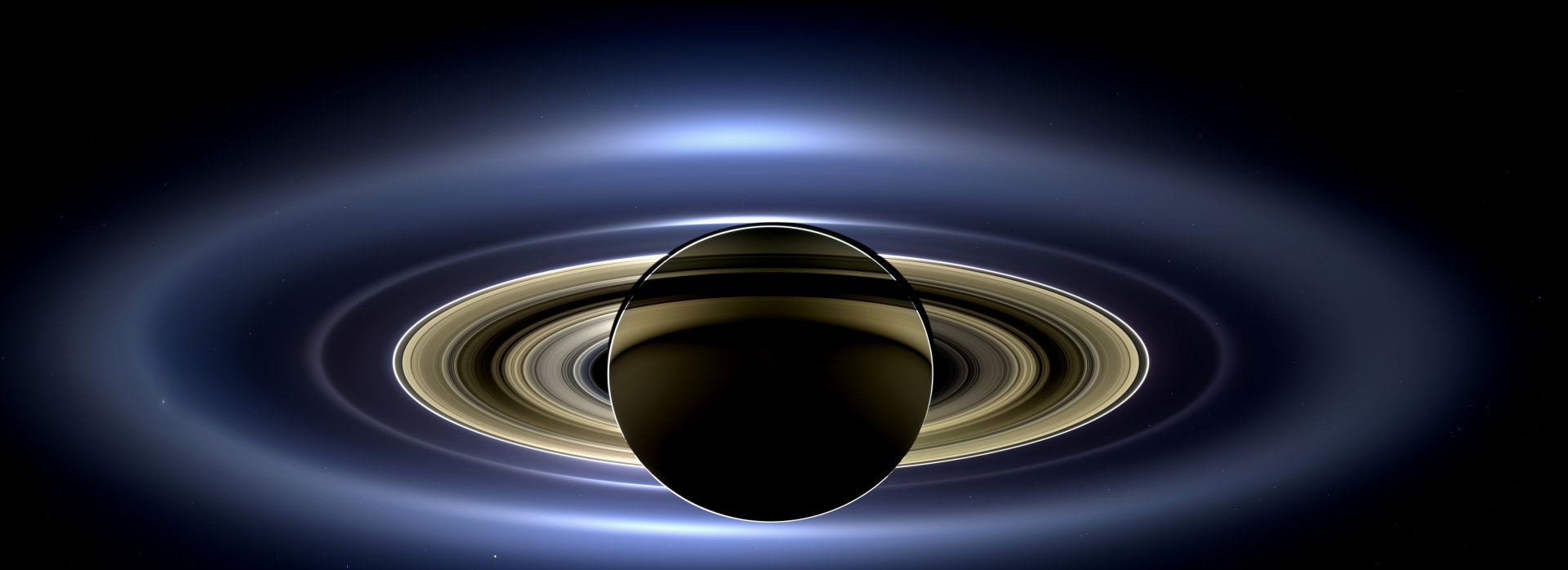
Surprises at Saturn: Cassini Mission Highlights

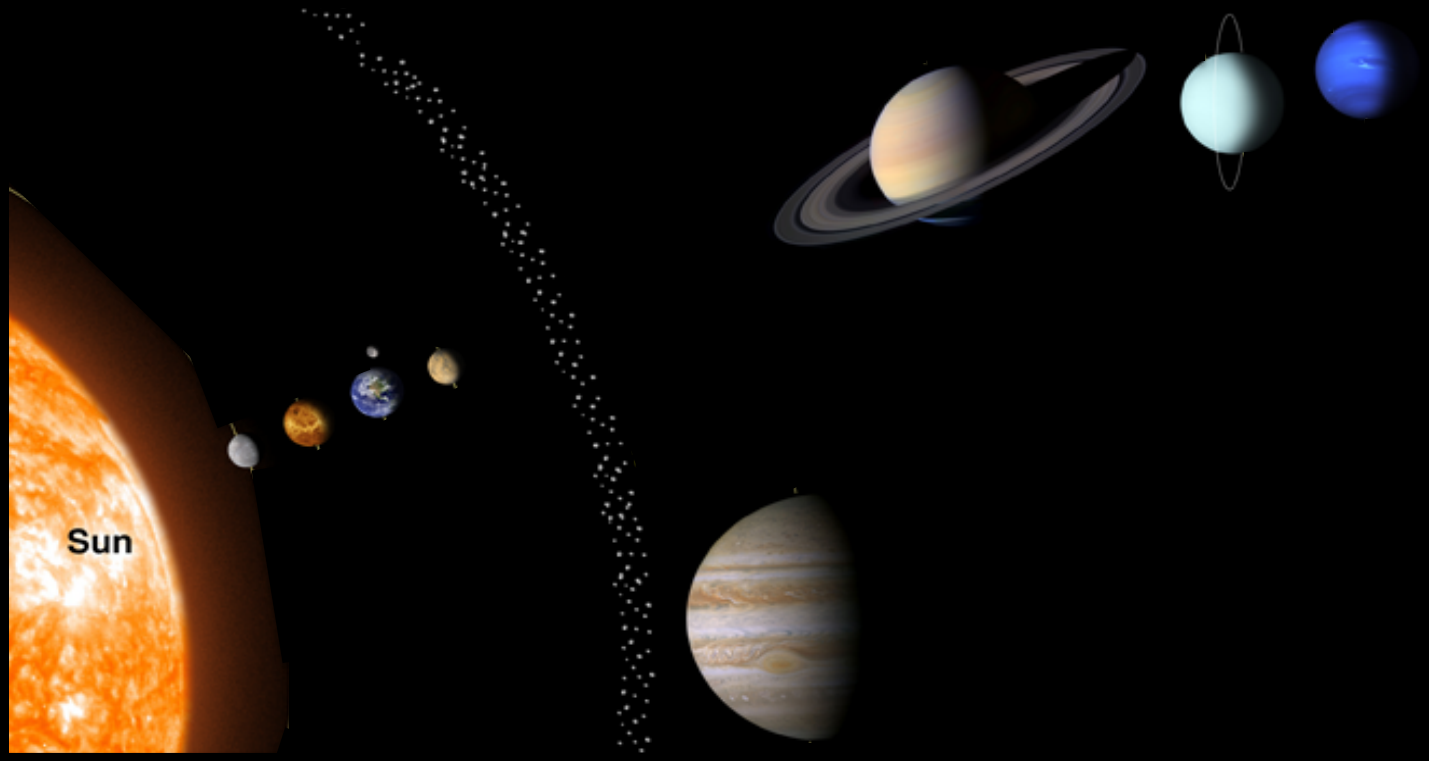


Dr. Linda Spilker
Cassini Project Scientist, JPL
Night Sky Network
21 September 2016

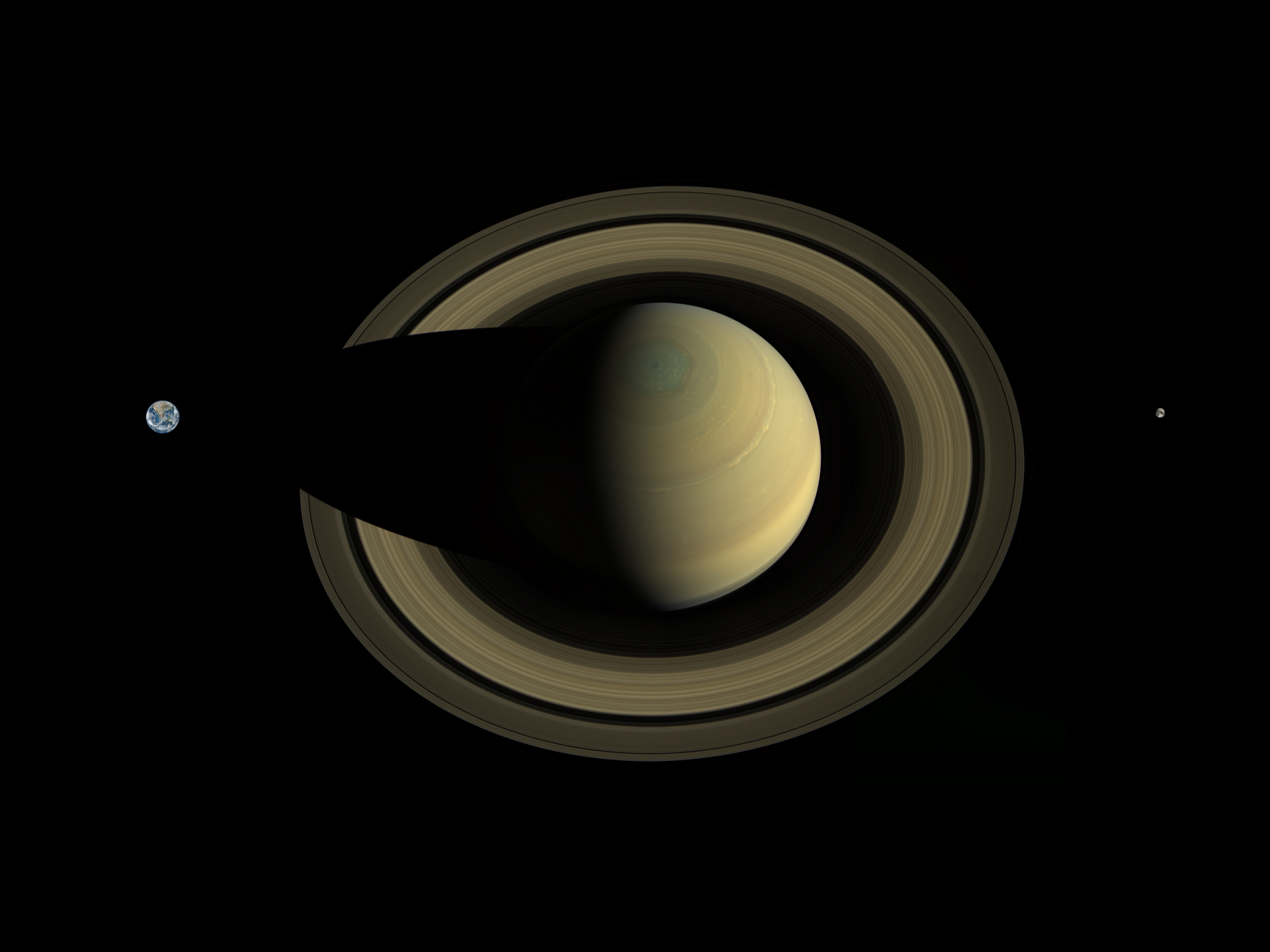
Grand Science Questions

- *Are We Alone in the Universe?*
  - Has life originated somewhere other than Earth?
  - How did life originate on Earth?

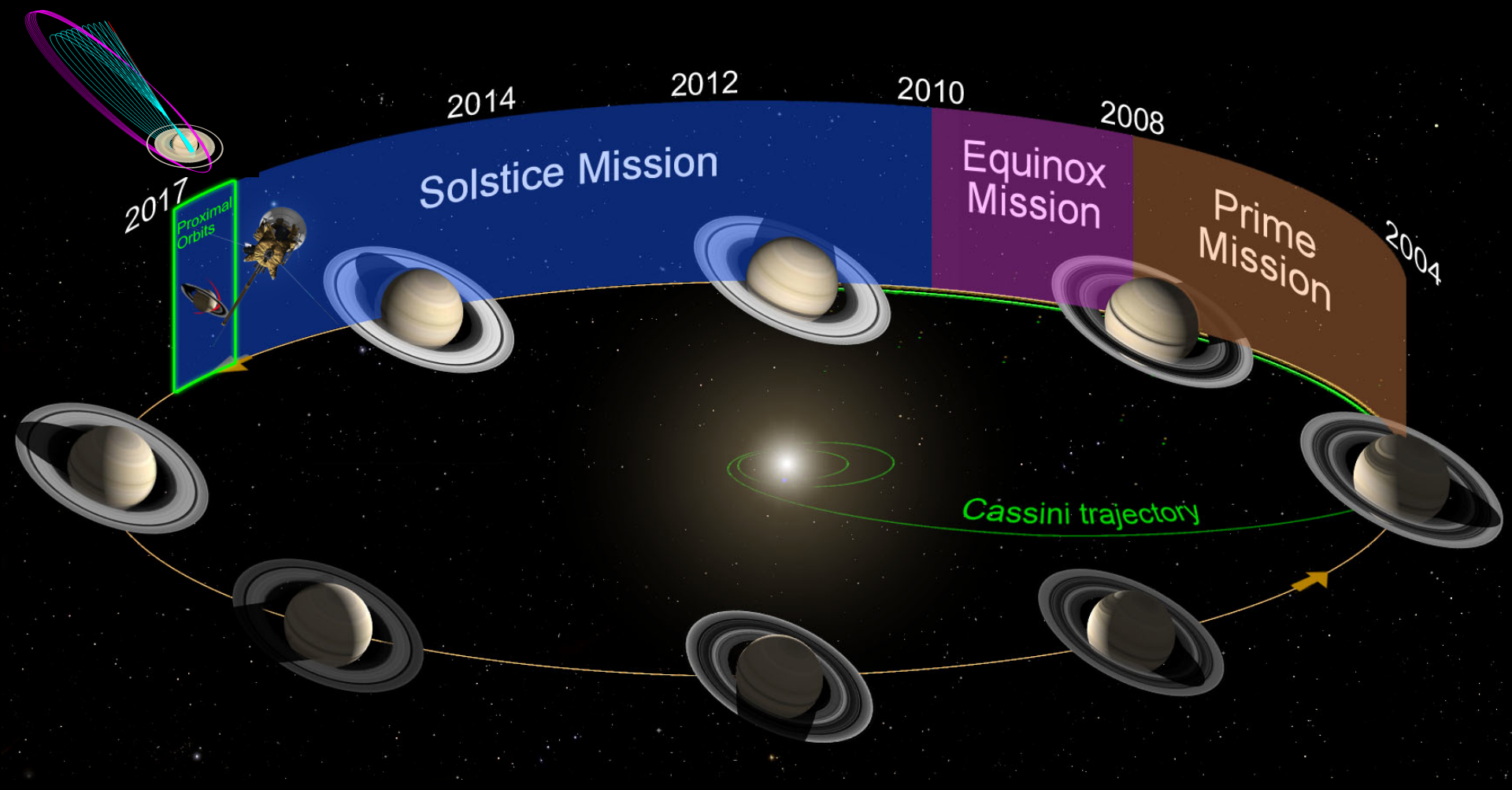
Grand Science Questions

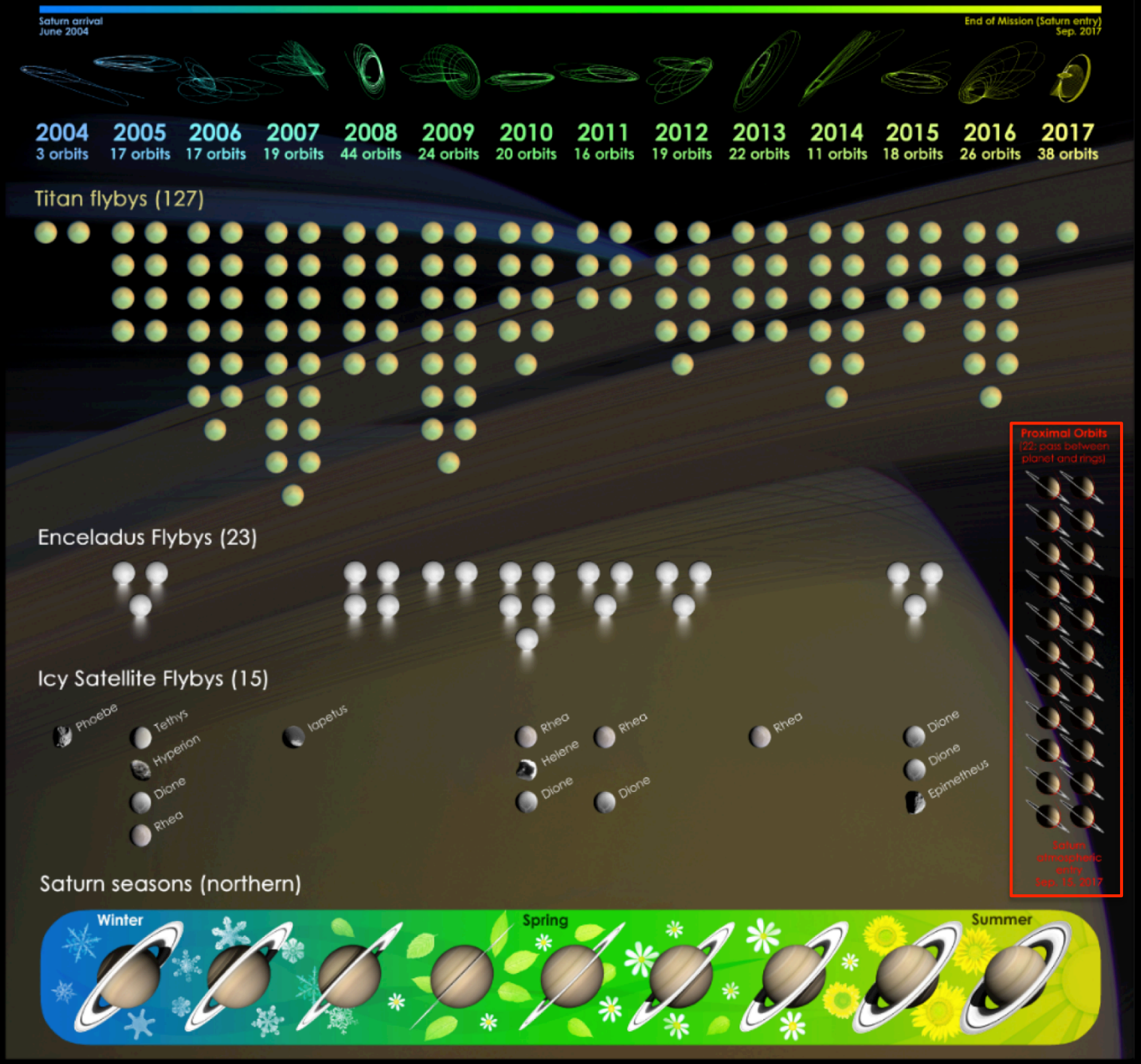


- *How did the solar system, and Earth within it, come to be?*
  - How is it evolving? Where is it headed?

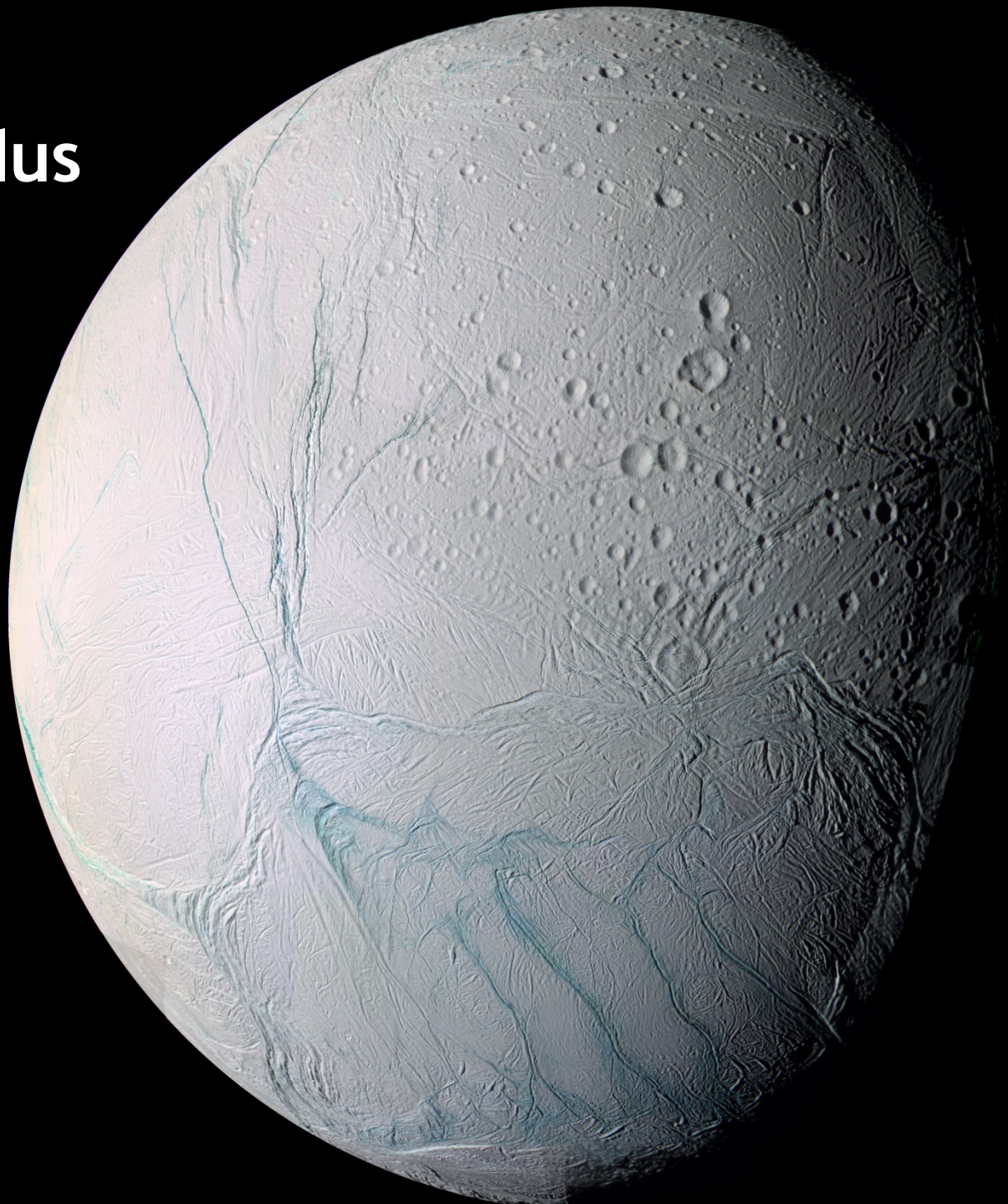


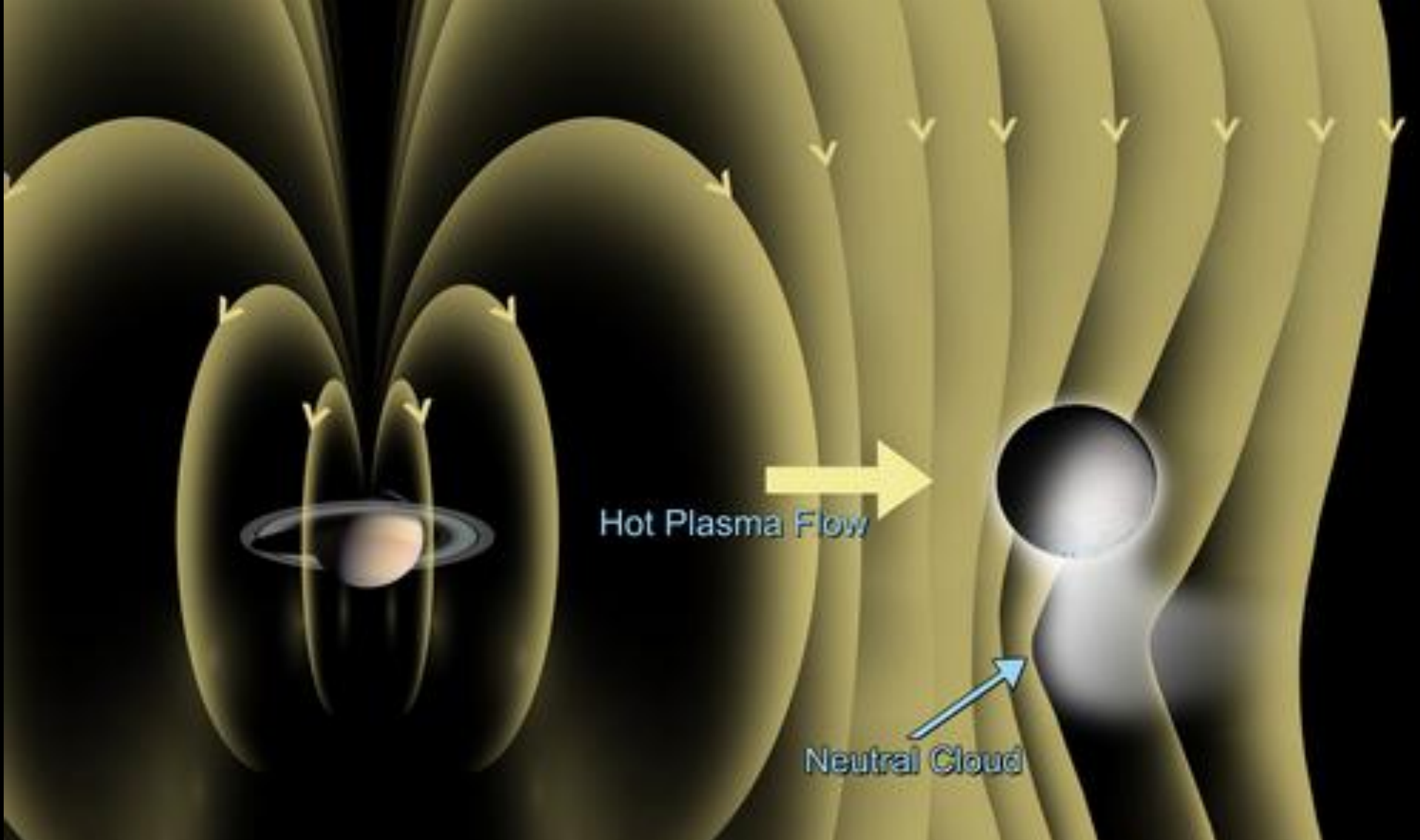
Cassini-Huygens Mission Overview




Saturn arrival
June 2004
End of Mission (Saturn entry)
Sep. 2017
2004 3 orbits
2005 17 orbits
2006 17 orbits
2007 19 orbits
2008 44 orbits
2009 24 orbits
2010 20 orbits
2011 16 orbits
2012 19 orbits
2013 22 orbits
2014 11 orbits
2015 18 orbits
2016 26 orbits
2017 38 orbits
Titan flybys (127)
Enceladus Flybys (23)
Icy Satellite Flybys (15)
Phoebe
Tethys
Hyperion
Dione
Rhea
Iapetus
Rhea
Helene
Dione
Rhea
Dione
Rhea
Dione
Dione
Epimetheus
Proximal Orbits
(22; pass between planet and rings)
Saturn atmospheric entry
Sep. 15, 2017
Saturn seasons (northern)
Winter
Spring
Summer

Enceladus

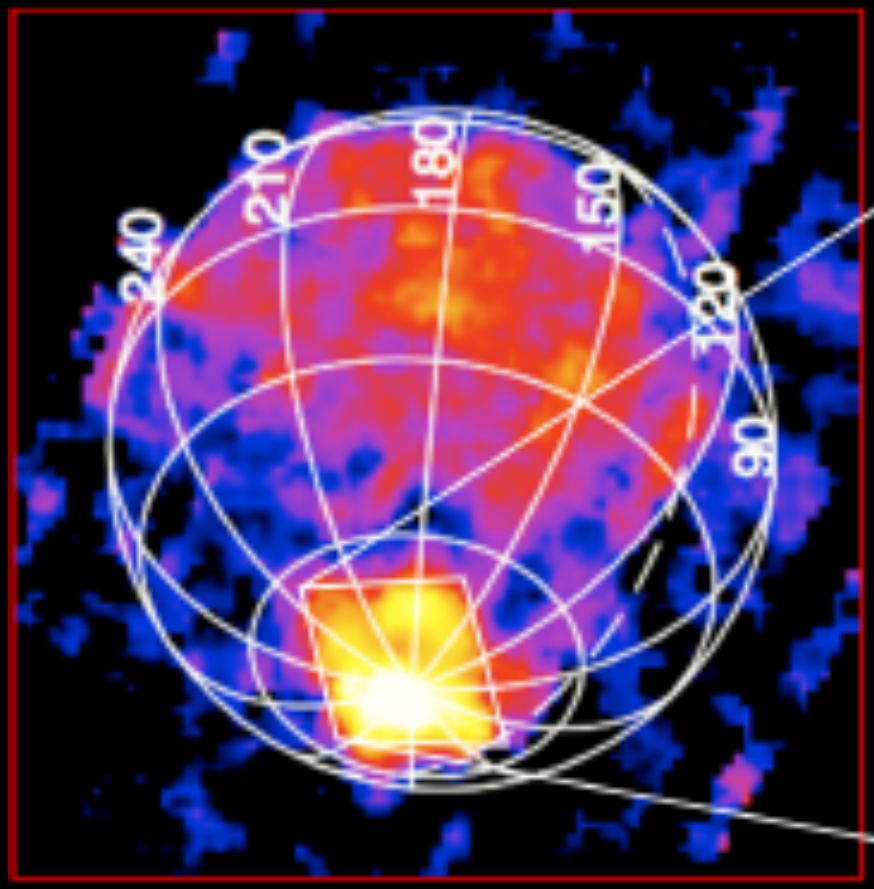


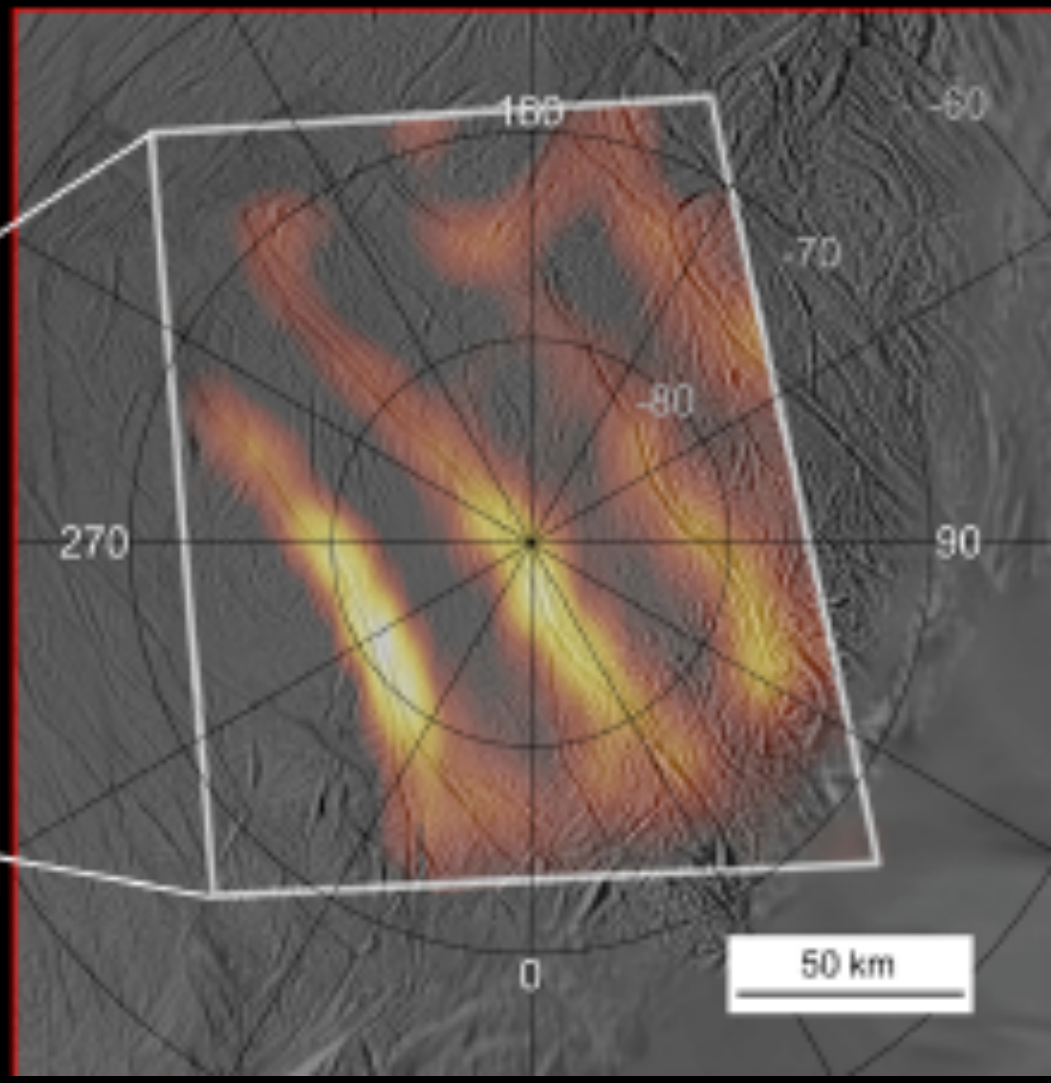


2005: First flyby close to Enceladus is 1000 km, unusual comet-like magnetic field signature detected

Second flyby altitude decreased to 175 km (Dougherty et al 2006)

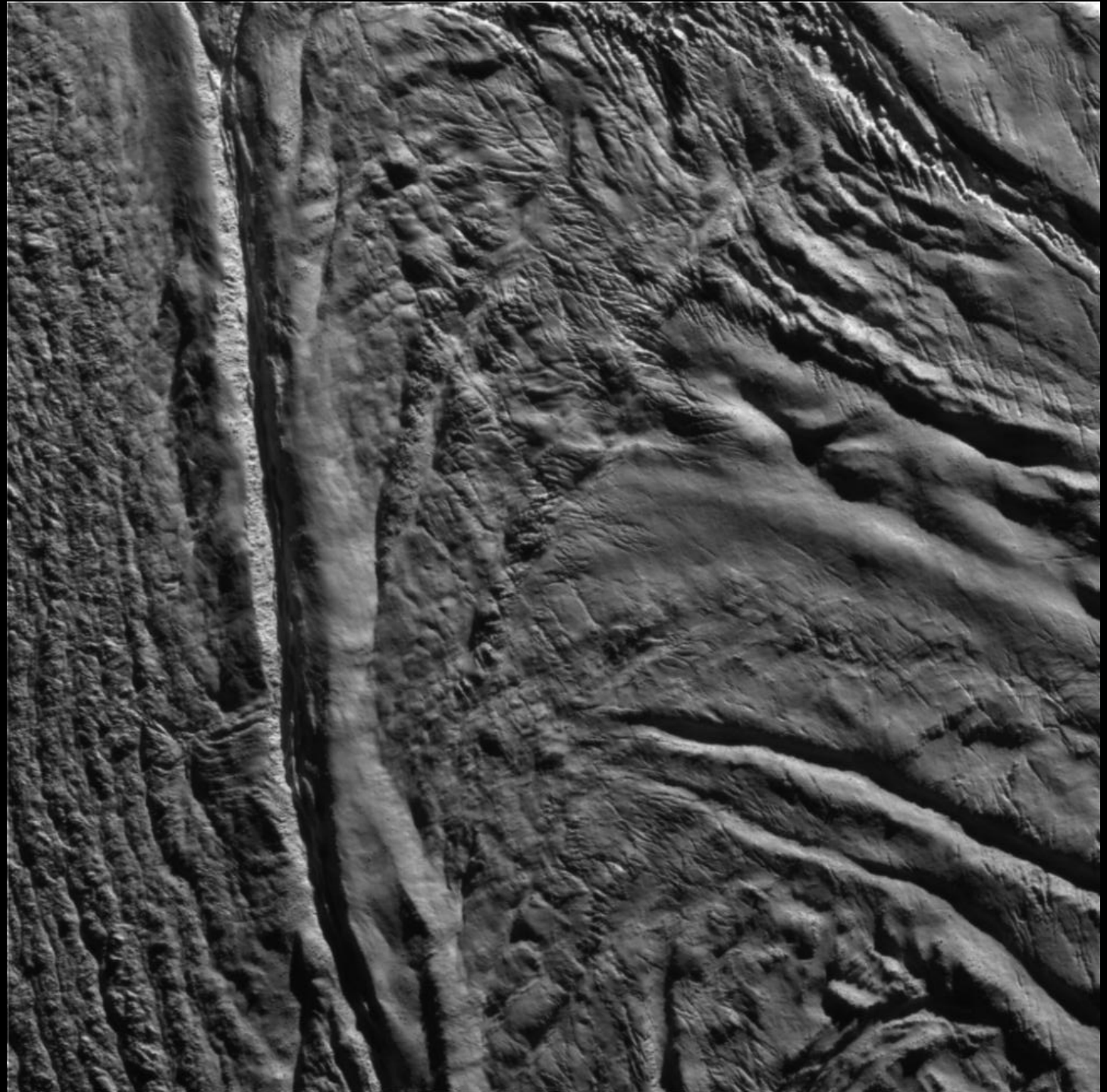
Infrared CIRS Heat measurement



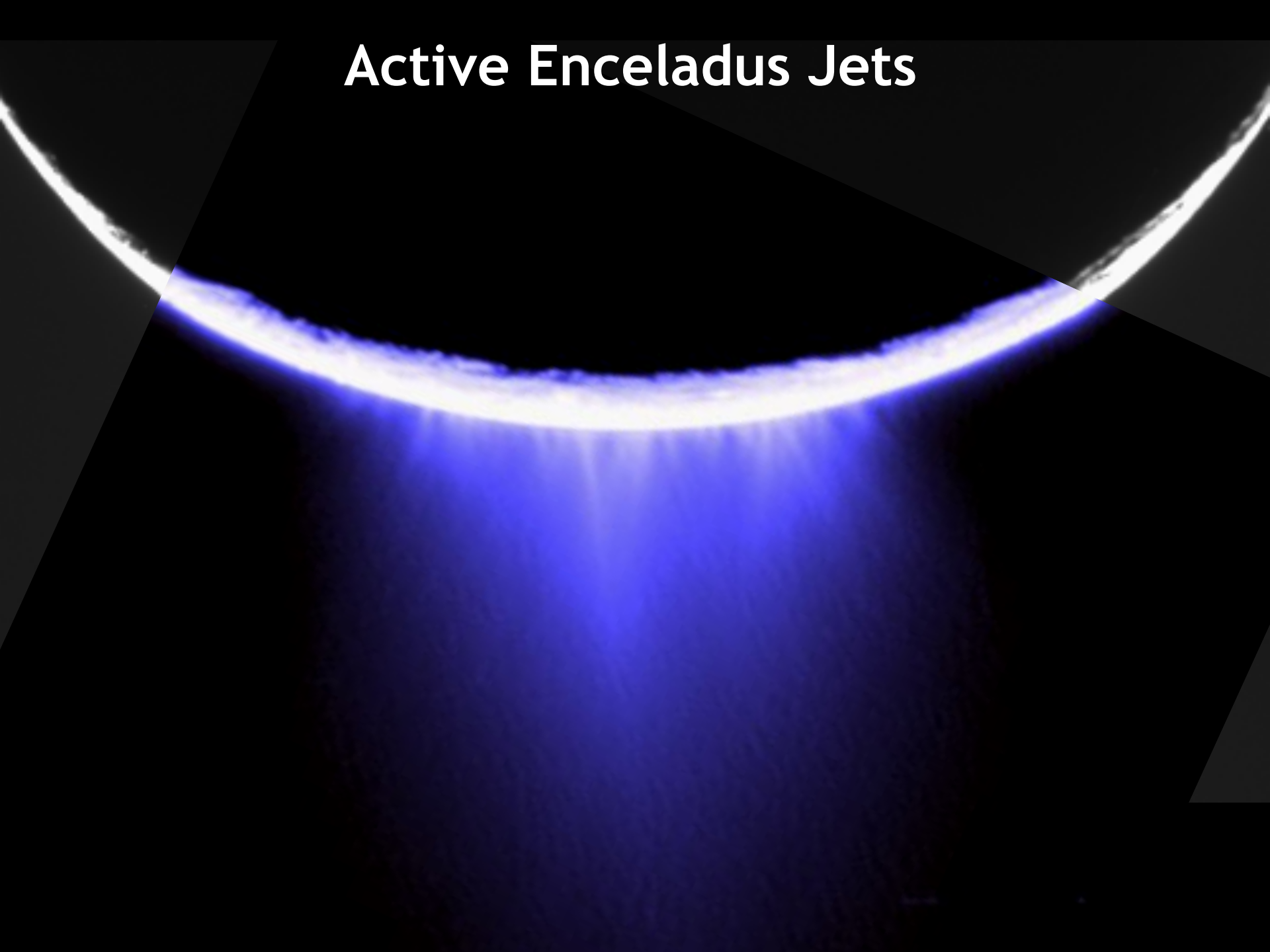


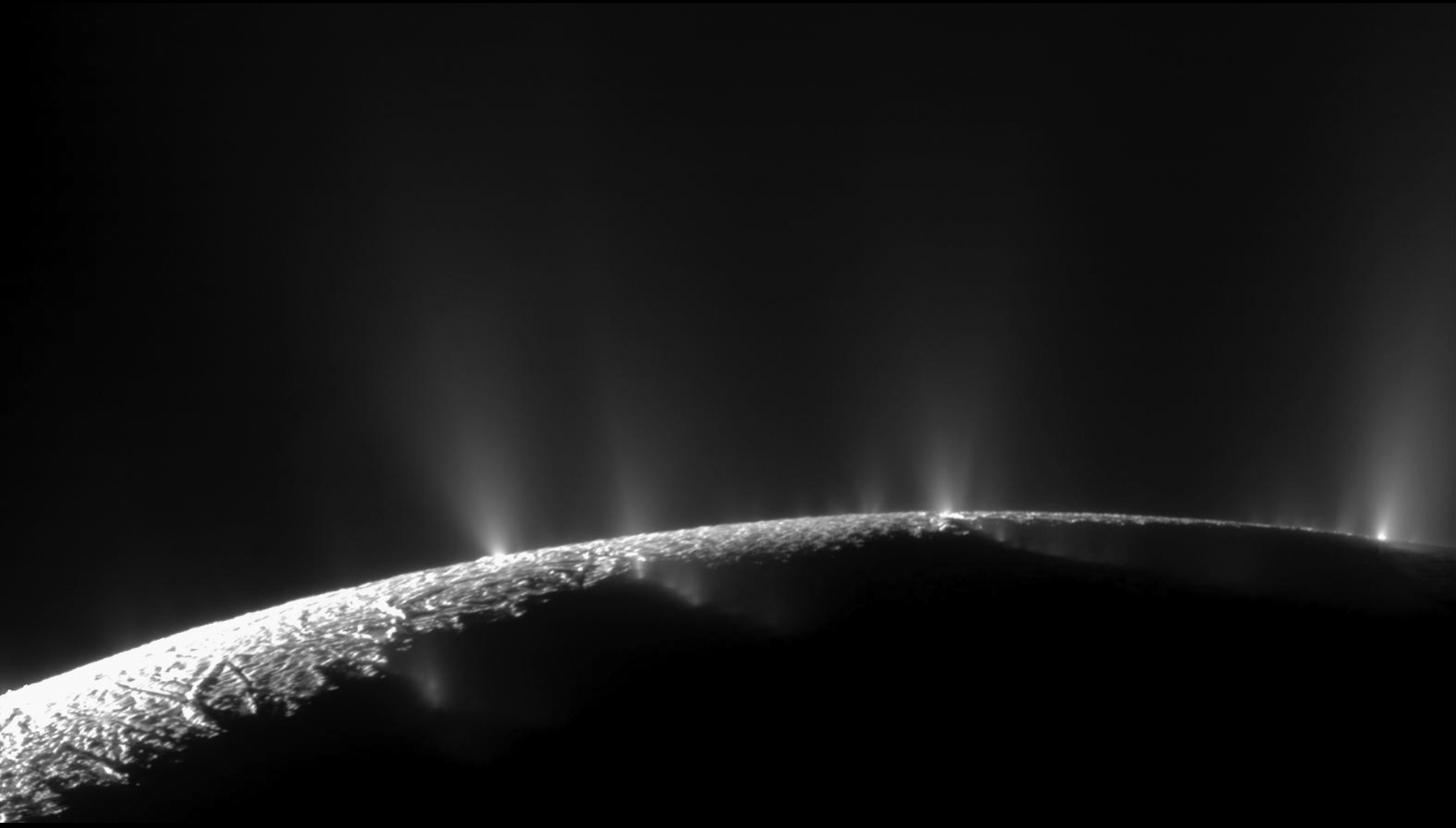
- Excess heat at south pole
- Tiger stripe origin

(Spencer et al., 2006)

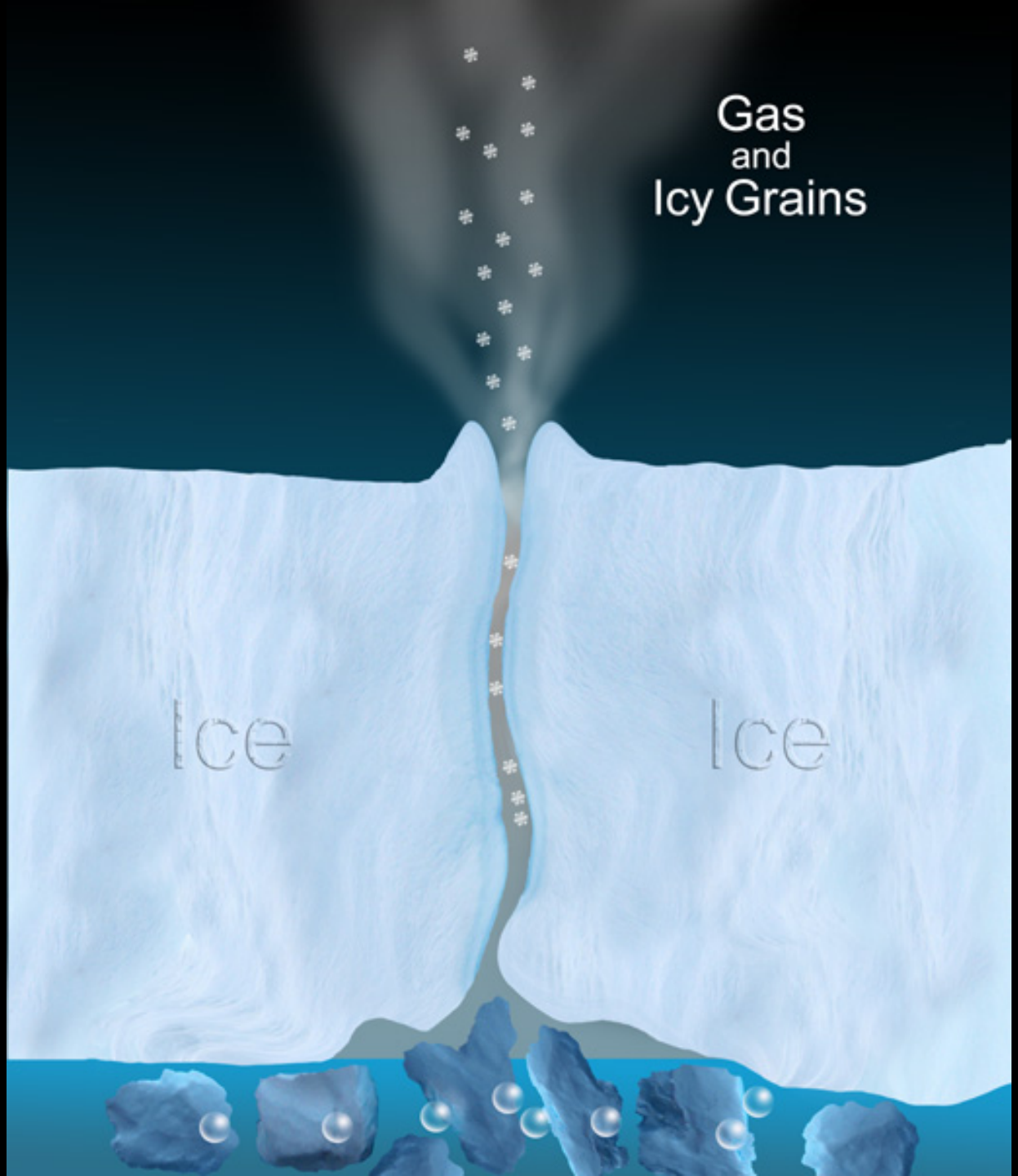


Active Enceladus Jets

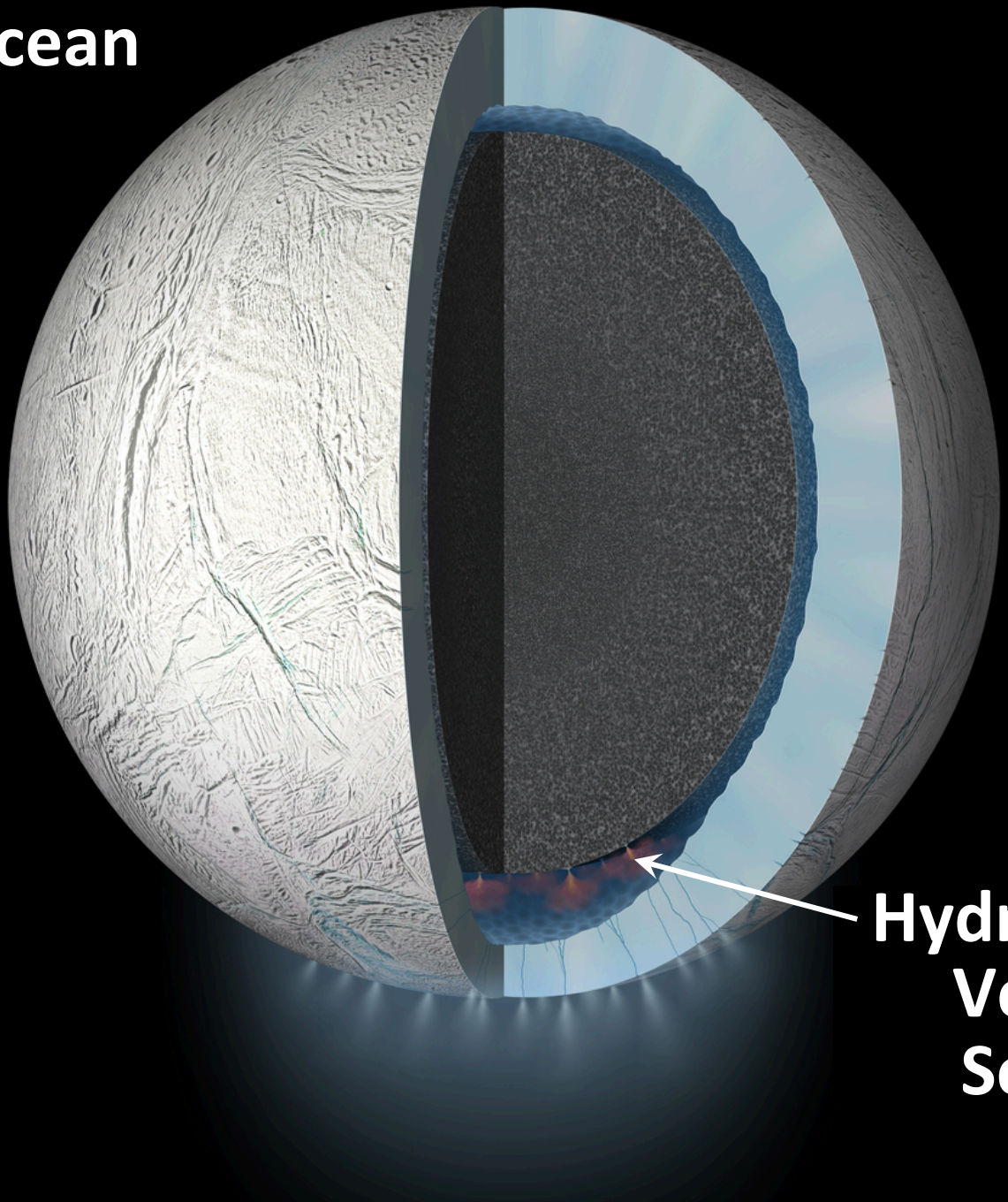




Enceladus fountain in France’s Versailles garden


Gas
and
Icy Grains
Ice
Ice

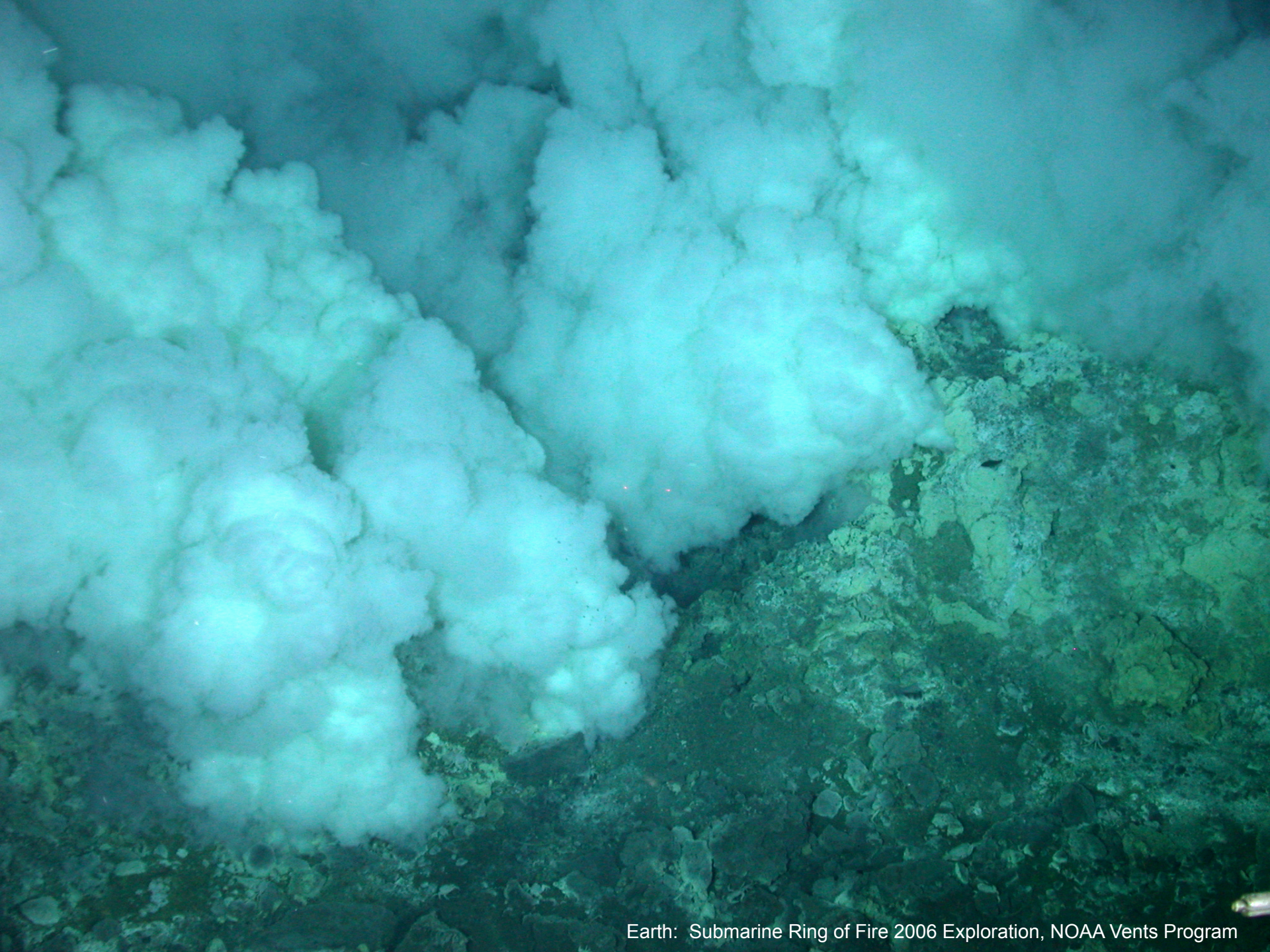
Global Ocean



Life *in* Enceladus' Ocean?

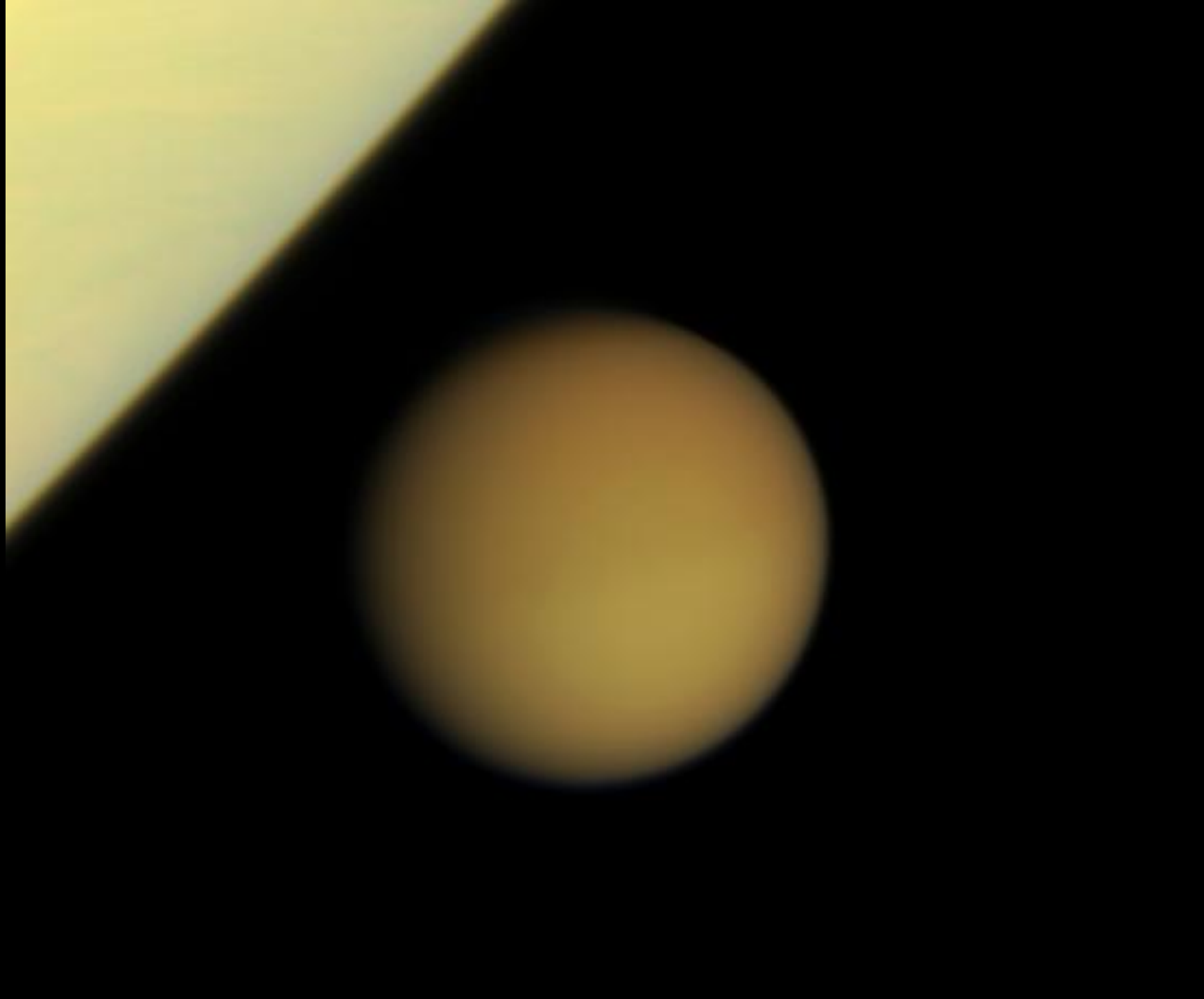
Multiple factors *make plausible the idea that life exists there:*

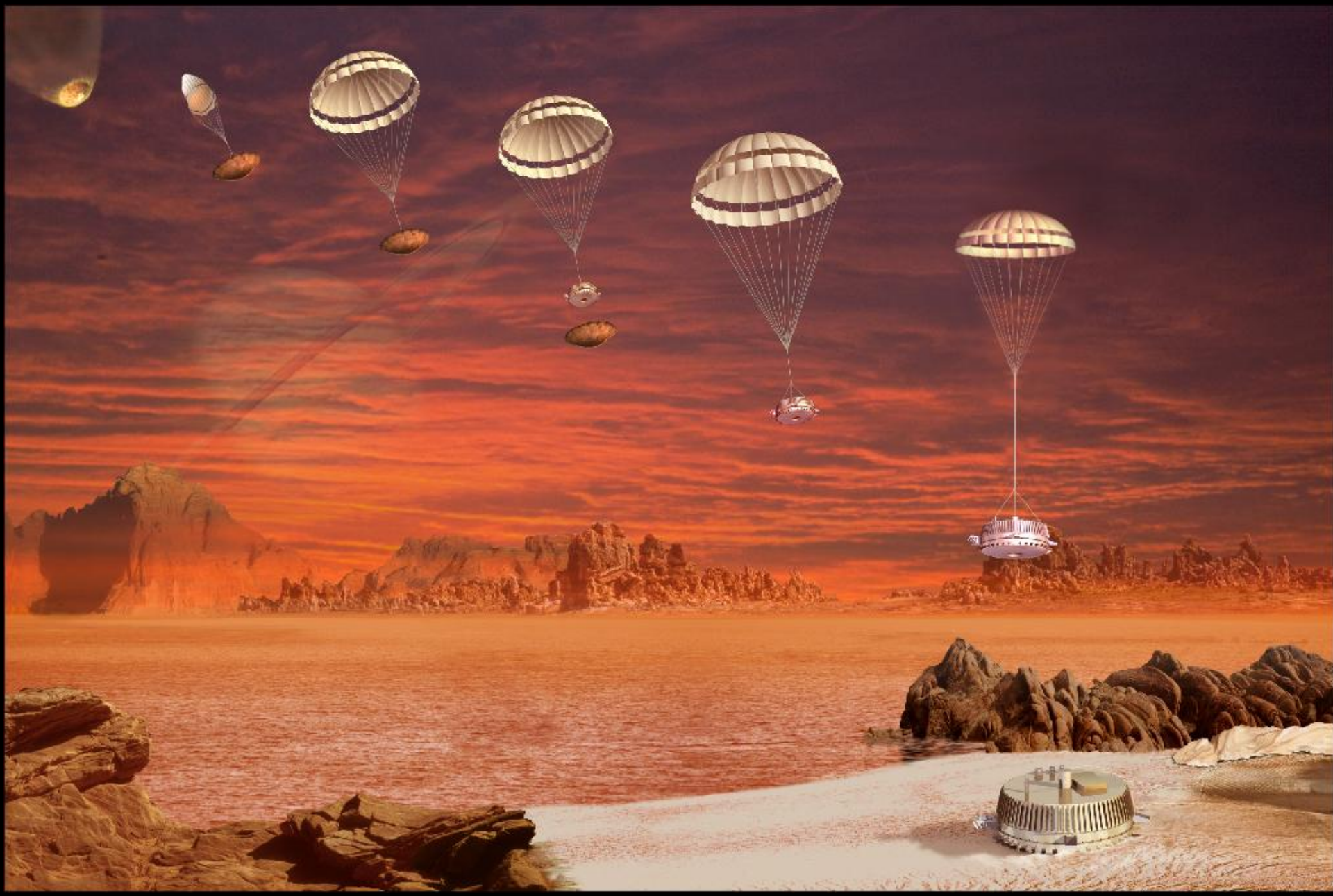
- Global, salty ocean
- Ocean is long-lived
- Organics in plume, coming from ocean
- Heat energy
- Hydrothermal vents on ocean seafloor



Earth: Submarine Ring of Fire 2006 Exploration, NOAA Vents Program

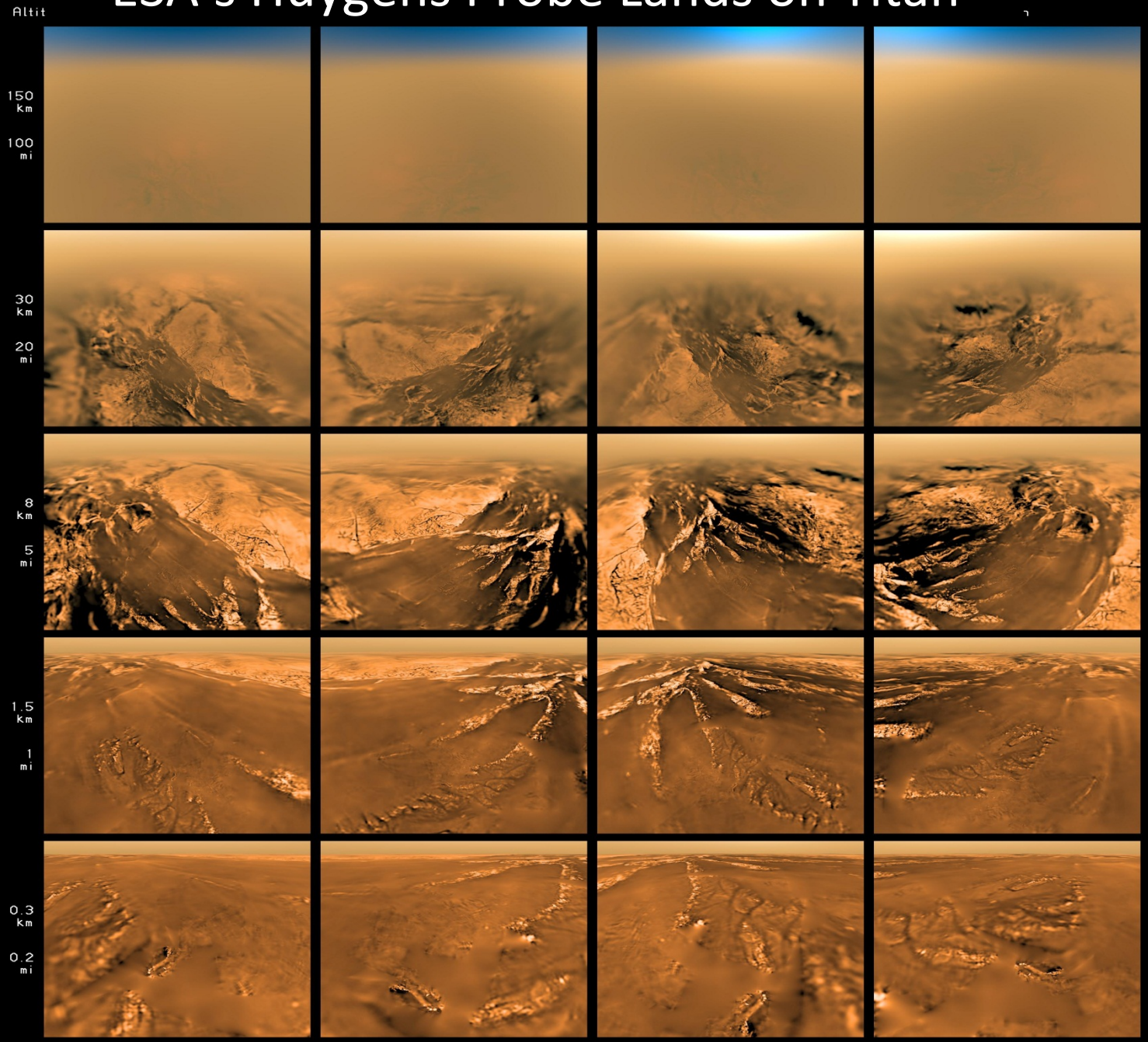
Earth: Submarine Ring of Fire 2006 Exploration, NOAA Vents Program



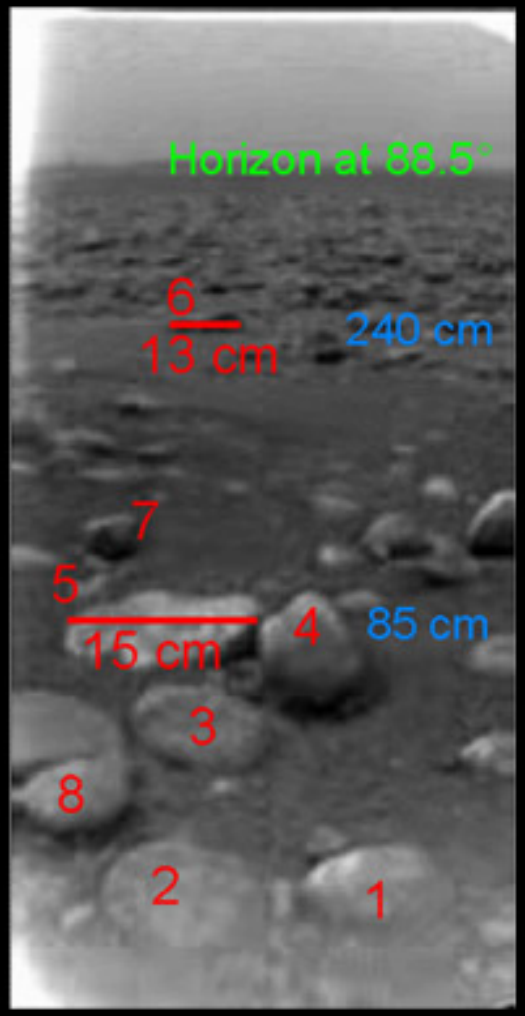


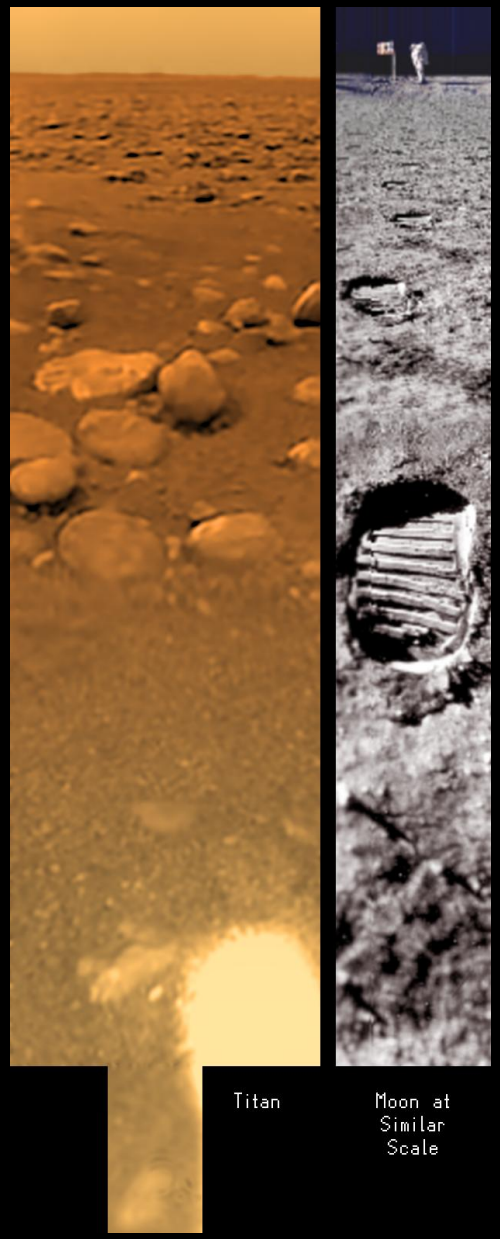
ESA's Huygens Probe Lands on Titan

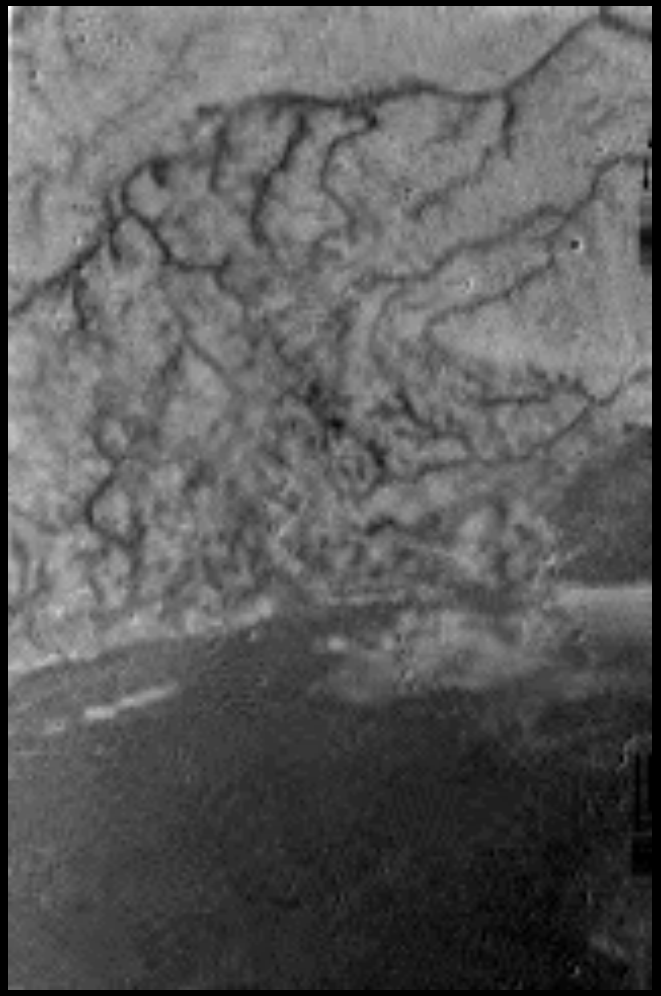
Haze clears at an altitude of 60 km



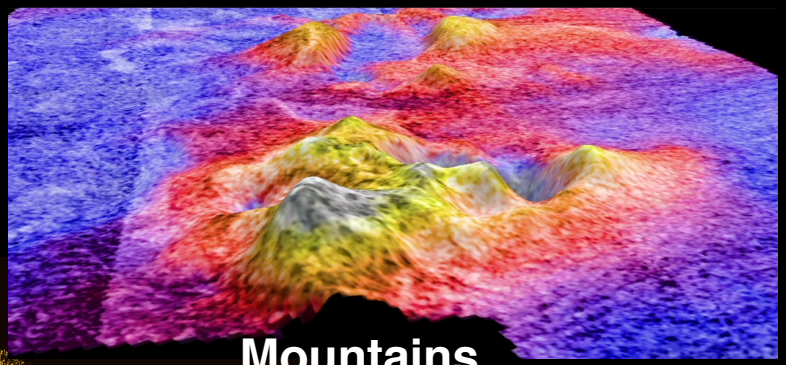
Huygens Images

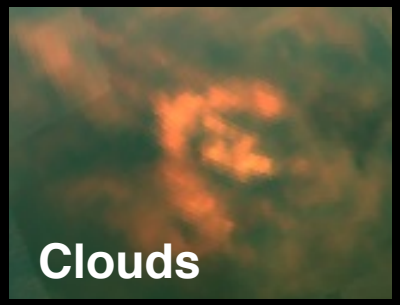


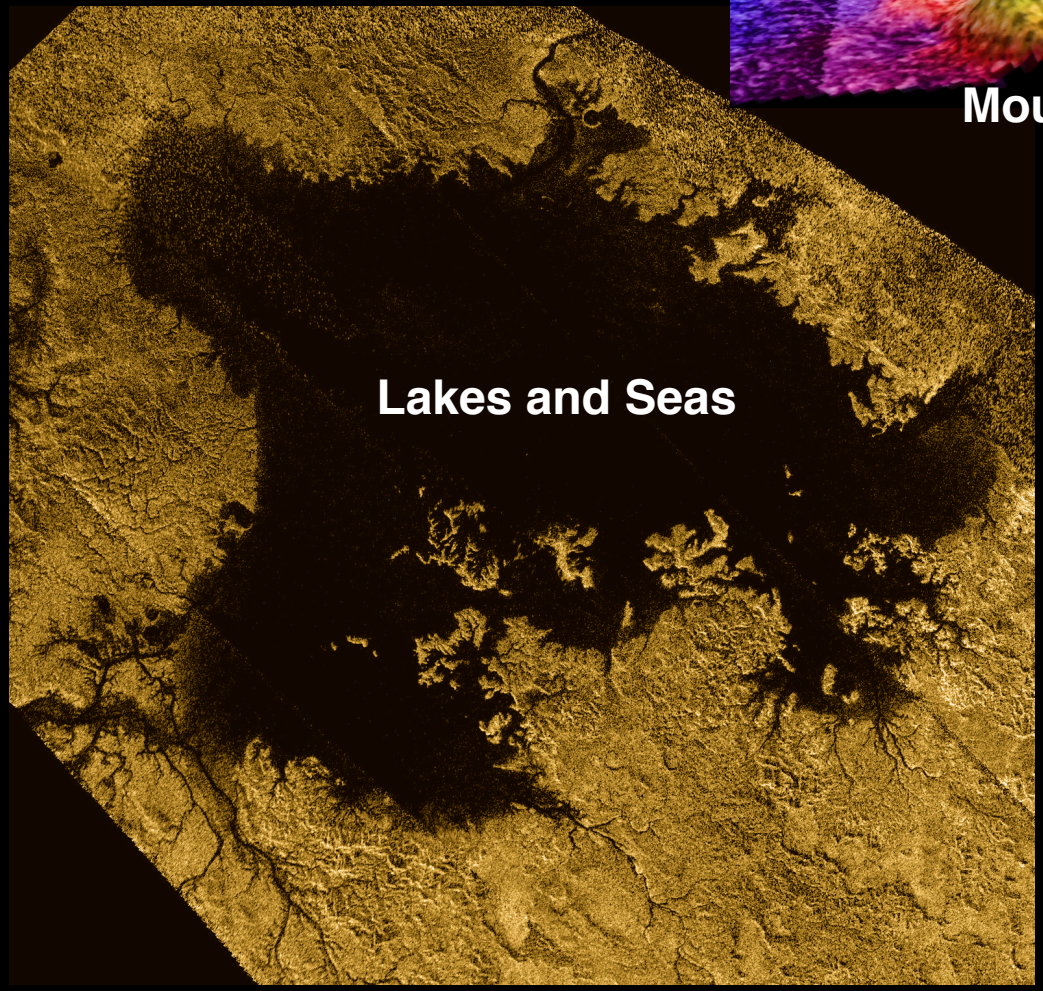


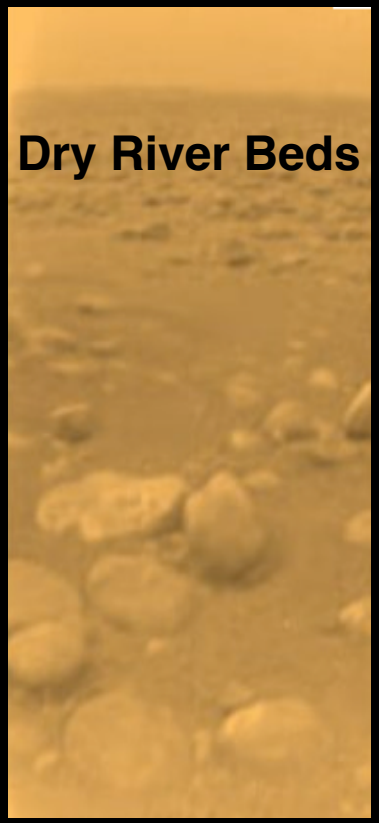


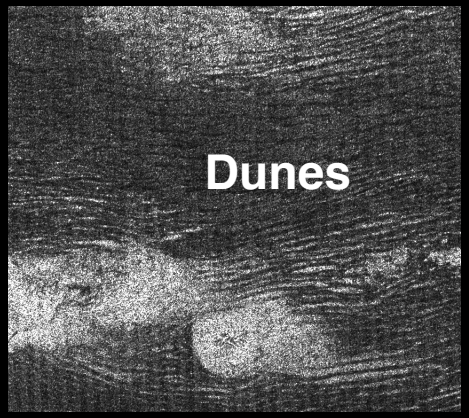
Titan: An Earth-like World

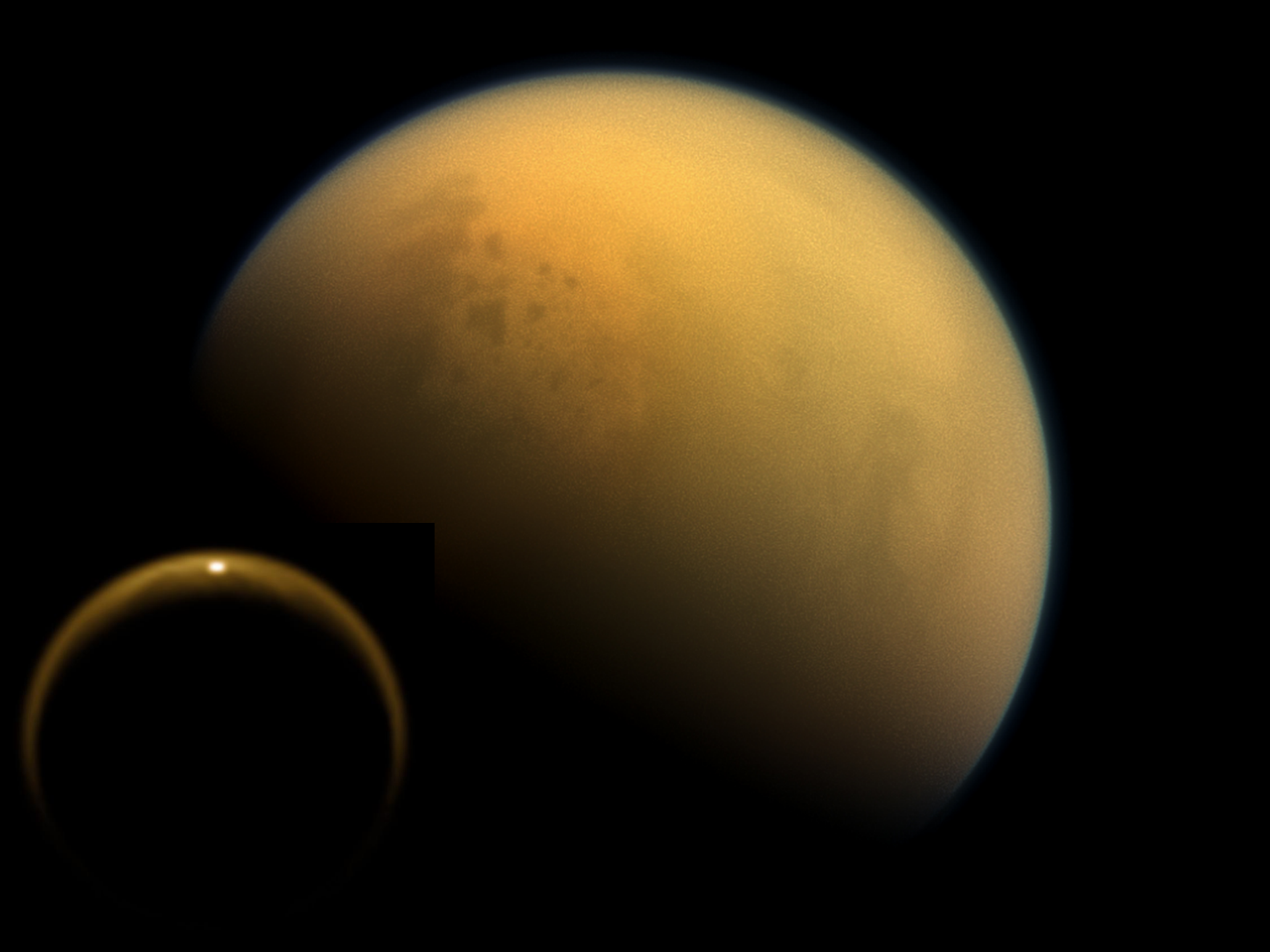




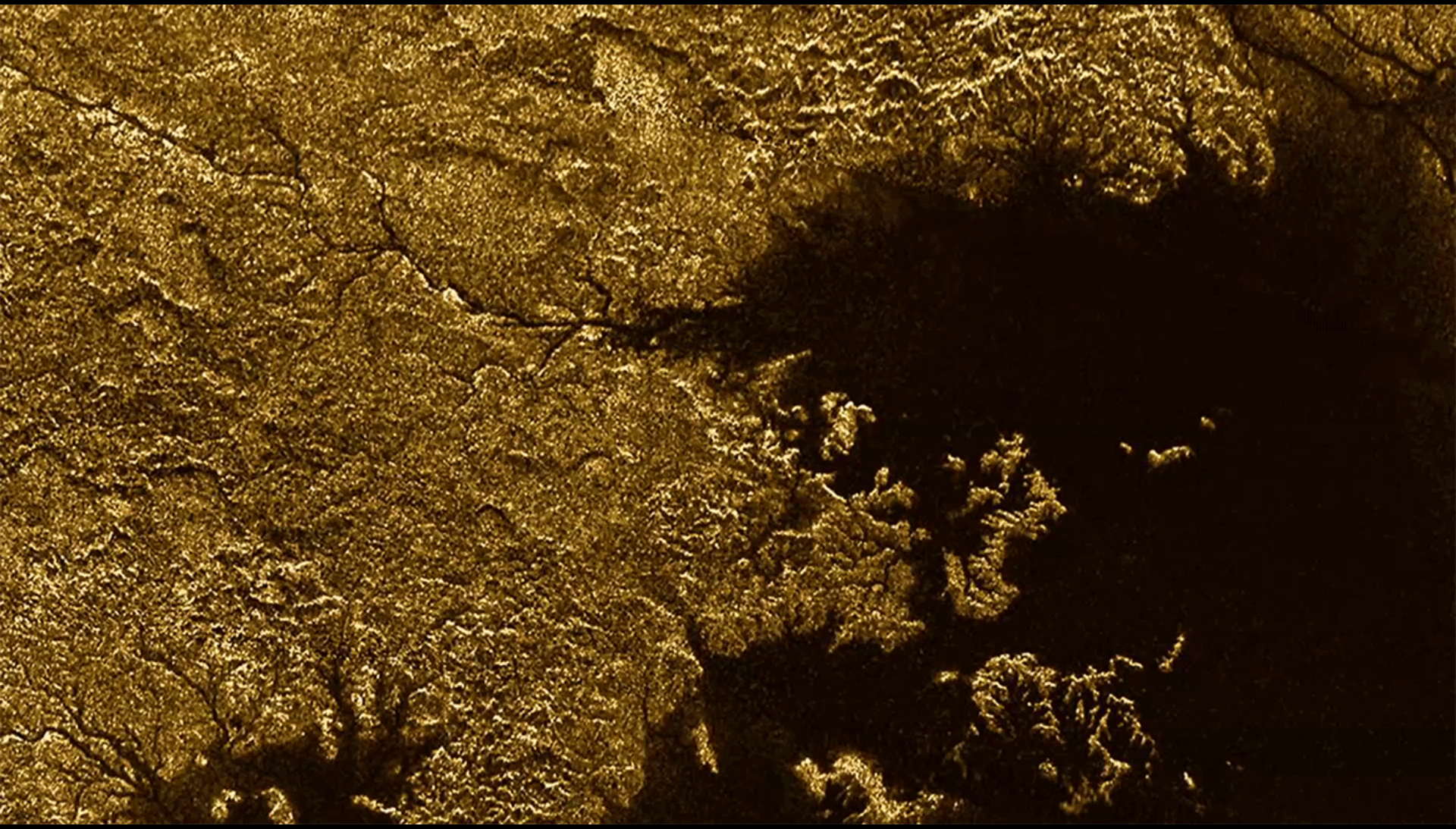






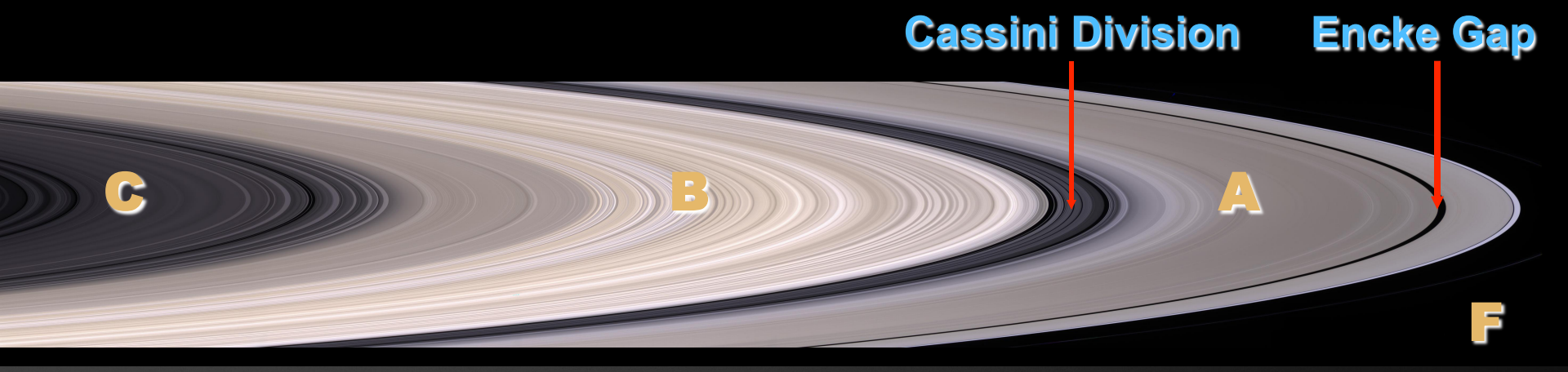


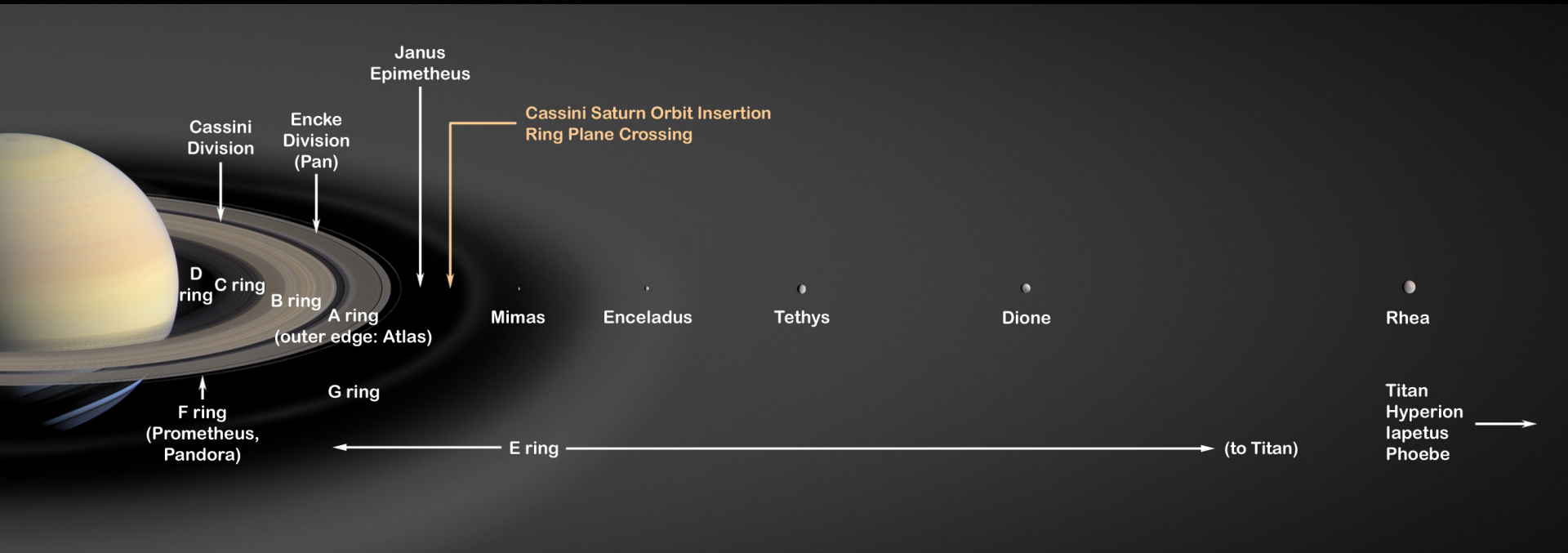
Canyons of Vid Flumina (upper left quadrant)

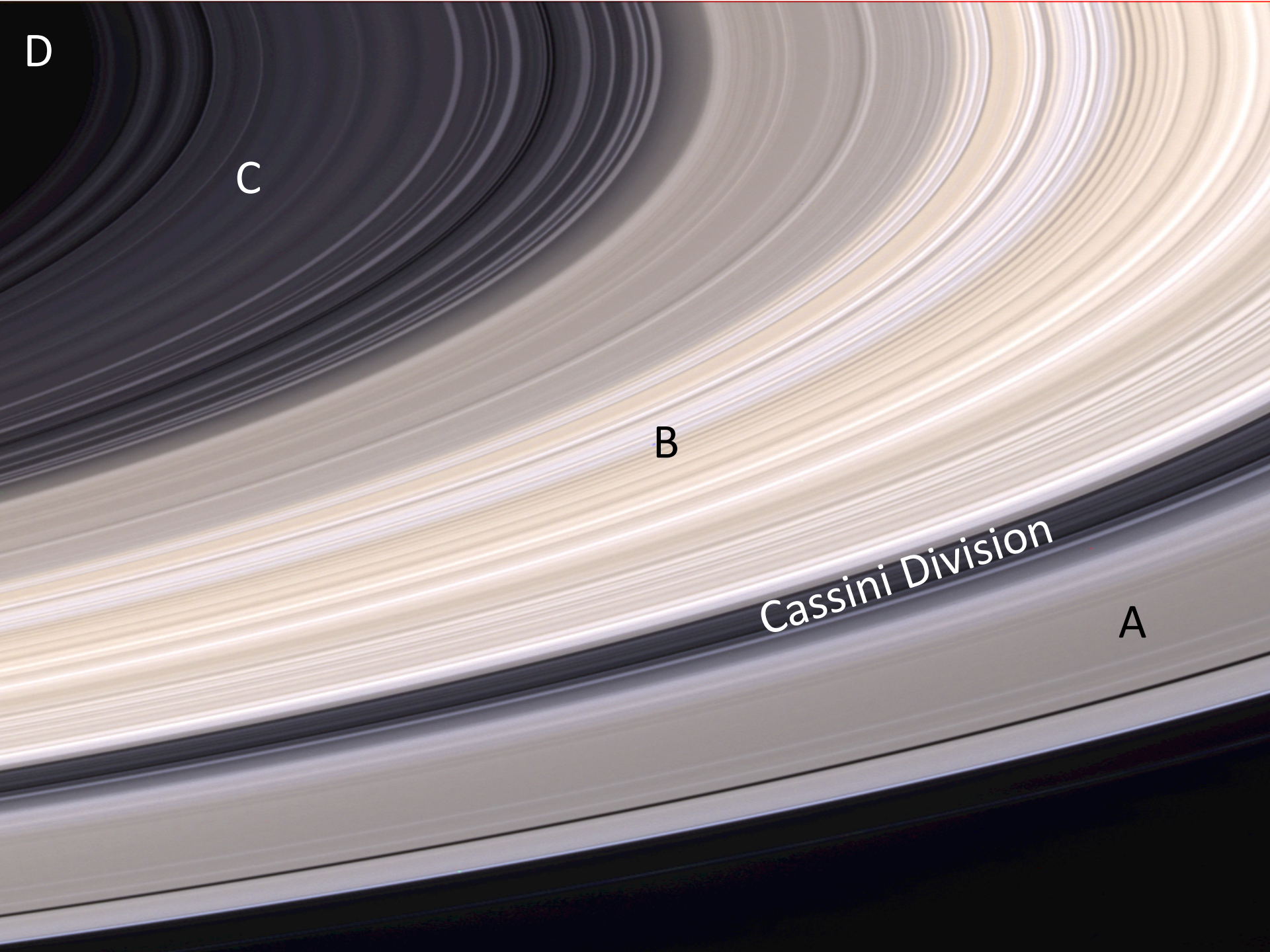


- Deep, steep-sided canyons (240 – 570 m deep) are flooded with liquid hydrocarbons
- Farther from sea, liquid is tens of meters higher than sea level

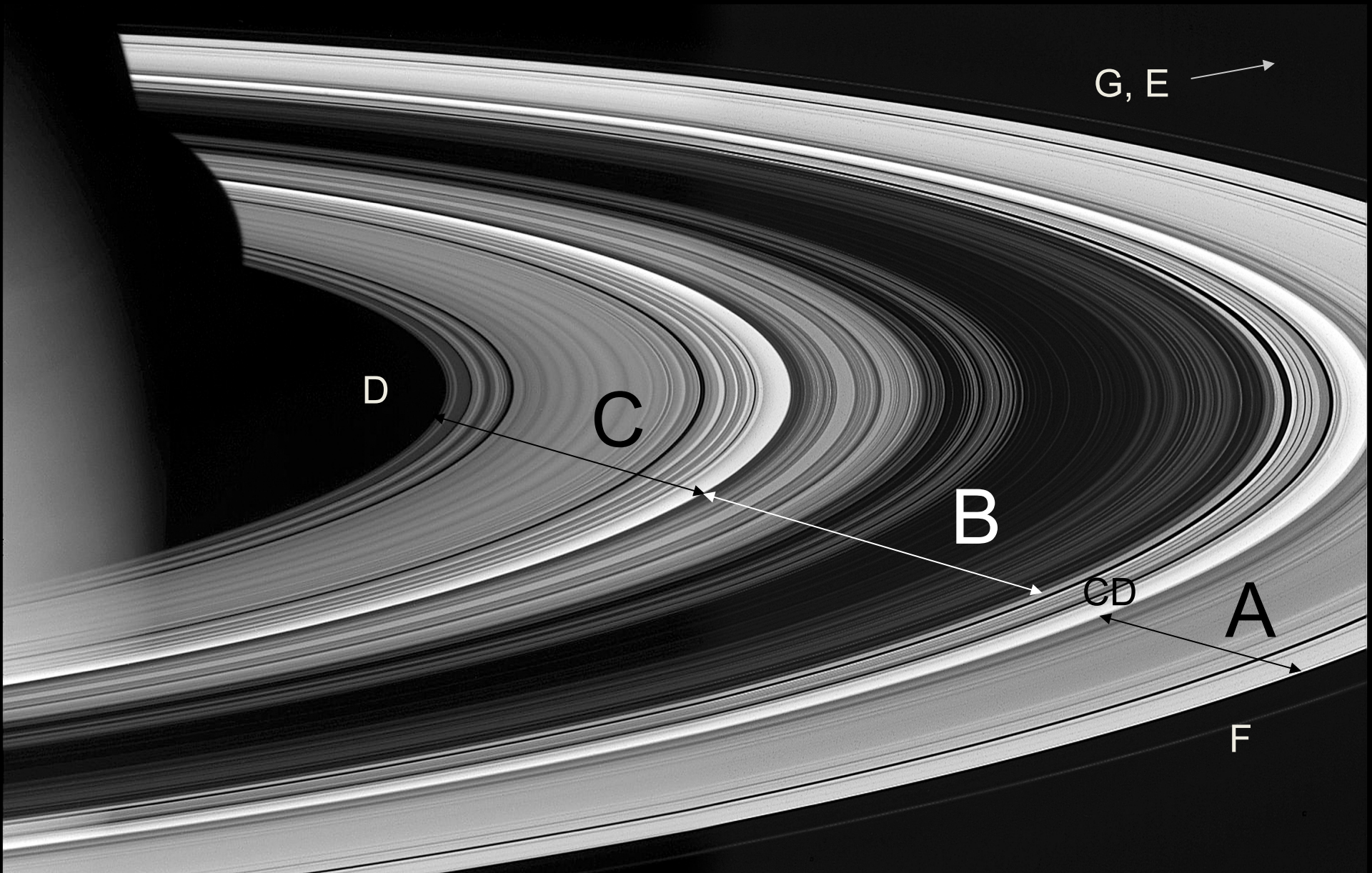
Saturn's Rings

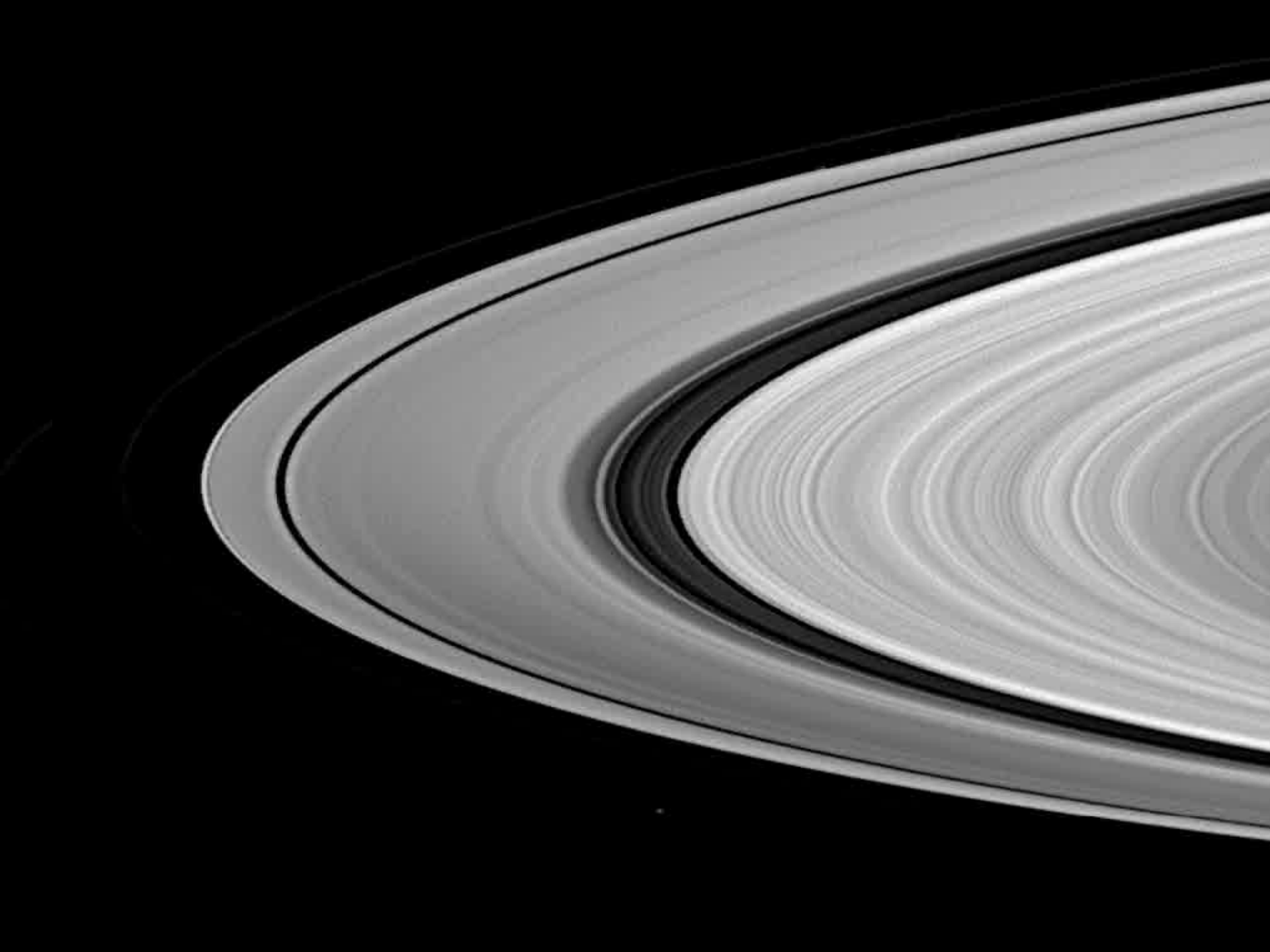




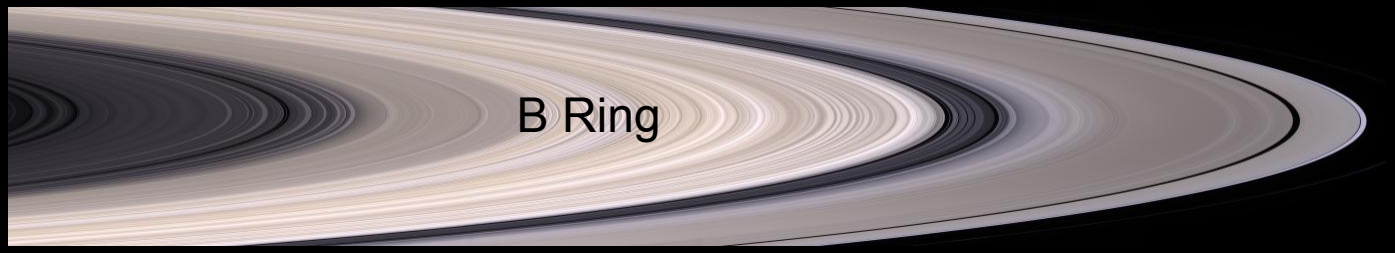

D
C
B
Cassini Division
A

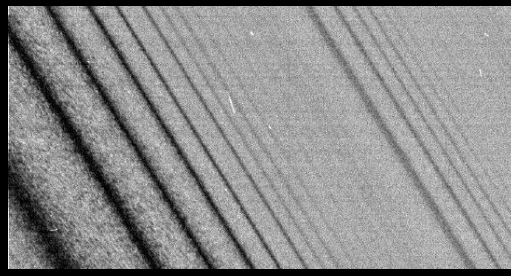
The Dark Side of the Rings





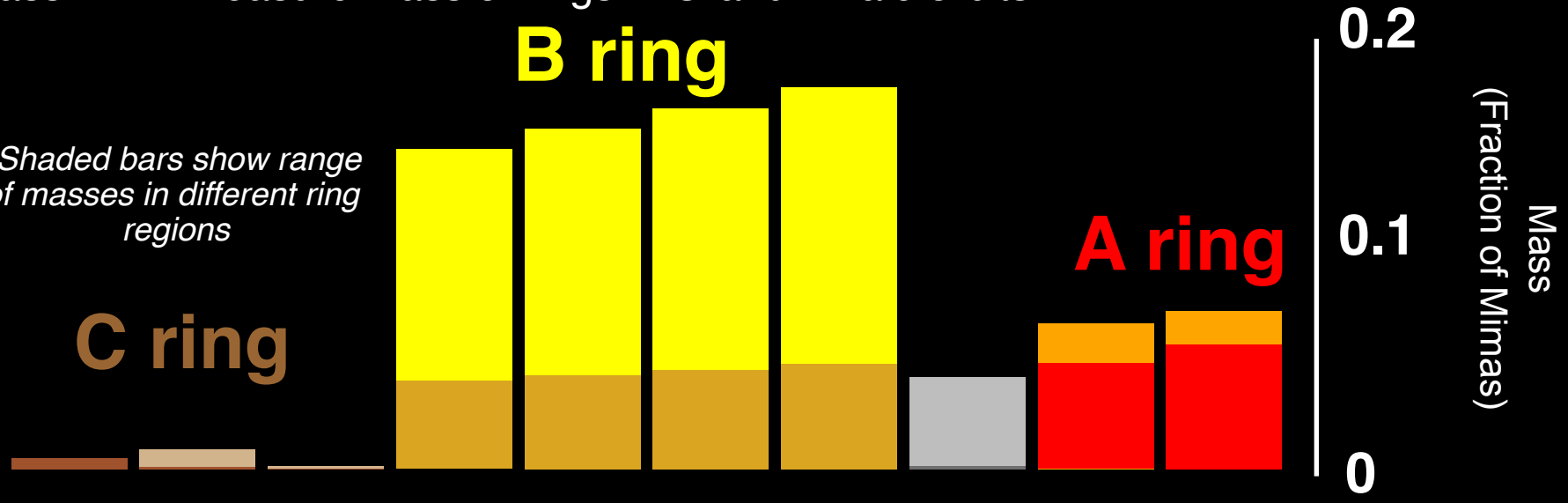
Saturn's Rings: Less Than Meets the Eye?





- Examples of similar spiral patterns in the A ring

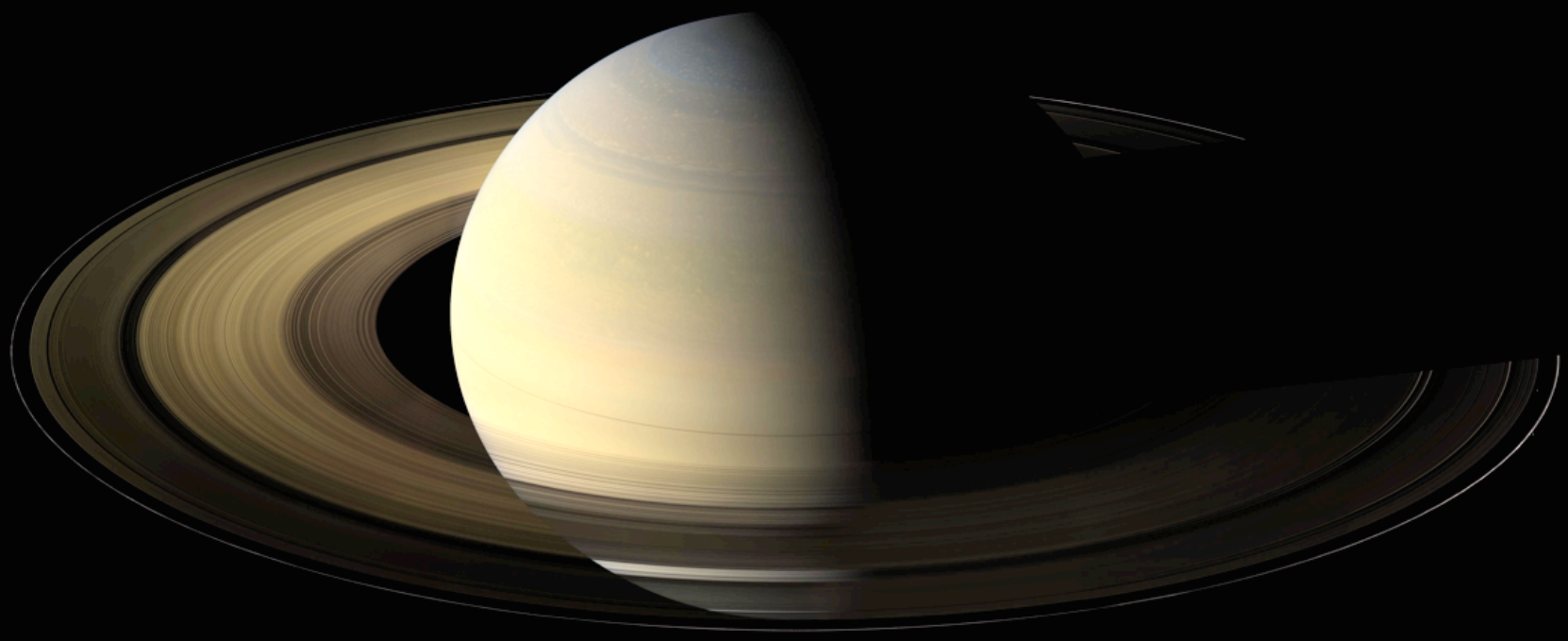
- Some parts of Saturn's B ring are 10 times more opaque than A ring, but only 2-3 times more massive.
- Mass of Saturn's rings has implications for their age, less massive rings are much younger
- Cassini will measure mass of rings in Grand Finale orbits



- *Shaded bars show range of masses in different ring regions*

- A new analysis of Cassini data uncovered spiral patterns in the B ring, the densest part of Saturn's rings, which reveal that the rings probably contain far less material than had been anticipated (less than Mimas).

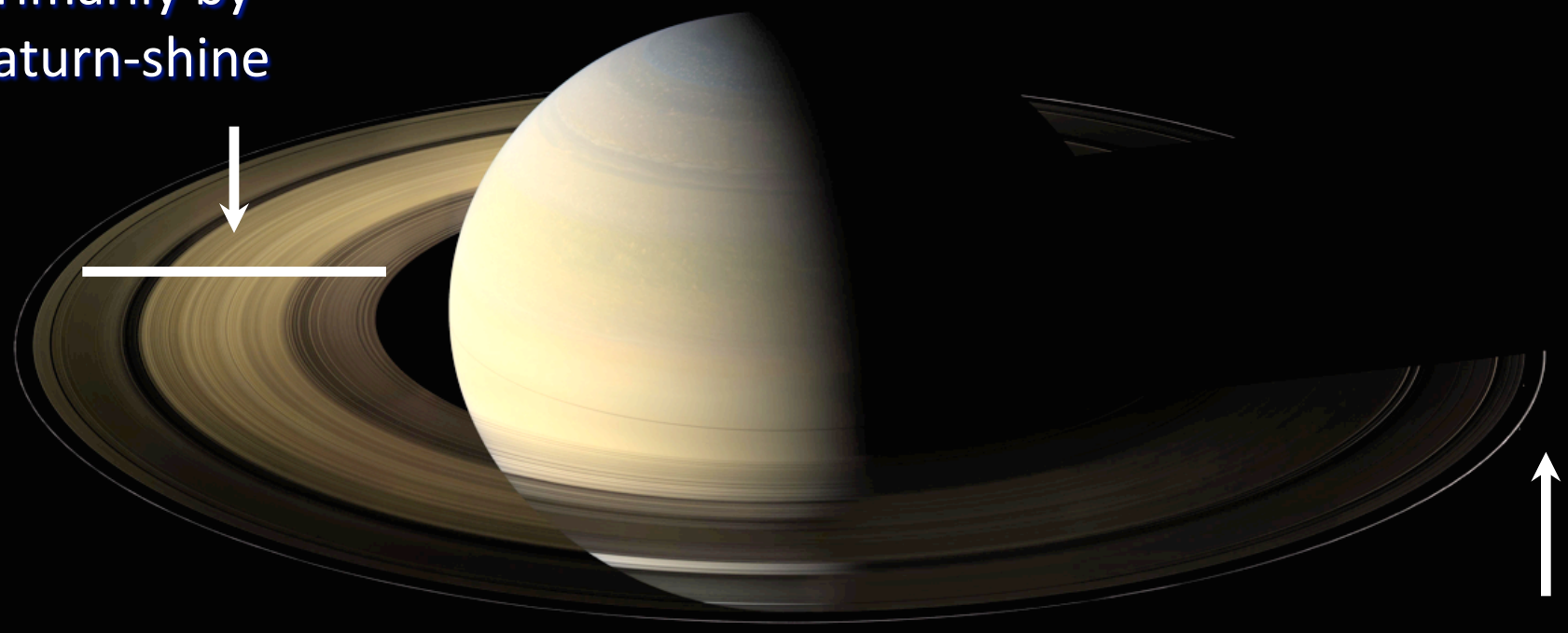
Saturn's Rings at Equinox



No Ring Shadow on the Planet which occurs only every ~15 Years!

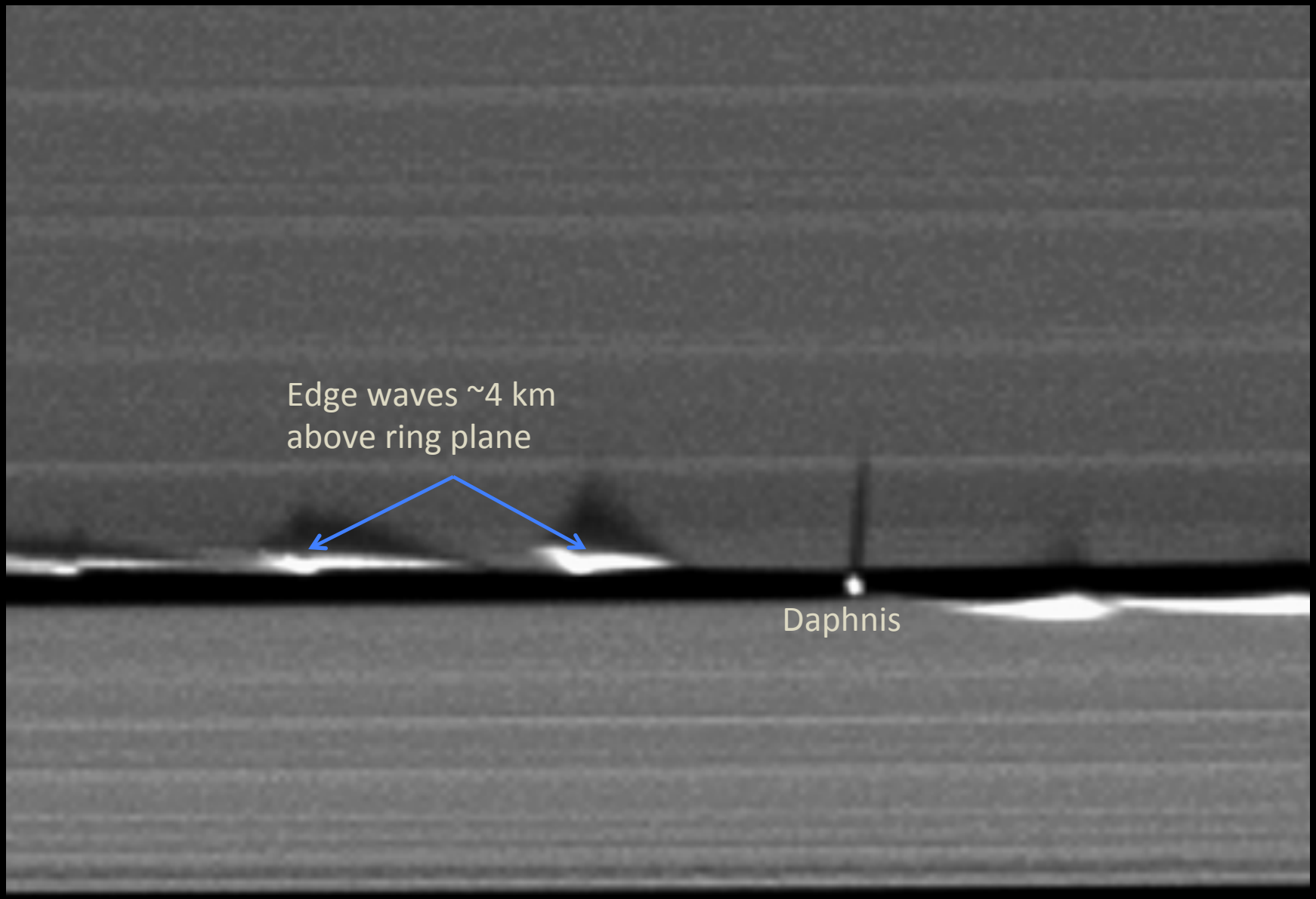
Saturn's Rings at Equinox

Rings illuminated primarily by Saturn-shine

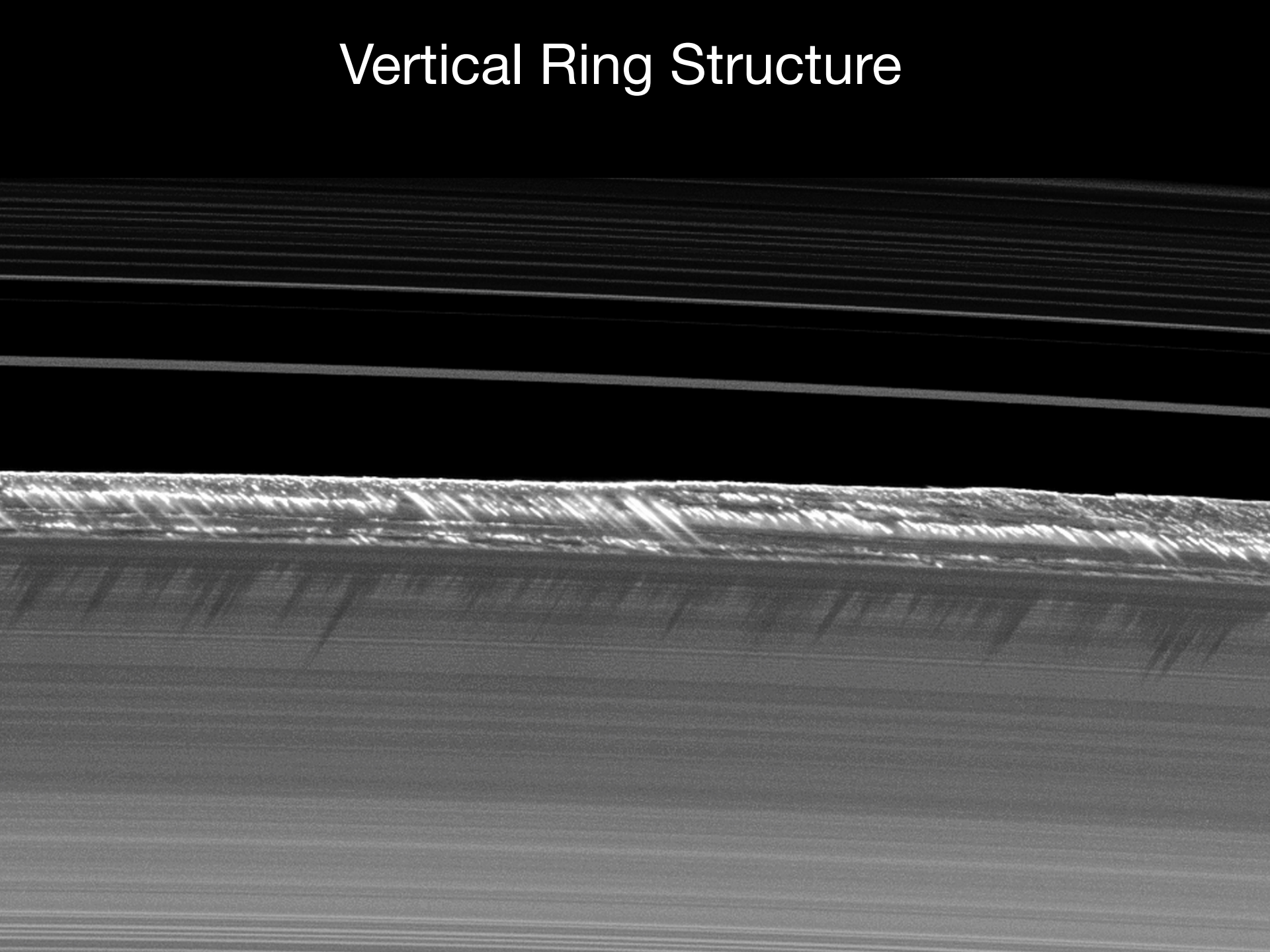


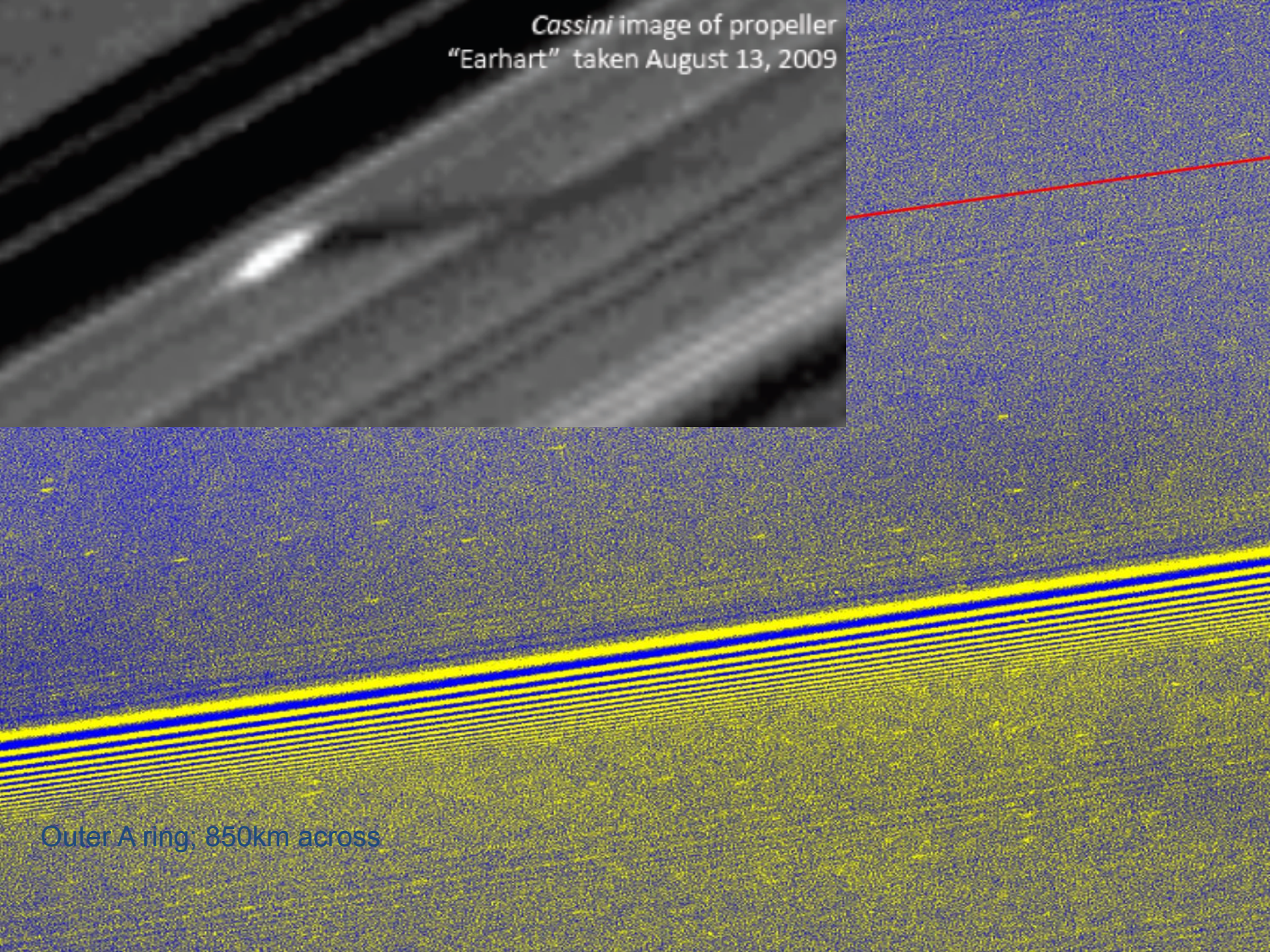
Only the F Ring is still glowing

Shadows on the Rings Show Vertical Relief

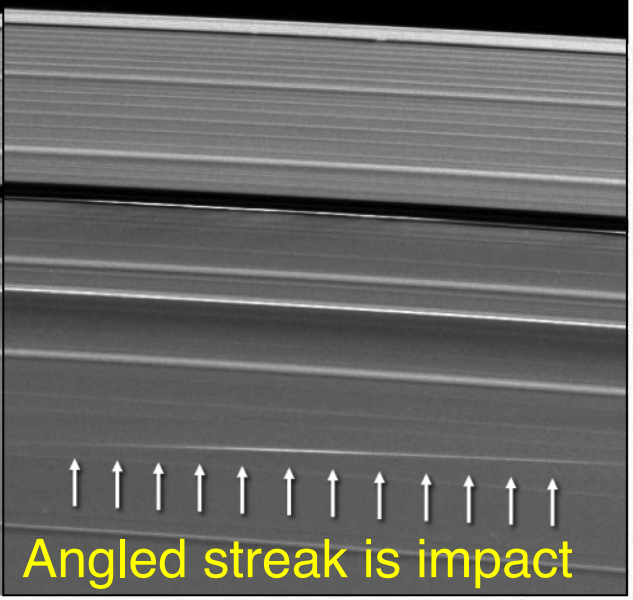


Vertical Ring Structure

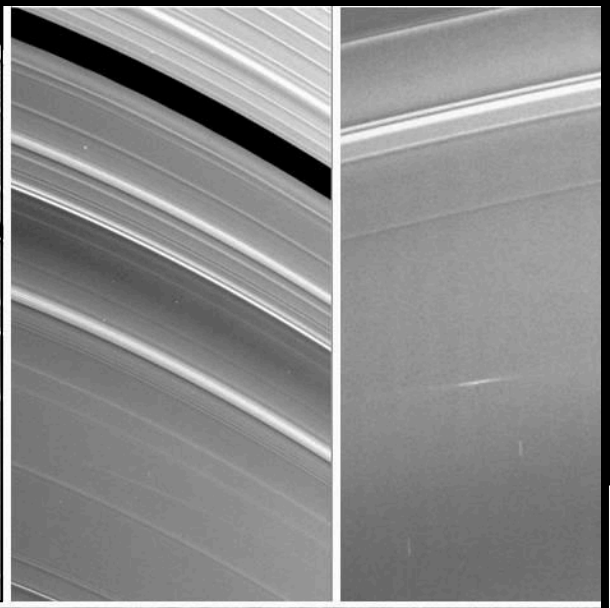


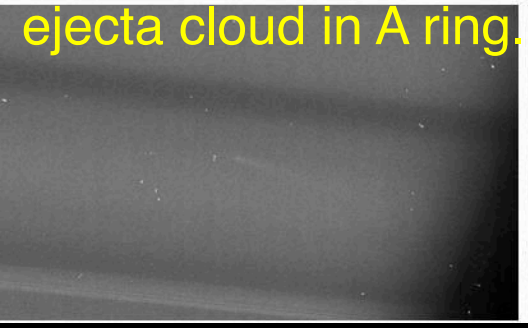

Cassini image of propeller
"Earhart" taken August 13, 2009
Outer A ring; 850km across

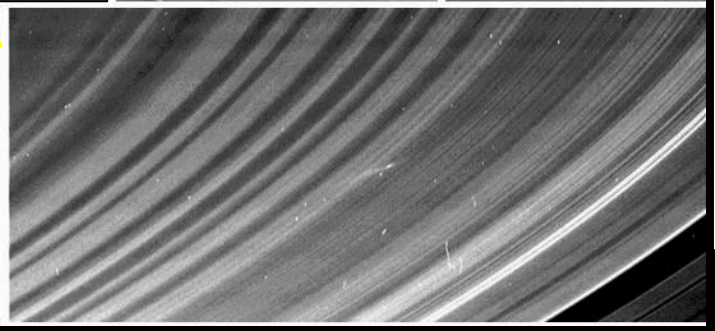
Meteor Strikes in Saturn's Rings



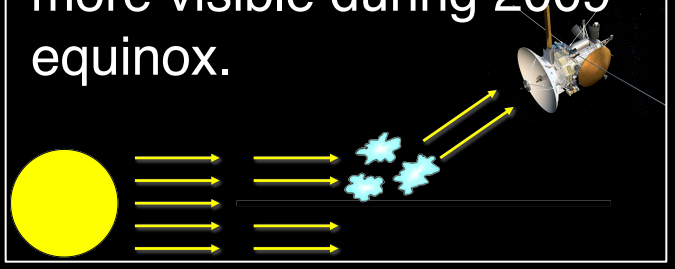
Angled streak is impact ejecta cloud in A ring.





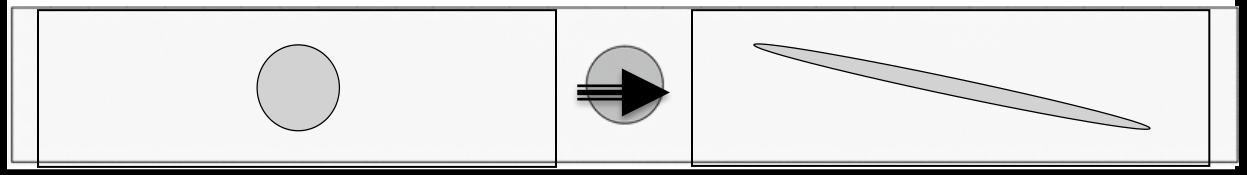


Ejecta clouds became more visible during 2009 equinox.

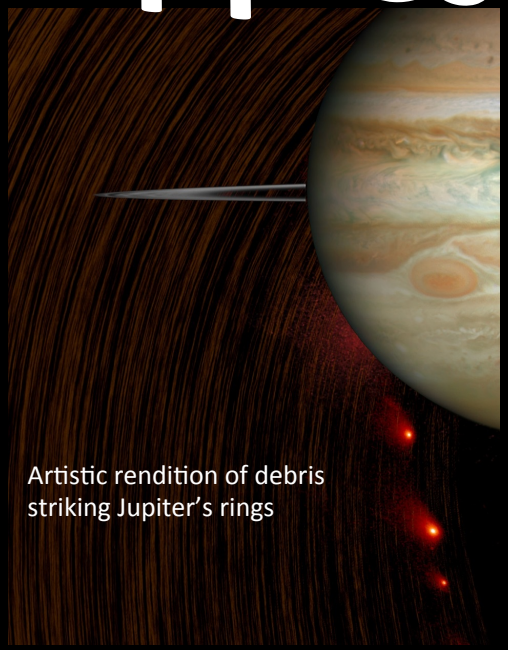


A-ring impactor similar in size to Chelyabinsk meteor.

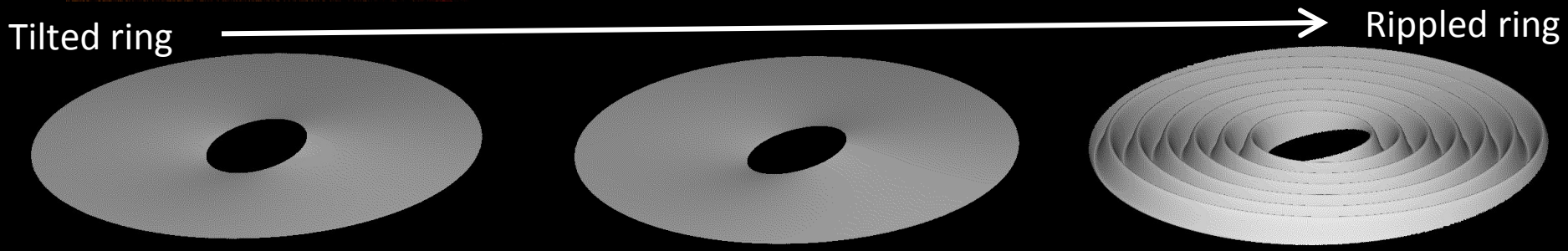
An orbiting cloud shears with time, as material closer to the planet orbits at a faster rate.

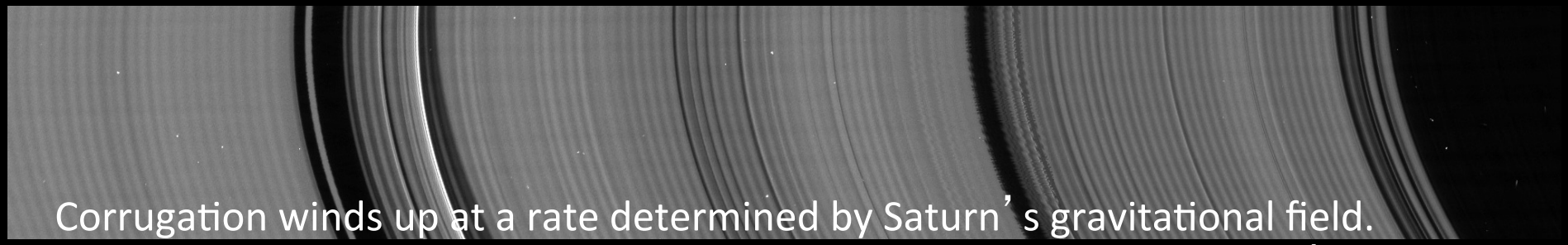


Ripples in Saturn's Rings


Artistic rendition of debris striking Jupiter's rings

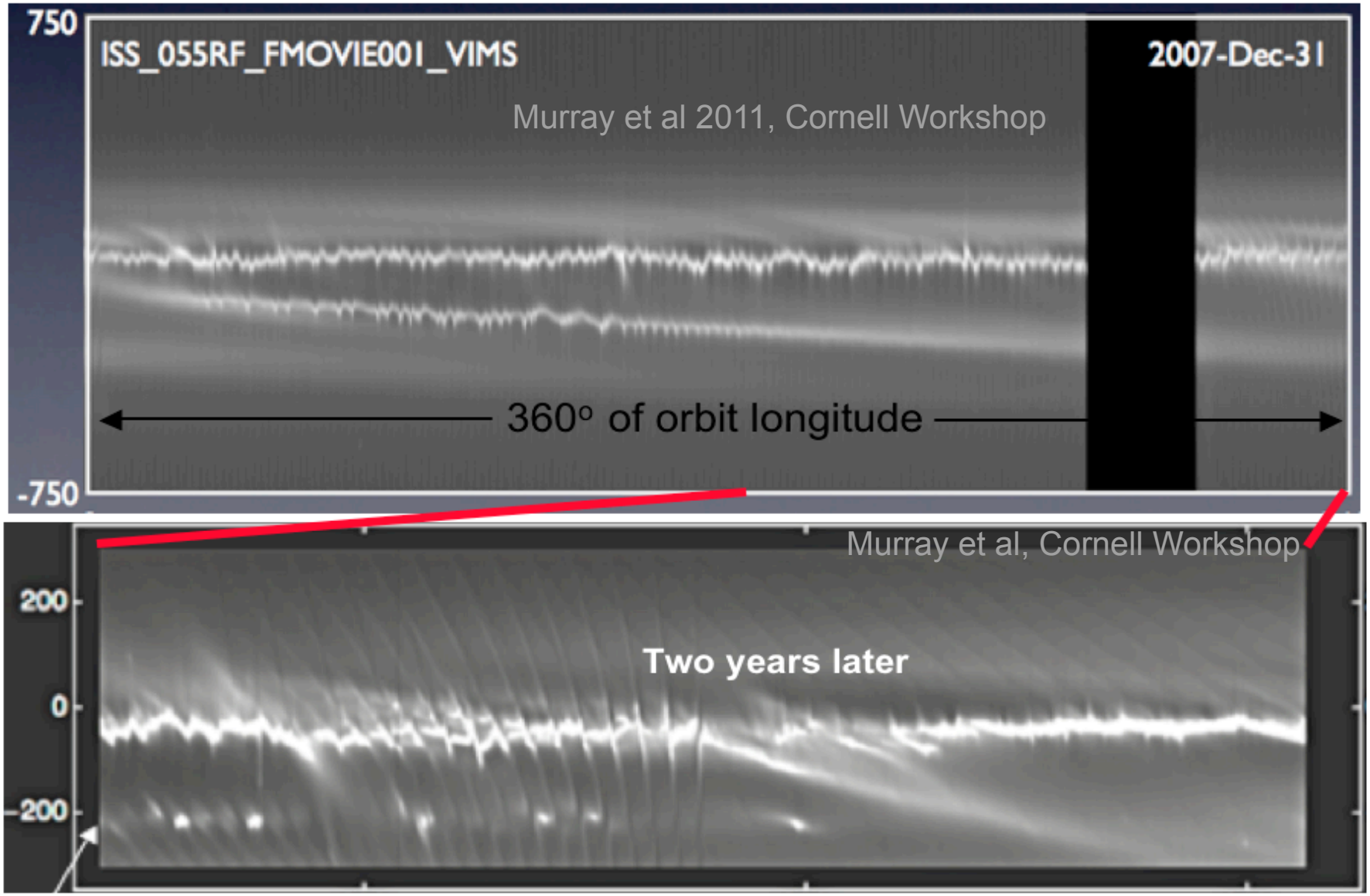
- Saturn's rings show over 10,000 miles of ripples, seen by Cassini cameras
- By unwinding the spiral, Cassini scientists have found that *debris from an unseen comet tilted the rings in 1983!*
- Jupiter's faint rings also show a ripple pattern – now known to have been caused by the collision of fractured comet Shoemaker-Levy 9 in 1994




Corrugation winds up at a rate determined by Saturn's gravitational field.

Cassini image of the ripples in Saturn's rings.

F Ring: Collision leads to new strand and moonlets(?)

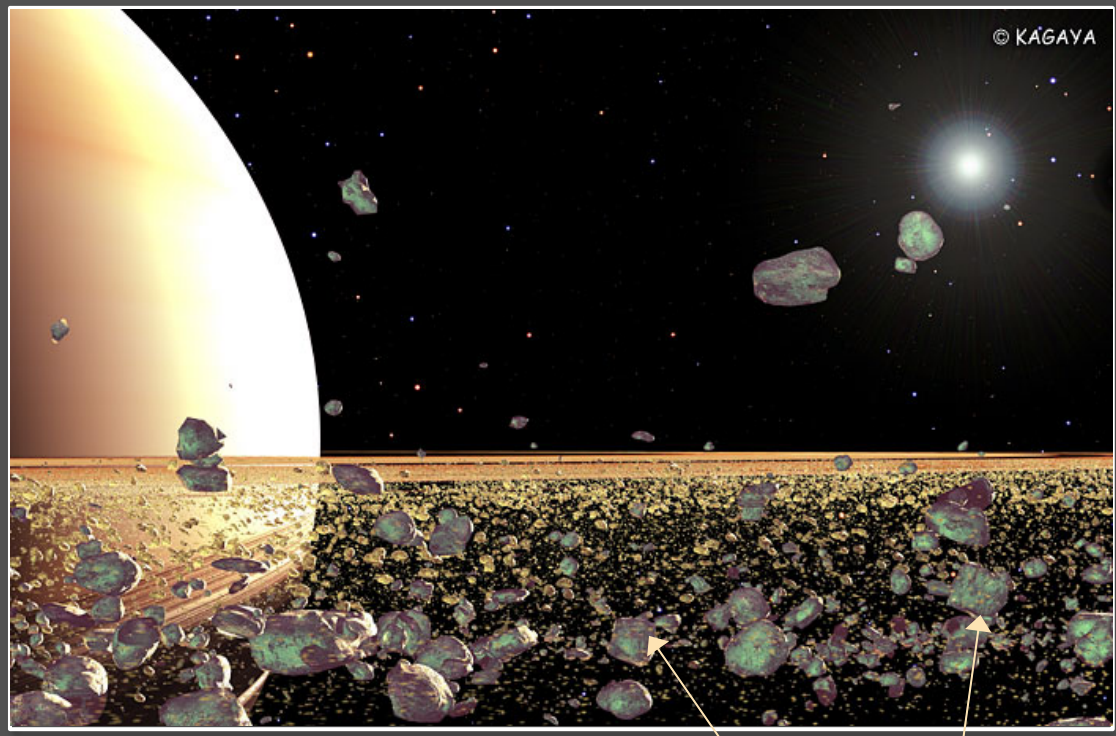


Surprisingly Young Region in Saturn's Rings

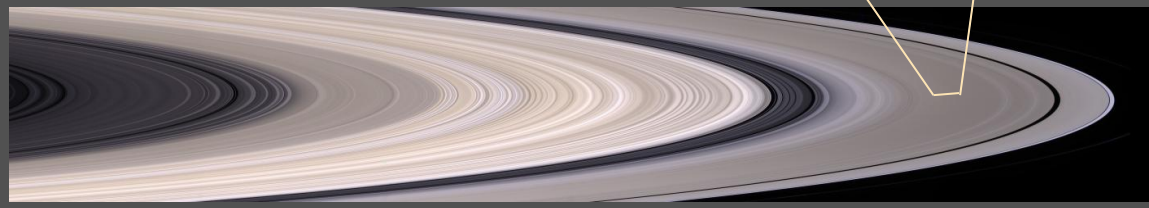
Chunks of solid ice in the middle of Saturn's A ring suggest an unexpectedly young ring region:

- Particles in one section of Saturn's rings are much denser than fluffy particles elsewhere;
- After equinox, one section of A ring did not cool down as much as expected providing a unique window into the interior of ring particles;
- Perhaps a tiny moon broke apart only 100 million of years ago and its solid, icy fragments are now slowly spreading through the rings;

Saturn's rings may be a mix of young and old material providing clues to their formation and evolution.

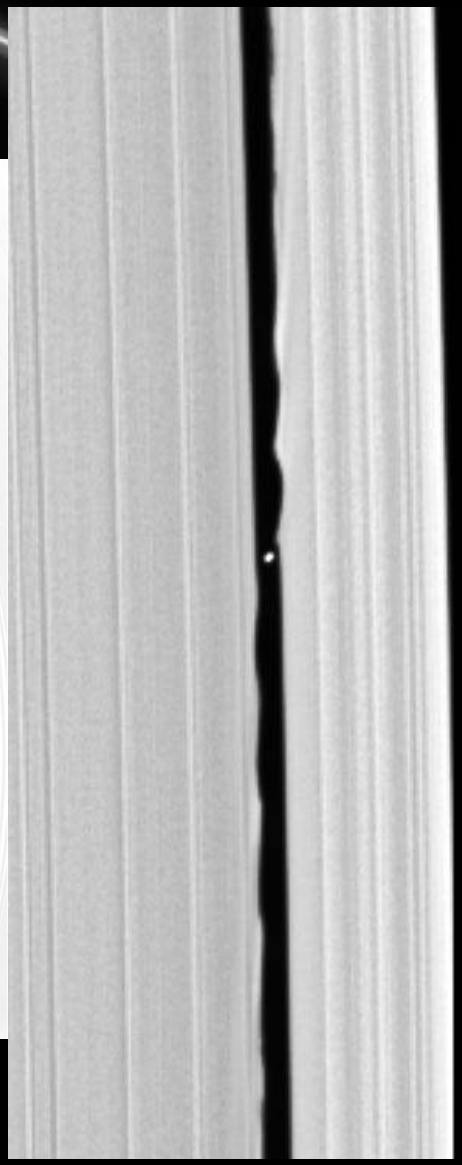


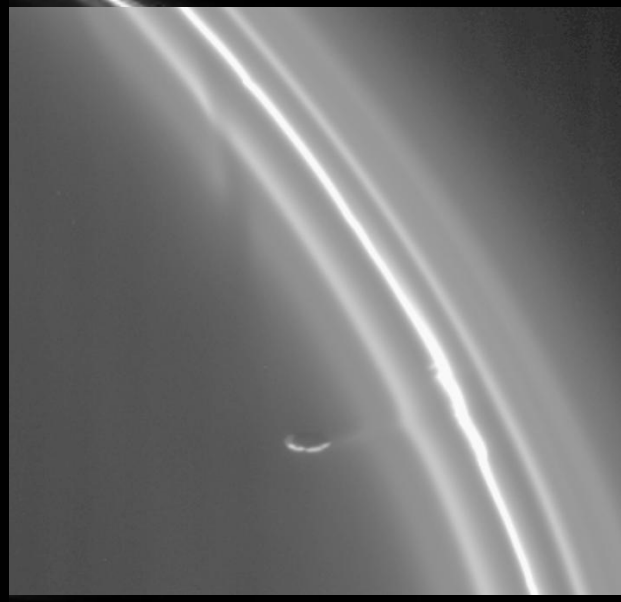
Model of Saturn's rings with both small and large particles



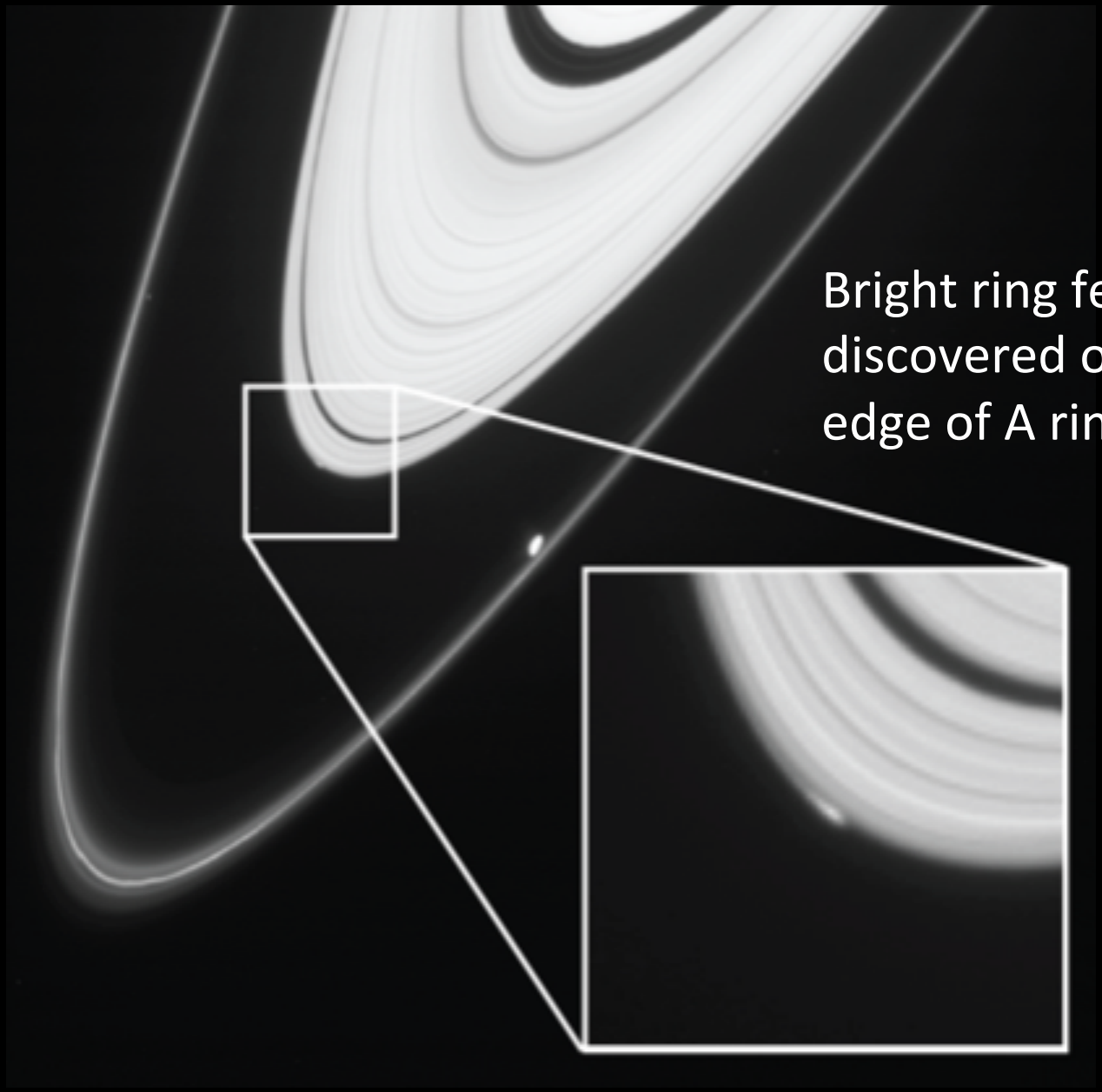
Morishima et al., 2016, Incomplete cooling down of Saturn's A ring at solar equinox: Implication for seasonal thermal inertia and internal structure of ring particles.

Moonlets Perturb Rings





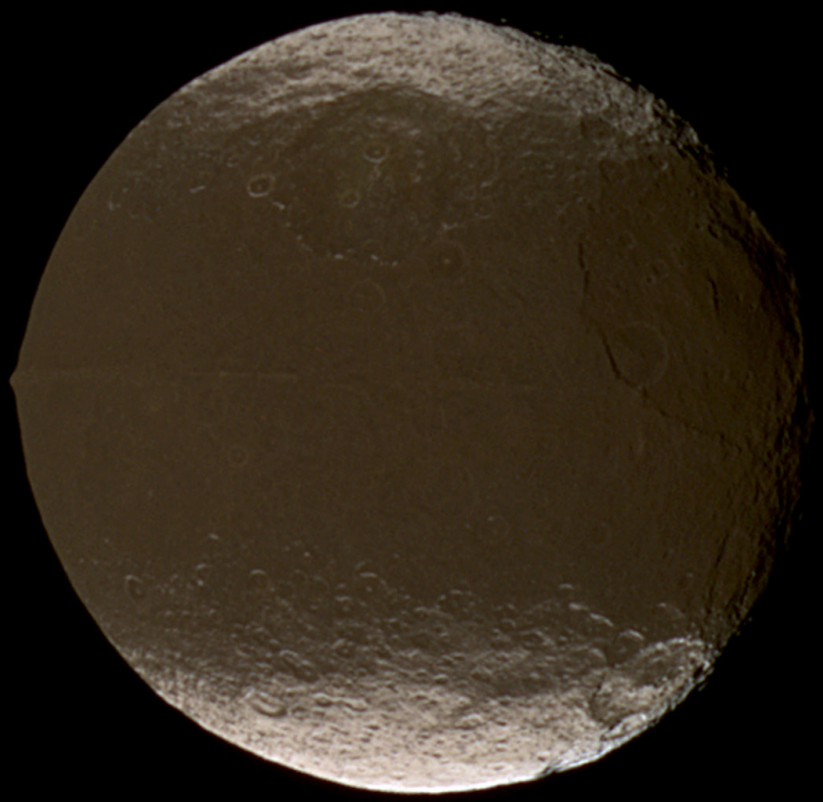
A New Moon is Born???

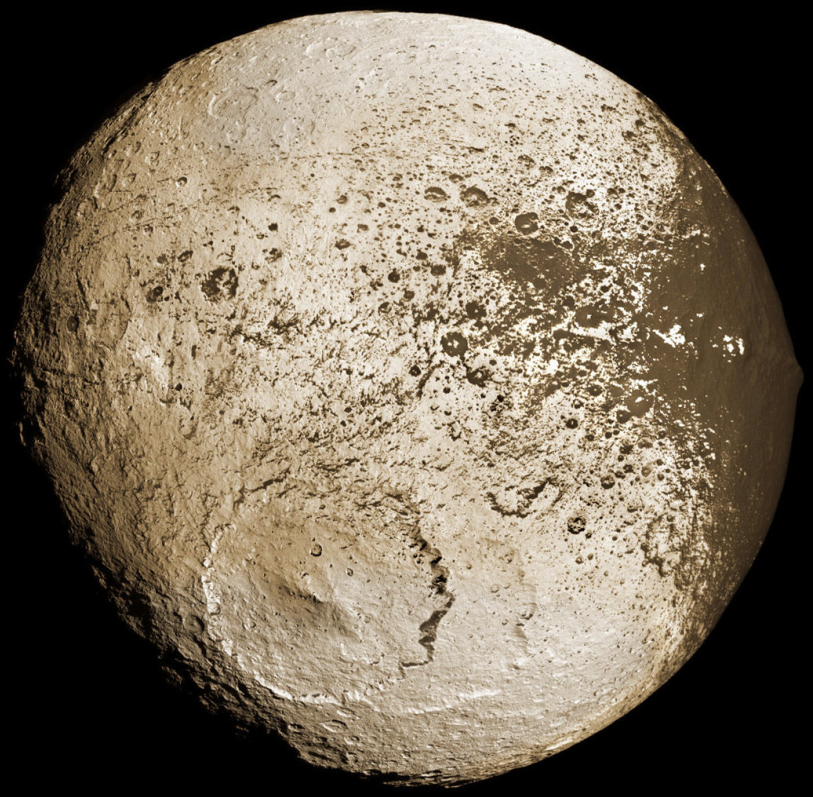


Bright ring feature discovered on outer edge of A ring

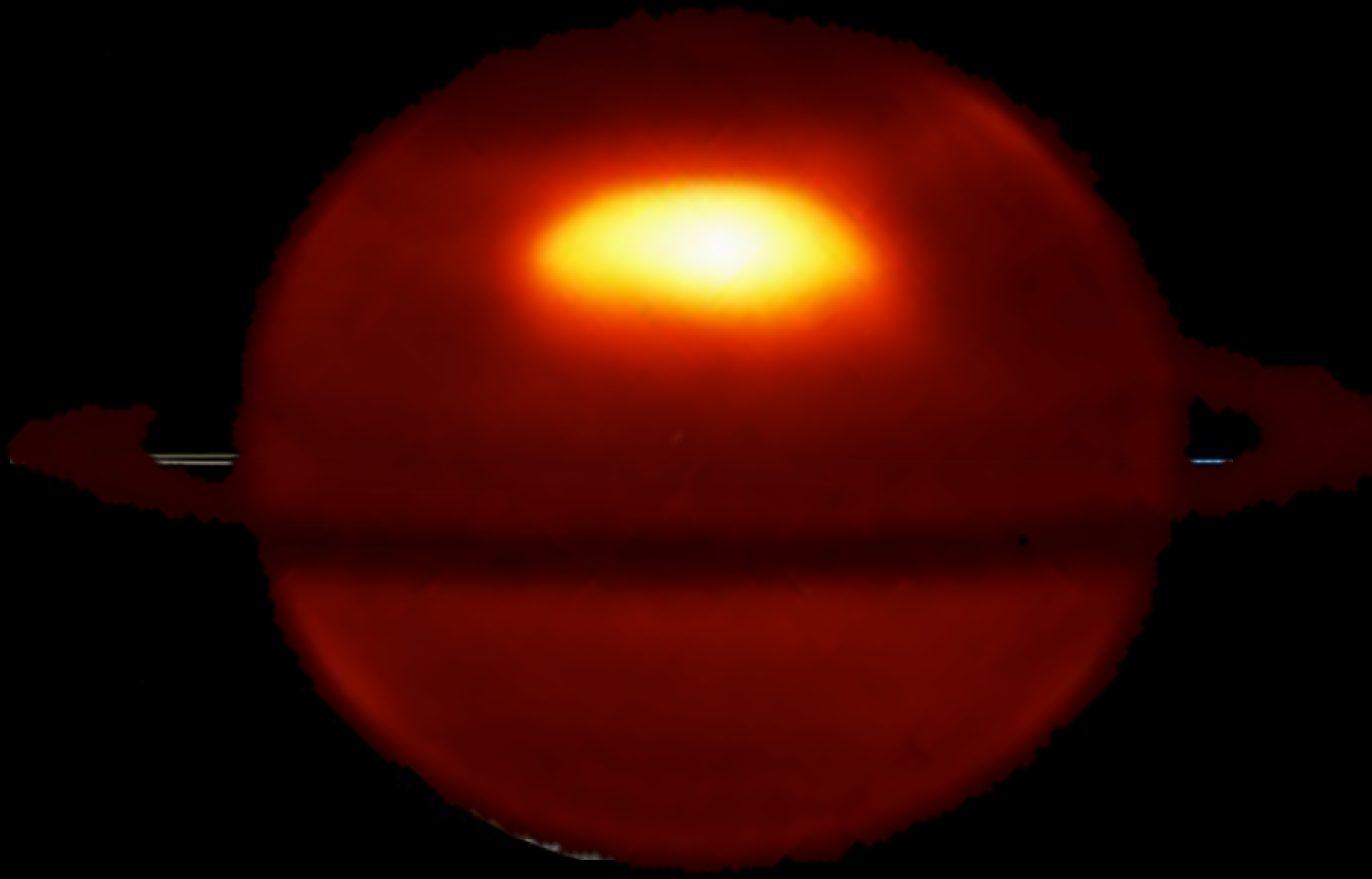
Appears to be associated with birth of small, icy infant moon nicknamed Peggy

Iapetus two-faced puzzle solved

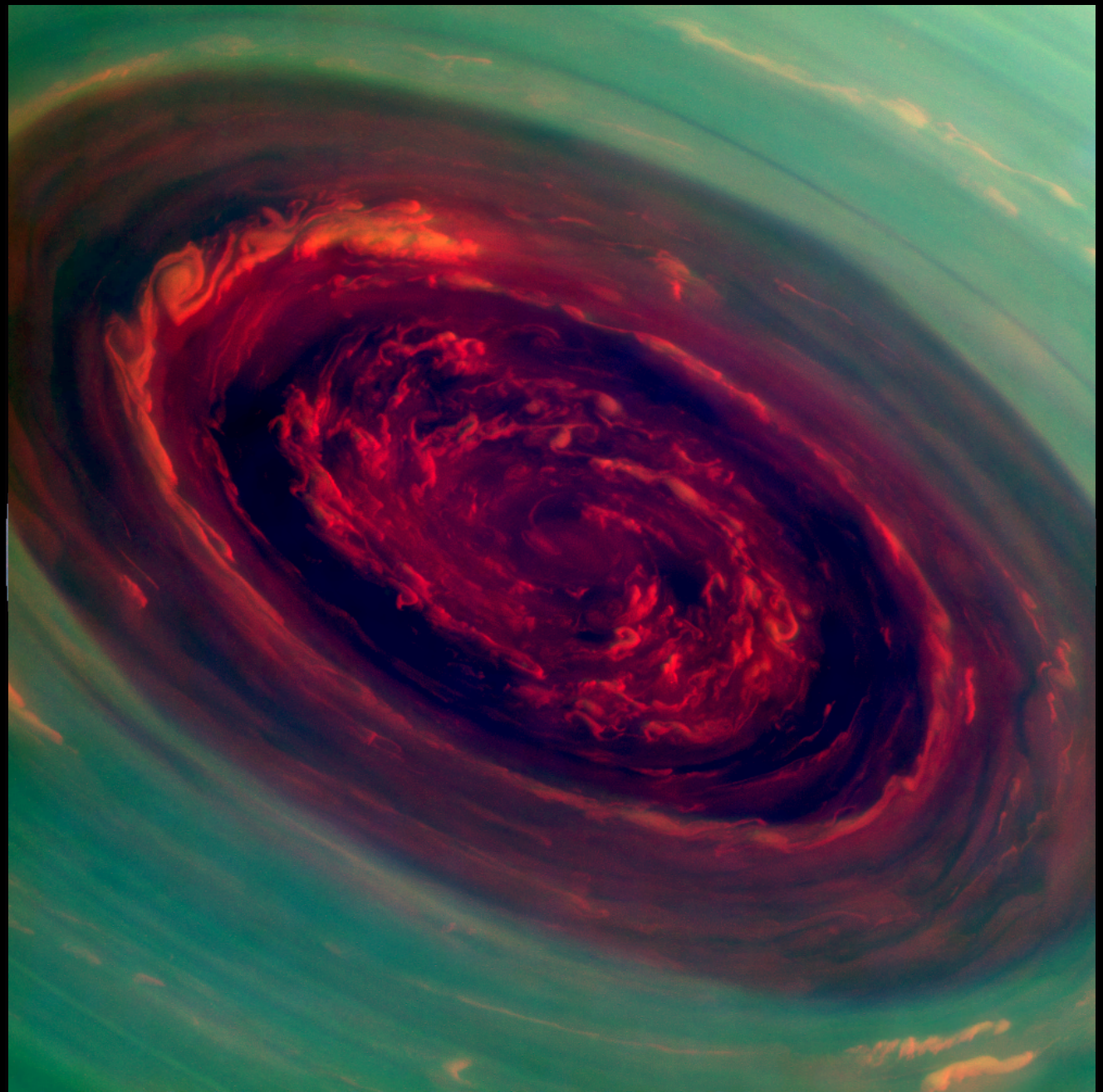




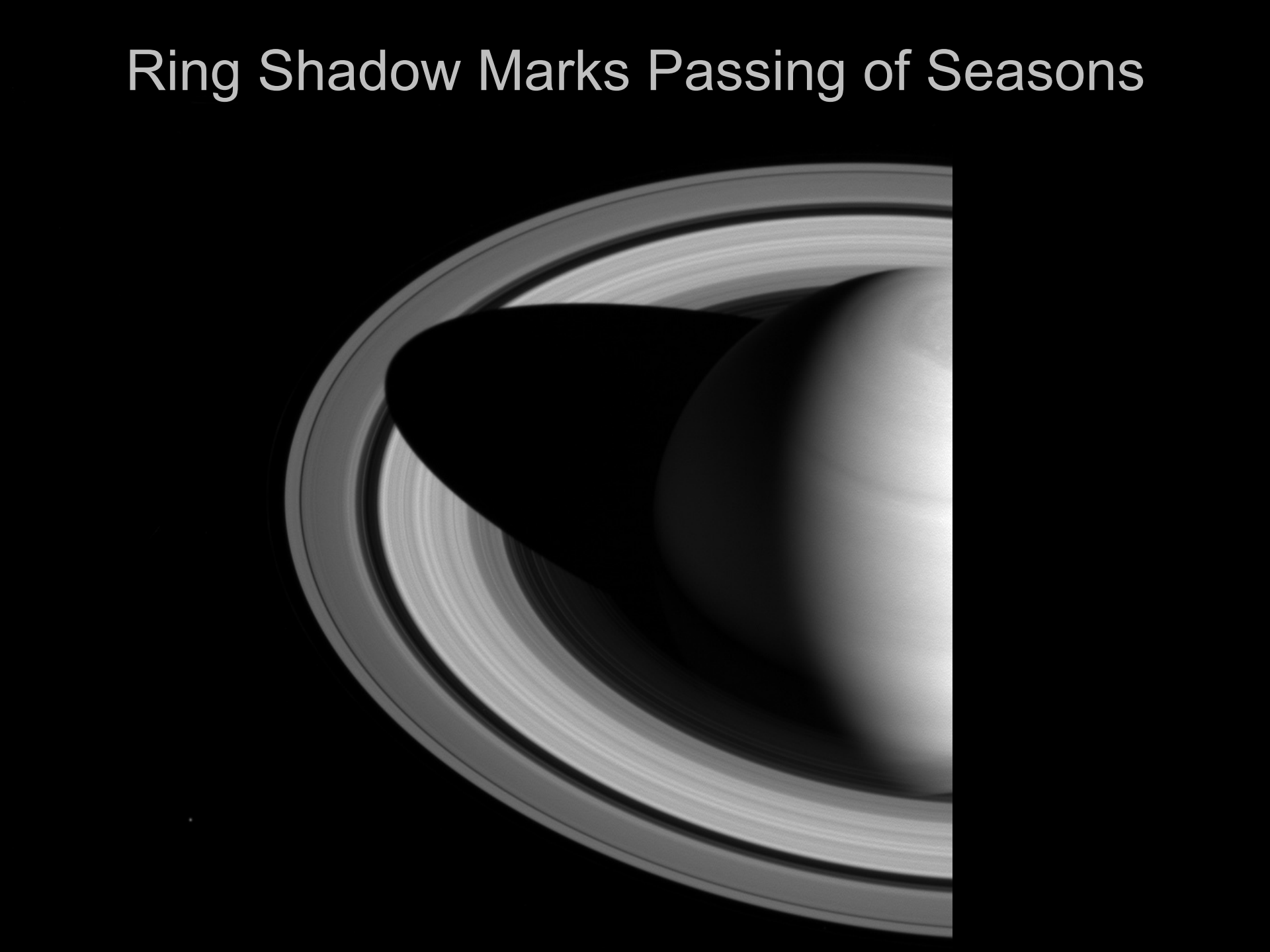
Giant Storm: Head eats tail



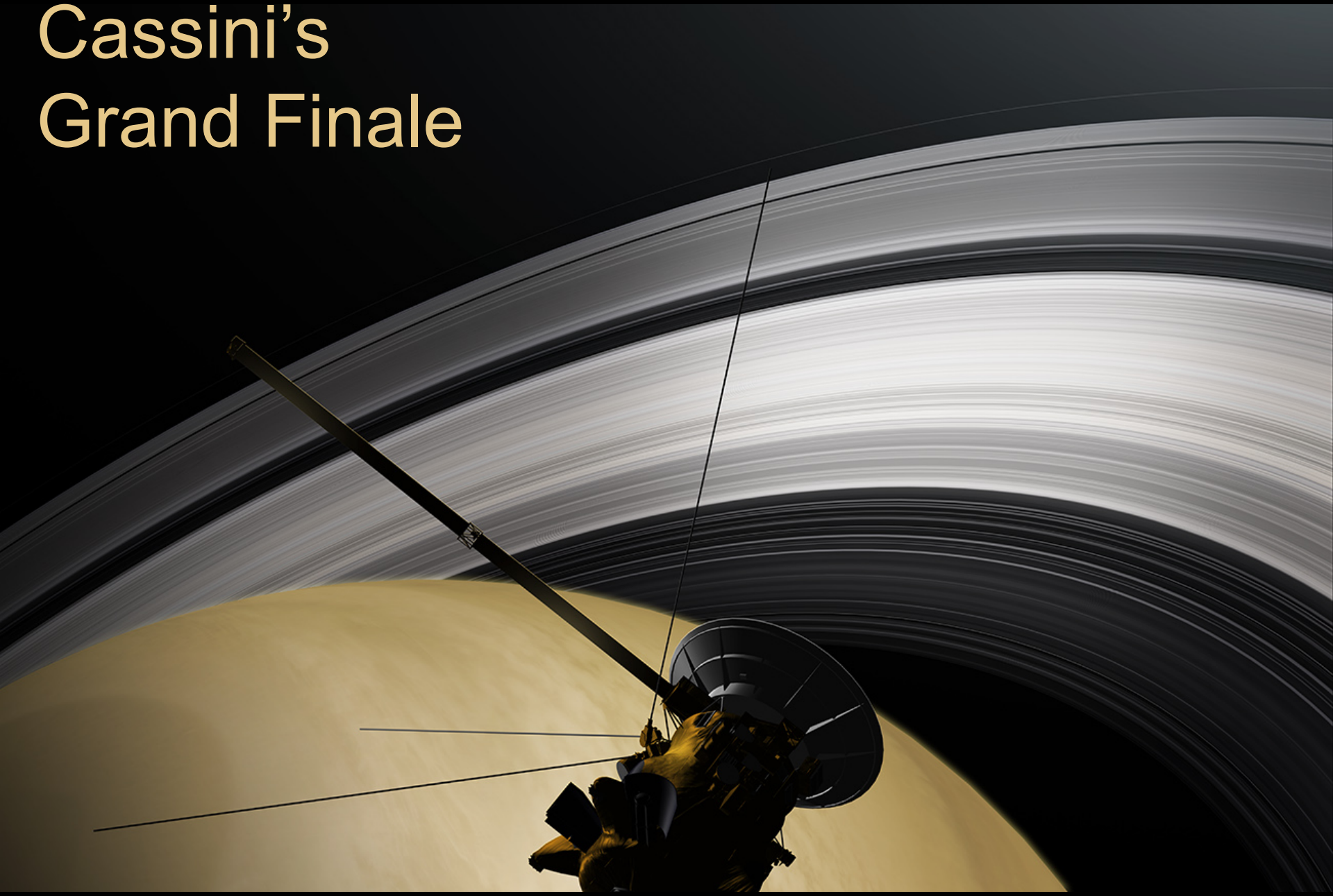
Hexagon and Giant hurricanes



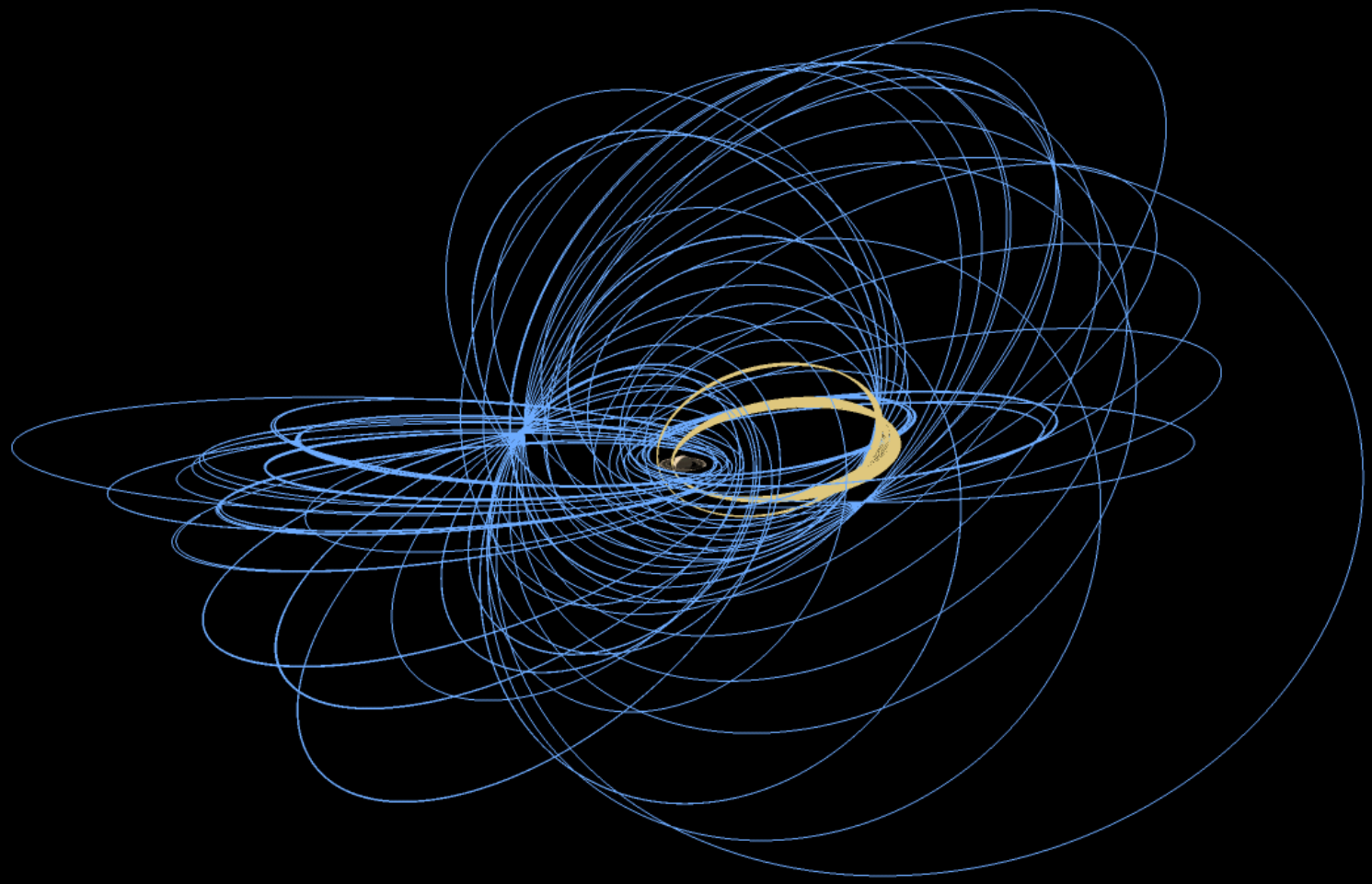
Ring Shadow Marks Passing of Seasons



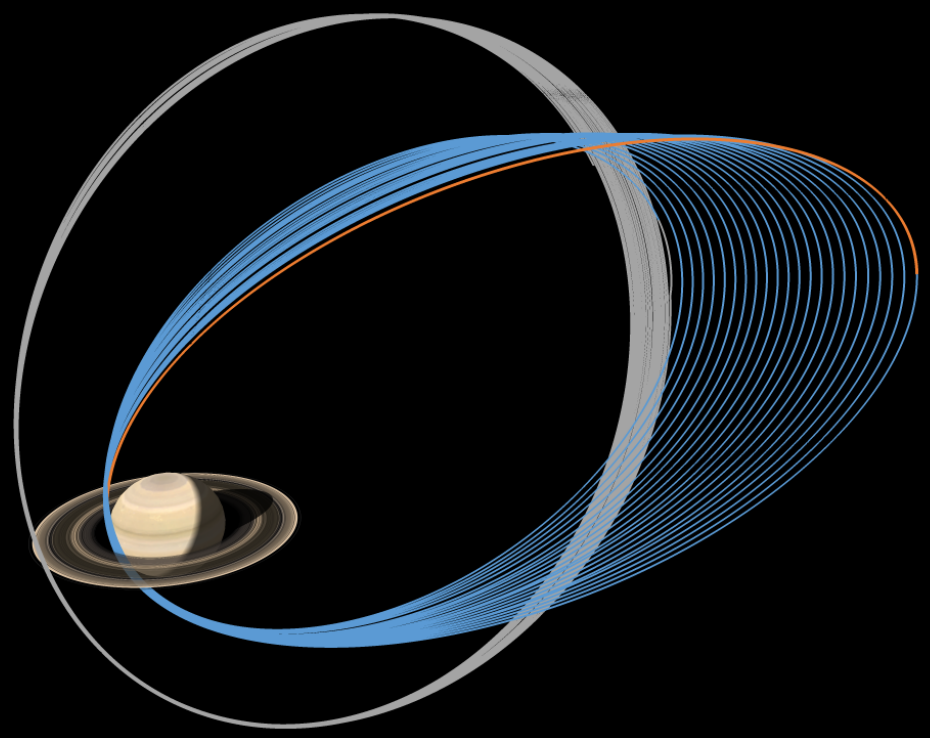
Cassini's Grand Finale



Solstice Mission Trajectory



Key Orbital Characteristics of Final Orbits



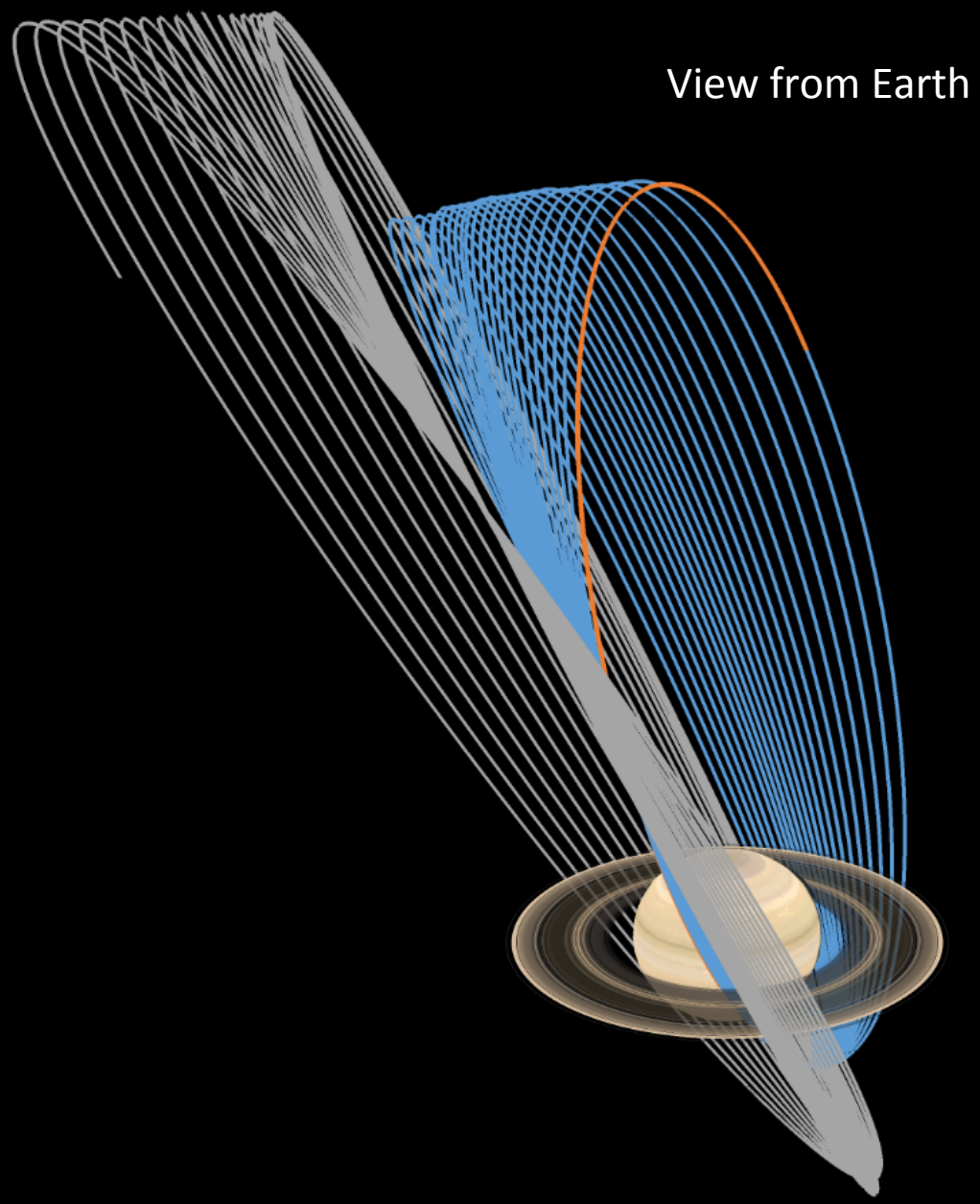
F-ring orbits
Grand Finale orbits
Impact orbit

- 42 short-period orbits
  - Nov. 2016 to Sept. 2017

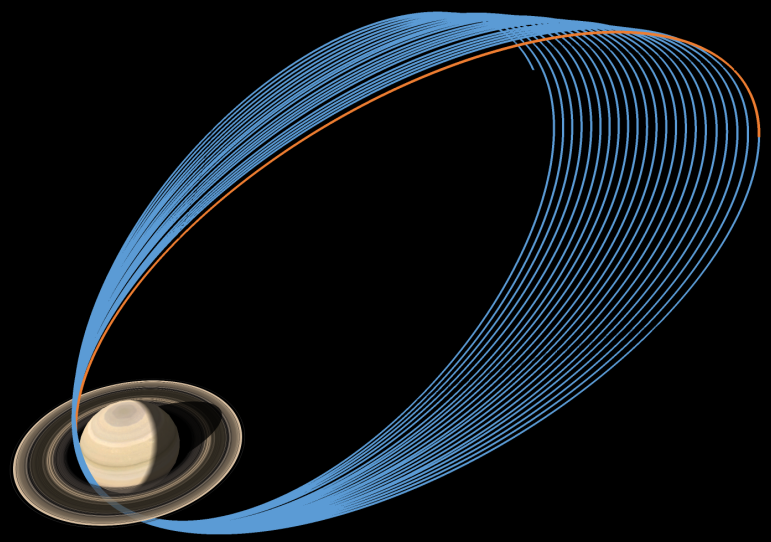
20 F-ring orbits

- Periapses just outside Saturn's F ring
- Sets up Cassini for final jump to orbits inside D ring
- Scientifically rich
  - High resolution F and A ring observations
  - Ring occultations (Earth and Solar)
  - Auroral field line crossings at r = 3.4 - 4 R_S

F Ring and Grand Finale Earth Occultations

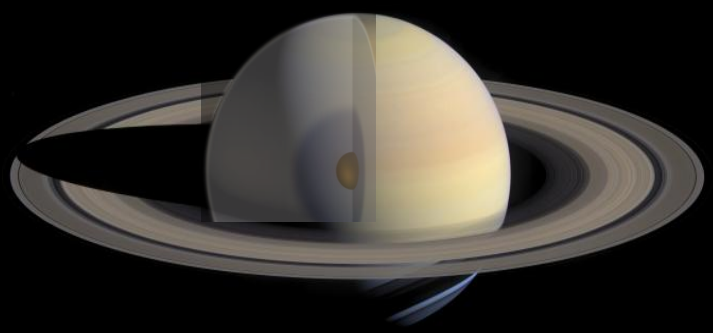


Grand Finale (Proximal) Orbits



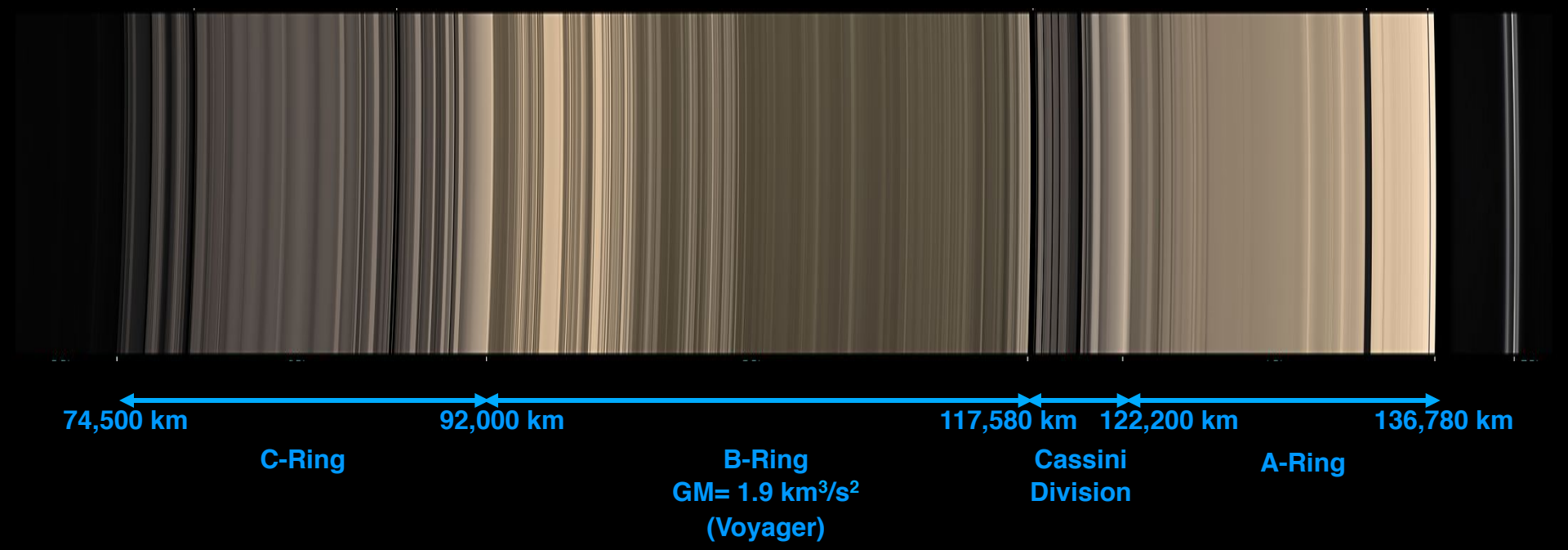
- 22 Grand Finale orbits
  - Periapses in 2,200 km “clear” region
  - First orbit April 2017
  - Critical inclination: 63.4°
- If delta v is available, go lower if Saturn upper atmosphere continues to shrink
- Current impact date: 15 September 2017
- Juno-like mission with Cassini instruments

Unique End-of-Mission Science



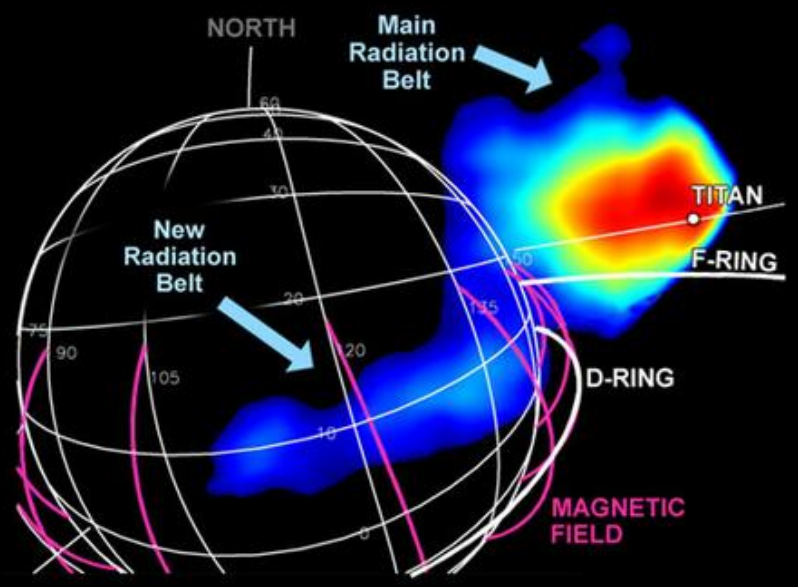
- Saturn internal structure
  - Gravitational & Magnetic Fields measurements
  - Determine Saturn's gravity field to order J_{10}
  - Determine Saturn's higher order magnetic field components
  - Measure Saturn's internal rotation rate

Ring Mass: Constrain age of rings



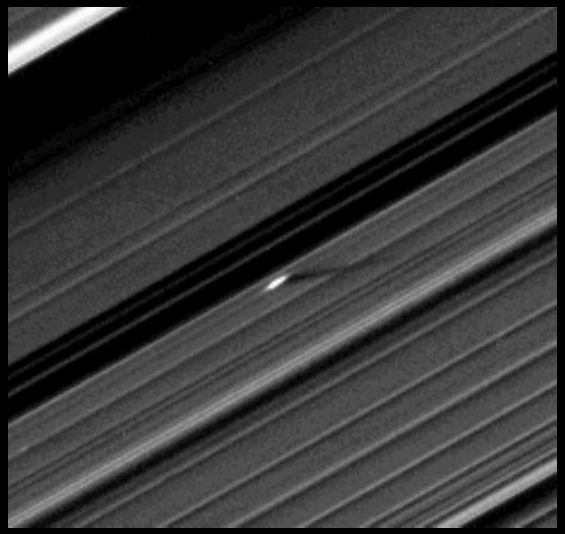
- Without proximal orbits, a-priori ring mass uncertainty is 100% of nominal values
- 6 orbital arcs for ring mass (and Saturn gravity) provide estimation accuracy for total ring $\delta GM \sim 0.34\ km^3/s^2$ (~5%)

Ionosphere, innermost radiation belts & inner D ring particles

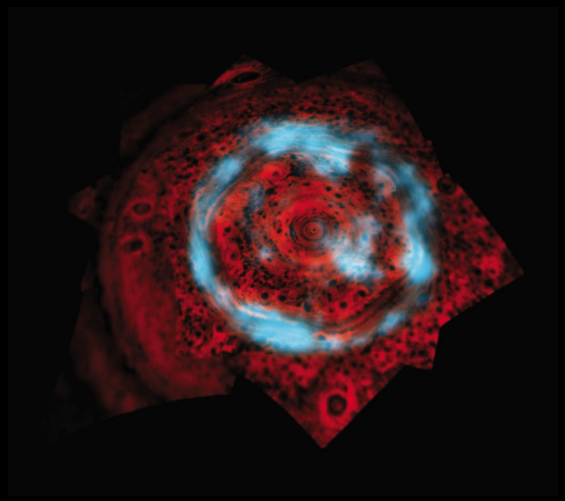


- Measure *in situ* plasma of Saturn's ionosphere, innermost radiation belts and D ring for the first time
- *In situ* observations of Saturn's auroral magnetosphere at solstice

Unique End-of-Mission Science

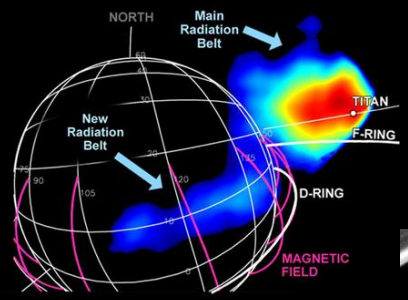


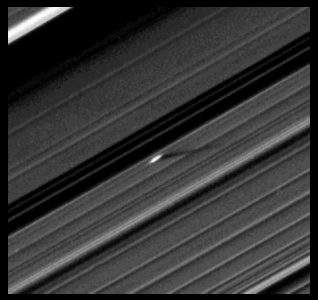
- Highest resolution main ring observations
  - First Active Radar of the Rings

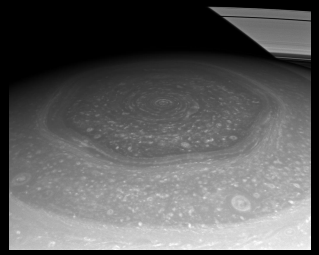


- Highest resolution Saturn atmospheric studies including polar observations and aurora

Science Summary







- Saturn internal structure
  - Gravitational & Magnetic Fields
- Ring mass
  - Address age of main rings
- Saturn's ionosphere, innermost radiation belts & inner D ring particles
- Highest resolution main ring observations
  - First Active Radar of the Rings
- Highest resolution Saturn polar observations and aurora

Cassini Saturn science complements that from Juno mission to Jupiter

Grand Finale Timeline

November 30, 2016
- F-ring Orbits Begin
  - 20 orbits
  - 3 maneuvers

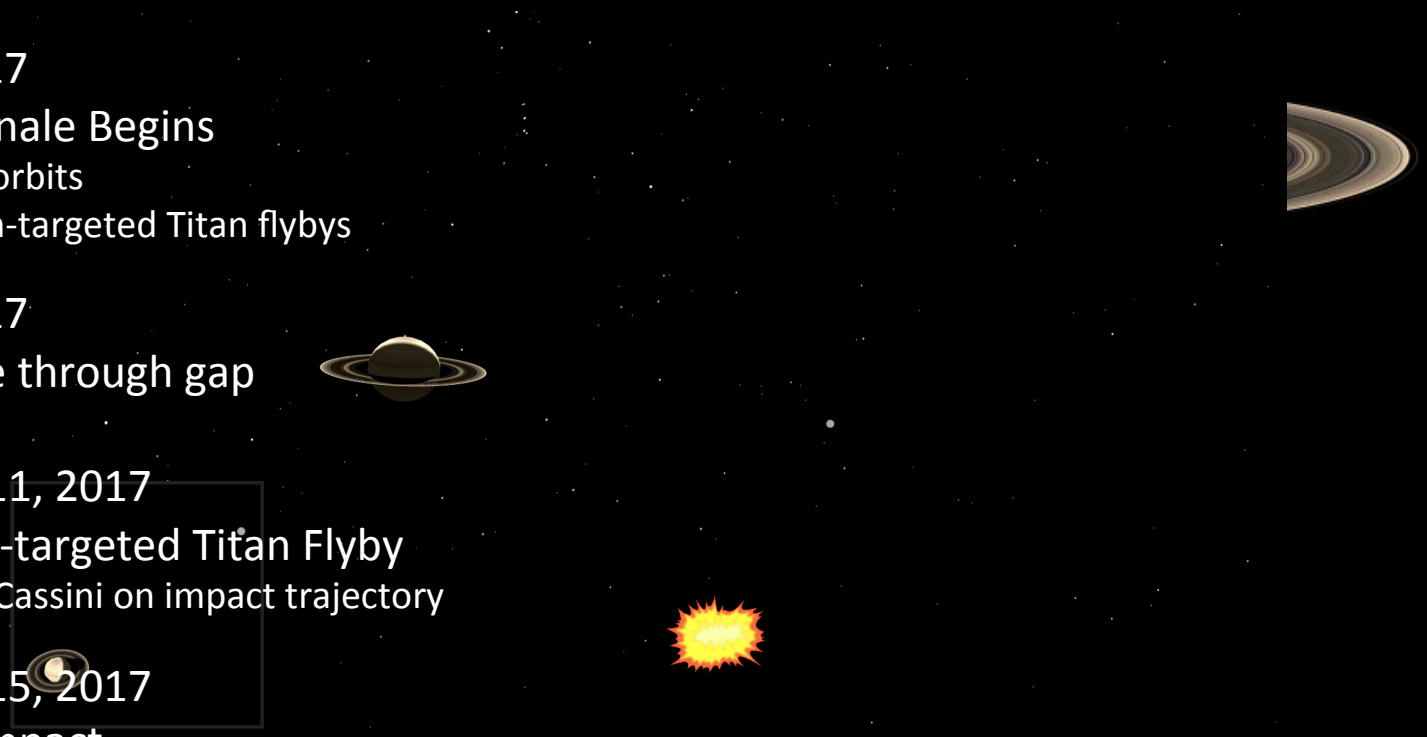
April 22, 2017
- Last Targeted Titan Flyby
  - Produces Grand Finale trajectory

April 23, 2017
- Grand Finale Begins
  - 22½ orbits
  - 9 non-targeted Titan flybys

April 26, 2017
- First dive through gap

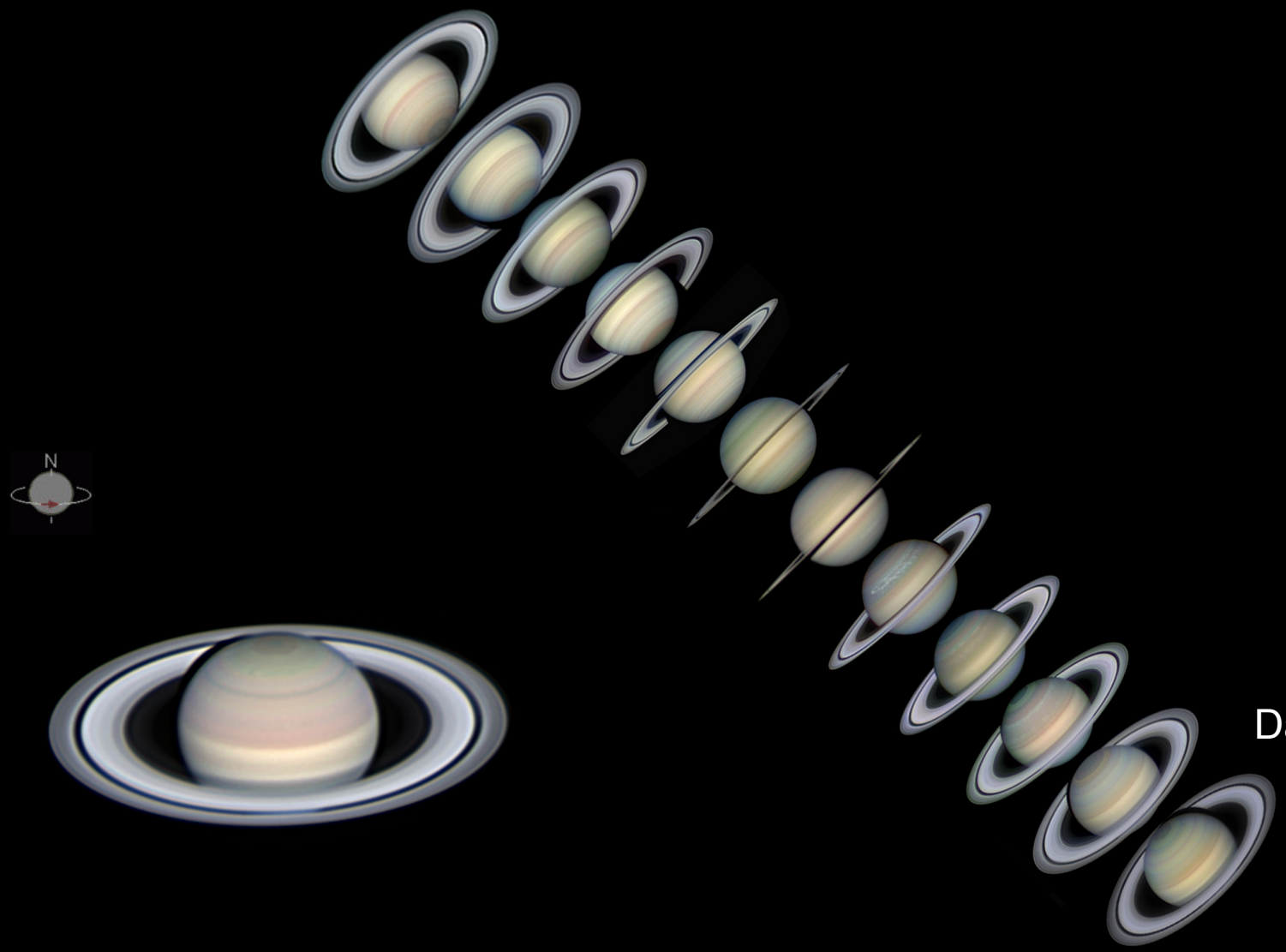
September 11, 2017
- Last Non-targeted Titan Flyby
  - Puts Cassini on impact trajectory

September 15, 2017
- Saturn Impact

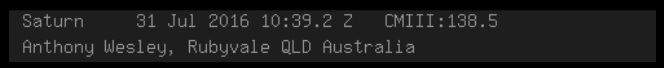


Cassini Family saying Goodbye…

After Cassini ends, observing Saturn…



Damian Peach

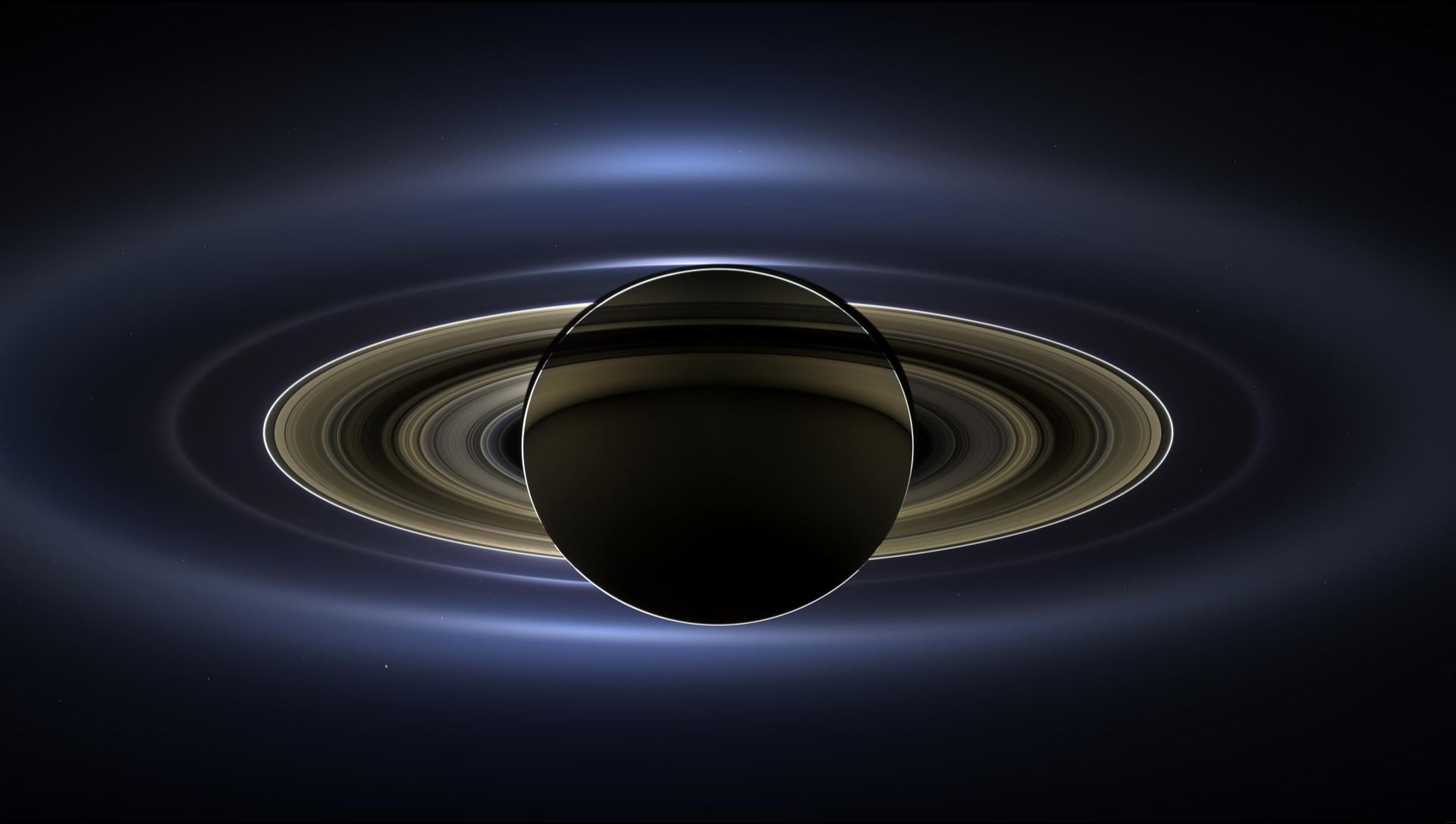


Anthony Wesley

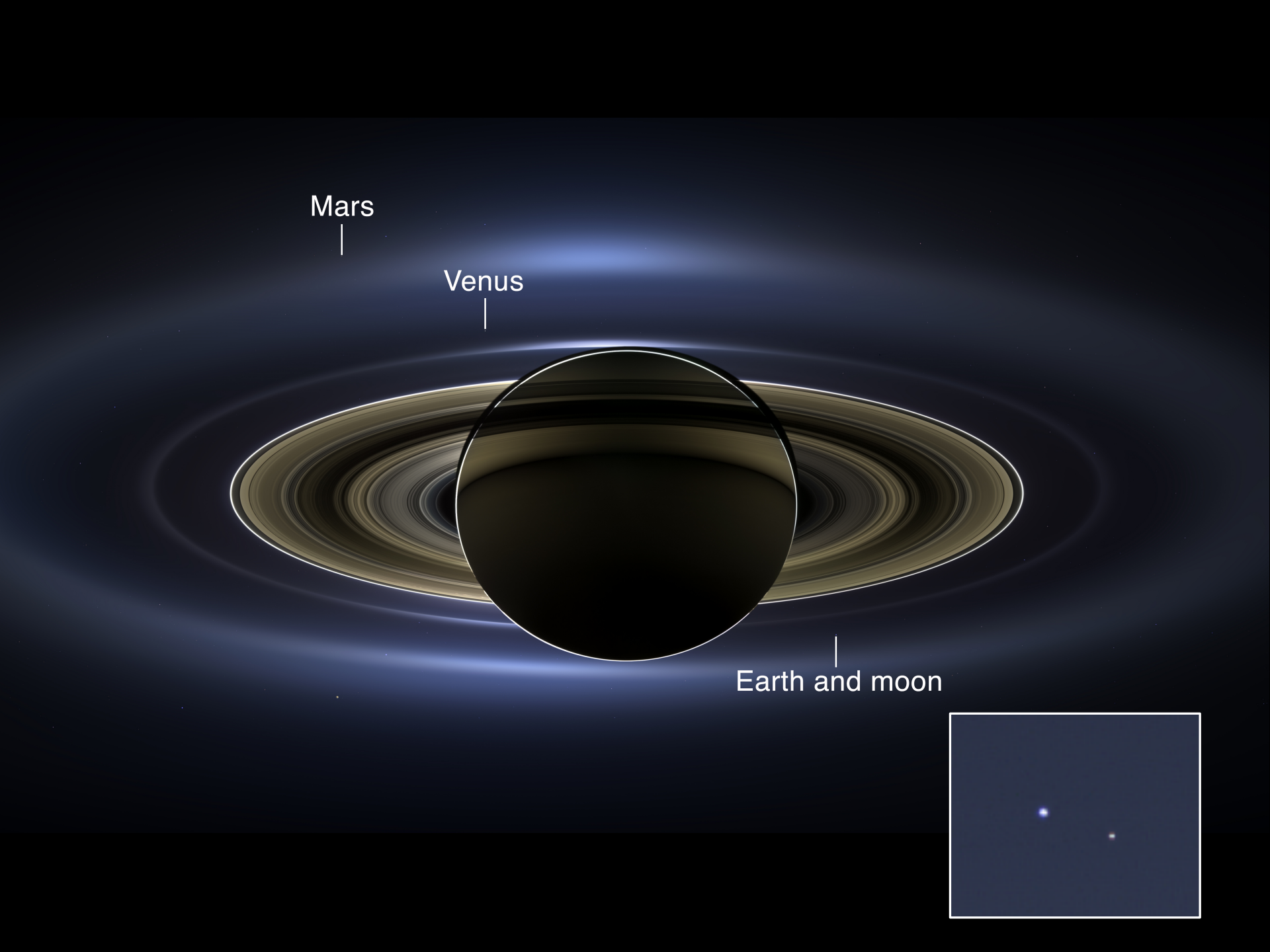
…is up to YOU!

SEN/D. Peach

Questions?



Backup Slides


Mars
Venus
Earth and moon