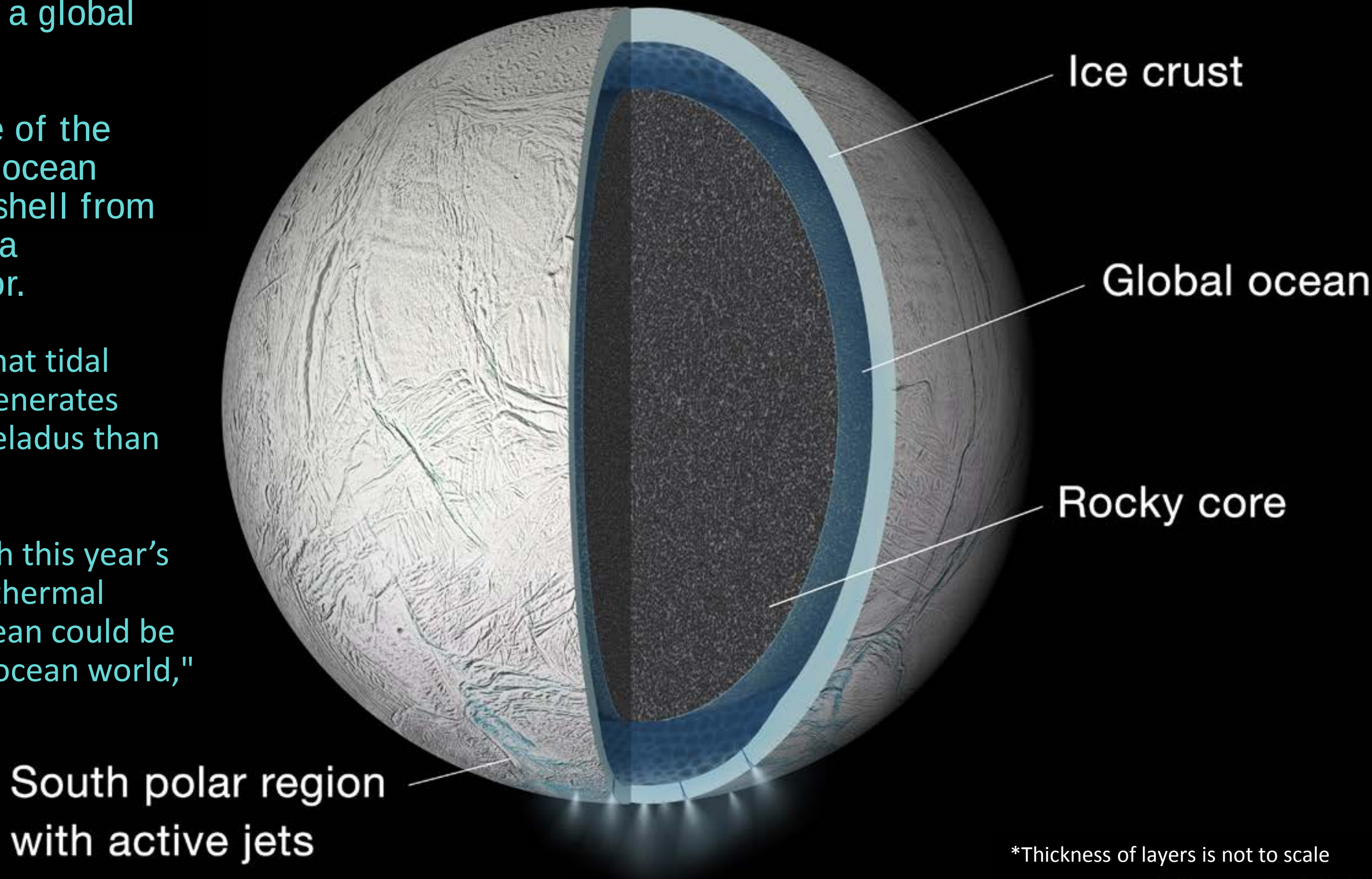
- The "Throat of Kraken," formally called "Seldon Fretum," may create turbulence similar to that in the Corryvreckan Strait off Scotland's coast.
- The Kraken strait may also limit mixing between liquid hydrocarbon basins, resulting in composition difference between the two.

Below: **Rough water in the Corryvrecken Strait results from the energetic tidal flow through the channel. Similar phenomena may occur on Titan.** *(The Corryvreckan Whirlpool - geograph-2404815-by-Walter-Baxter.jpg)*

Global Ocean Inside Enceladus

Press Release - http://1.usa.gov/1NDHVlV

- Cassini imaging observations of Enceladus' rotation and its wobble (libration) as it orbits Saturn revealed the presence of a global ocean[1].
- Explaining the magnitude of the wobble requires a global ocean separating the outer ice shell from the interior. It rules out a completely frozen interior.
- A global ocean may mean that tidal flexing by Saturn's gravity generates much more heat inside Enceladus than previously thought.
- This discovery, together with this year's discovery of seafloor hydrothermal activity[2,3], indicates that ocean could be long-lived. Enceladus, the "ocean world," invites exploration.



*Thickness of layers is not to scale

[1]"Enceladus's measured physical libration requires a global subsurface ocean," P.C. Thomas, et al., 2015. doi:10.1016/j.icarus.2015.08.037
[2]"Ongoing hydrothermal activities within Enceladus," Hsu et al., Nature, 519, 207-210, 2015.
[3]"Possible evidence for a methane source in Enceladus' ocean ," Bouquet et al., Geophysical Research Letters, 42, 1334-1339, 2015.

A Surprise Twist in Titan’s Origin Story

Saturn’s moon Titan, like comets, may retain tracers of some of the primordial ingredients from which the solar system formed. Measurements of two nitrogen isotopes indicate that Titan’s chemical heritage traces straight to the original material in the protoplanetary nebula – the cold disk of gas and dust from which the sun formed – and not to gas and dust local to Saturn.

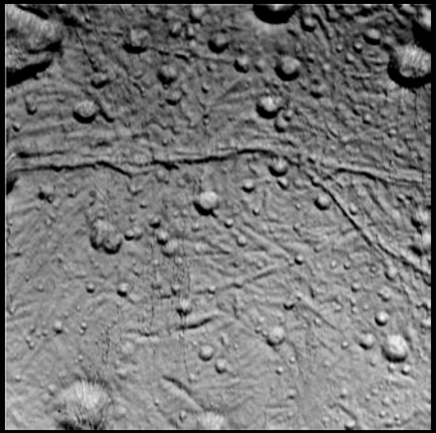
- **The finding from NASA’s Cassini spacecraft may help answer fundamental questions about the original building blocks of the planets.**
- **It will also help address whether meteorites and comets brought nitrogen to Earth or whether nitrogen was part of our planet’s original makeup.**

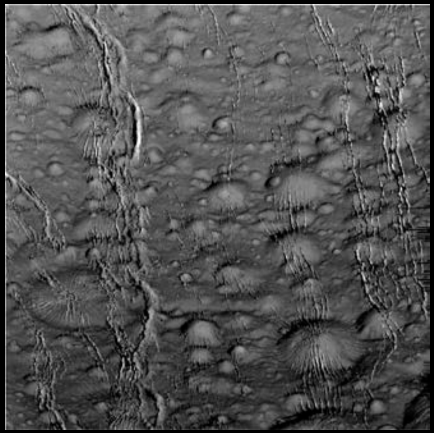
“Protosolar ammonia as the unique source of Titan’s Nitrogen,” K.E. Mandt, et al., Astrophysical Journal Letters, 788, L24-L28, 2014.

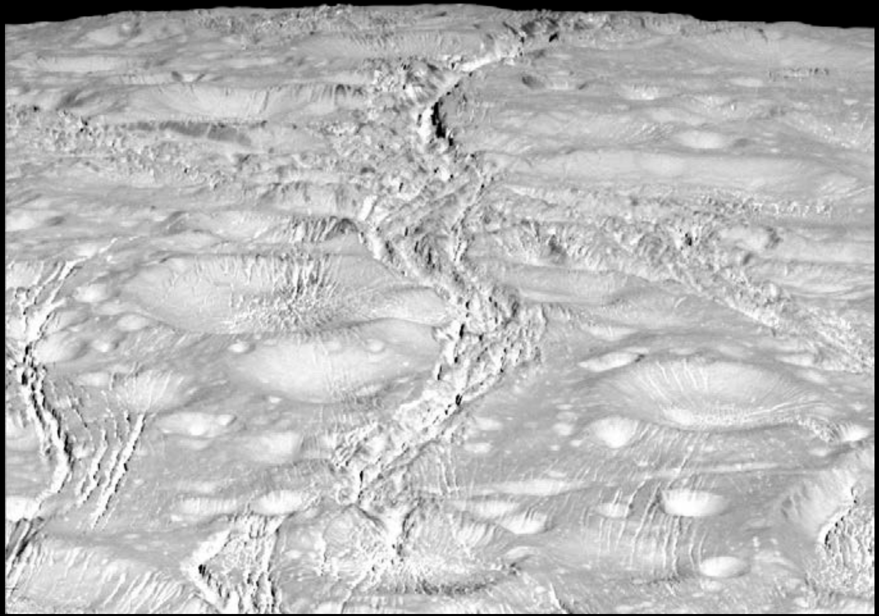
Revealing Enceladus’ North Pole

On October 14, 2015 Cassini captured its final views of the north polar region of Saturn’s moon Enceladus. This pole was in darkness earlier in the mission.

Scientists will use these images to look for hints of past cryovolcanic and tectonic activity on this unusual Ocean World.







http://go.nasa.gov/1jIqQL2

Note that any data presented here are unpublished, minimally processed, and undergoing refinement and analysis

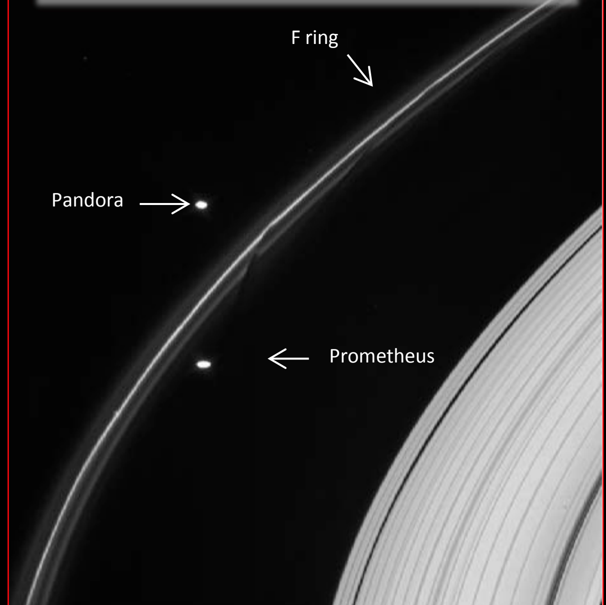
Saturn’s F Ring: A Calm Core in the Midst of Chaos

Long-term stability of the narrow F ring core (center) has been difficult to explain. Prometheus and Pandora each stir the region into a chaotic state in which orbits of particles and moonlets sporadically change in unpredictable ways. This has complicated the tracking of small objects occasionally seen in the region for the last decade.

However, at select, very narrow locations, orbits of particles can remain essentially constant for long periods of time because Prometheus’ perturbations at one encounter are promptly cancelled at the next encounter. *The long-lived F ring core lies precisely at one of these locations.*

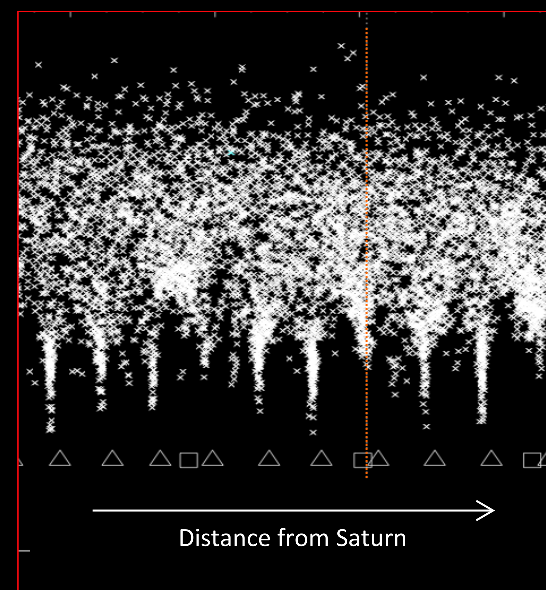
Cassini scientists have generated numerical integrations of tens of thousands of test particles over tens of thousands of Prometheus orbits to map out the effect. Findings show that one novel kind of “antiresonance” with Prometheus alone, with no help from Pandora, can help the ring particles maintain stable orbits.

Prometheus and Pandora, create chaotic lumps and tendrils in the ring. They also are responsible for narrow stable zones including the F ring core.



Computer simulations (lower right) reveal the presence of narrow, stable zones (the icicle-like clusters of points) . These stable zones are slightly offset from traditional gravitational resonances with Prometheus and Pandora (triangle and square symbols). The orange, dotted line shows the observed location of the F ring core, lying in one of the theoretically stable zones. A question remains, why only this one?

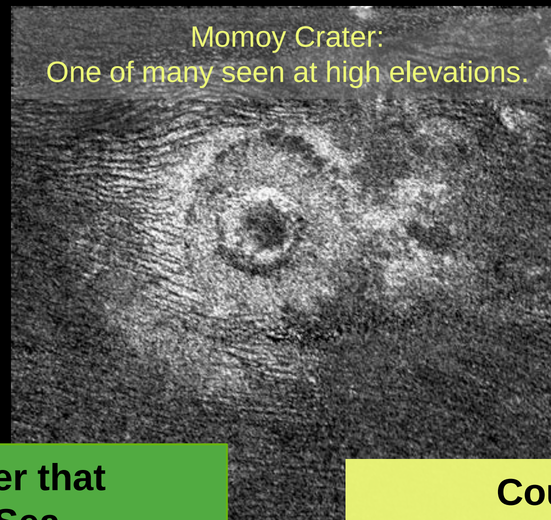
These top-down views (above), with Saturn removed from the images, show both the stability of the F ring core and the chaos of the ring’s edges.



Saturn’s F Ring Core: Calm in the Midst of Chaos, J. N. Cuzzi, et al., Icarus, 232, 157-175, 2014.

Impacts on Titan: Do They Splash or Thud?

The lack of craters on Titan at mid-to-high latitudes has been perplexing. Comets and other solar system debris that impact Saturn's moon Titan may splash into wetlands, leaving only subtle traces in a marine environment, according to findings by Cassini.


Momoy Crater:
One of many seen at high elevations.

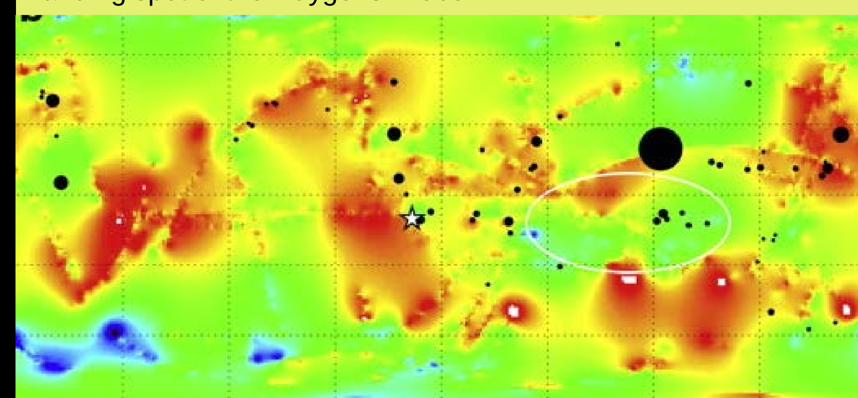
Researchers say it is possible that many impacts could have fallen on extensive wetlands or a global sea that could have existed on Titan in the last few hundred million years. Such wetlands would be fed by an aquifer of liquid methane or ethane.

An Example of an Earth Crater that Disappeared in a Shallow Sea

A 35 million-year-impact crater (outlined in white) went undiscovered in Chesapeake Bay until 1994. The hidden 50-mile wide crater hints at how some of Titan's impact craters could have disappeared into a shallow ocean.

Could Impact Craters be Hiding in Wetlands on Titan?

There are fewer craters (black dots) in Titan's lower elevations (regions in green), which may signal the presence of past or present wetlands. Xanadu (inside the white oval) is the only low-lying area with numerous craters. A white star marks the 2005 landing spot of the Huygens Probe.



"Elevation distribution of Titan's craters suggests extensive wetlands," C.D. Neish and R.D. Lorenz,, Icarus, 228, 27-34, 2014.