Cassini's Science: Past and Future

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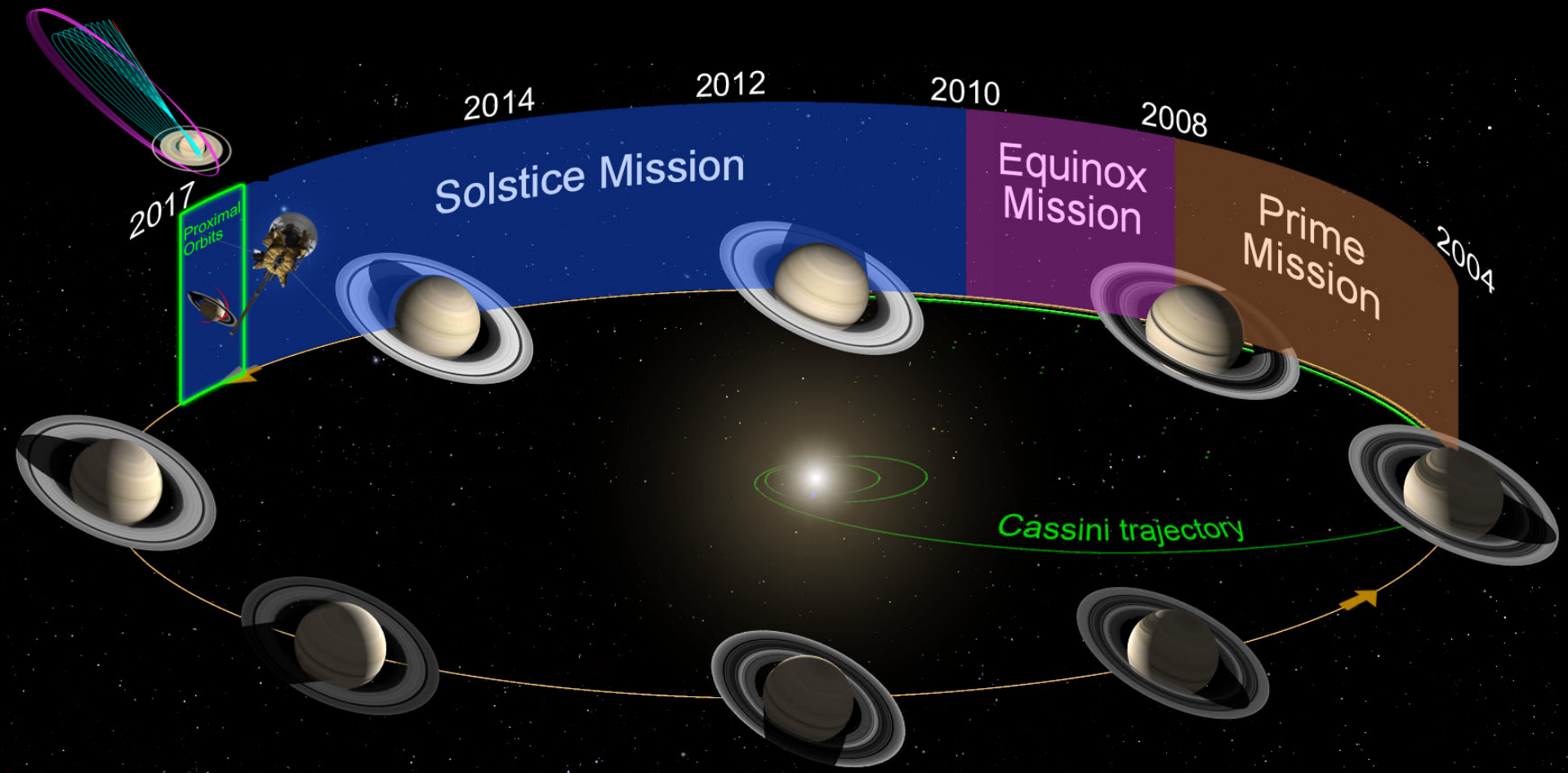
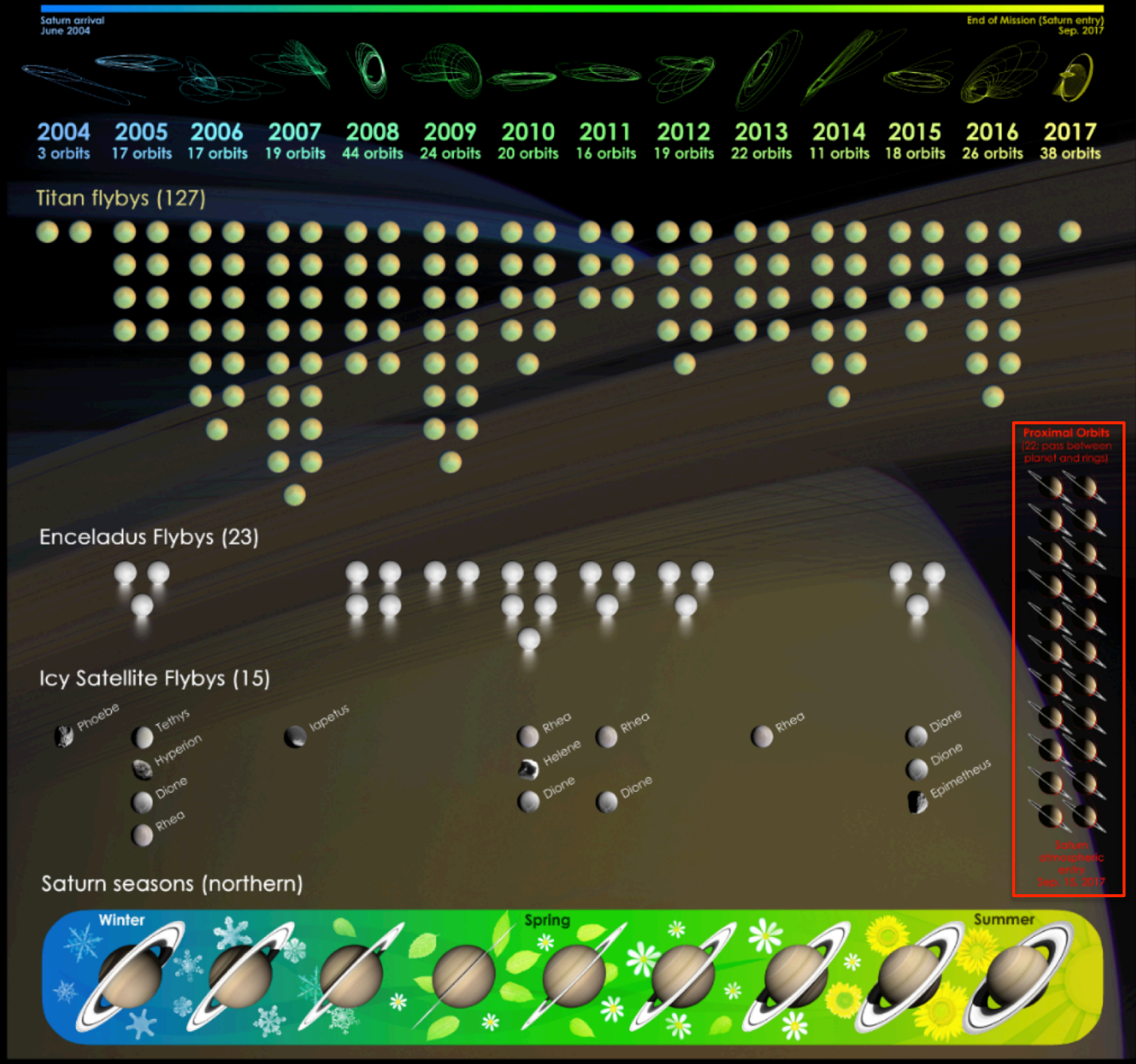
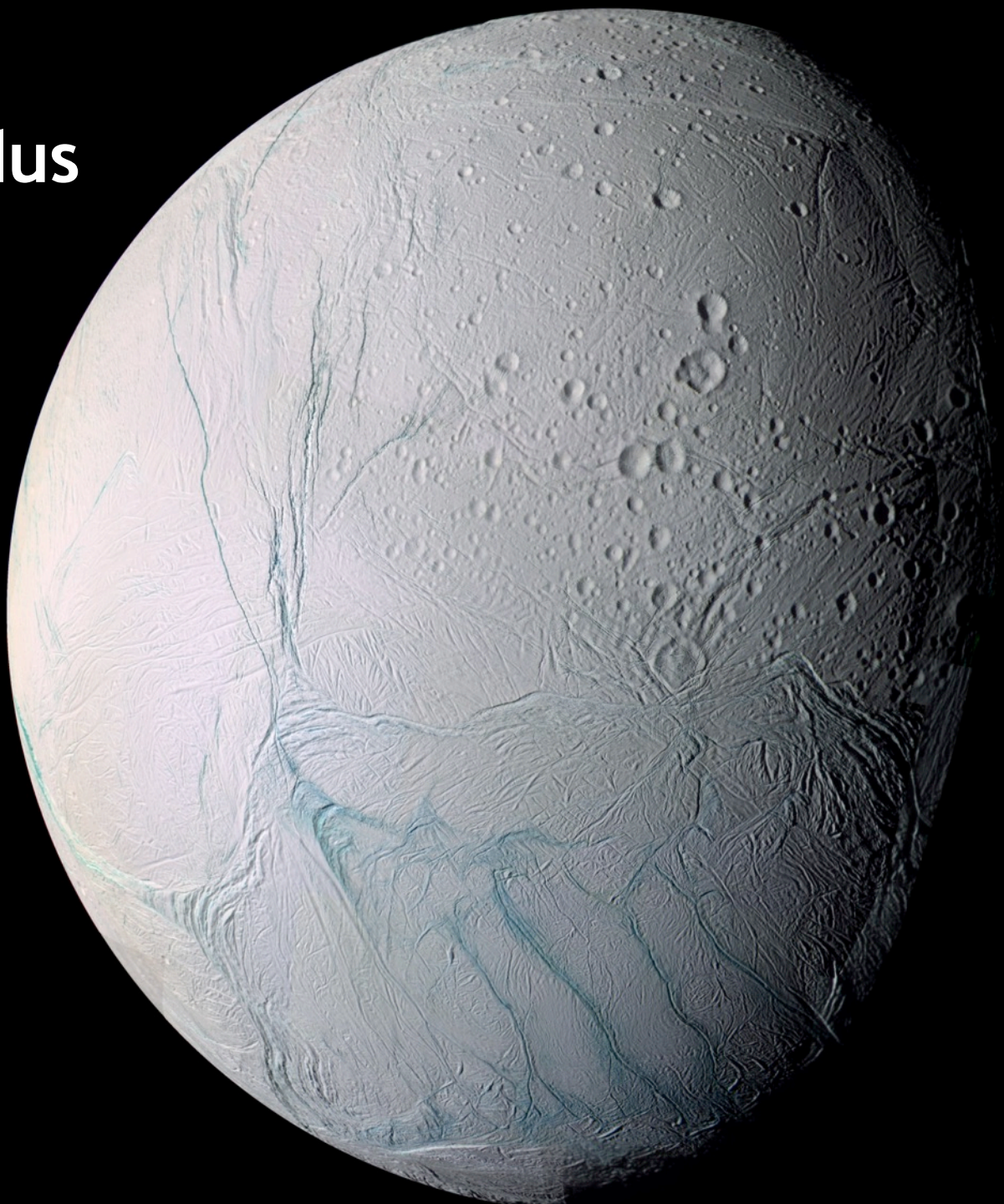
National Academies CAPS Meeting
15 September 2016

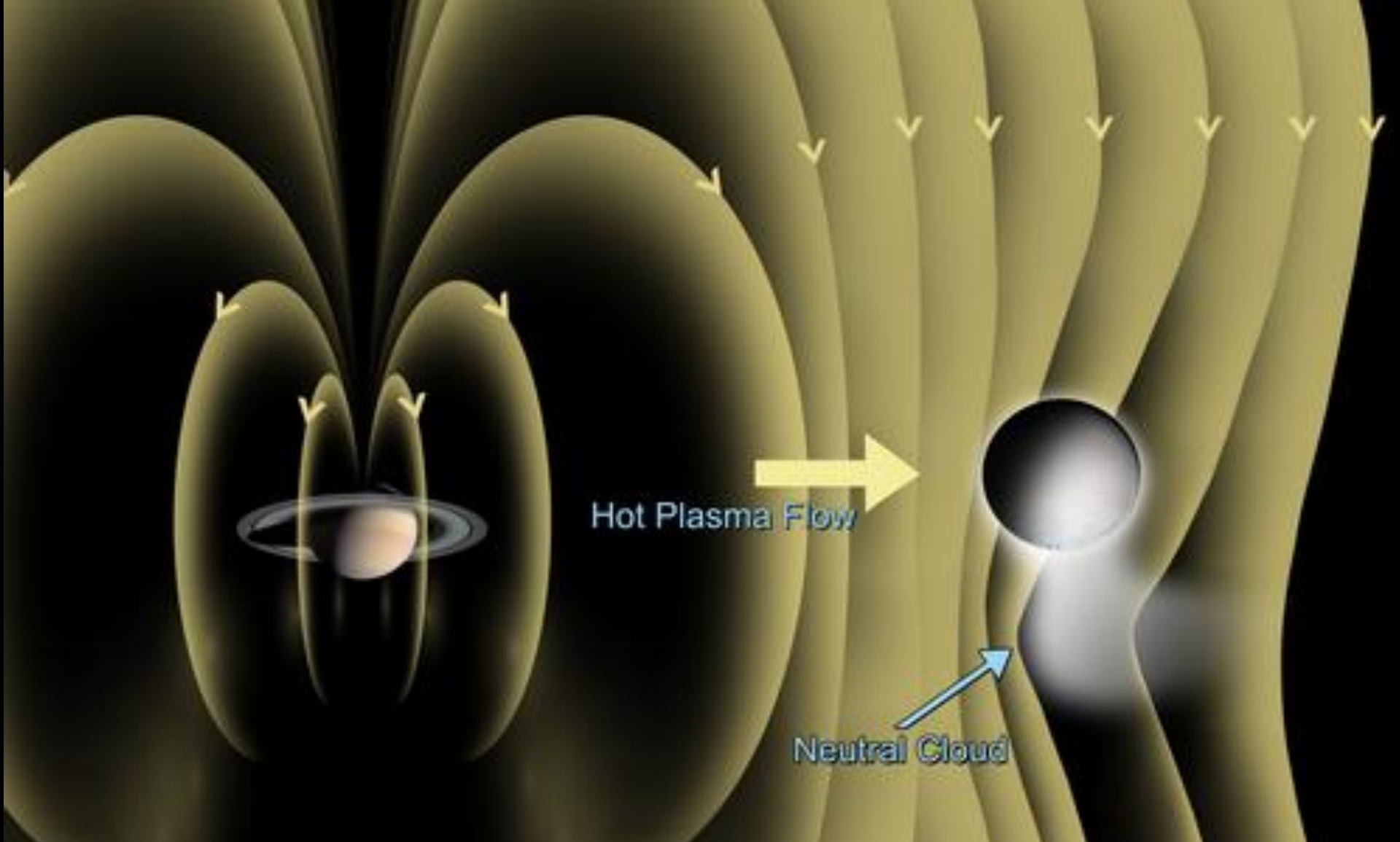
Cassini-Huygens Mission Overview




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)
Proximal Orbits
(22; pass between planet and rings)
Saturn atmospheric entry
Sep. 15, 2017
Enceladus Flybys (23)
Icy Satellite Flybys (15)
Phoebe
Tethys
Hyperion
Dione
Rhea
Iapetus
Rhea
Helene
Dione
Rhea
Dione
Rhea
Dione
Dione
Epimetheus
Saturn seasons (northern)
Winter
Spring
Summer

Enceladus

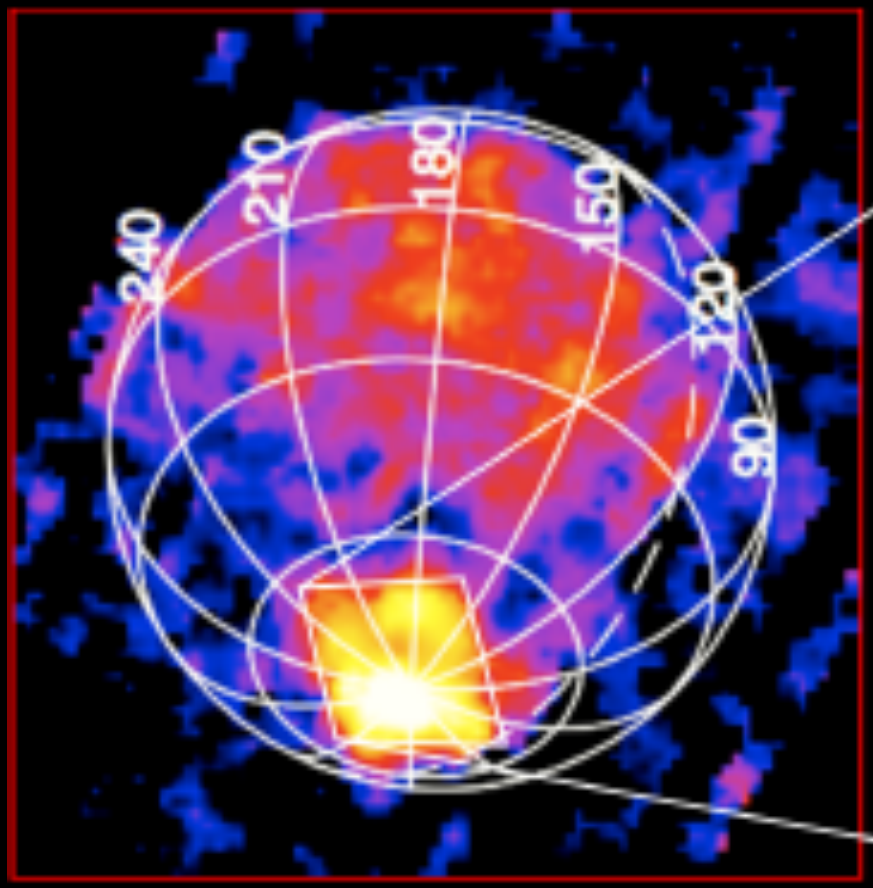


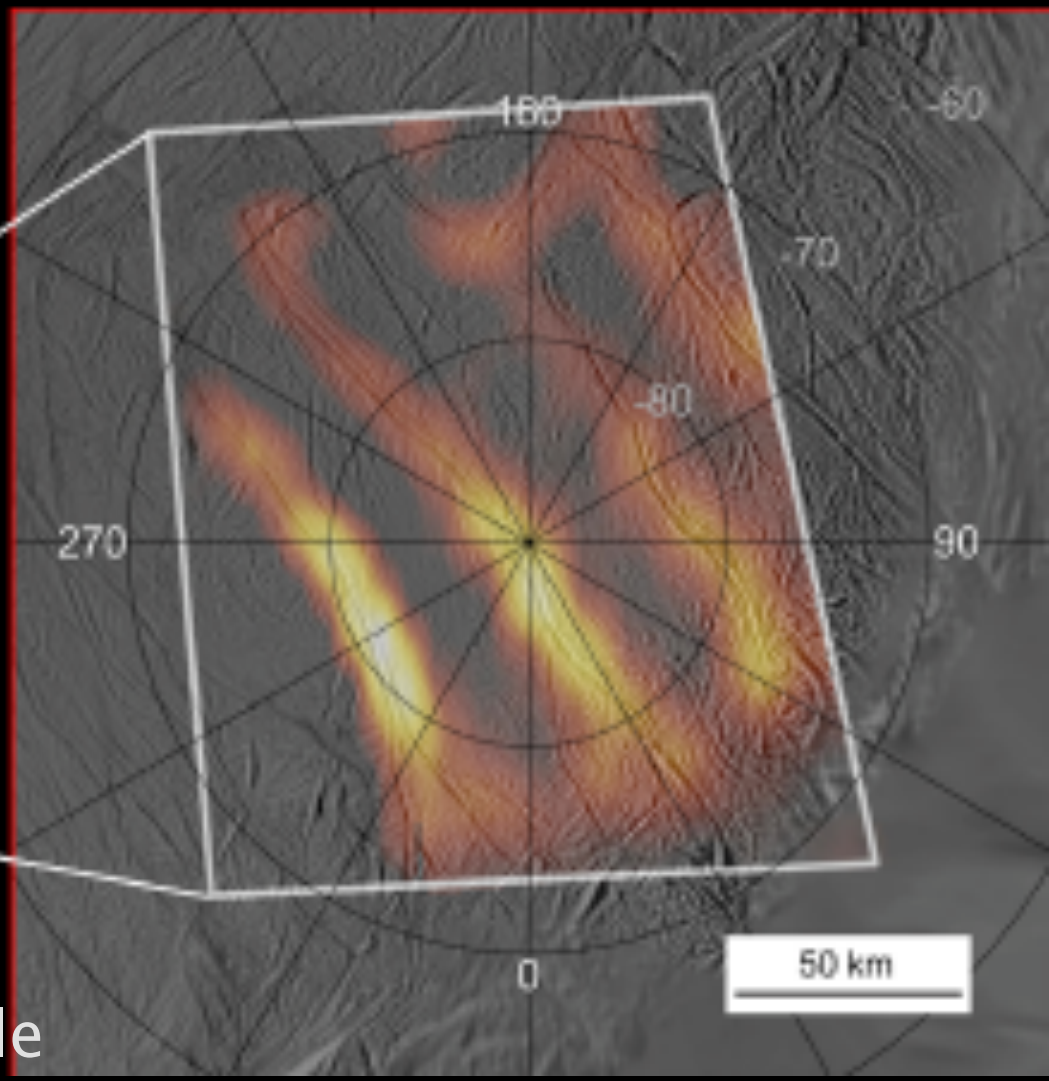


2005: First flyby close to Enceladus is 1000 km, unusual comet-like magnetic field signature detected

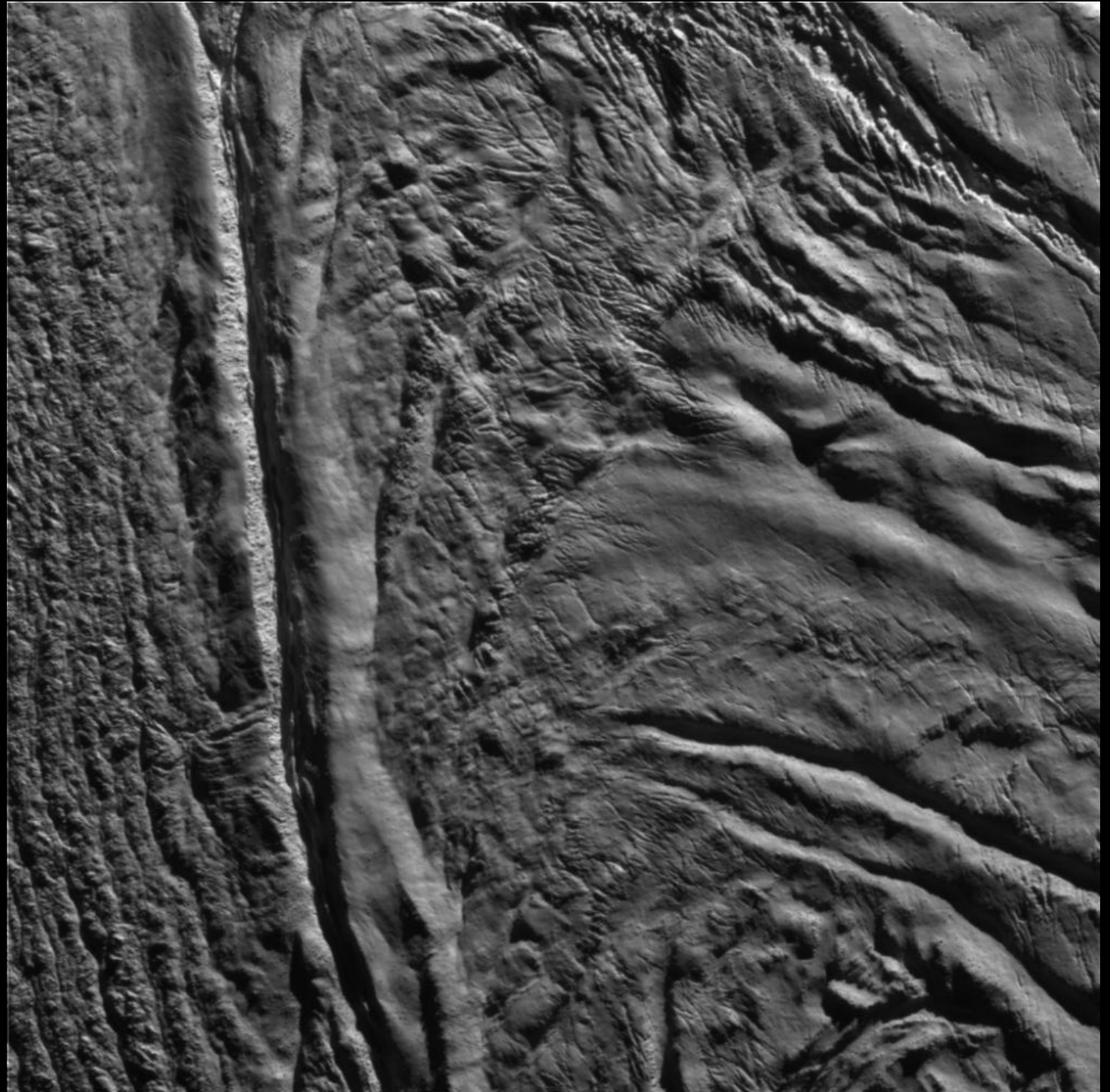
Second flyby altitude decreased to 175 km (Dougherty et al

Infrared CIRS Heat measurement

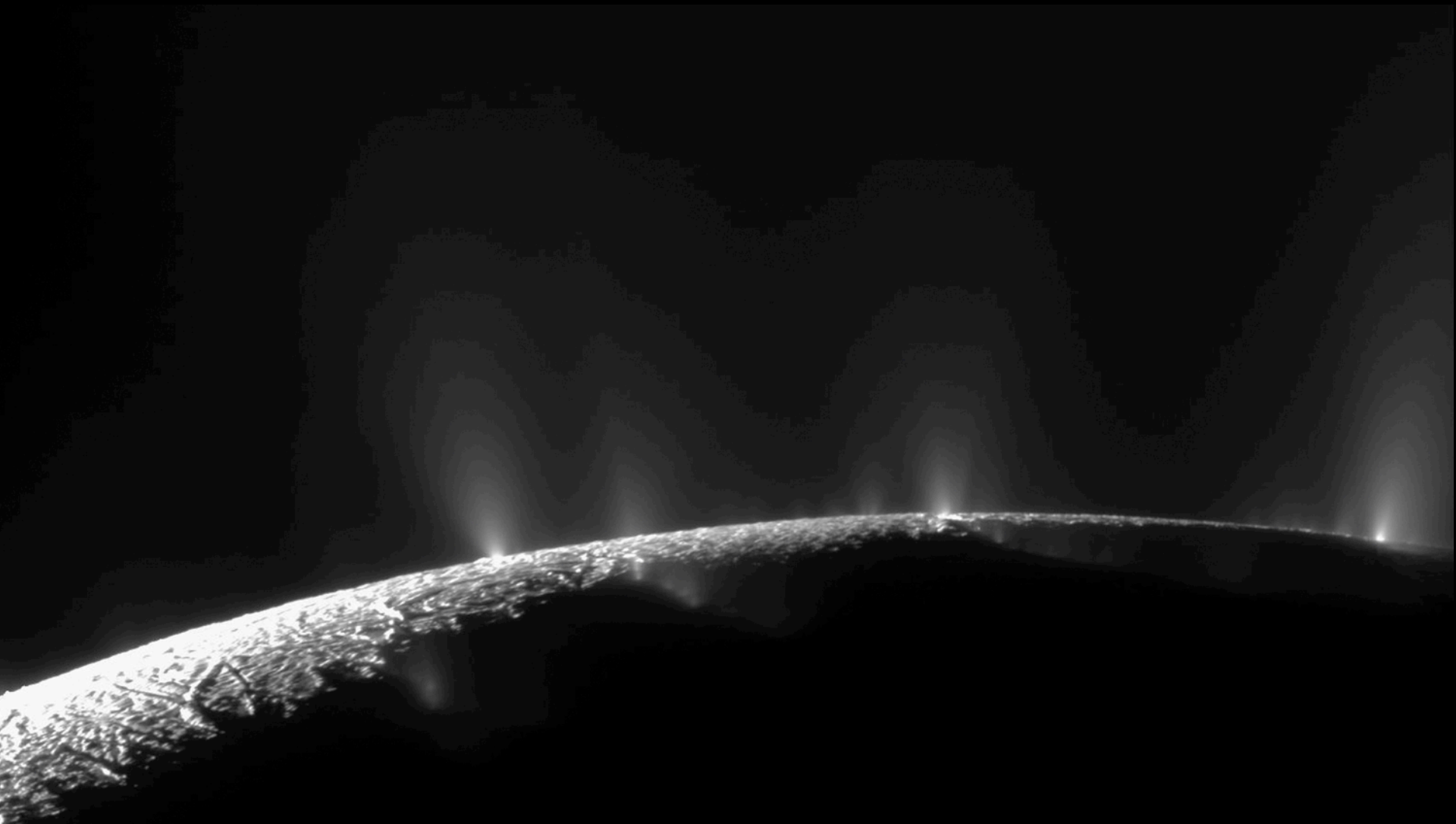




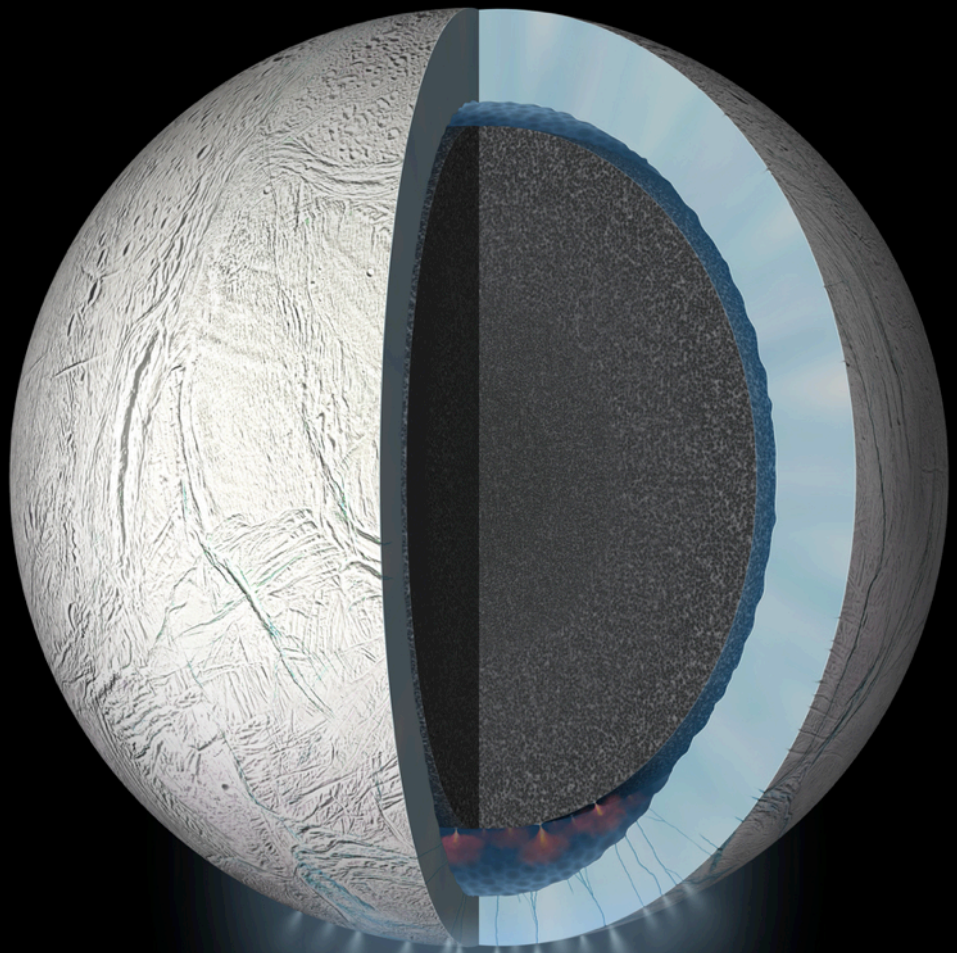
- Excess heat at south pole
- Tiger stripe origin
  (Spencer et al., 2006)



Active Enceladus Jets

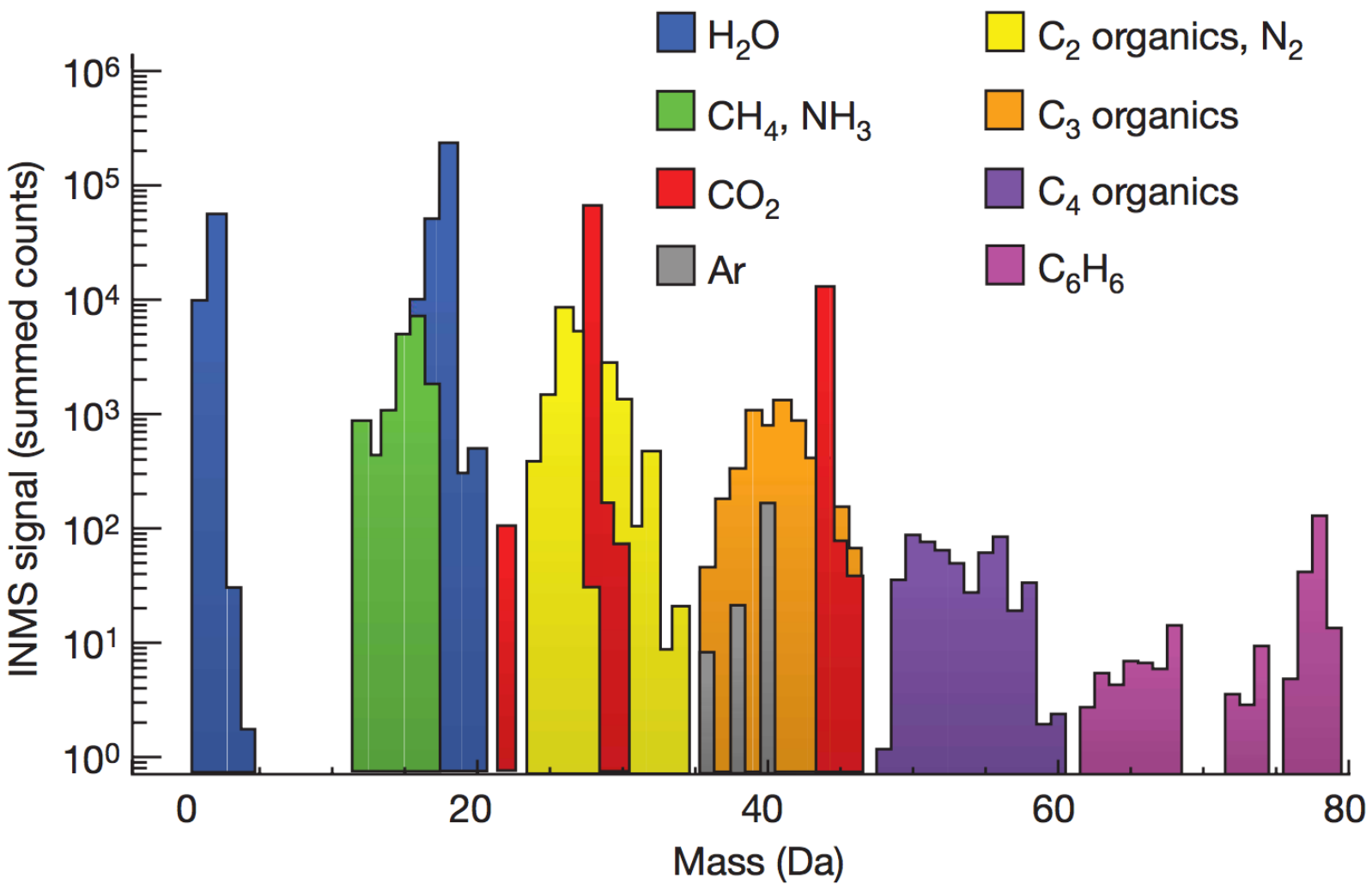


Enceladus: Cassini's Discoveries

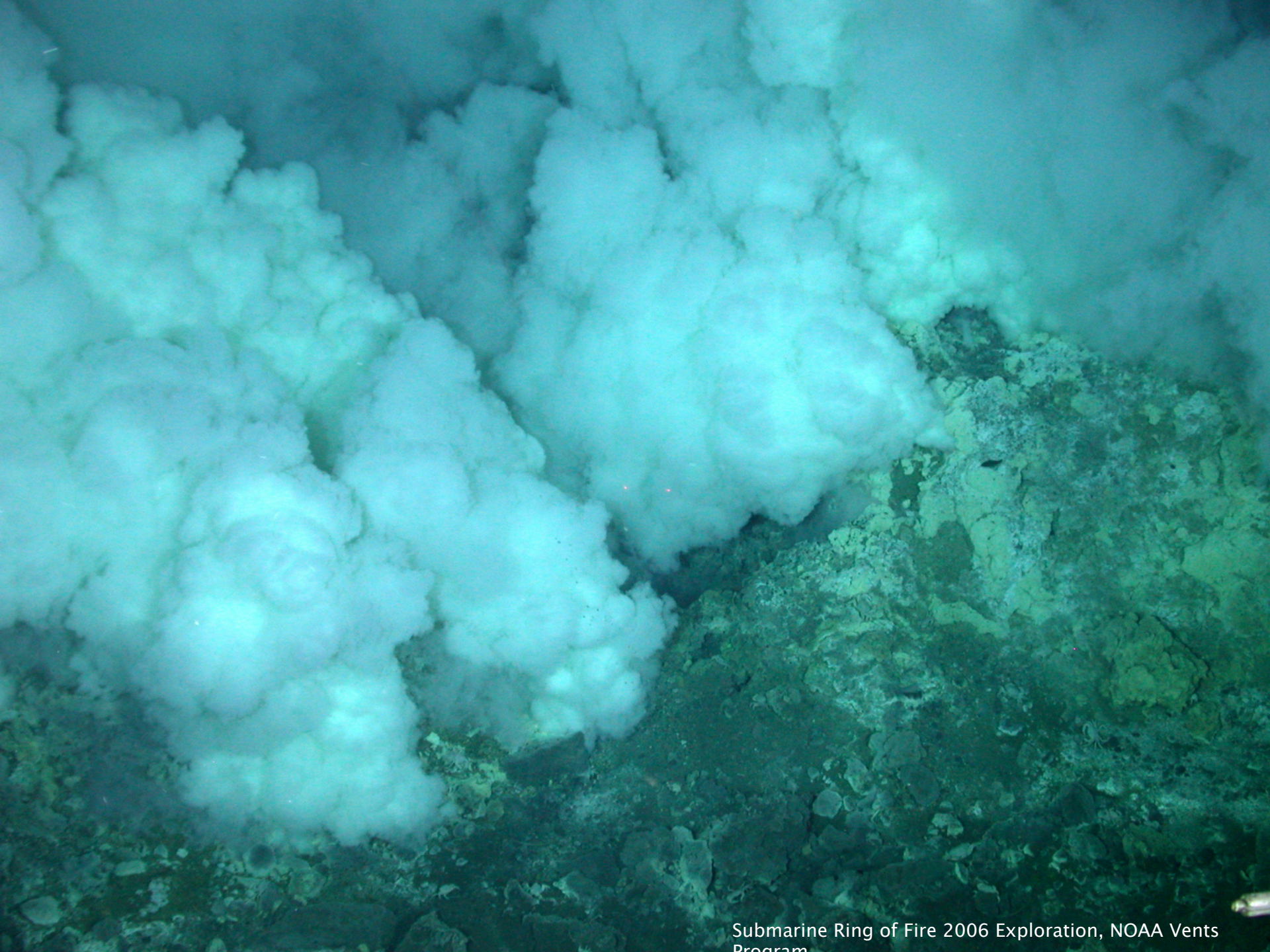


- Global ocean!
- Ocean is long-lived
- Alkaline pH of ocean
- Hydrothermal vents
  - Silica nanograins
  - Excess Methane
  - Molecular hydrogen?
- Organics in plume

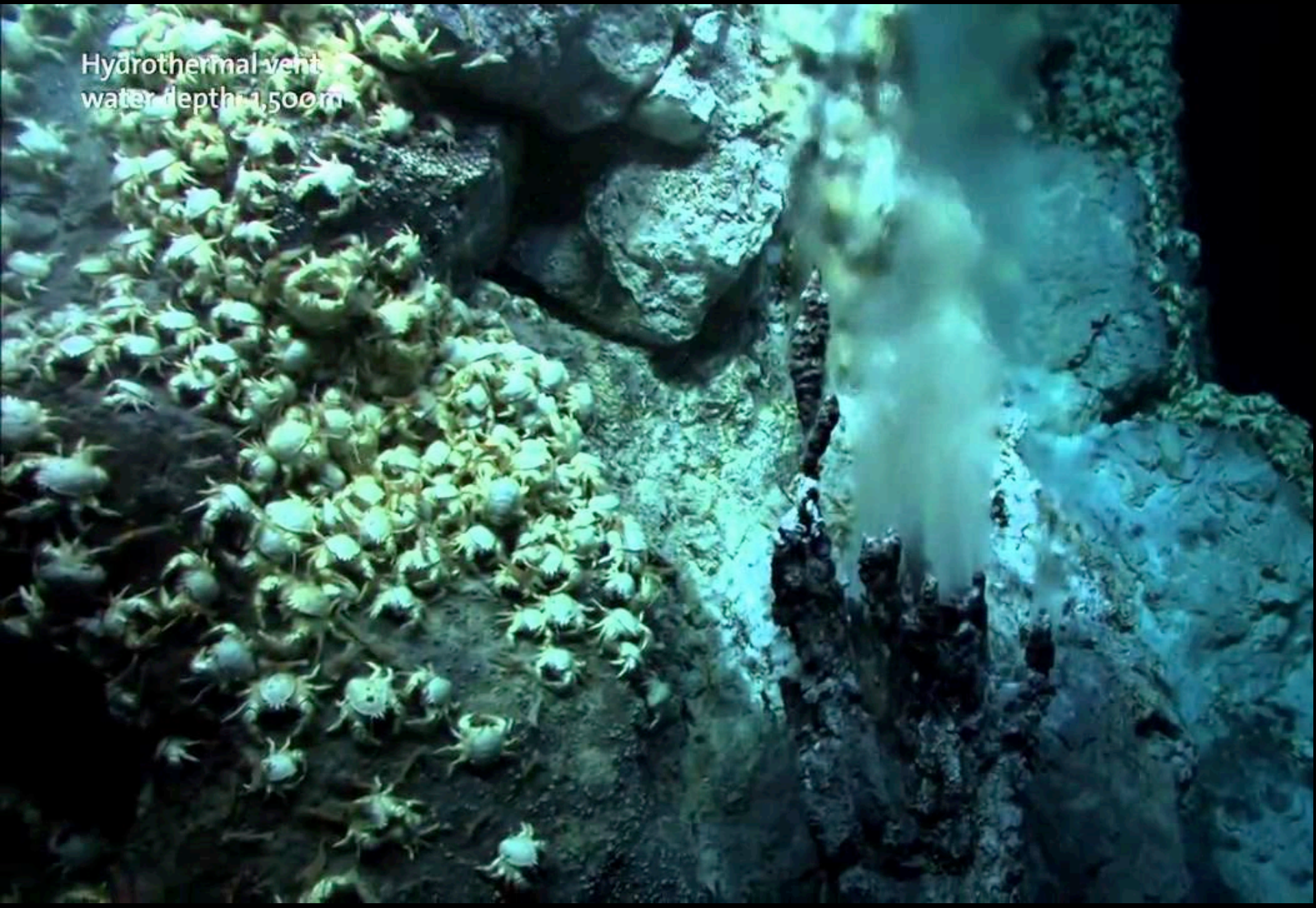
Organics in the Plume



Waite et al, *Nature*, 2009.

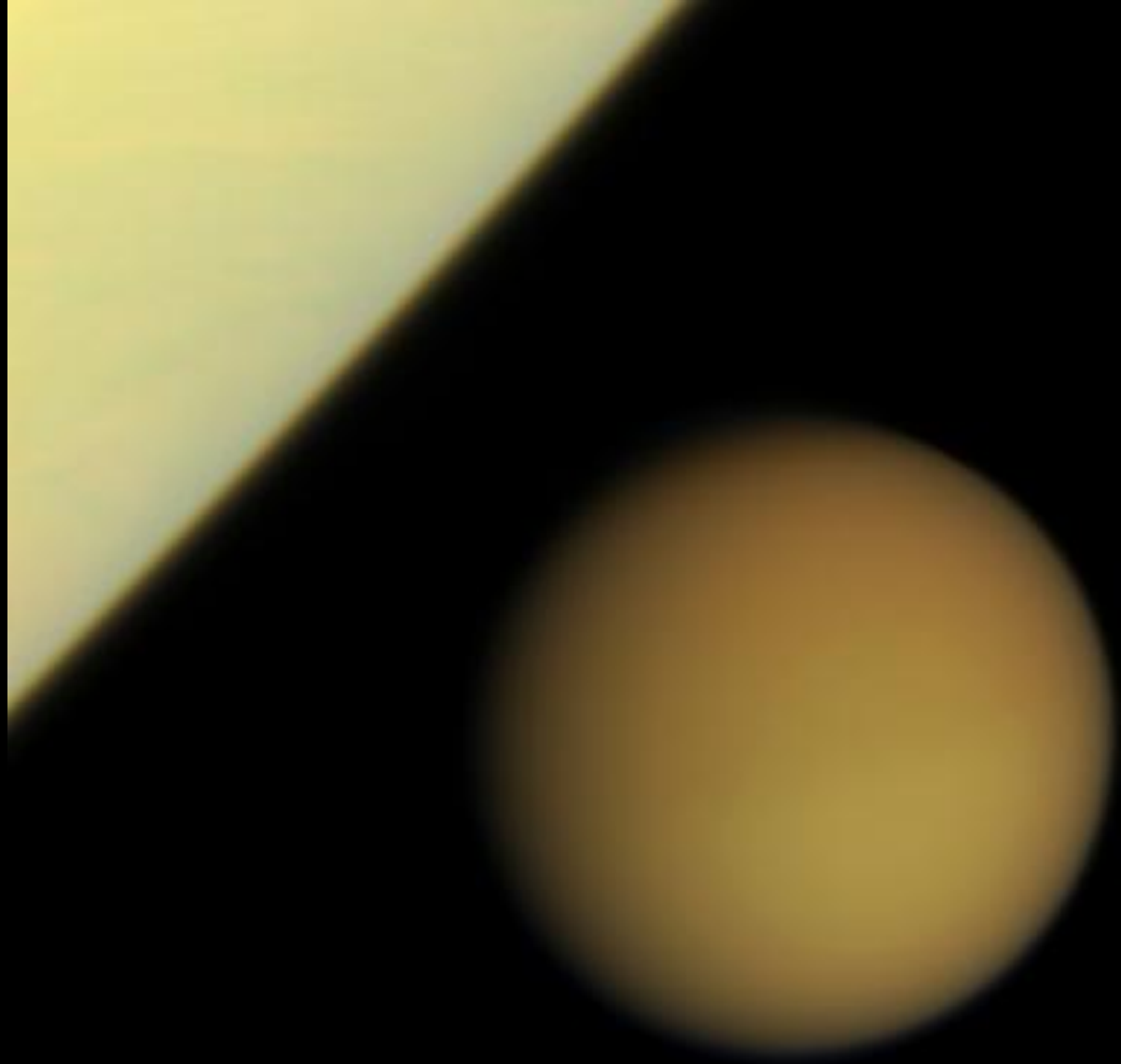


Submarine Ring of Fire 2006 Exploration, NOAA Vents Program


Hydrothermal vent
water depth: 1,500m

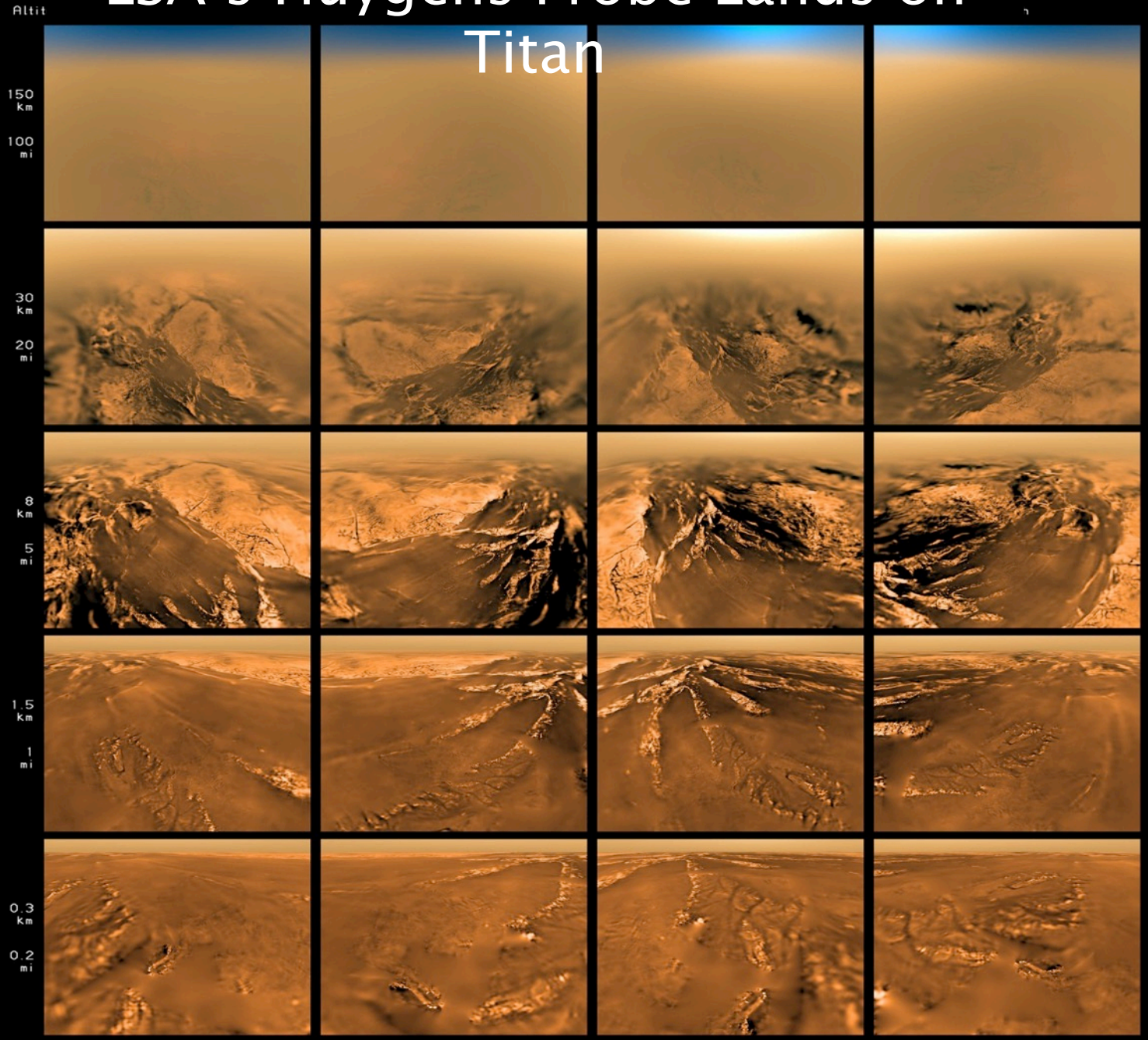
Distant Enceladus Plume Occultation

-- UVIS stellar occultation of Epsilon Orionis through Enceladus plume to see variation of plume gas with time.
-- Occultation near apoapse, which shows maximum particle emission
-- Gas increase: only 20% in plume, factor of 4 in jet

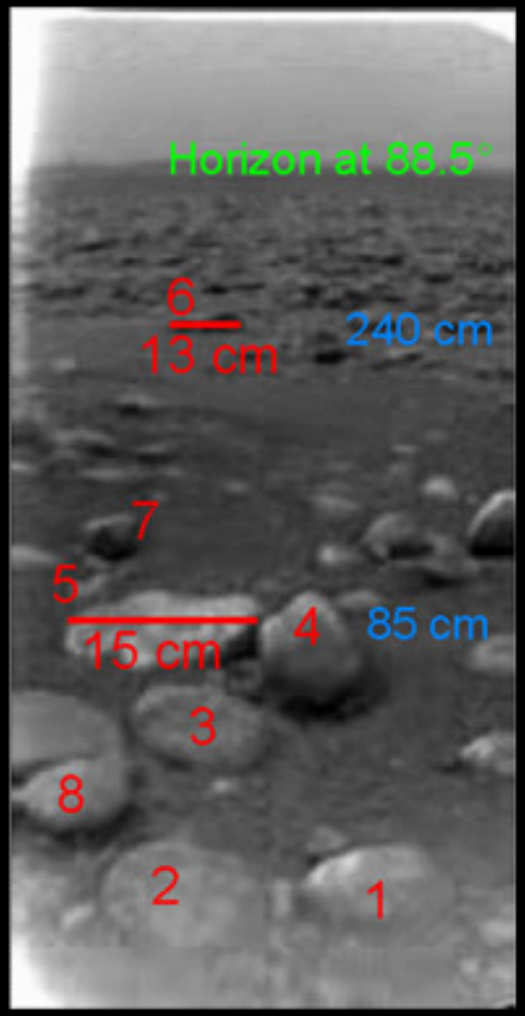


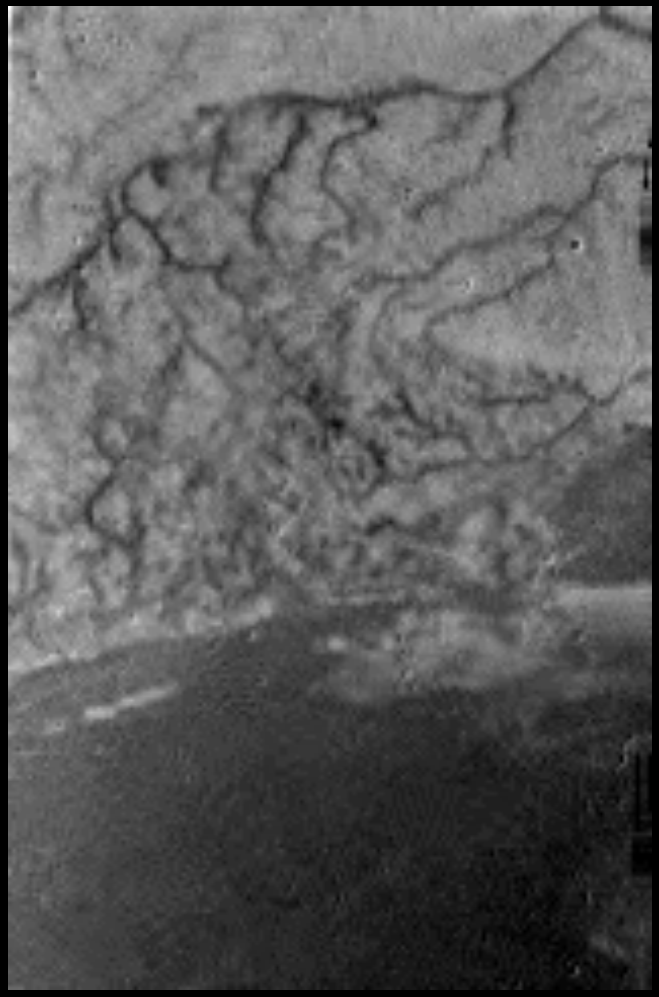
ESA's Huygens Probe Lands on Titan

Haze clears at an altitude of 60 km

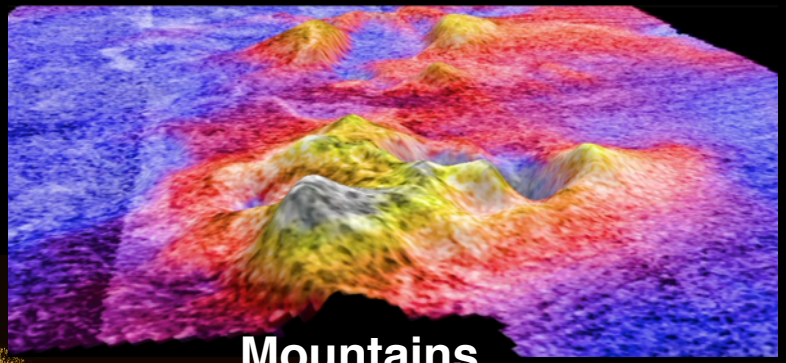


Huygens Images

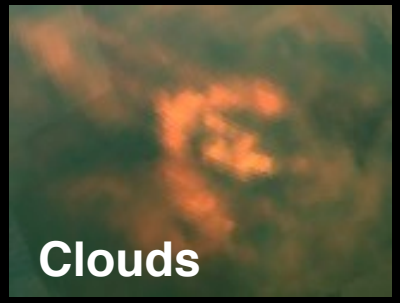




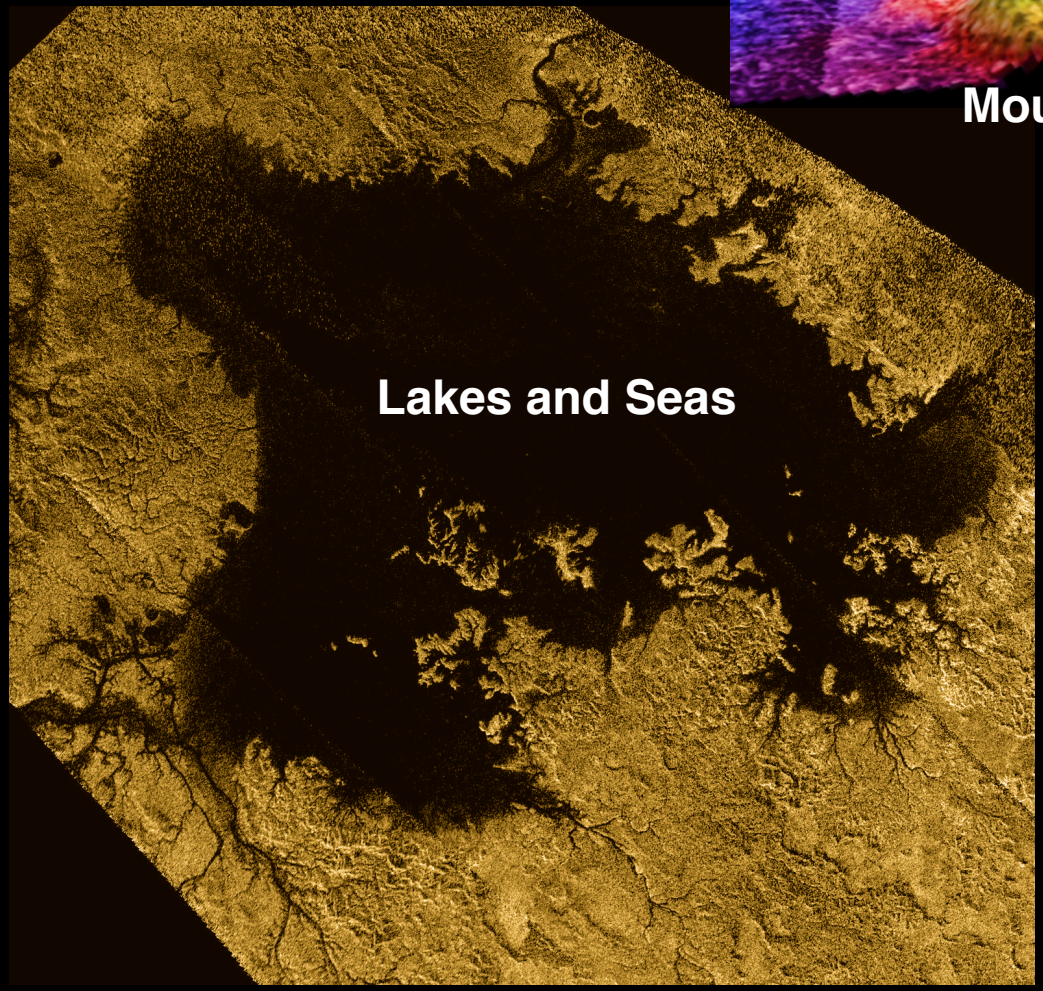
Titan: An Earth-like World



Mountains

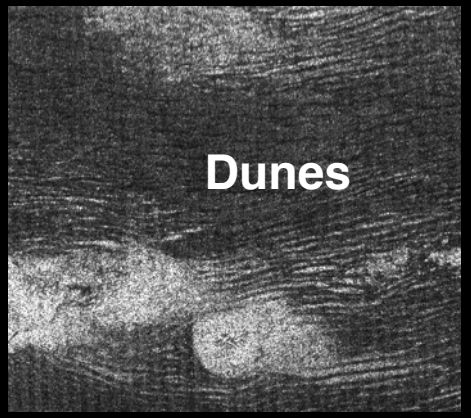


Clouds

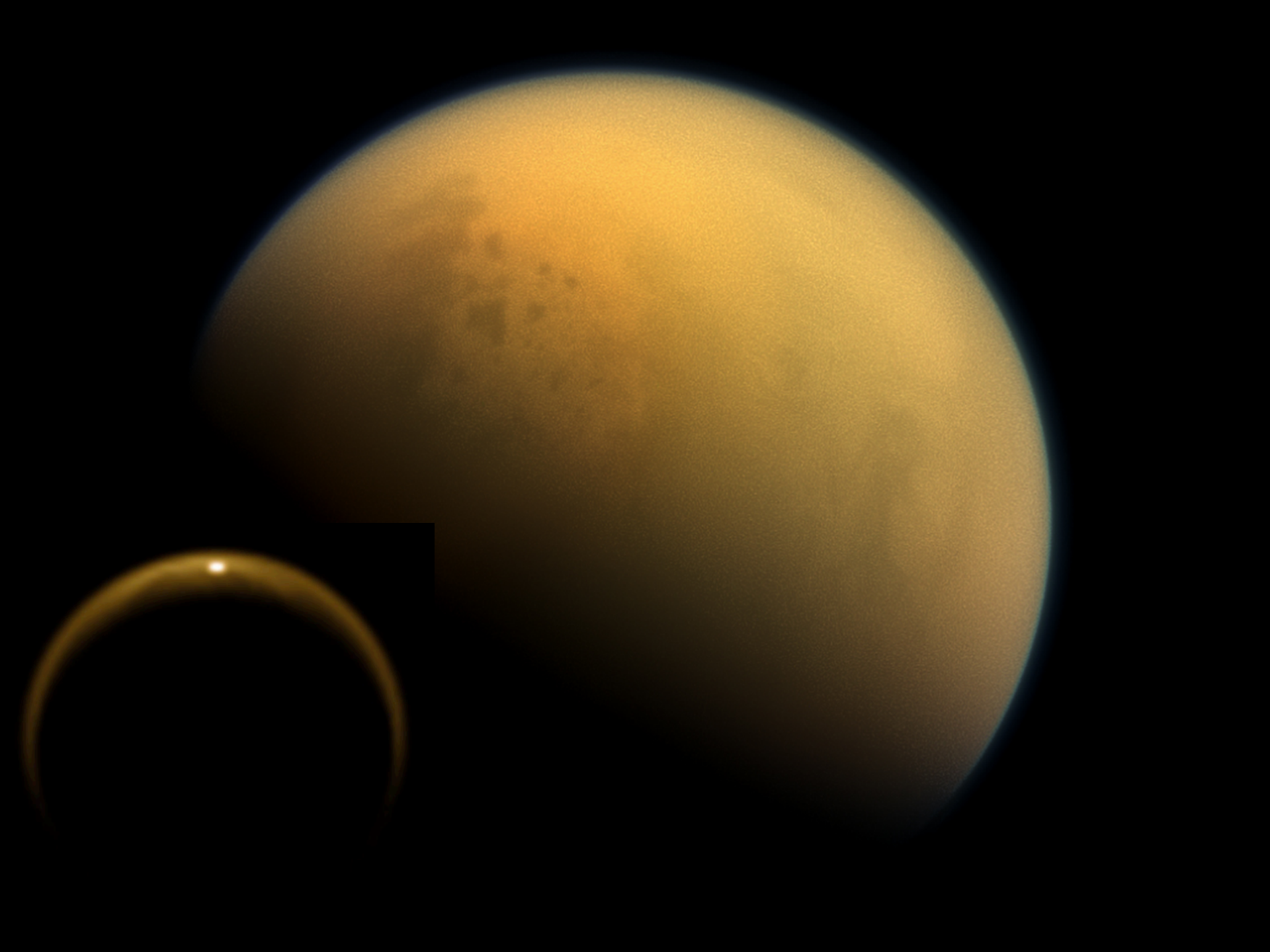


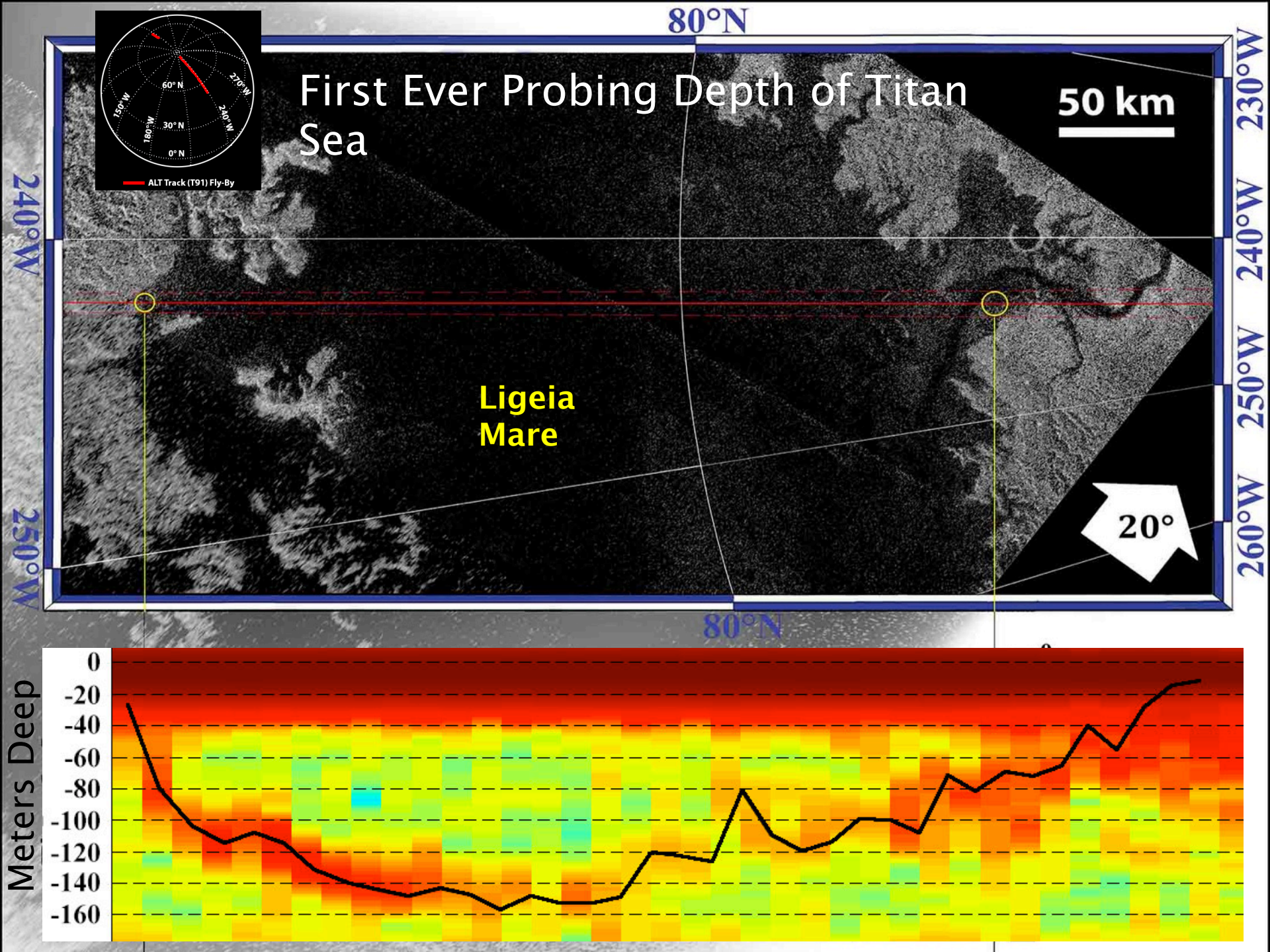
Lakes and Seas

Dry River Beds

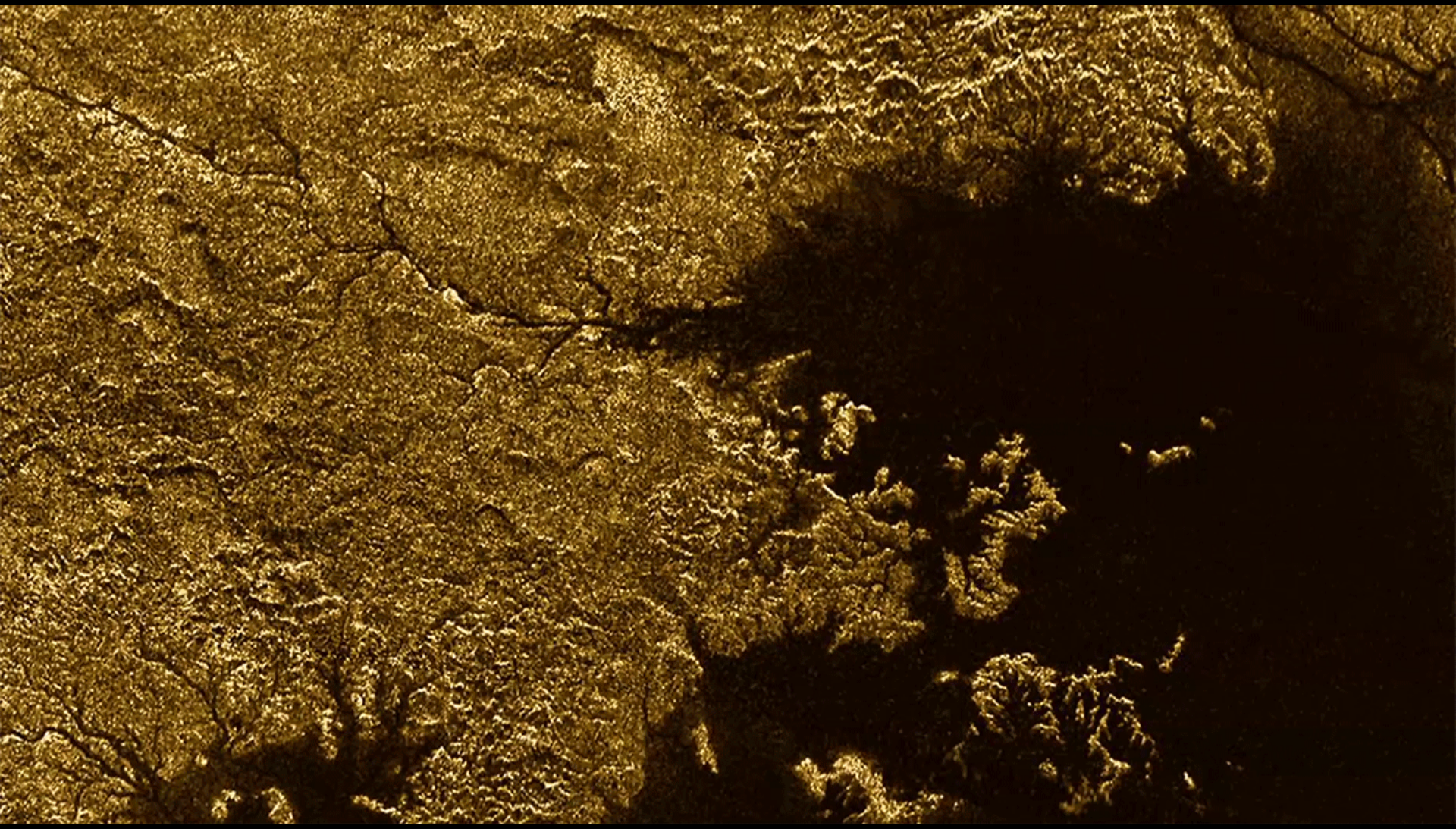


Dunes

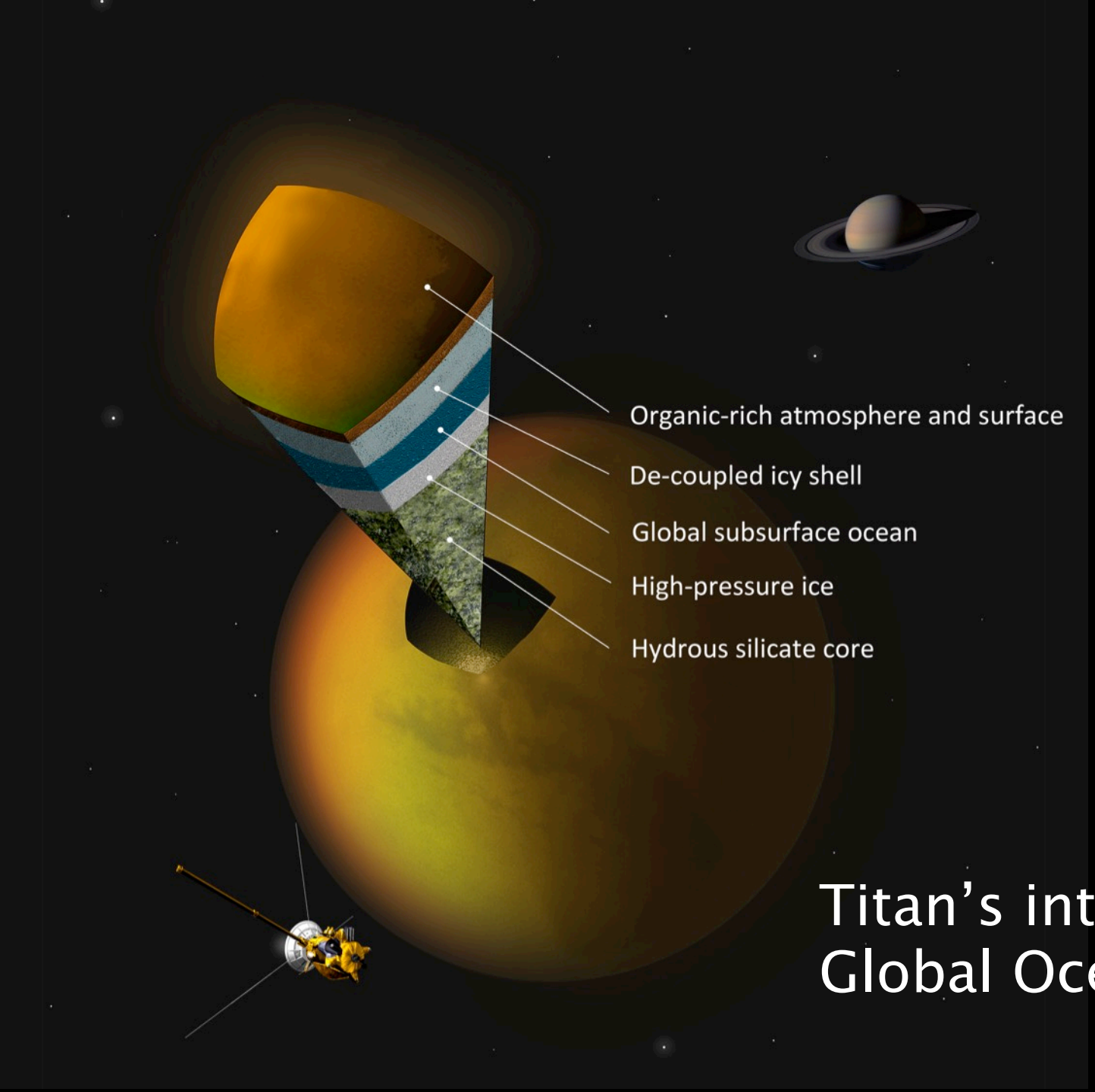



80°N
First Ever Probing Depth of Titan Sea
50 km
60° N
30° N
0° N
150° W
180° W
270° W
240° W
ALT Track (T91) Fly-By
240°W
250°W
230°W
240°W
250°W
260°W
Ligeia Mare
20°
80°N
Meters Deep
0
-20
-40
-60
-80
-100
-120
-140
-160

Canyons of Vid Flumina (upper left quadrant)

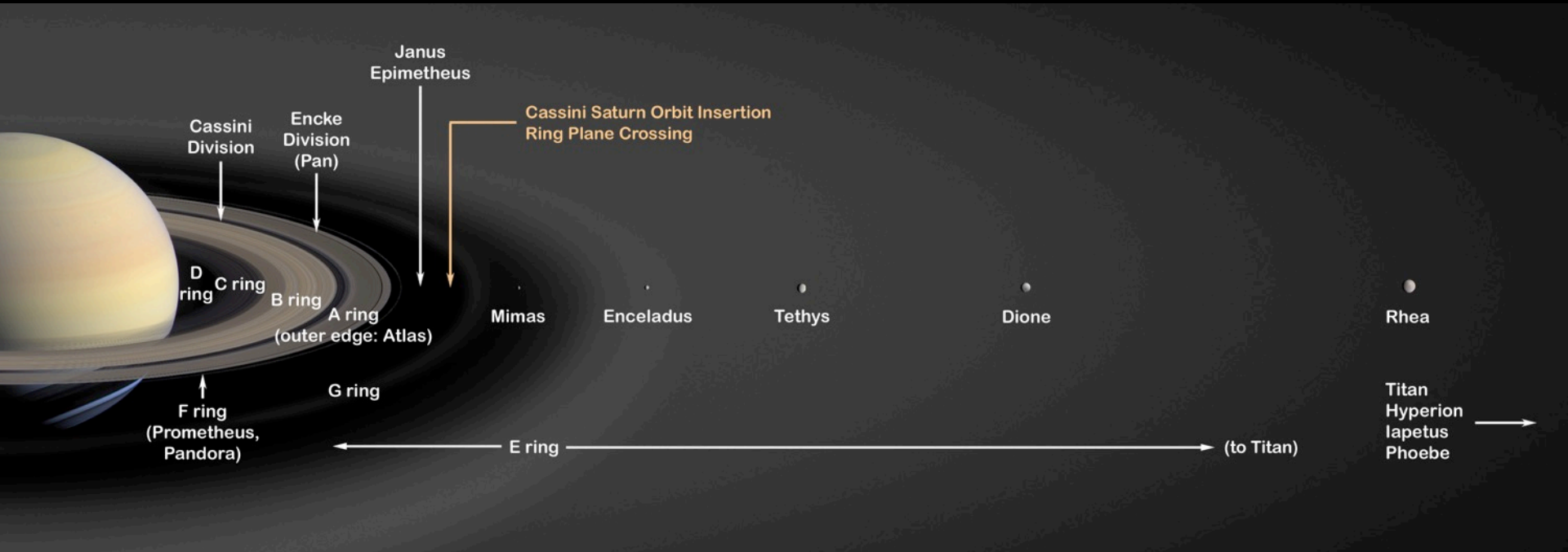


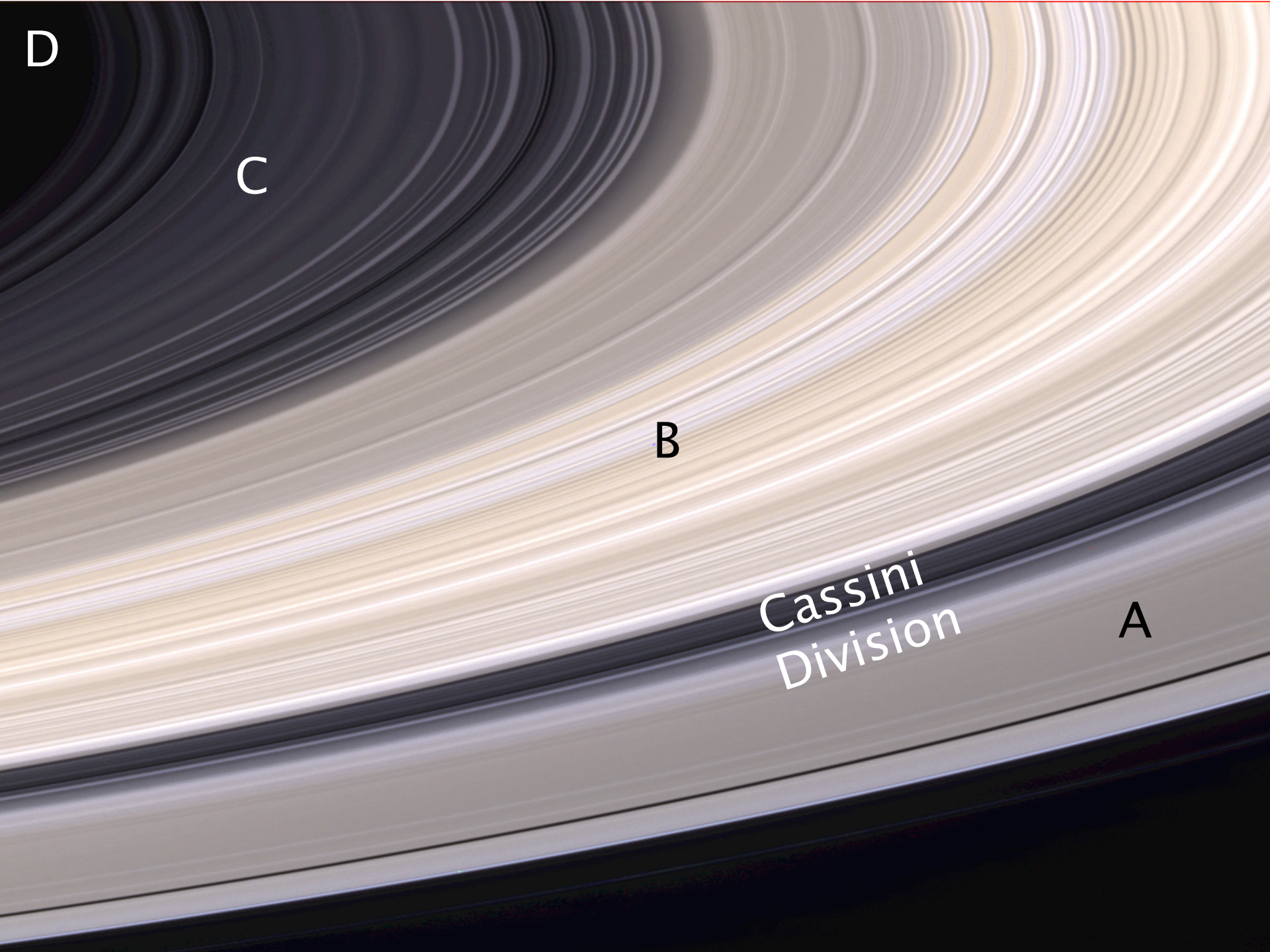
- Deep, steep-sided canyons (240 – 570 m deep) are flooded with liquid hydrocarbons
- Farther from sea, liquid is tens of meters higher than sea level



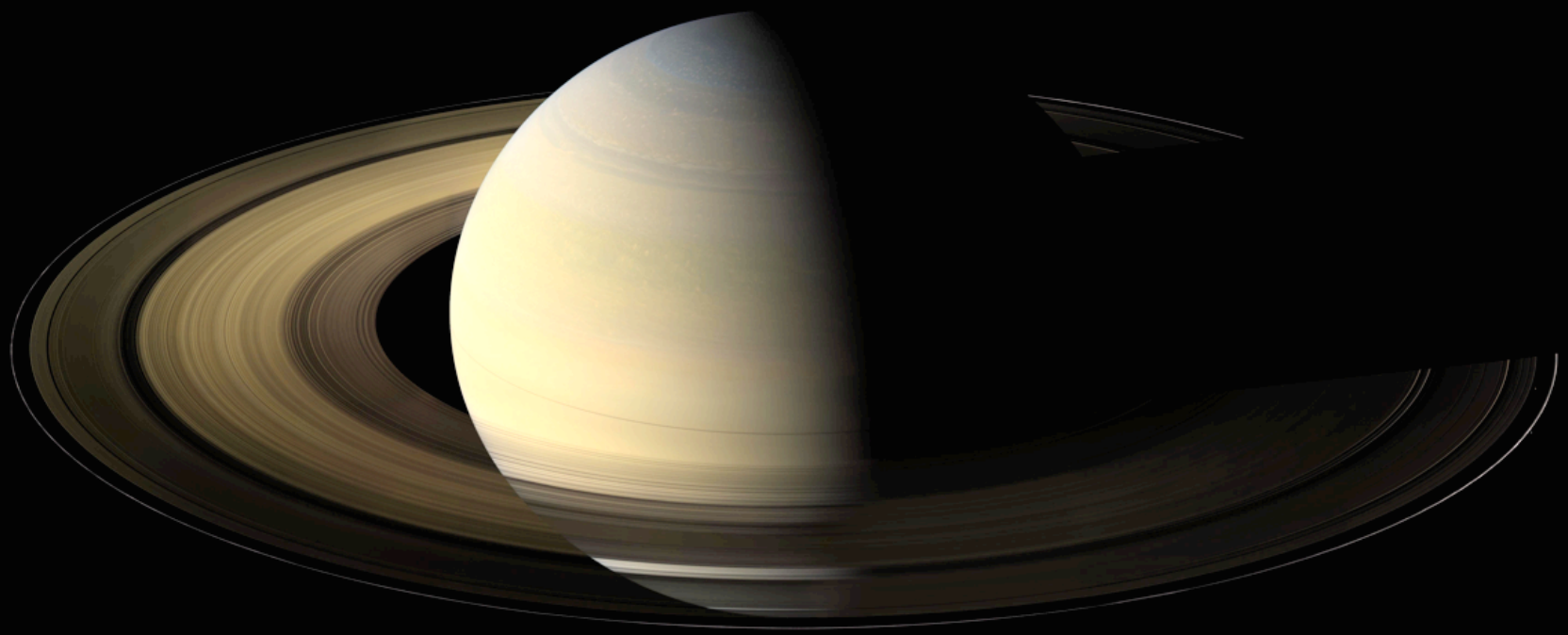
Titan's interior structur
Global Ocean

Saturn's Rings



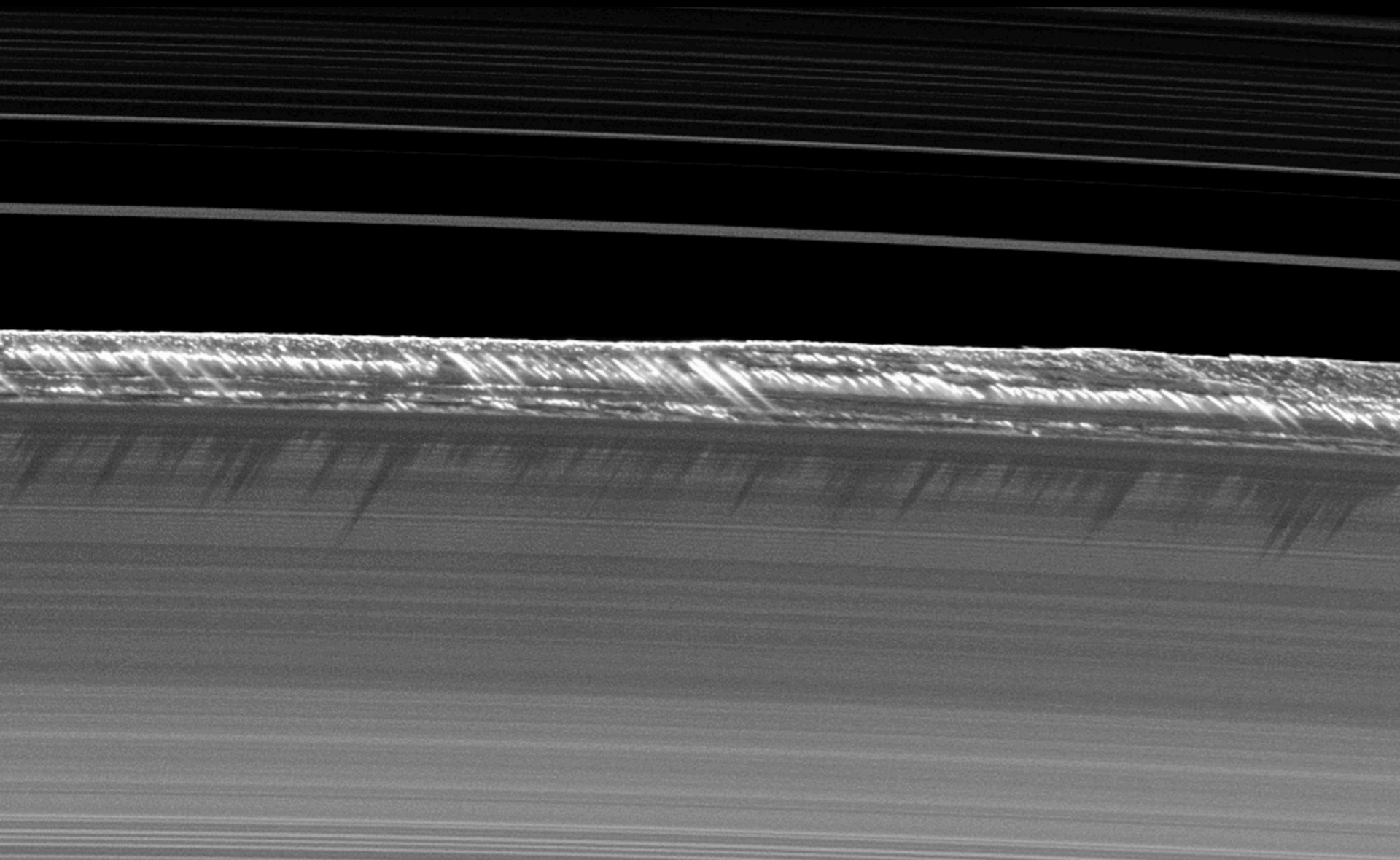

D
C
B
Cassini
Division
A

Saturn's Rings at Equinox

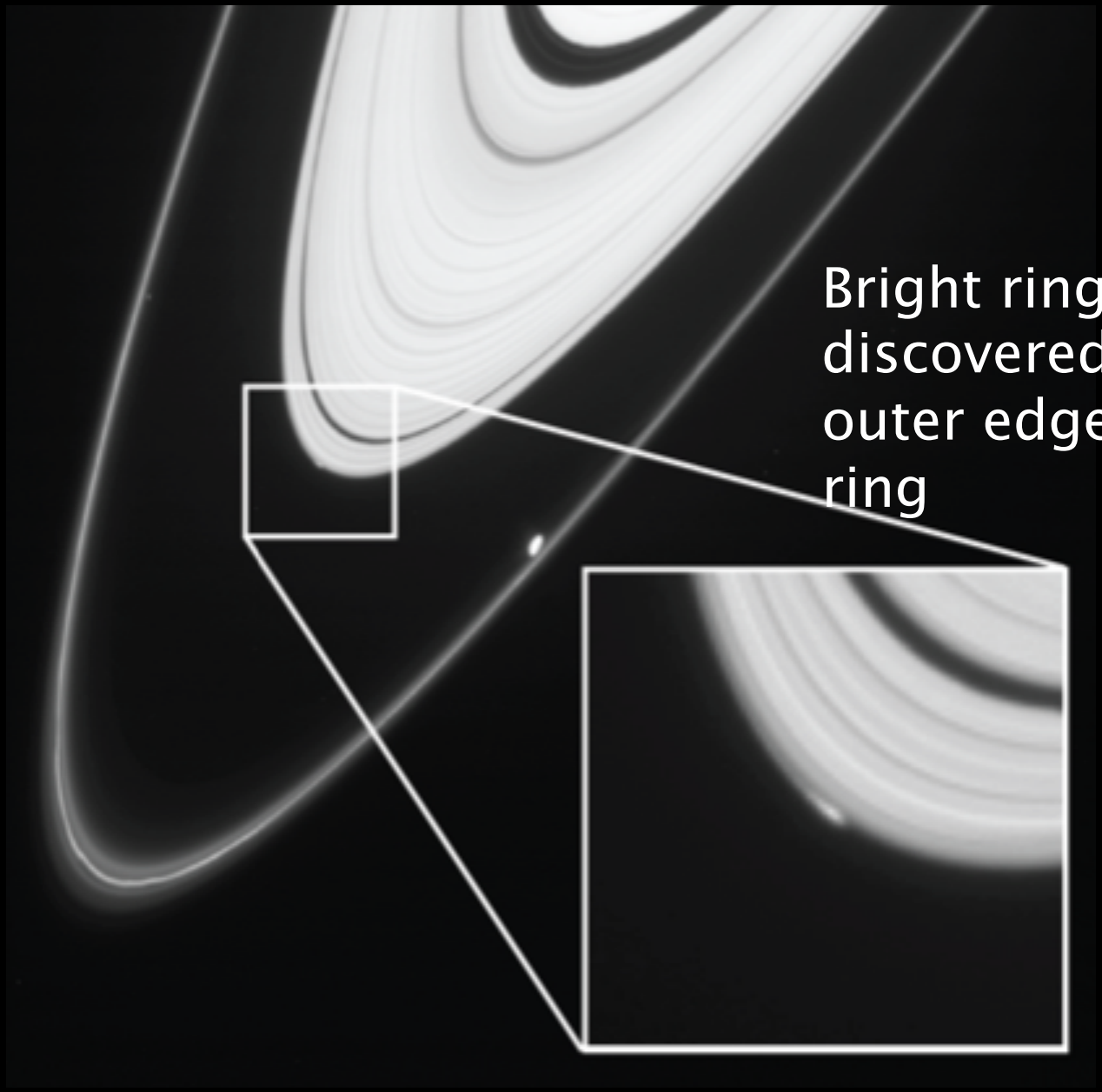


No Ring Shadow on the Planet which occurs only every ~15 Years!

Vertical Ring Structure



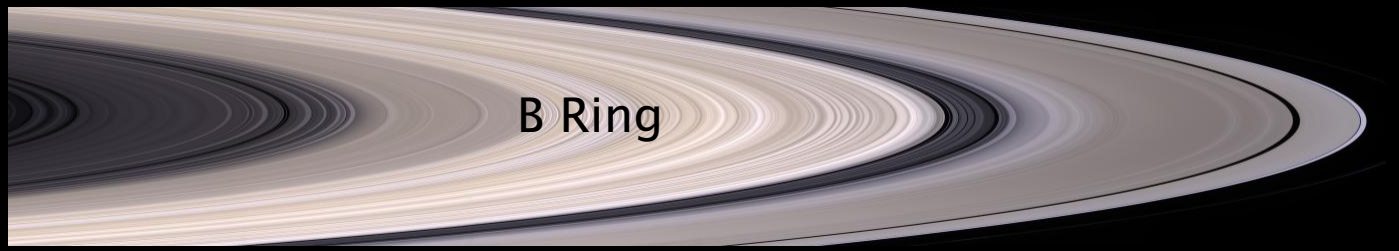
A New Moon is Born???

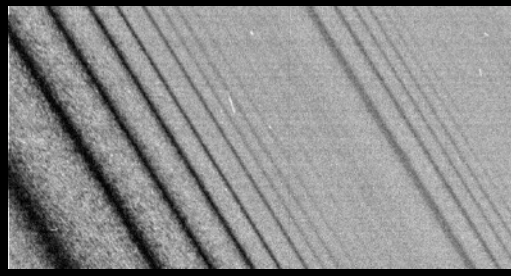


Bright ring feature discovered on outer edge of A ring

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

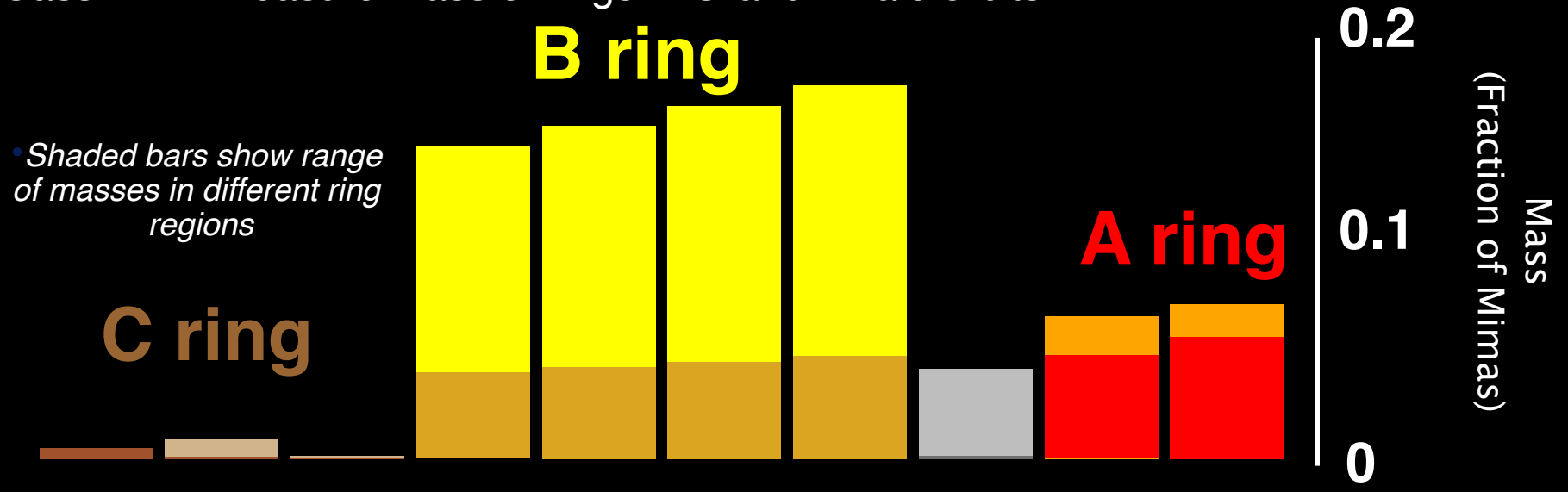
Saturn's Rings: Less Than Meets the Eye?





- Examples of similar spiral patterns in the A ring

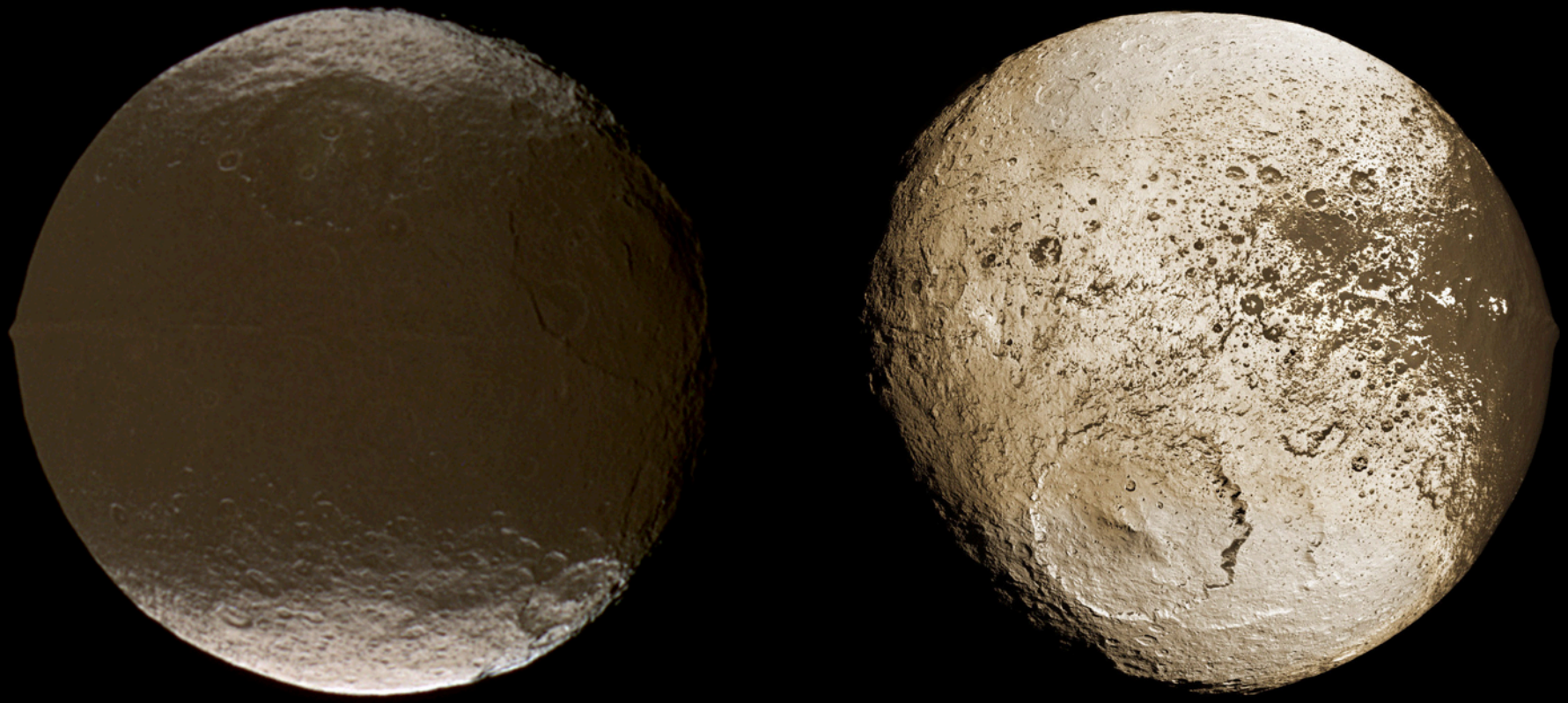
- Some parts of Saturn's B ring are 10 times more opaque than A ring, but only 2-3 times more massive.
- Mass of Saturn's rings has implications for their age, less massive rings are much younger
- Cassini will measure mass of rings in Grand Finale orbits



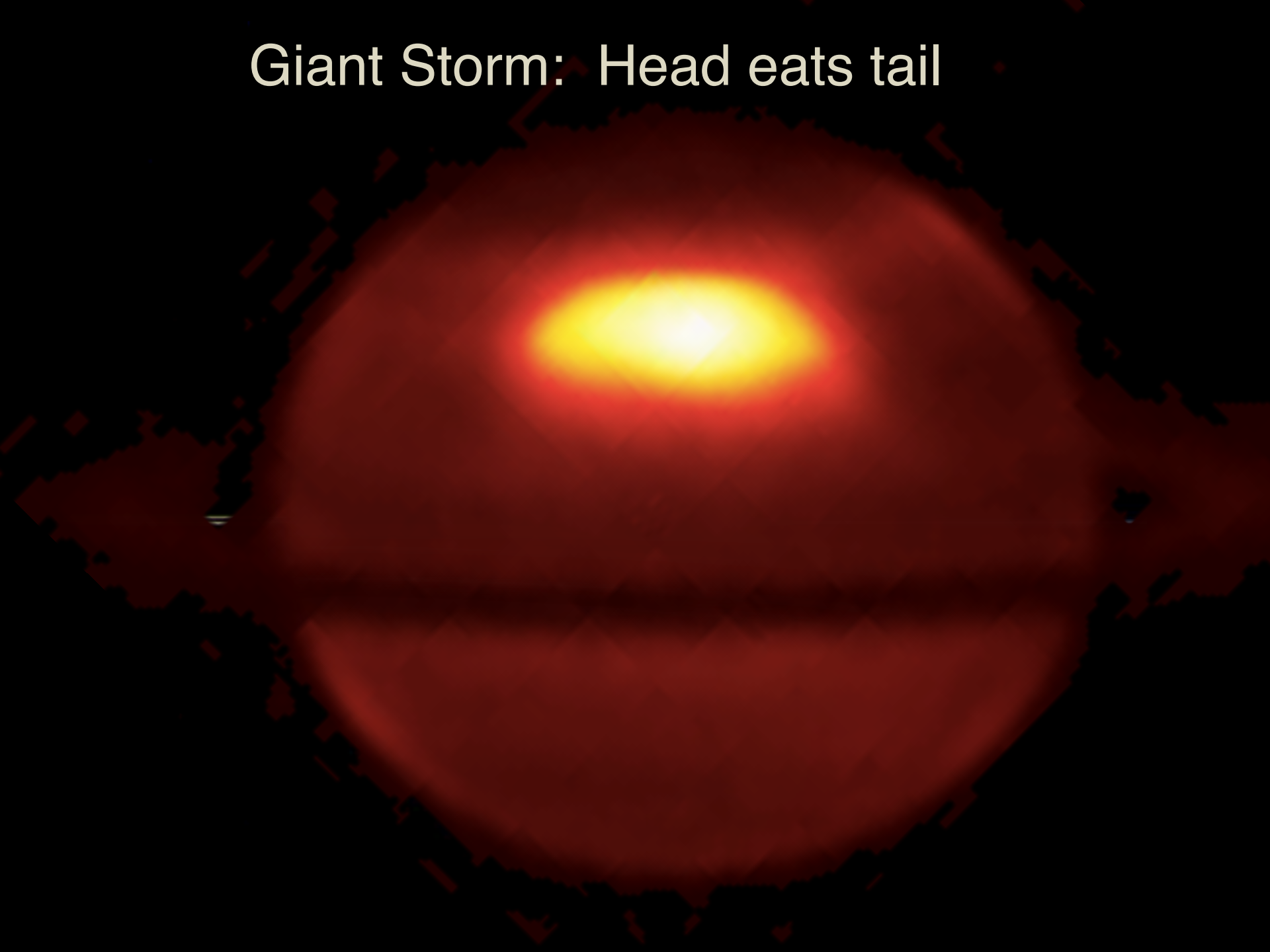
- *Shaded bars show range of masses in different ring regions*

- 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).

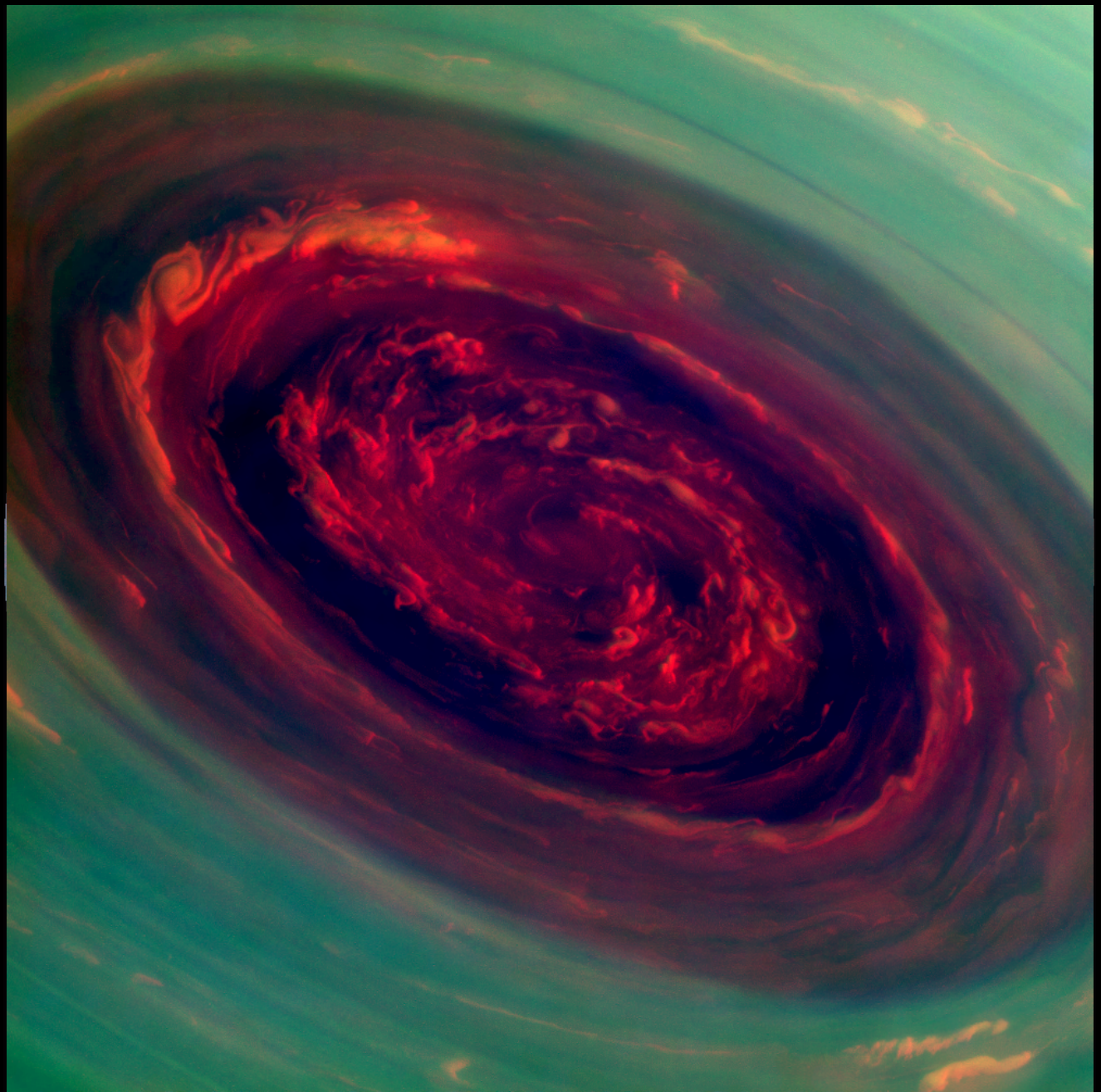
Iapetus two-faced puzzle solved



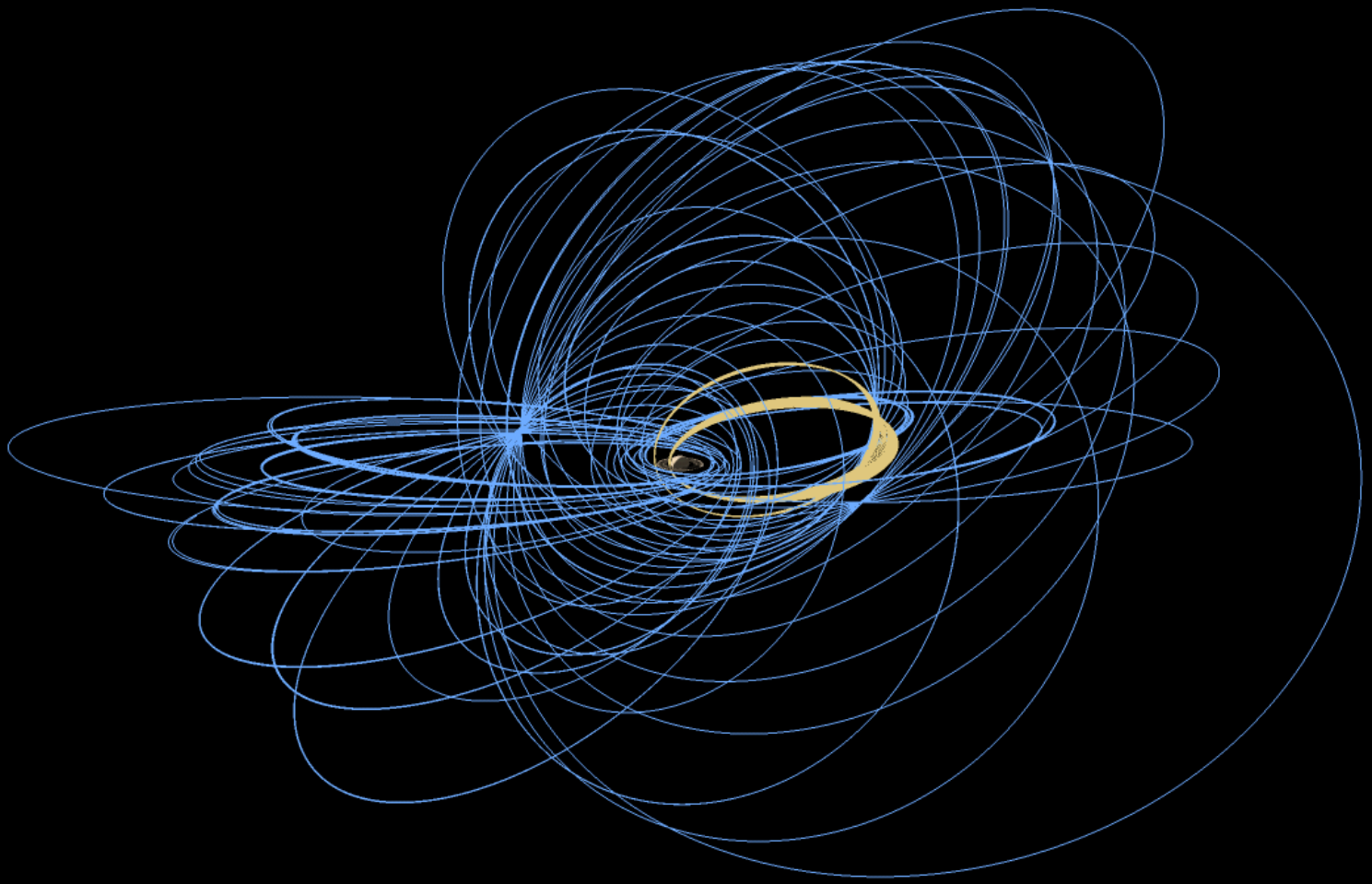
Giant Storm: Head eats tail



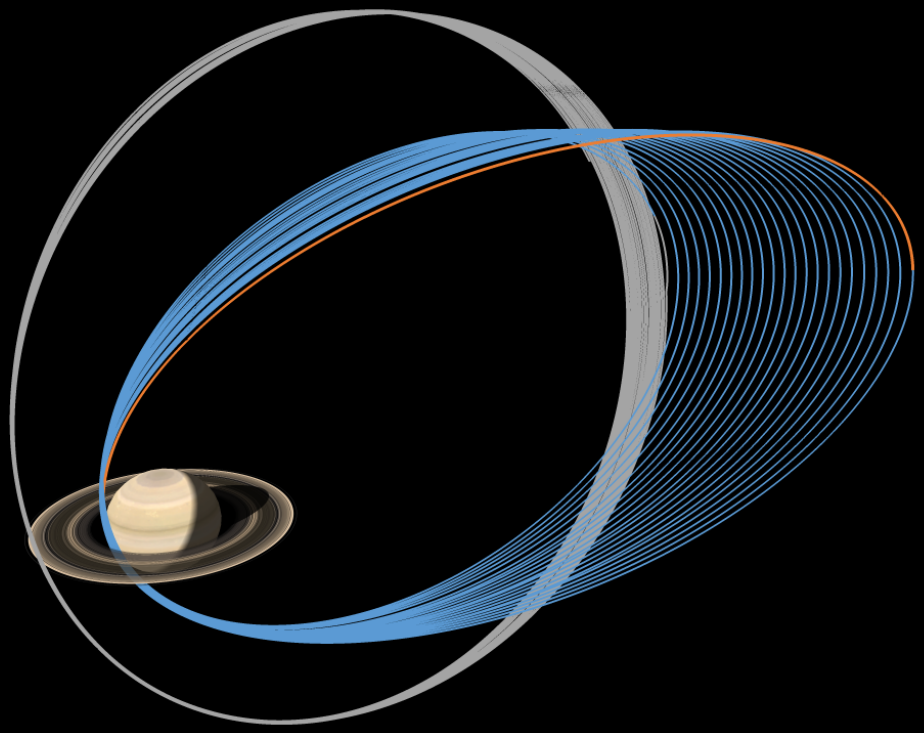
Hexagon and Giant hurricanes



Solstice Mission Trajectory



Key Orbital Characteristics of Final Orbits



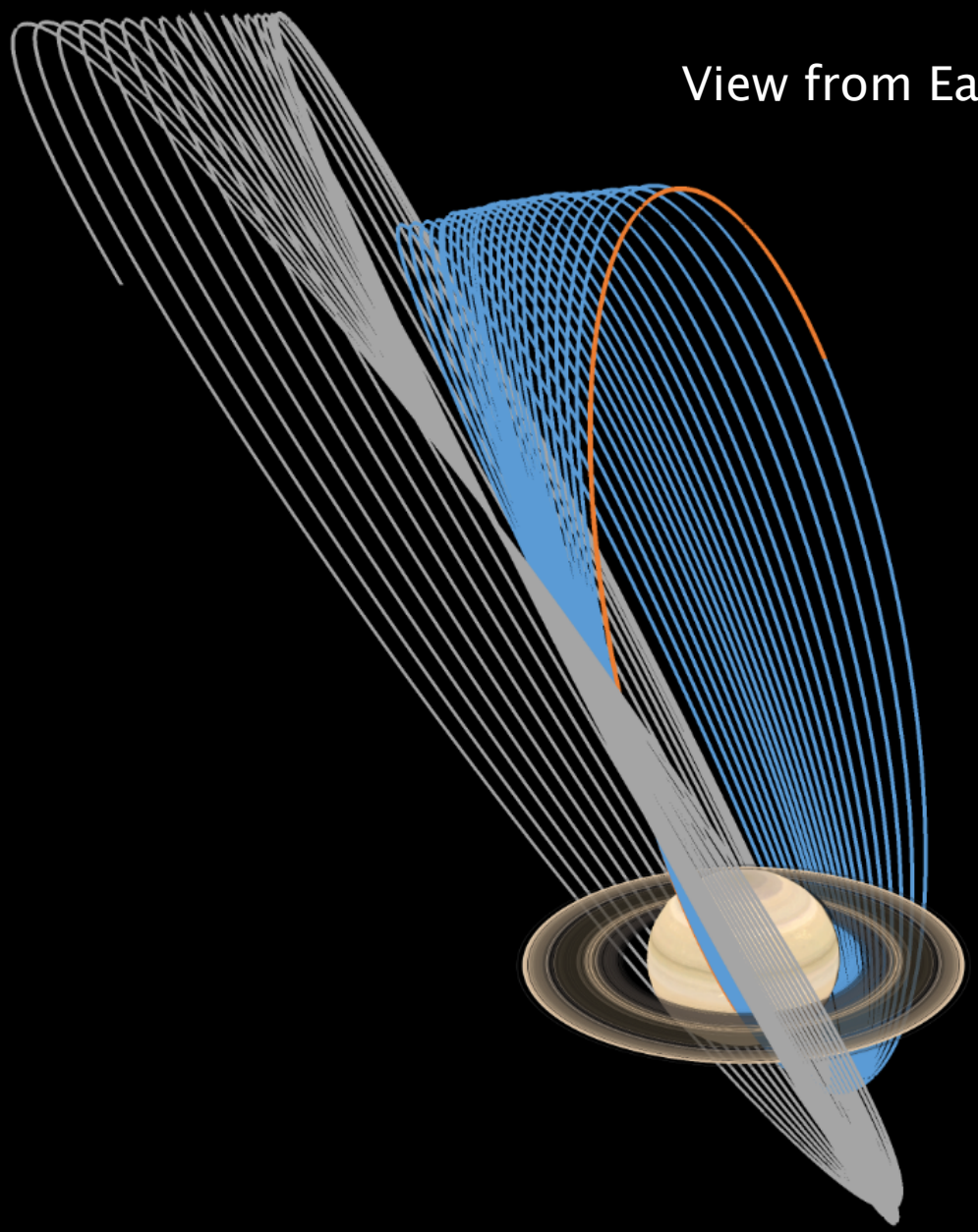
F-ring orbits
Grand Finale orbits
Impact orbit

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

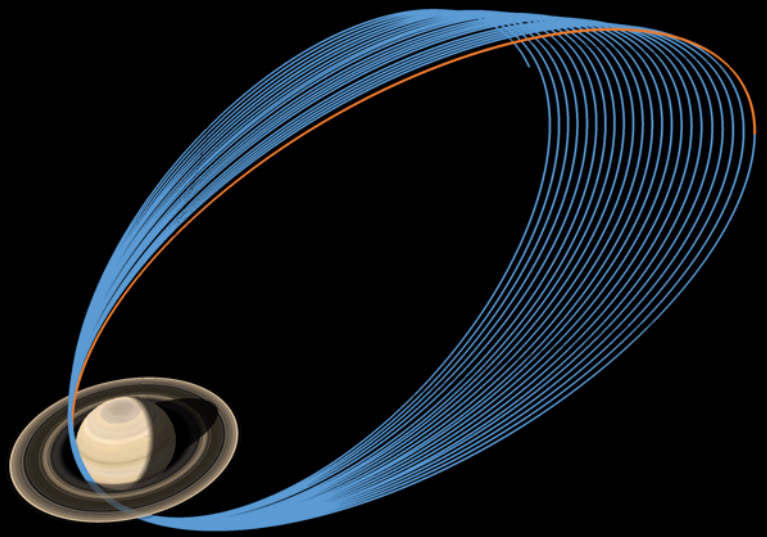
20 F-ring orbits

- 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

F Ring and Grand Finale Earth Occultations

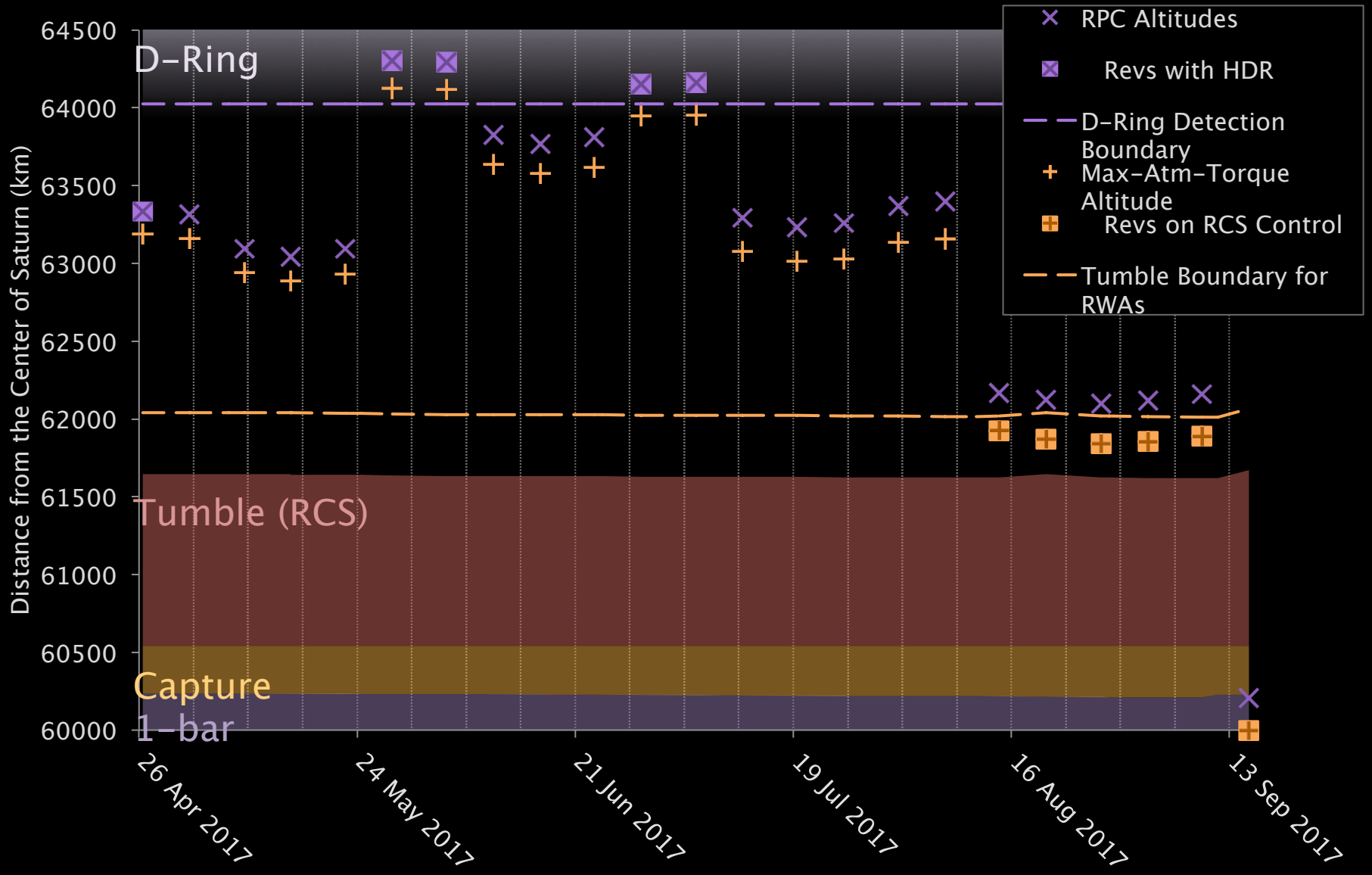


Grand Finale (Proximal) Orbits

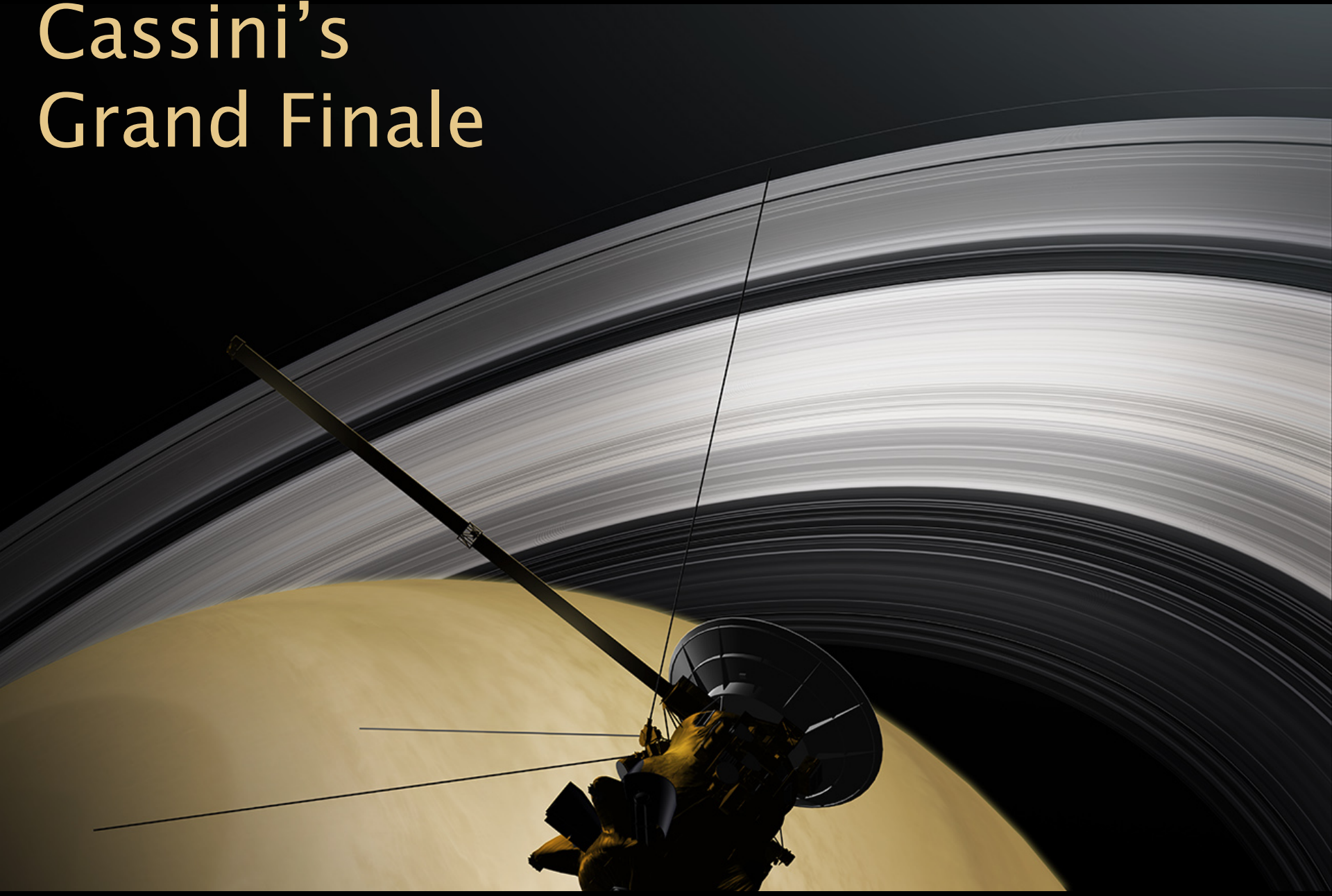


- 22 Grand Finale orbits
  - Periapses in 2,200 km “clear” region
  - First orbit April 2017 (next year during EGU!)
  - Critical inclination: 63.4°
- If delta v is available, go lower if Saturn upper atmosphere continues to shrink
- Current impact date: 15 September 2017
- Juno-like mission with Cassini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

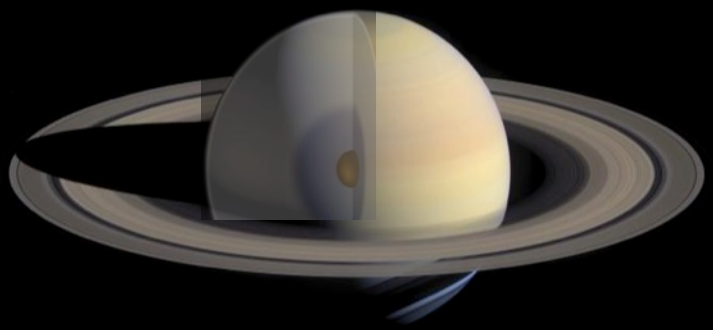
Grand Finale Corridor



Cassini's Grand Finale

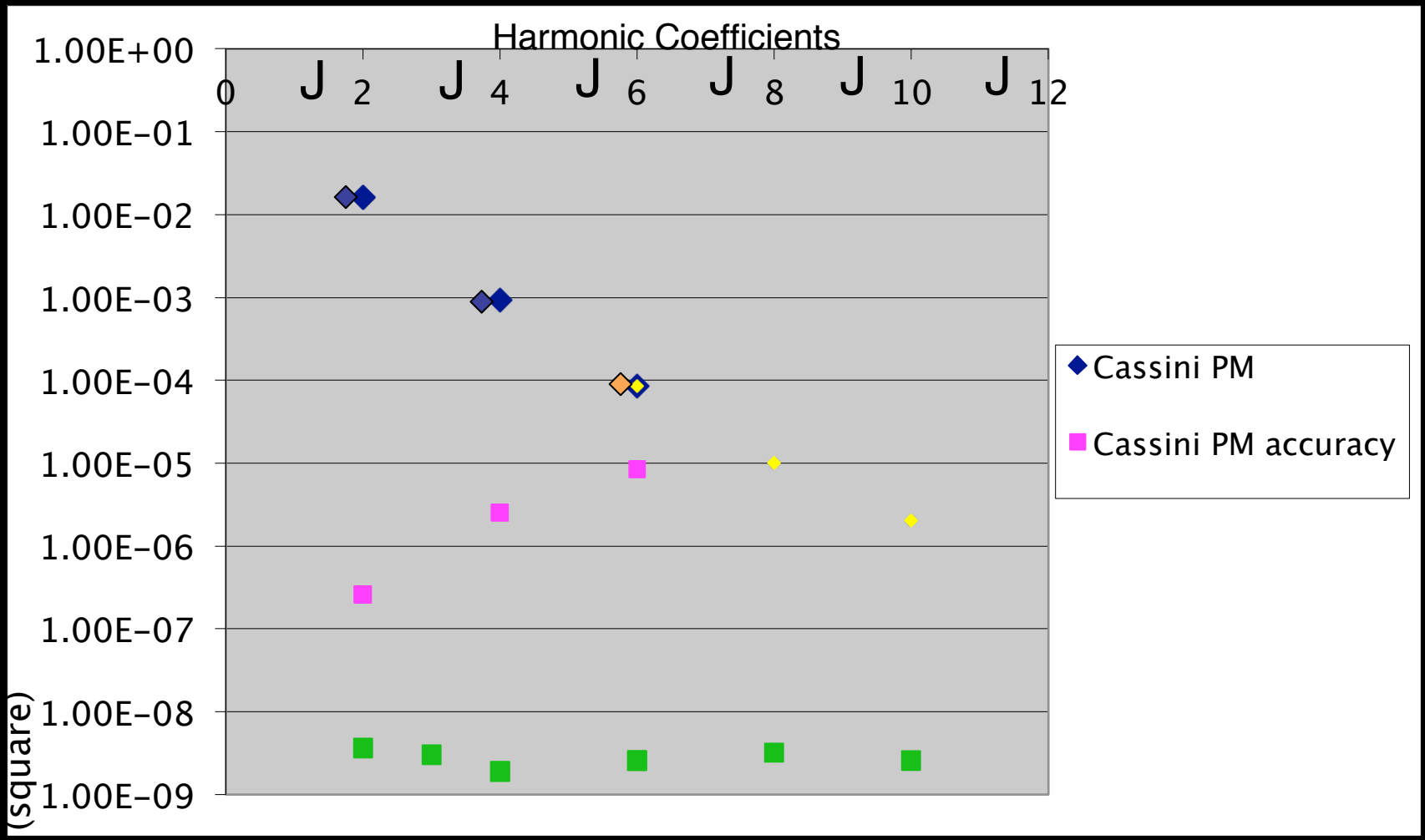


Unique End-of-Mission Science



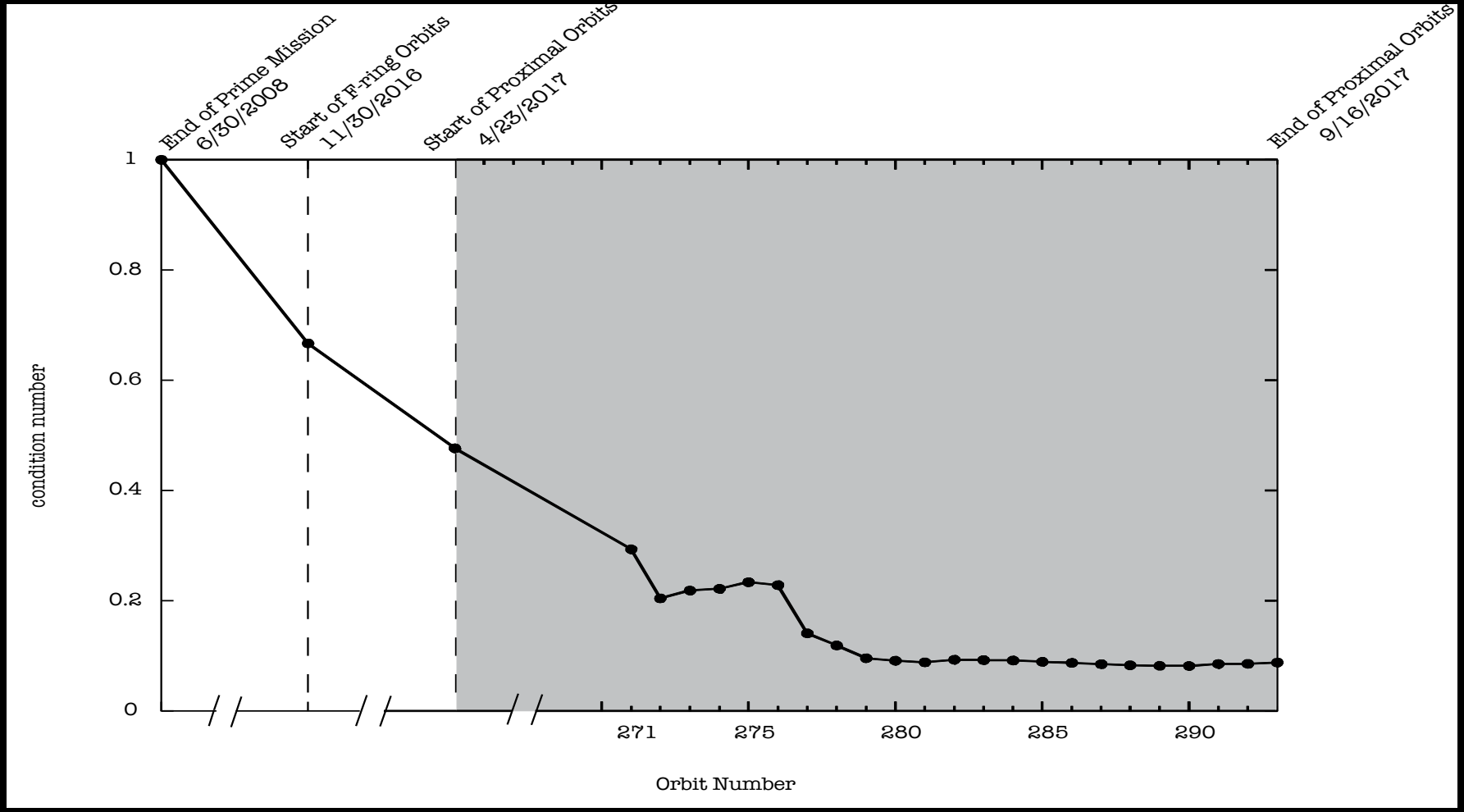
- Saturn internal structure
  - Gravitational & Magnetic Fields measurements
  - Determine Saturn's gravity field to order J_{10}
  - Determine Saturn's higher order magnetic field components
  - Measure Saturn's internal rotation rate

Saturn Internal Structure: Gravity Harmonics



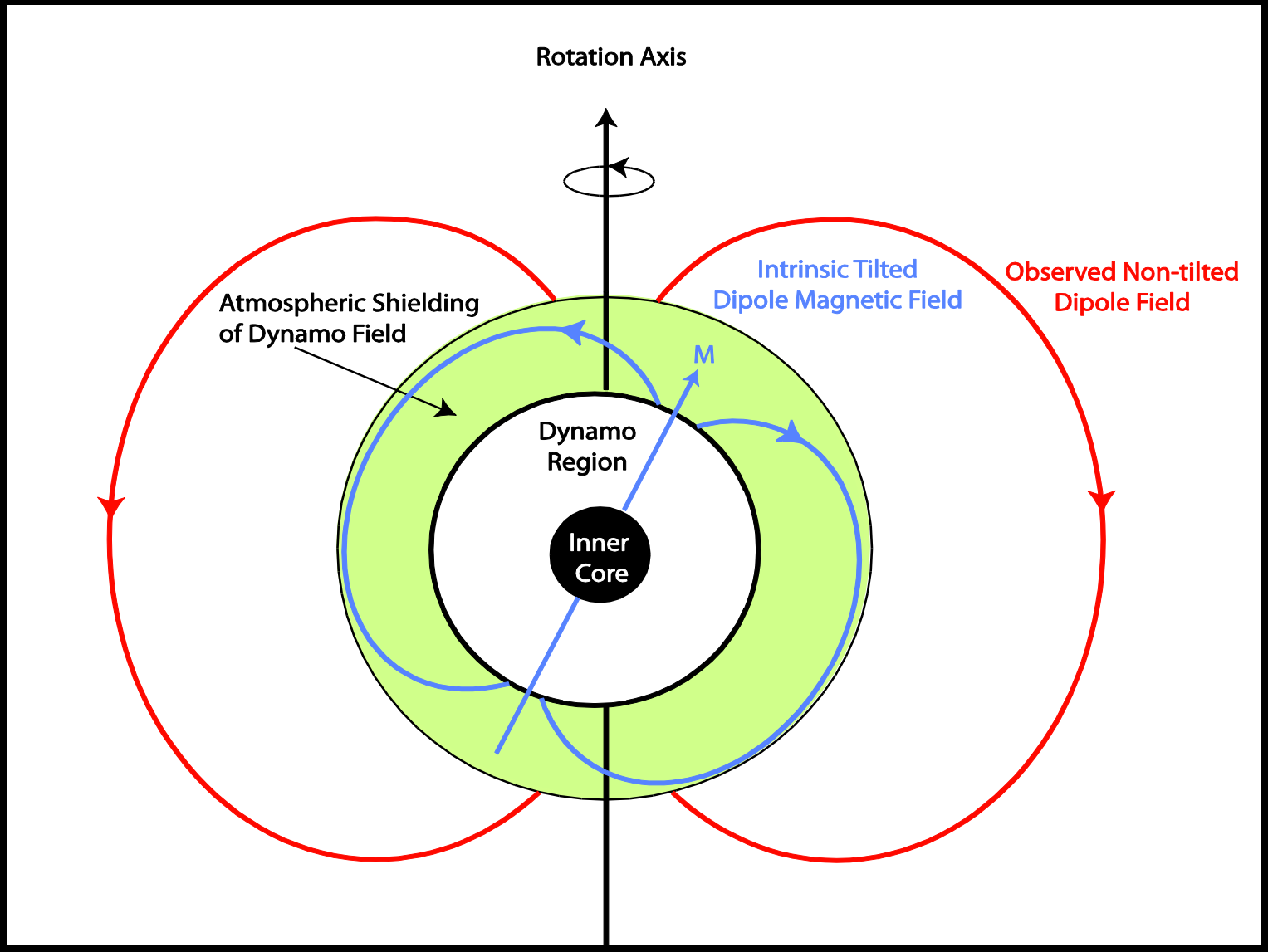
- Saturn gravity harmonics (zonal) up to degree 10 can be estimated with an accuracy < 10^{-8} (with multiarc solution using 6 proximal orbits for gravity passes)

Saturn Internal Structure: Magnetic field

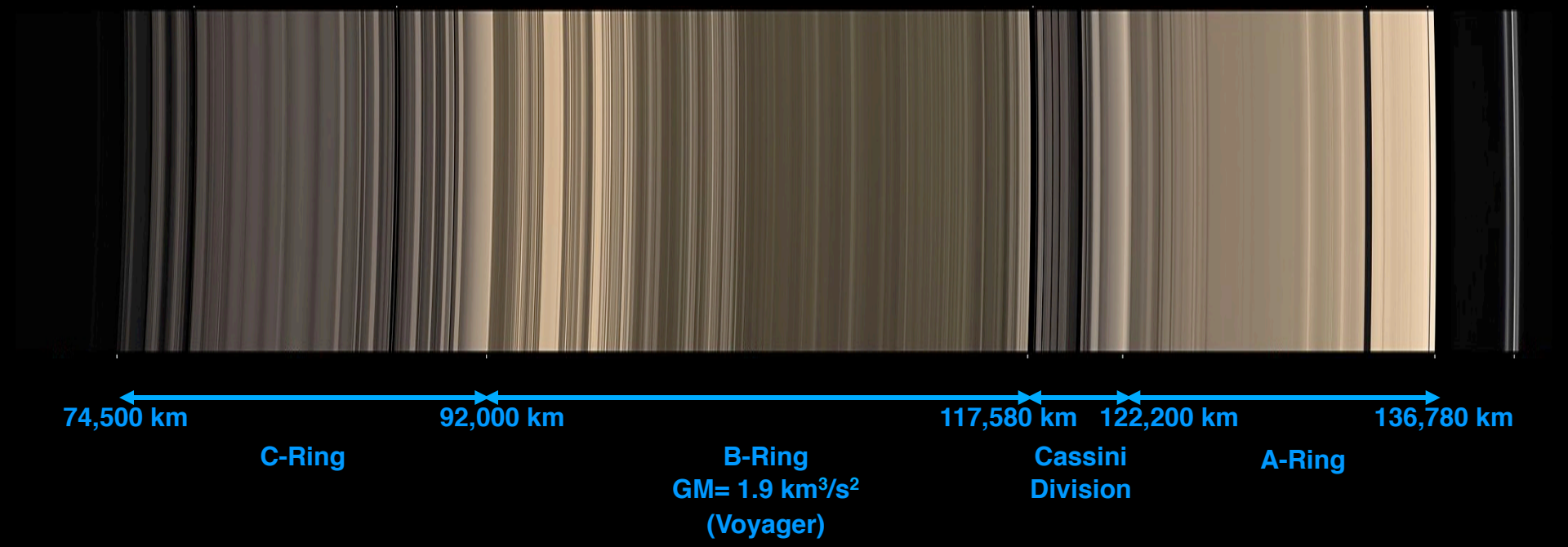


- Condition number is a measure of the accuracy with which a magnetic field model
  can be determined based on spacecraft trajectory.
- Significant improvement possible with periapse inside D ring.
- May be possible to determine depth of Saturn's conducting, metallic core.

Saturn Internal Magnetic field: Tilted Dipole?

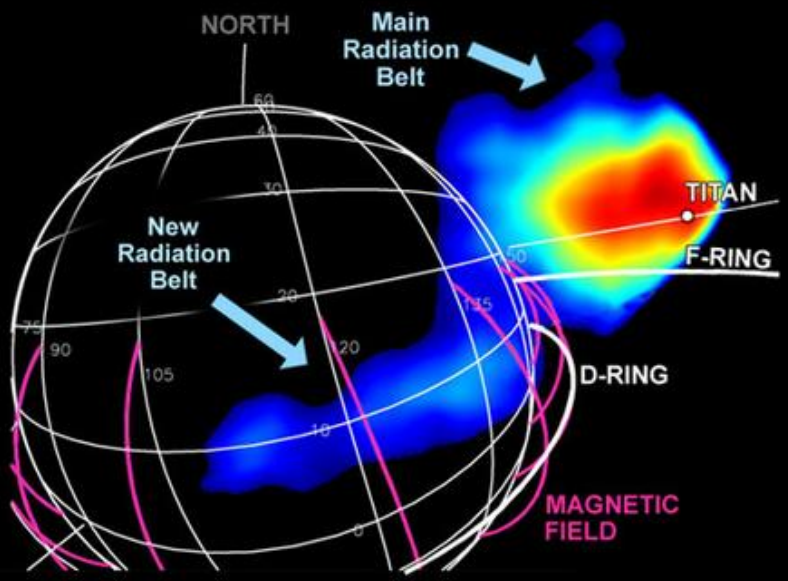


Ring Mass: Constrain age of rings



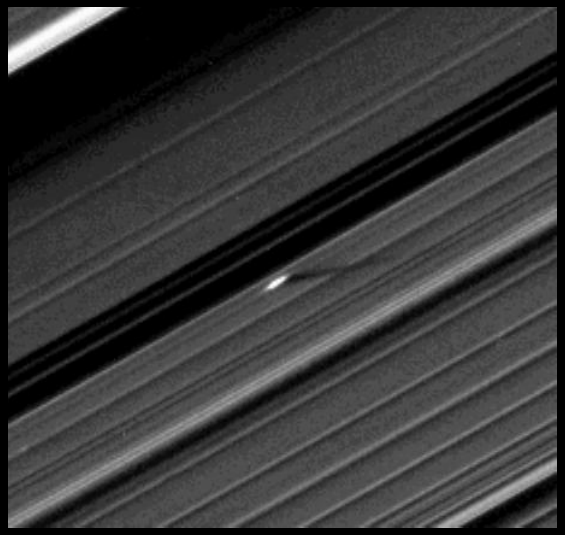
- Without proximal orbits, a-priori ring mass uncertainty is 100% of nominal values
- 6 orbital arcs for ring mass (and Saturn gravity) provide estimation accuracy for total ring δGM ~ 0.34 km^3/s^2 (~5%)

Ionosphere, innermost radiation belts & inner D ring particles

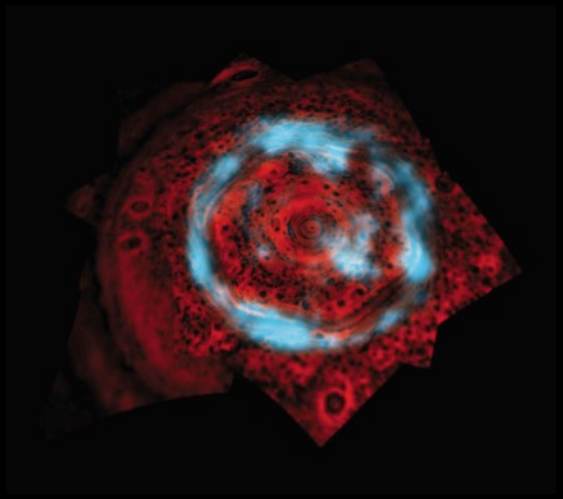


- Measure *in situ* plasma of Saturn's ionosphere, innermost radiation belts and D ring for the first time
- *In situ* observations of Saturn's auroral magnetosphere at solstice

Unique End-of-Mission Science

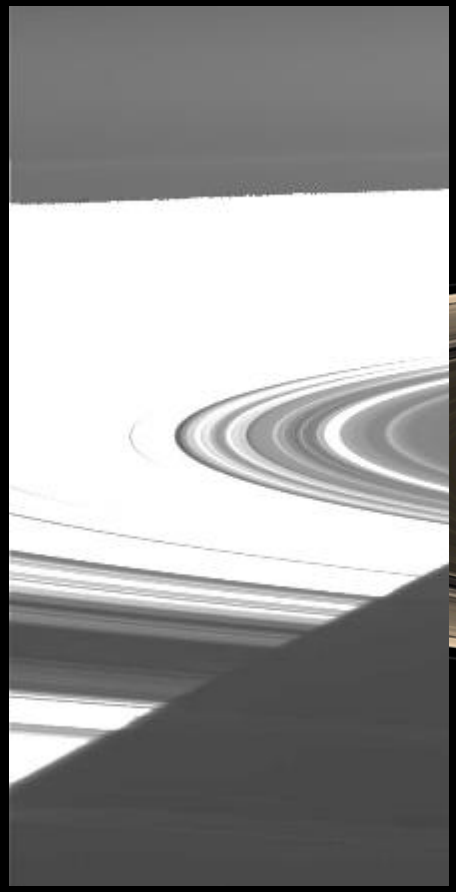


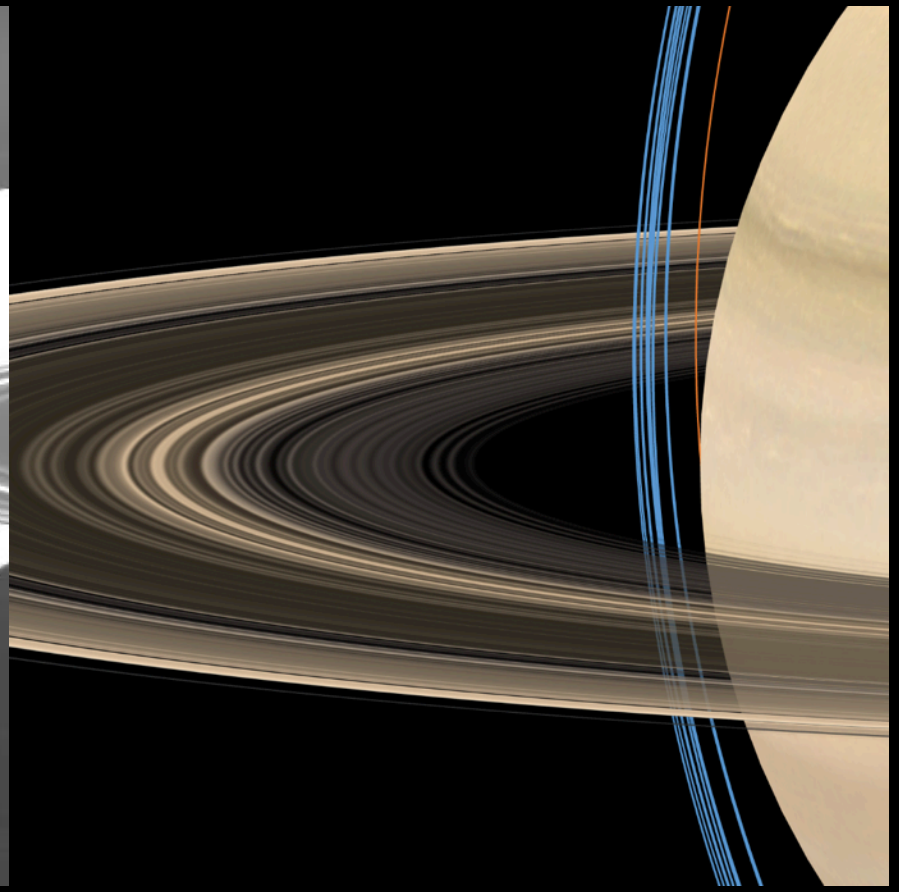
- Highest resolution main ring observations
  - First Active Radar of the Rings



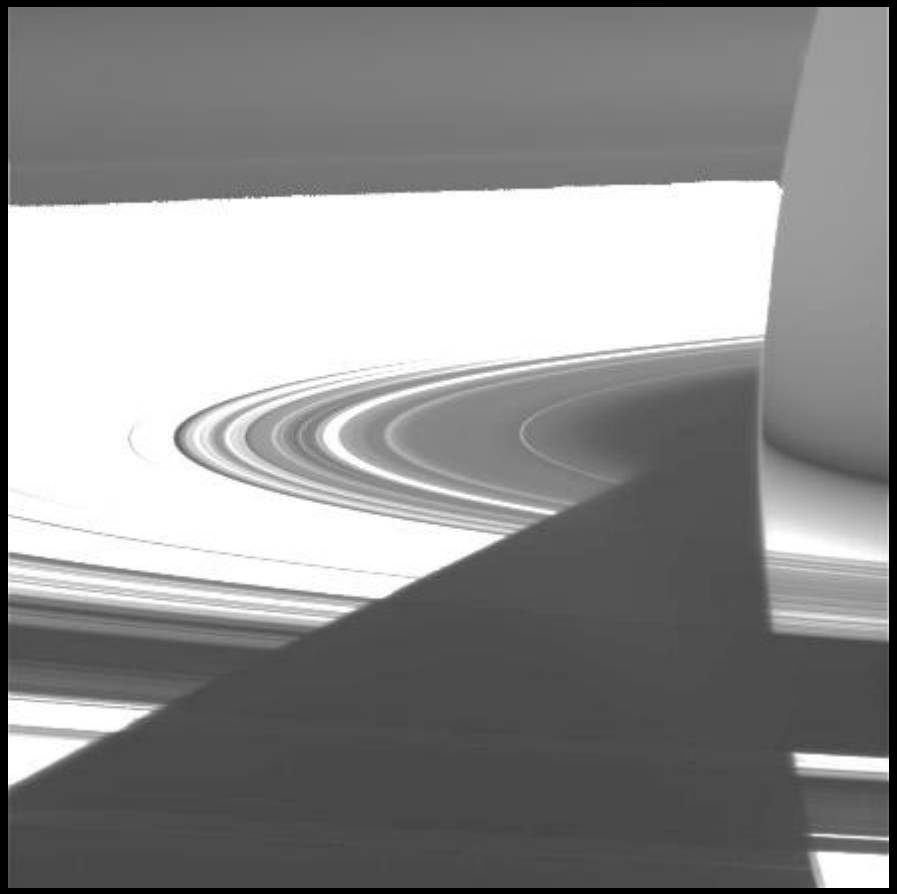
- Highest resolution Saturn atmospheric studies including polar observations and aurora

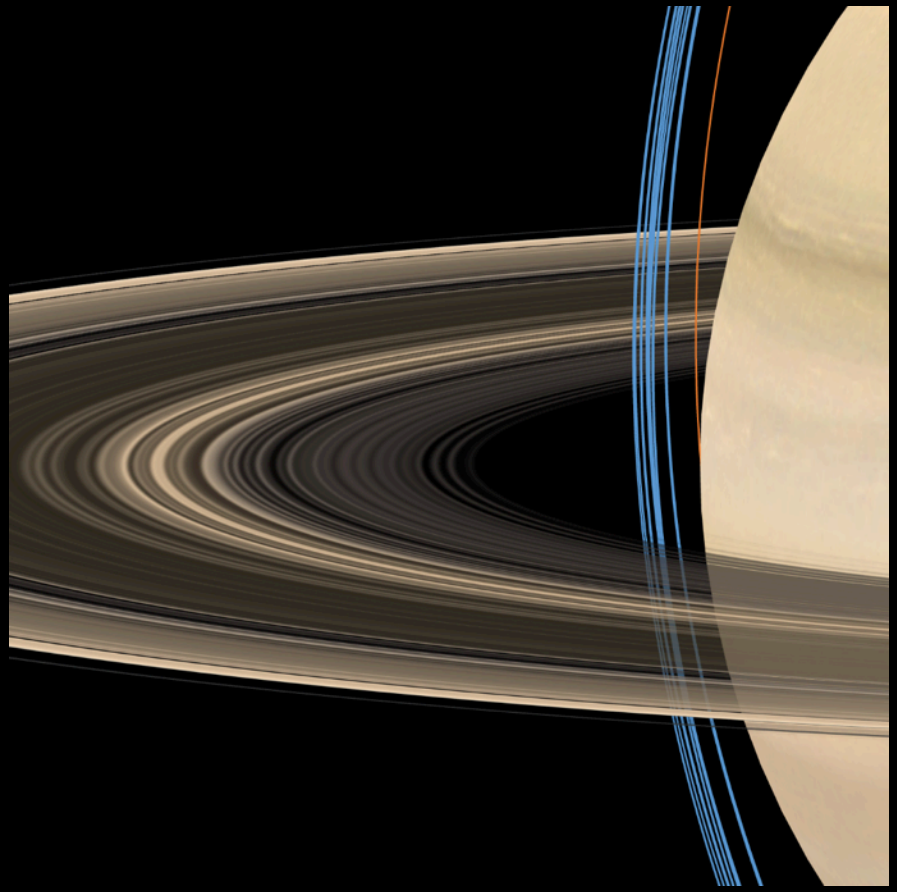
Grand Finale Environment



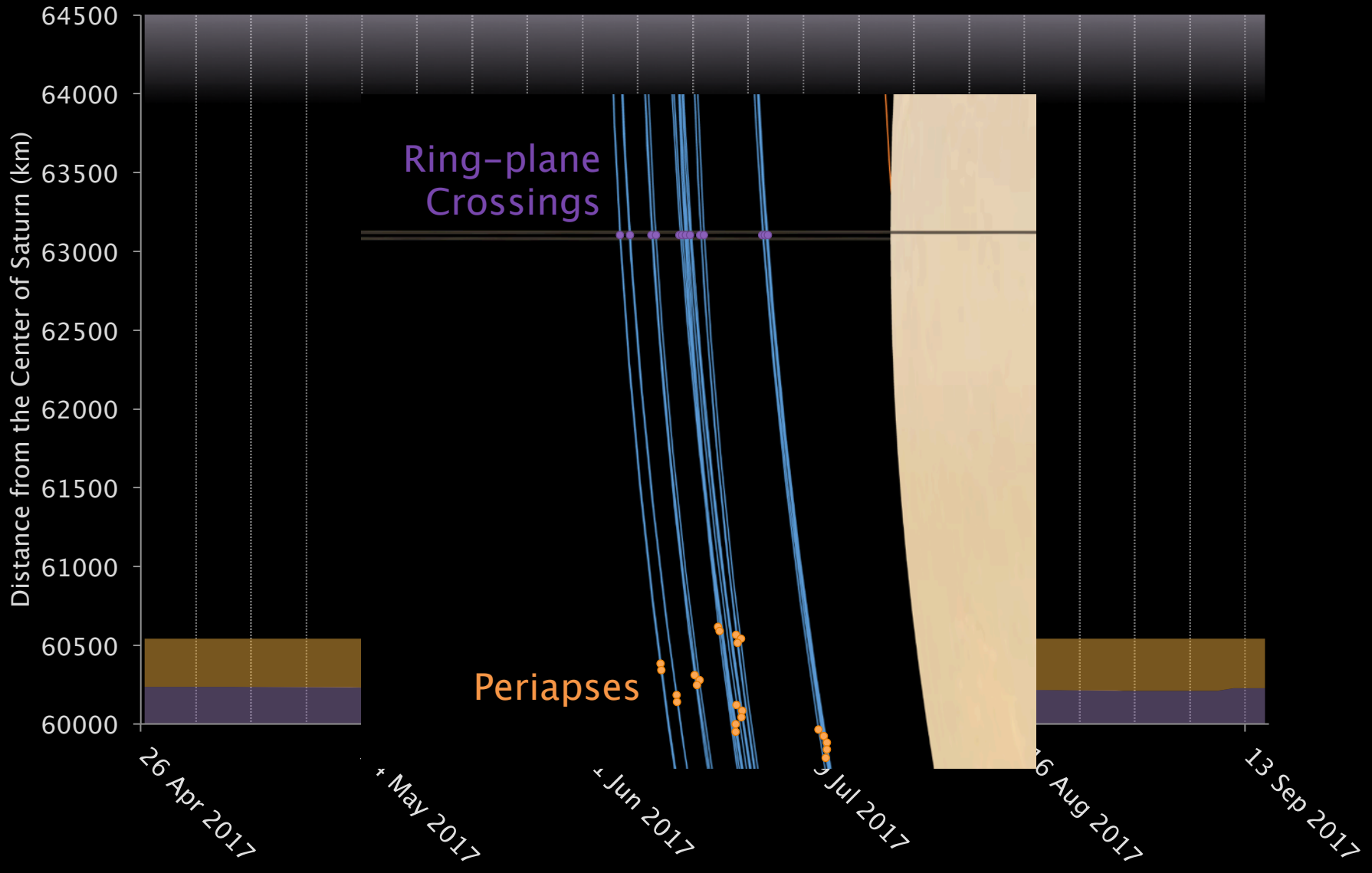


Grand Finale Environment

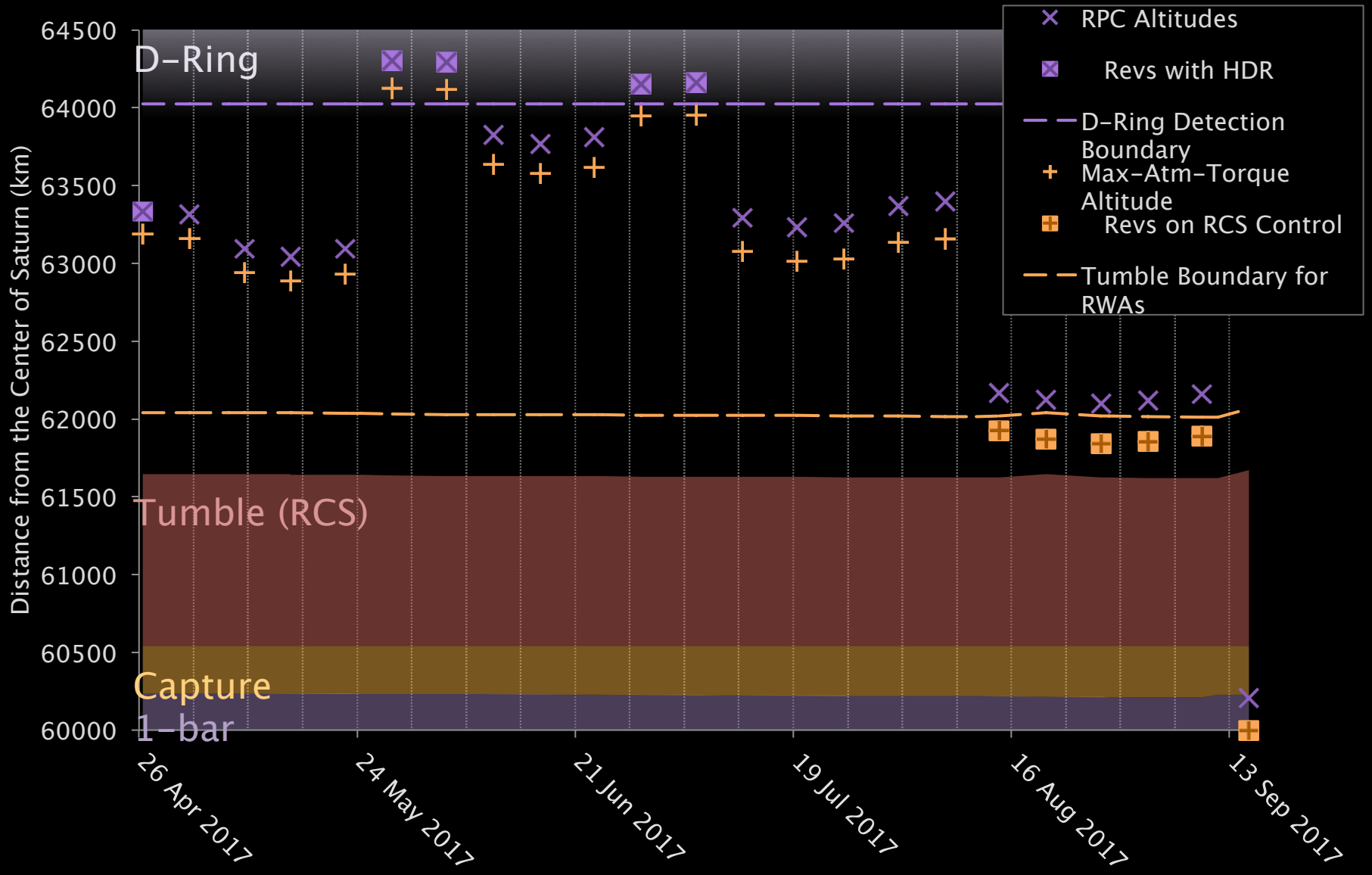




Grand Finale Environment

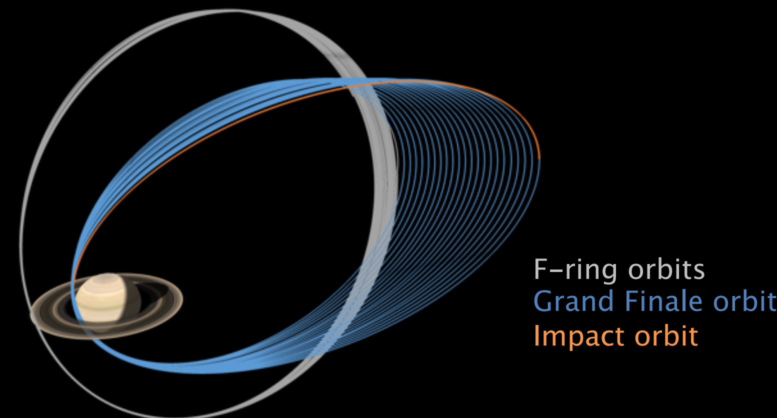


Grand Finale Corridor



Cassini DSN Requests

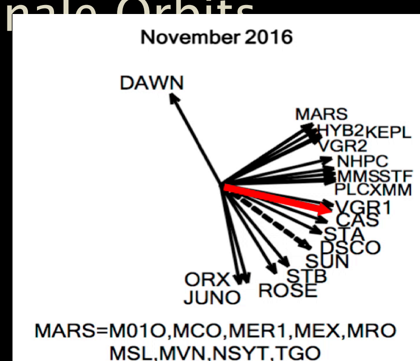
- DSN *essential* for last year of Cassini mission
  - Implementing Radio Science experiments
  - Downlinking science data
  - Tracking spacecraft (Navigation)
- 70m track usage increases for Grand Finale orbits compared to recent years
- Timeline: Nov 2016 – Sept 2017
  - Weeks 49 – 16: F-Ring Orbits
  - Weeks 16 – 37: Grand Finale Orbits
  - Week 37: Final Week
    - Includes Saturn Entry



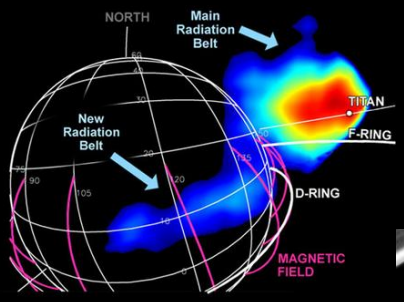
Average Weekly DSN Station Projected Use

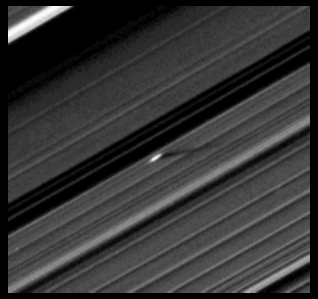
Mission Phase	Average Number of 9 hour Tracks per Week	
	34m	70m
Nominal Solstice Mission (2010-2016)	3	2
F-Ring	2	3
Grand Finale	3	4
Final Week	2	6
Saturn Entry	1 BWG or 70m (CAN)	

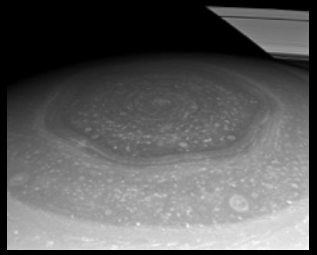
2009 and 2013



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

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

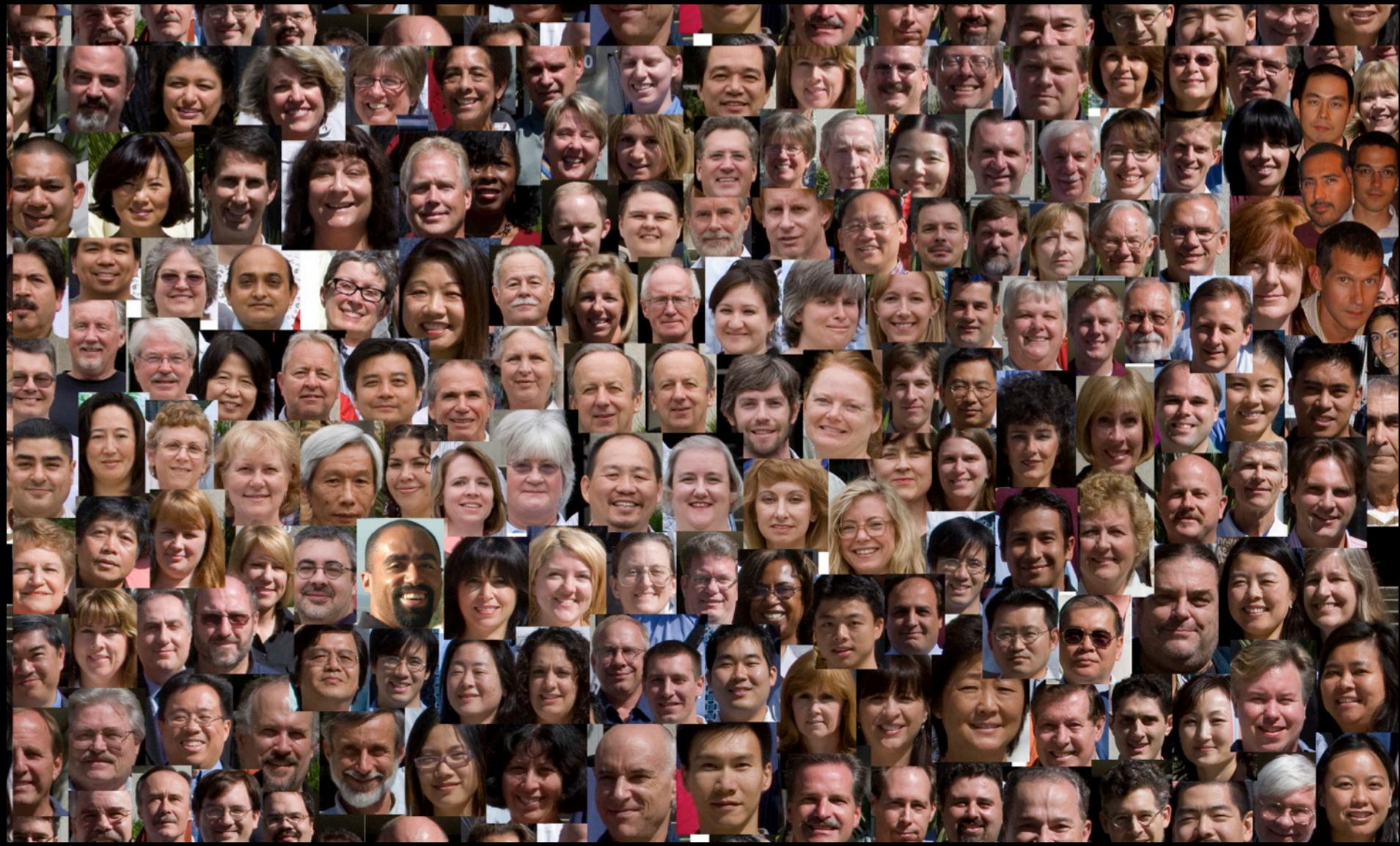
April 23, 2017
- Grand Finale Begins
  - 22½ orbits
  - 9 non-targeted Titan flybys

April 26, 2017
- First dive through gap

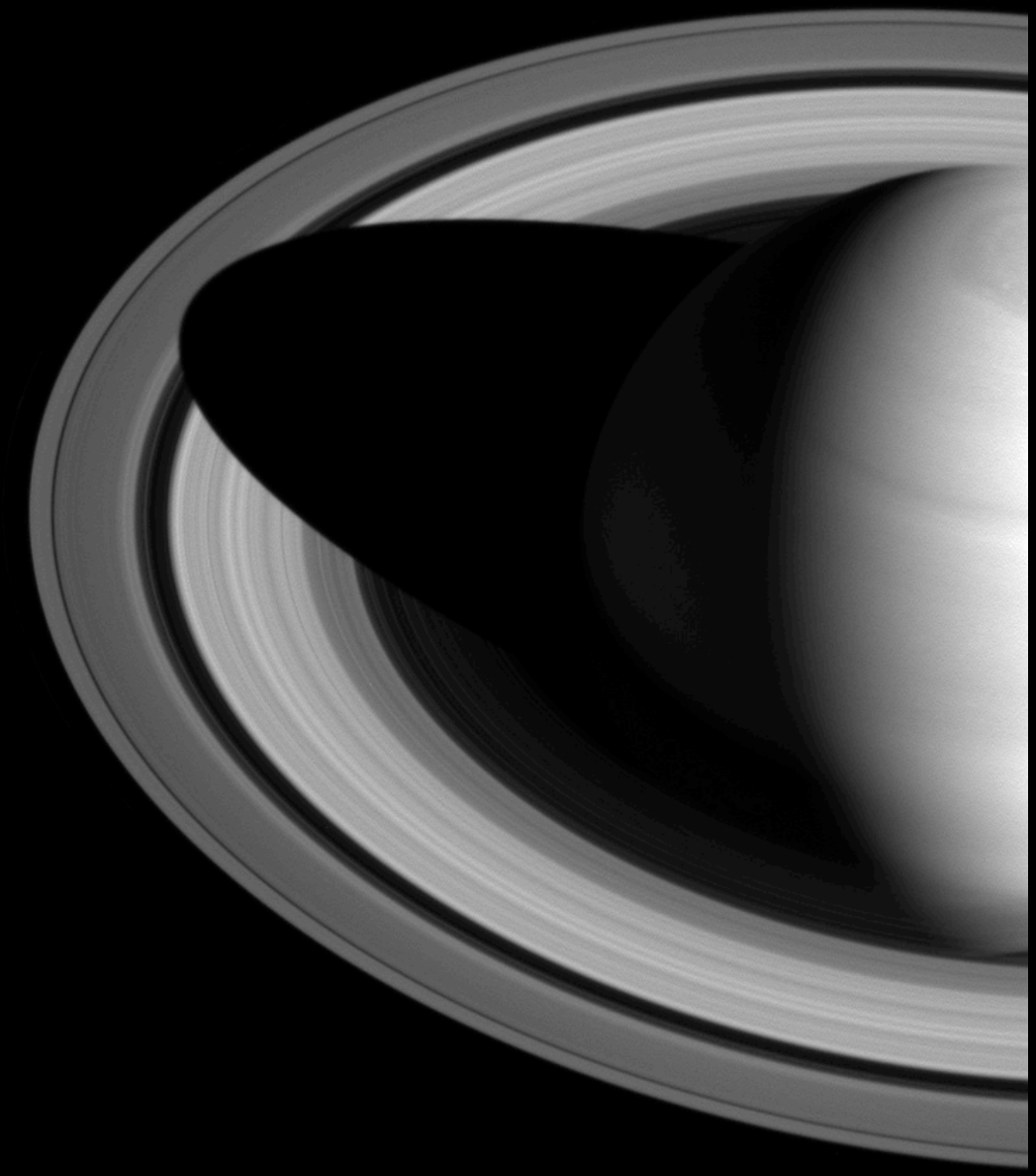
September 11, 2017
- Last Non-targeted Titan Flyby
  - Puts Cassini on impact trajectory

September 15, 2017
- Saturn Impact

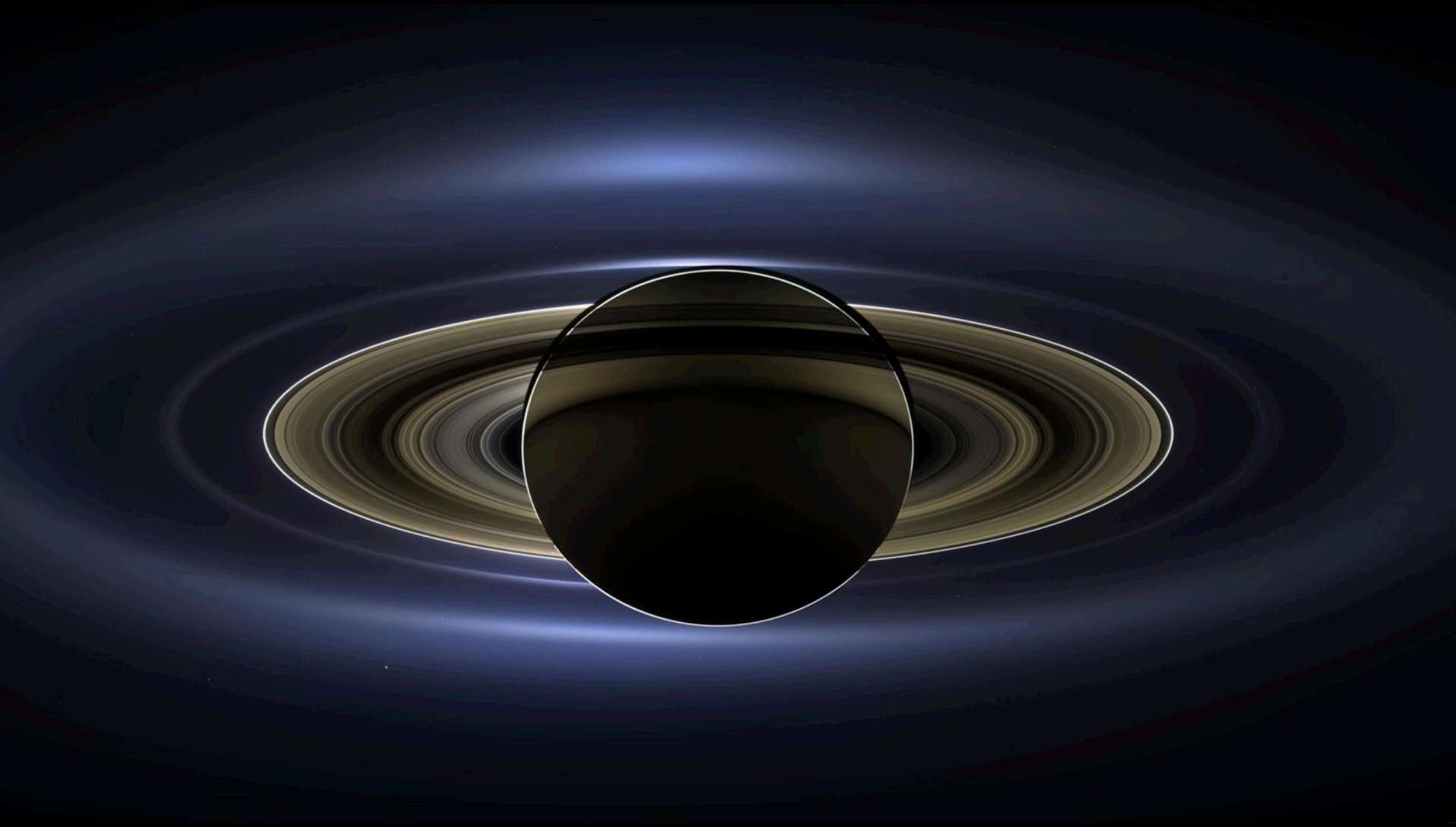
Cassini Family saying Goodbye…



Ring Shadow Marks Passing of Seasons

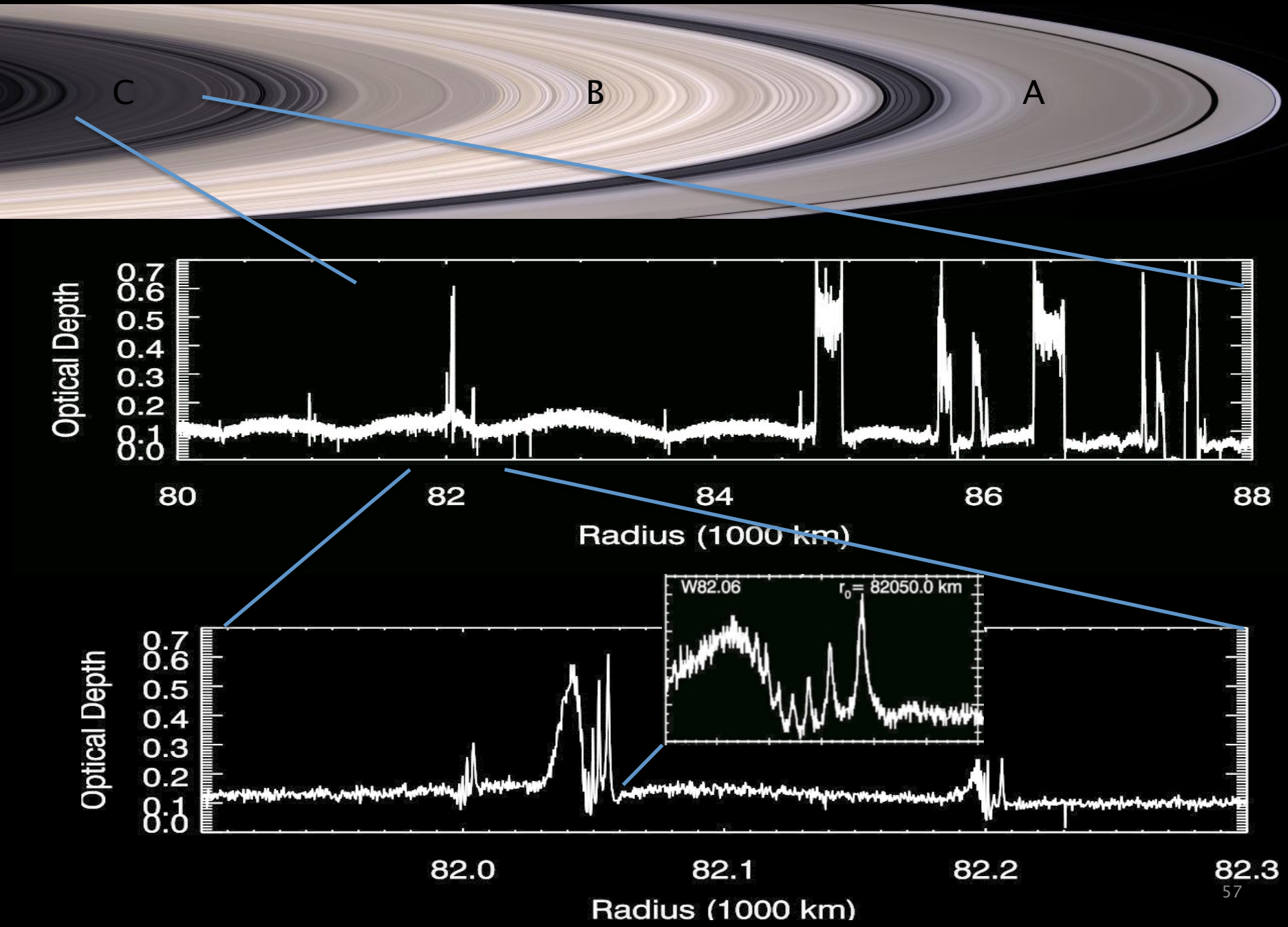


Questions?

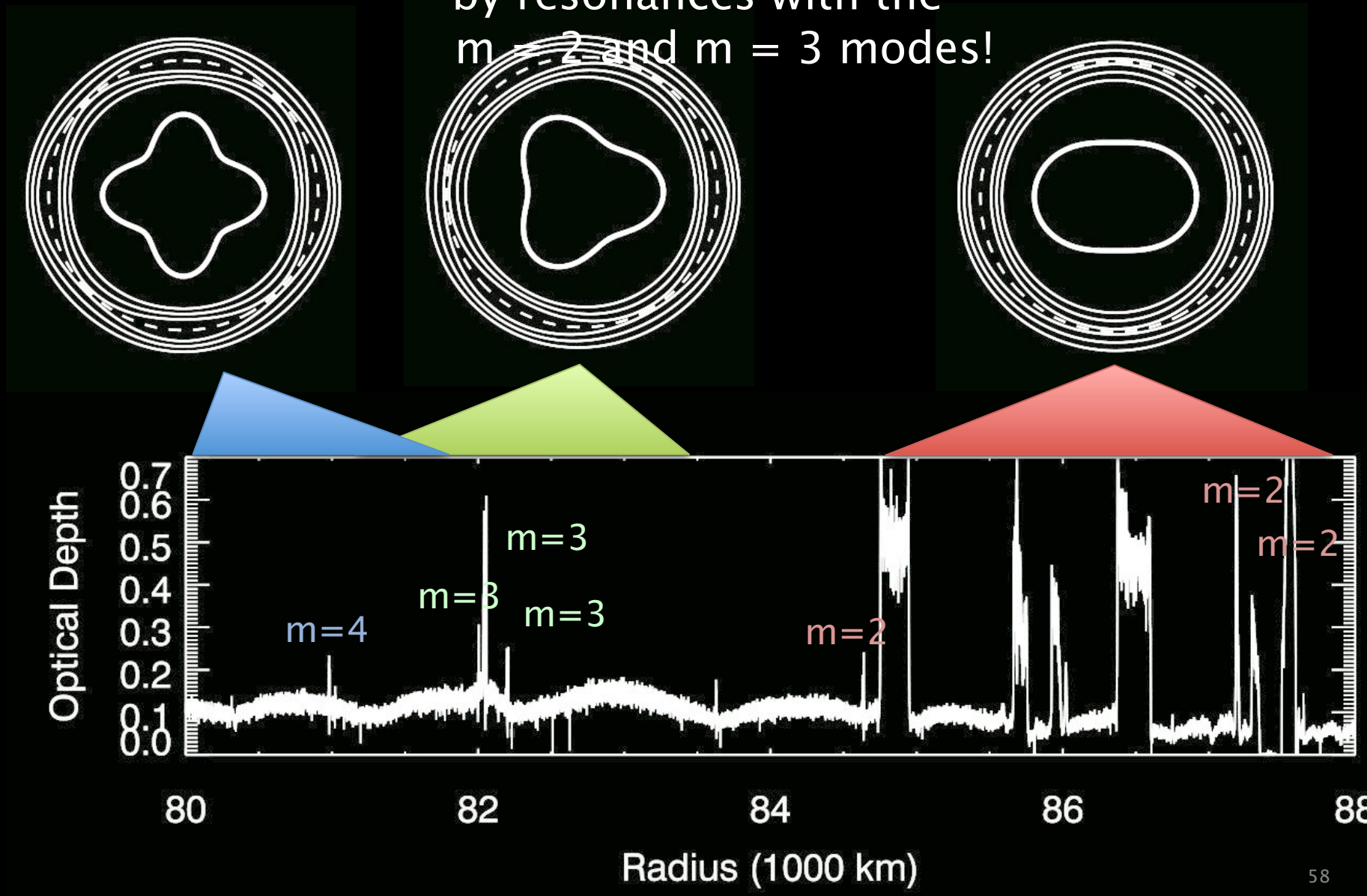


Backup Slides

Planetary Resonances in Saturn's C ring



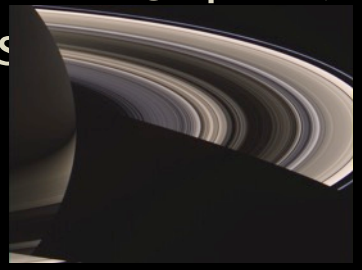
For several waves, the derived mode-number is close to the predicted value, but there appear to be multiple waves generated by resonances with the
m = 2 and m = 3 modes!



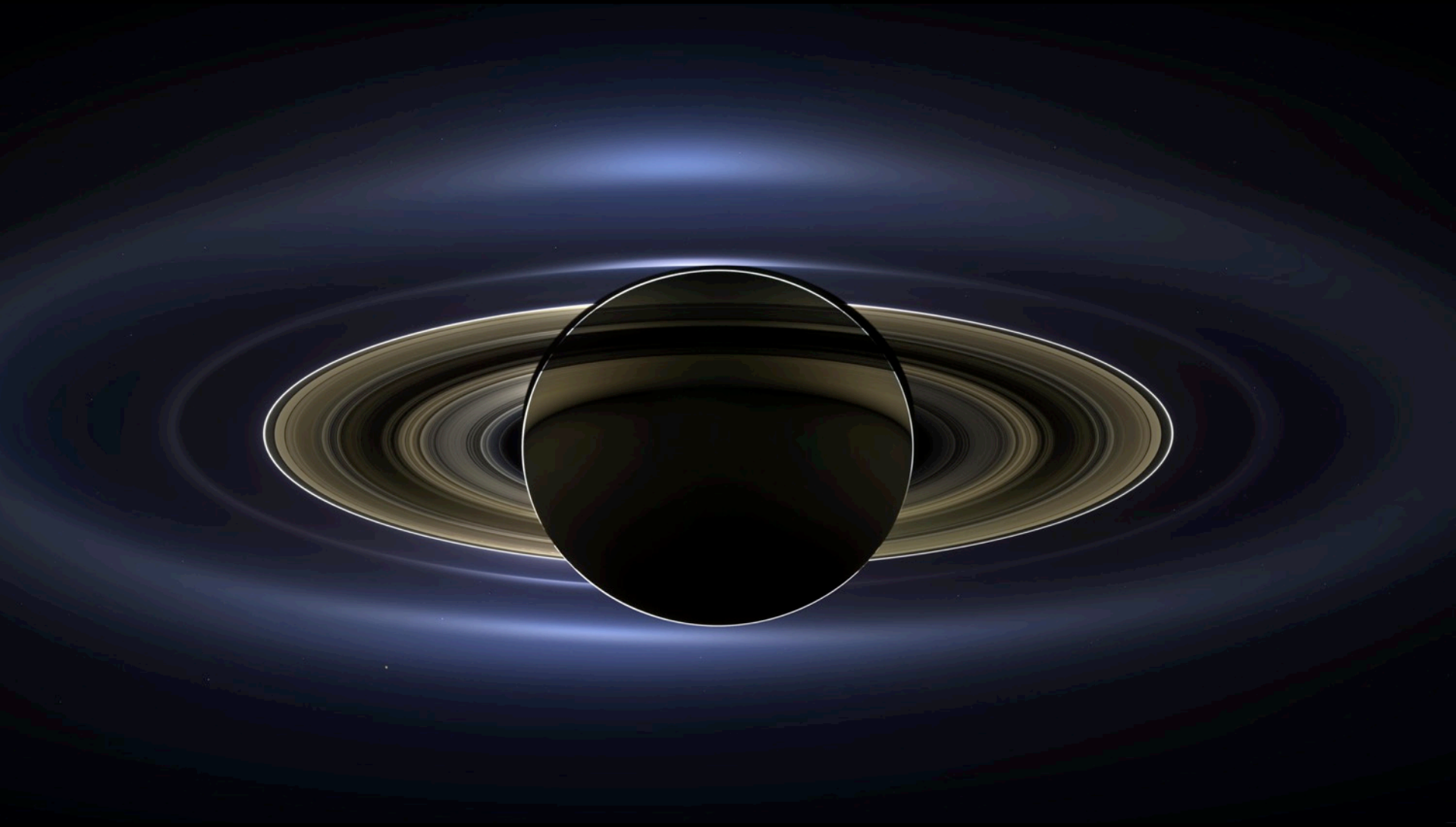
F ring/Grand Finale Science compared to Juno Science

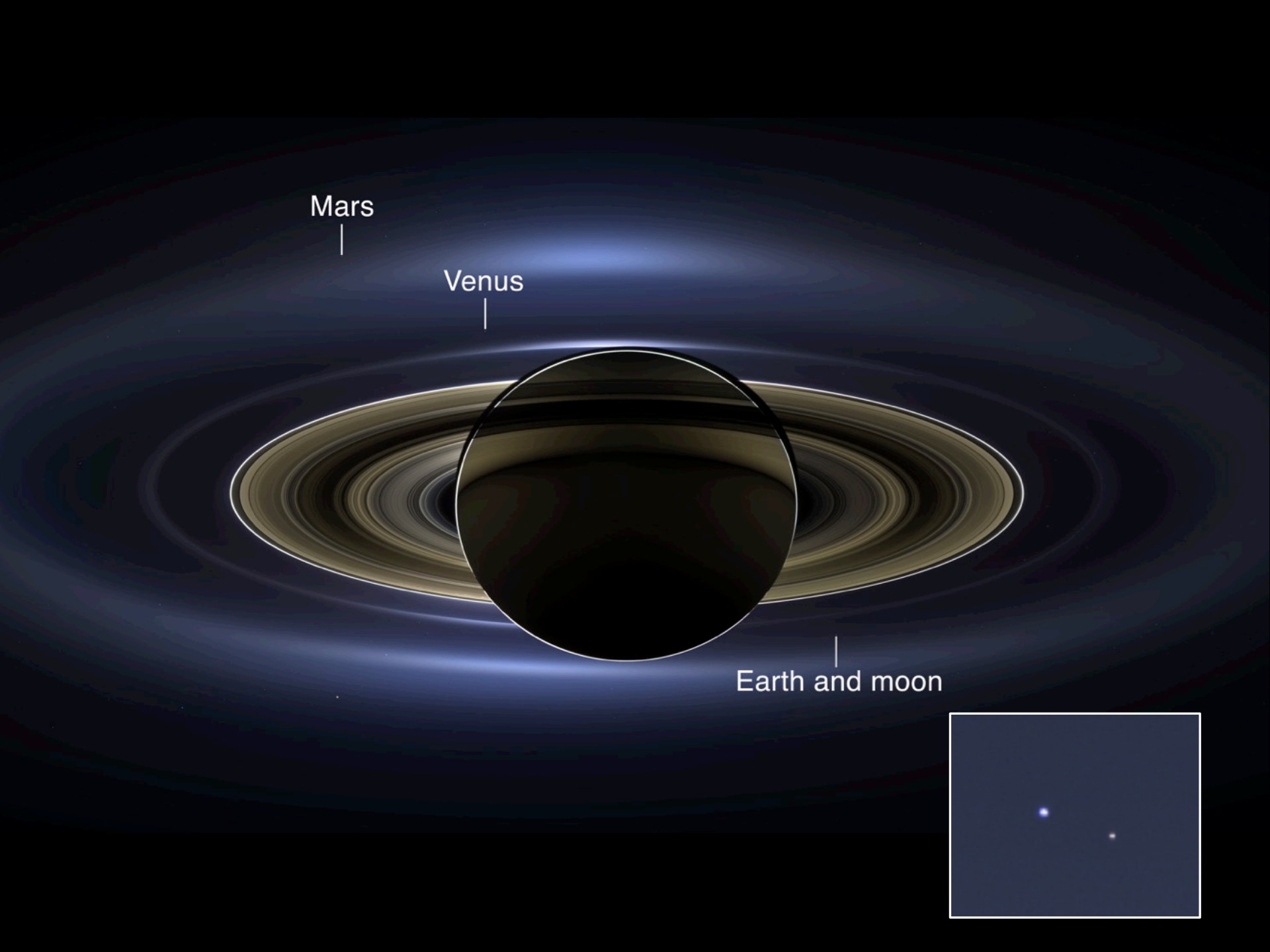
- Common science goals:
  - Interior structure of the giant planets: Gravity and magnetic field mapping
  - Dynamics of the polar ionosphere and auroral magnetosphere
  - Very high resolution measurements of giant planet atmospheres
  - In situ measurements of the giant planet ionospheres

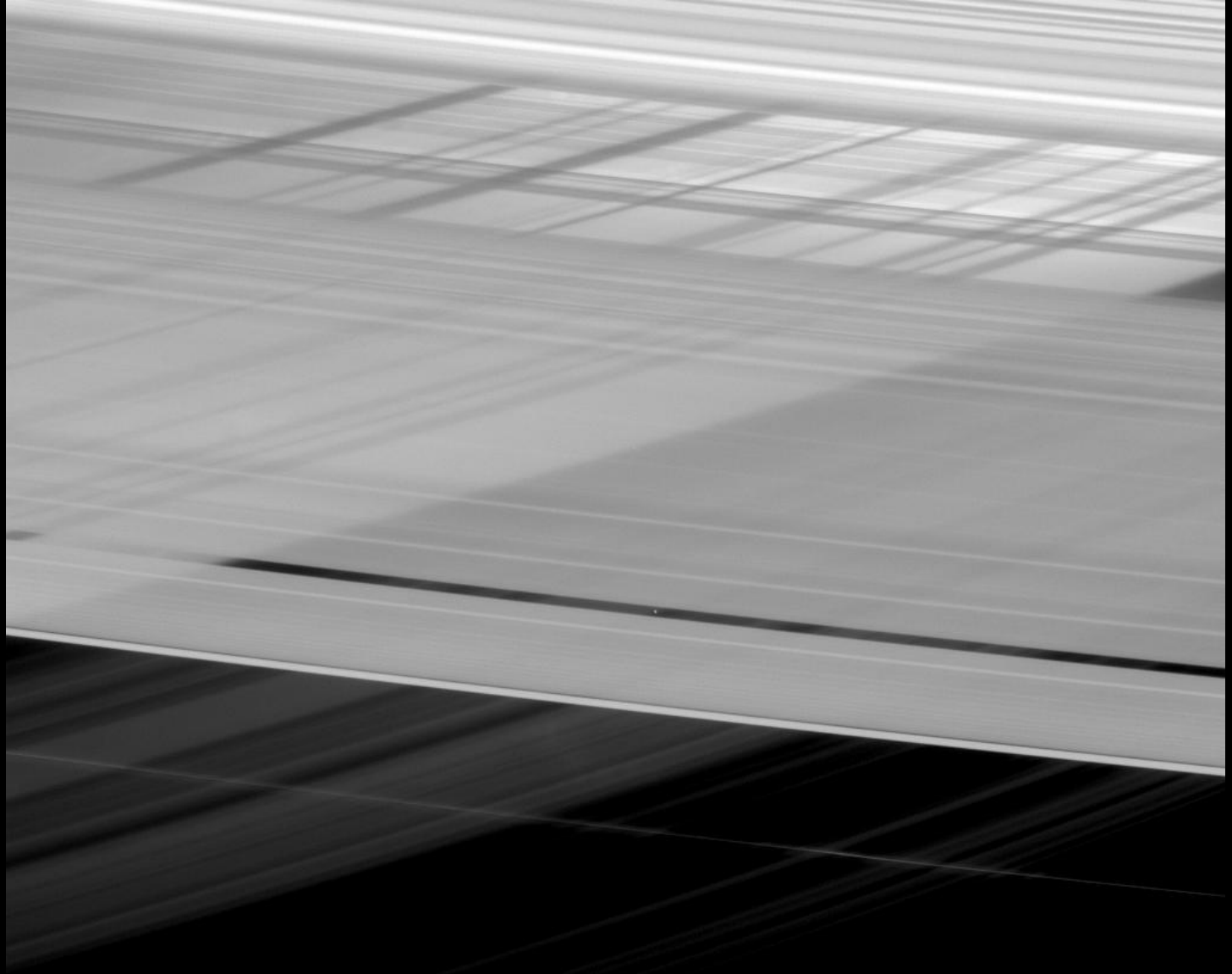
- Differences in science goals:
  - Juno: Deep interior composition/water abundance
  - Cassini: Rotation rate of the planet (well known for Jupiter)
  - Cassini: Saturn's ring mass and detailed ring s



Questions?



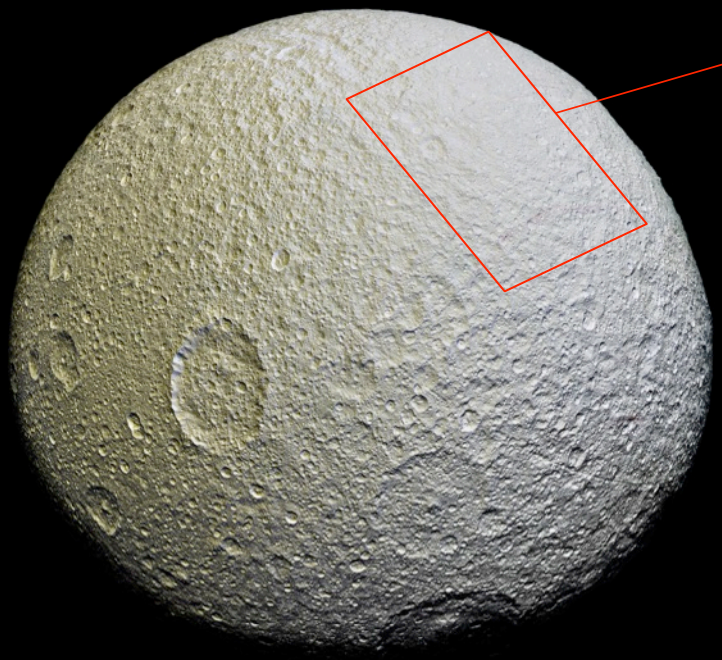

Mars
Venus
Earth and moon

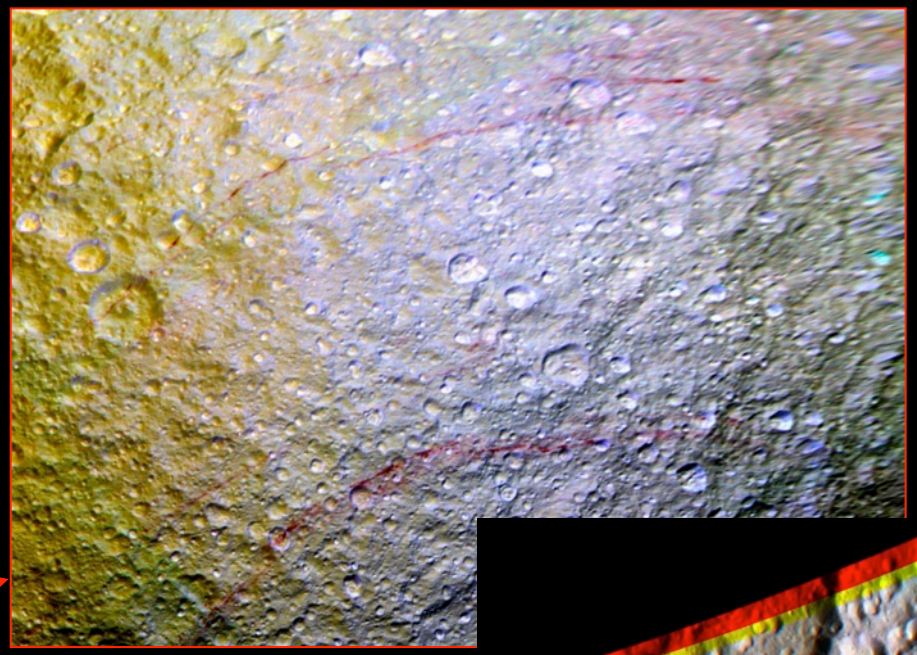


Slight of hand in the rings?

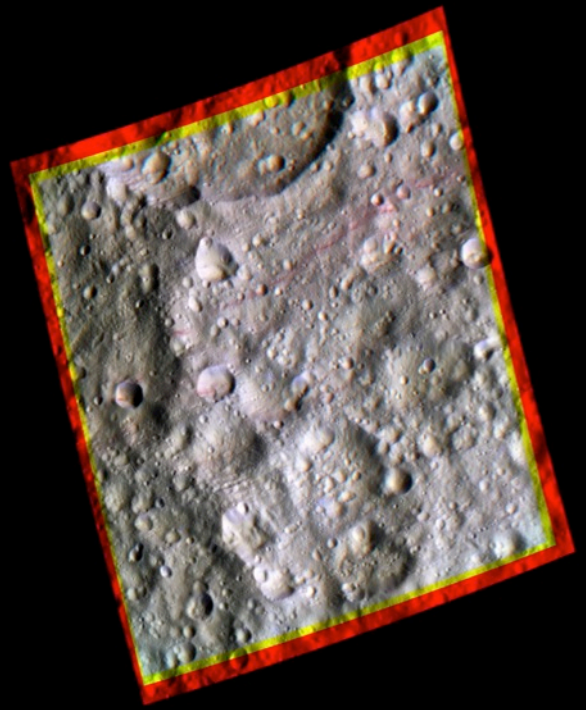
Who Graffitied Tethys?

- Newly discovered red arcs on Saturn's moon Tethys are mystifying because they are not linked to any obvious geologic features.
- 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.

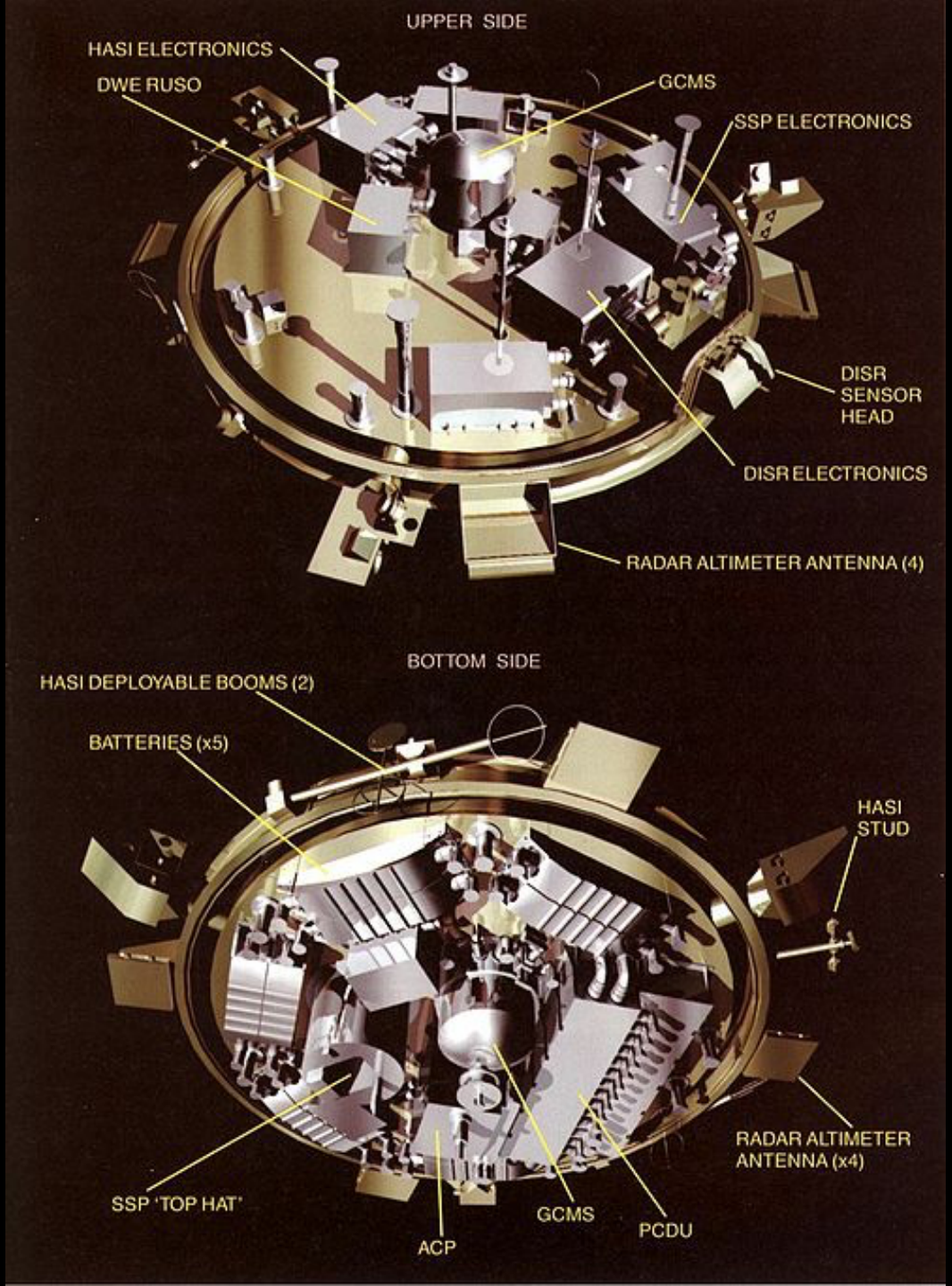




April 11, 2015



Nov 11, 2015
~80m/pixel


UPPER SIDE
HASI ELECTRONICS
DWE RUSO
GCMS
SSP ELECTRONICS
DISR SENSOR HEAD
DISR ELECTRONICS
RADAR ALTIMETER ANTENNA (4)
BOTTOM SIDE
HASI DEPLOYABLE BOOMS (2)
BATTERIES (x5)
HASI STUD
RADAR ALTIMETER ANTENNA (x4)
SSP 'TOP HAT'
GCMS
PCDU
ACP