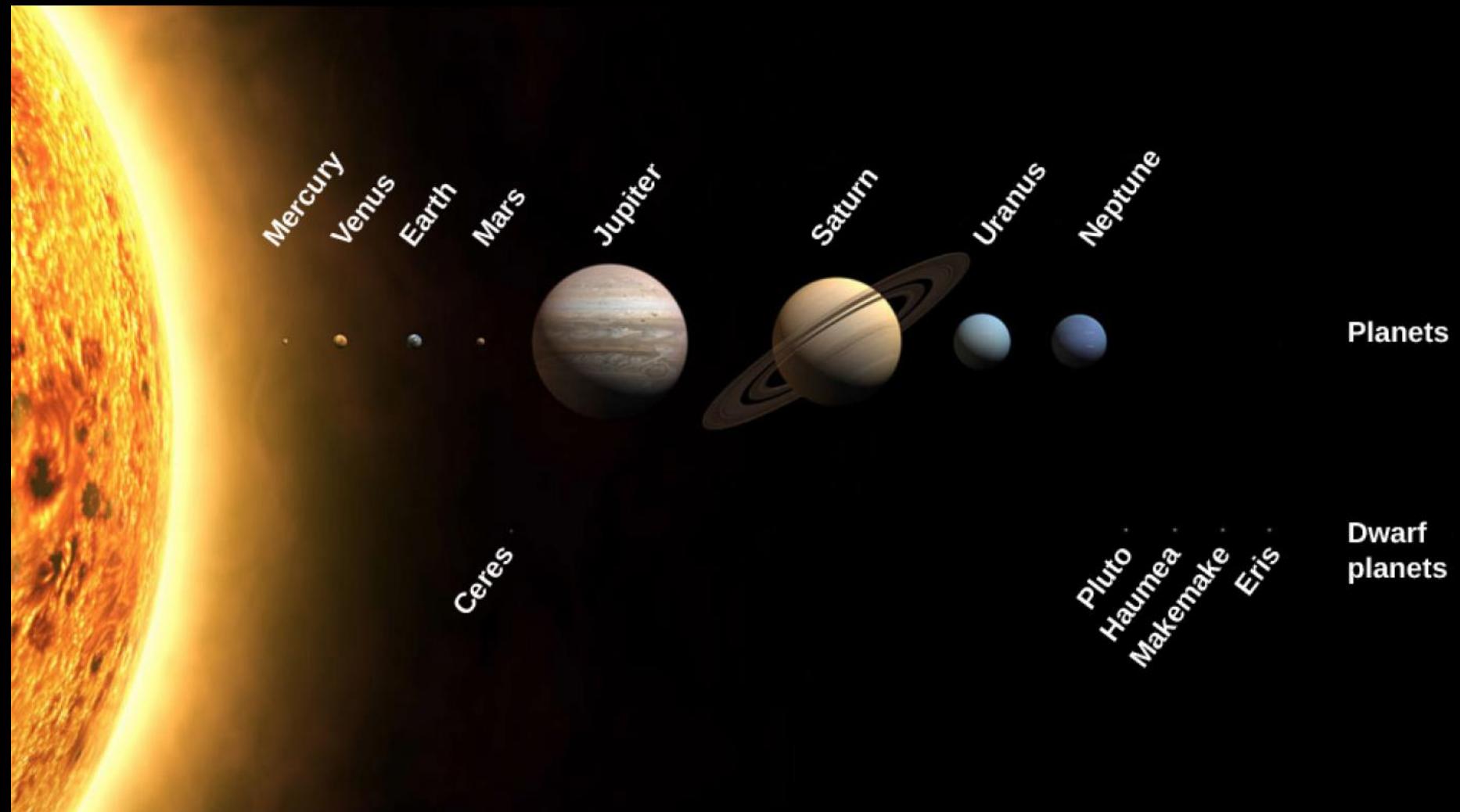
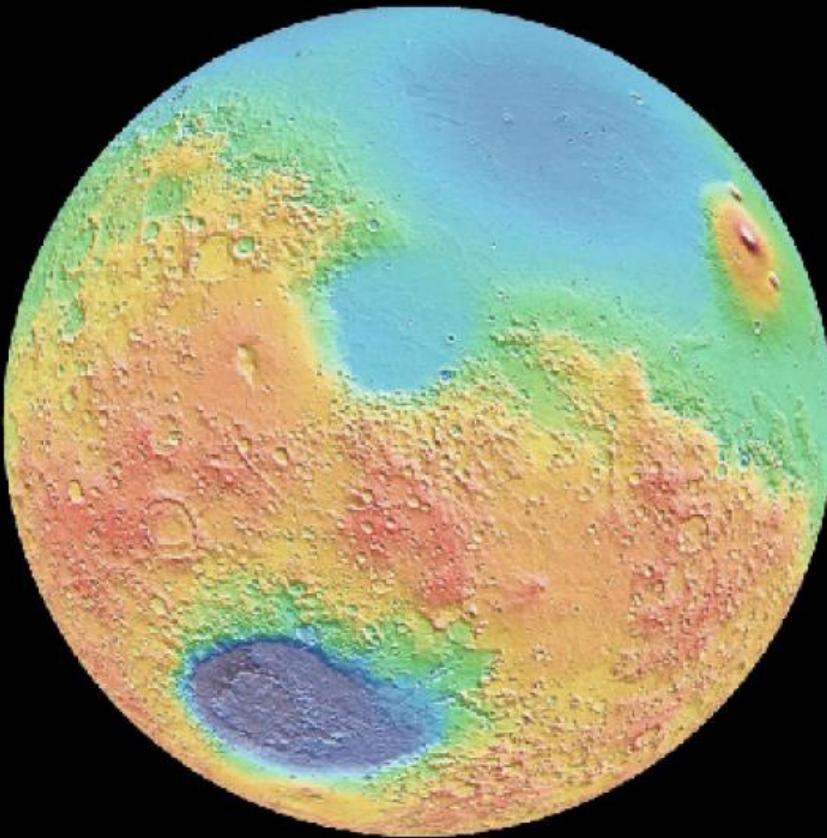
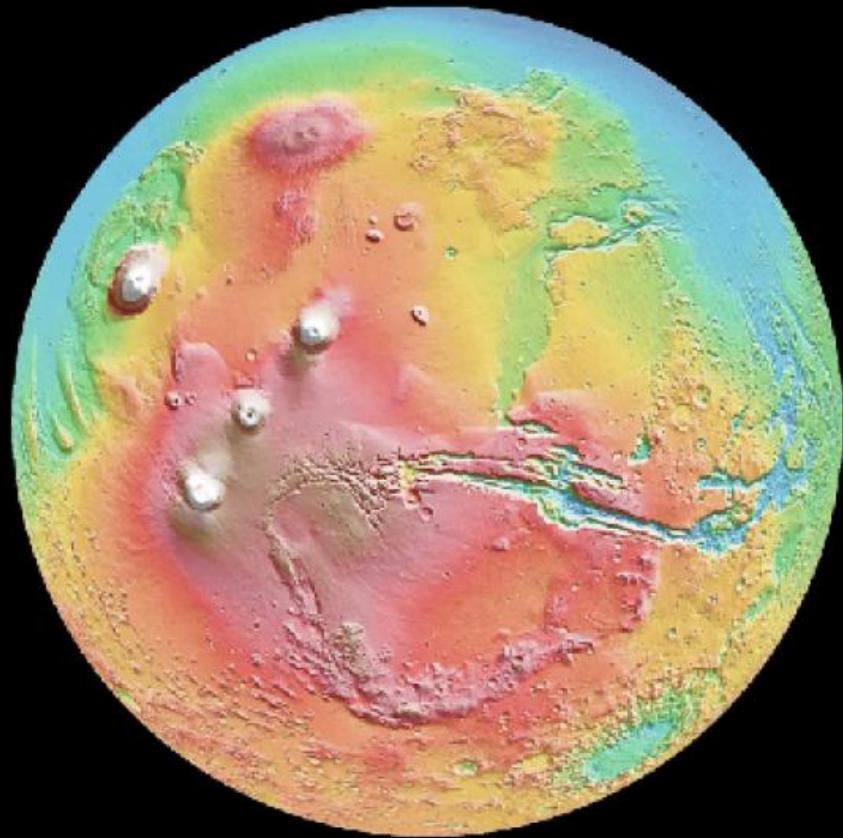


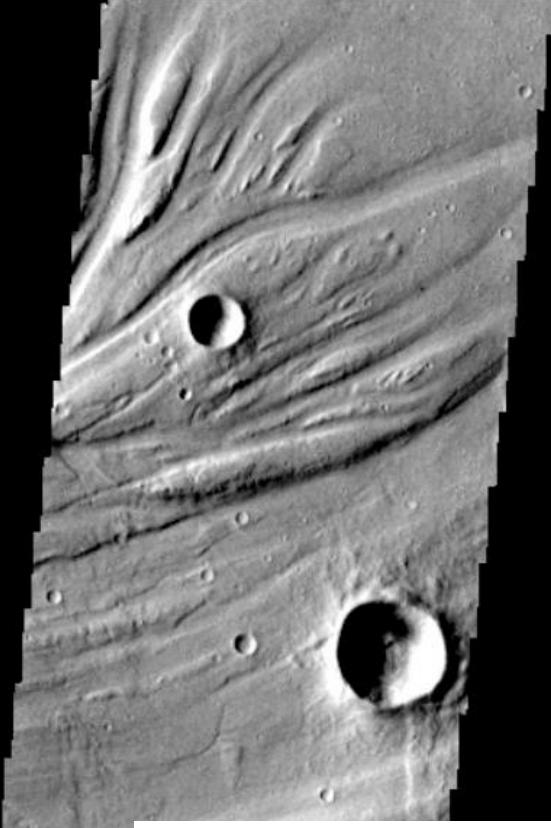
Our solar system: the giant planets and their moons



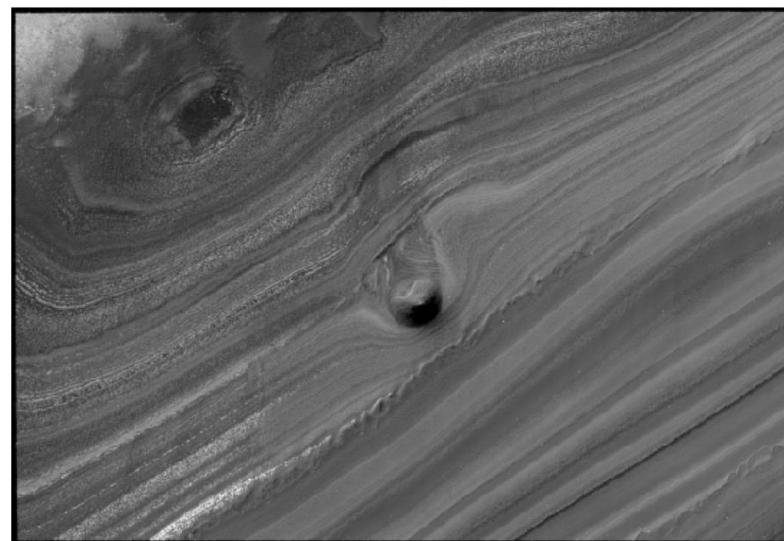
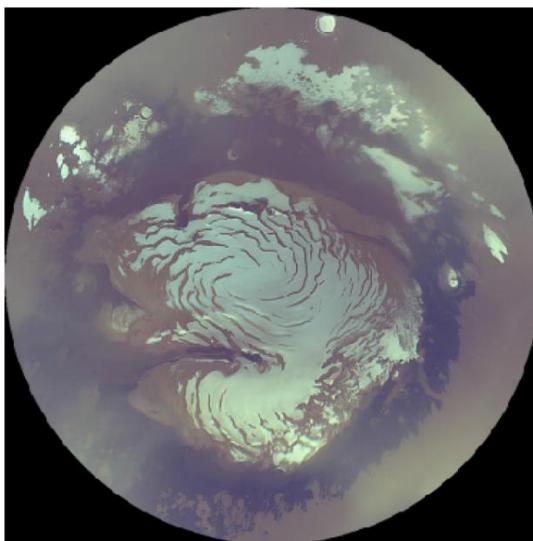
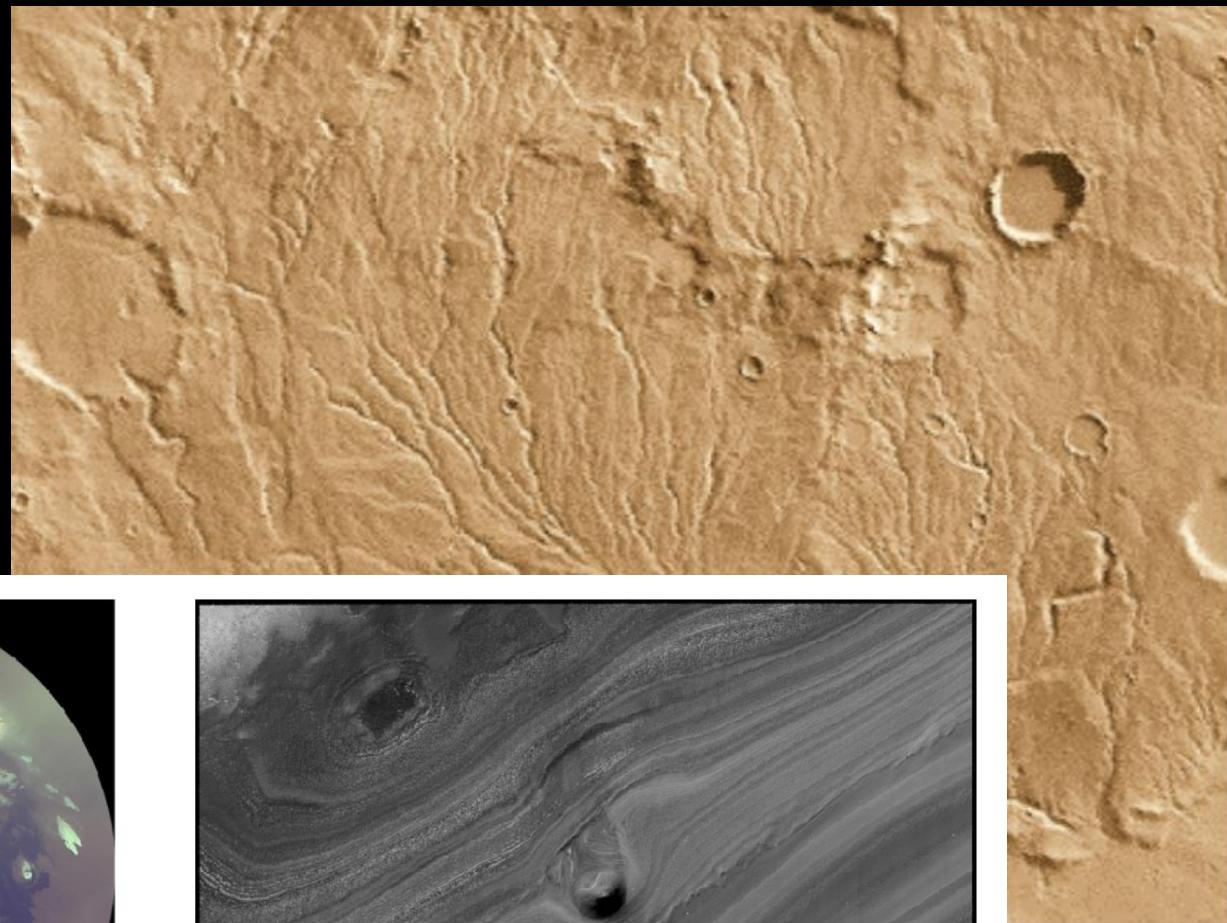
The terrestrial planets – *rocky worlds*







Water?



HISTORY OF WATER ON MARS

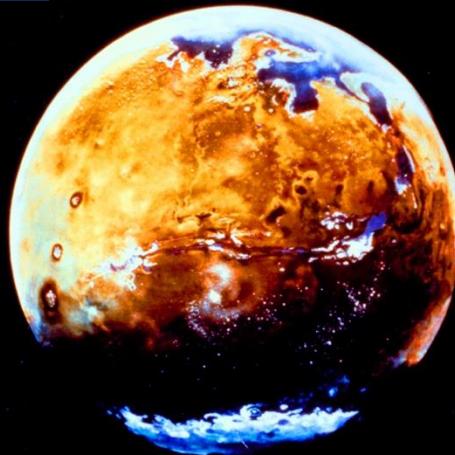
Billion years ago



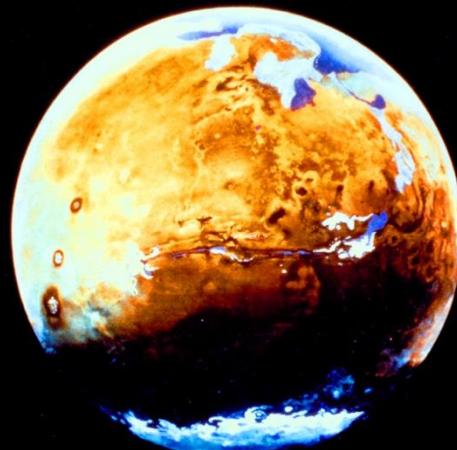
4.0



3.8



3.5



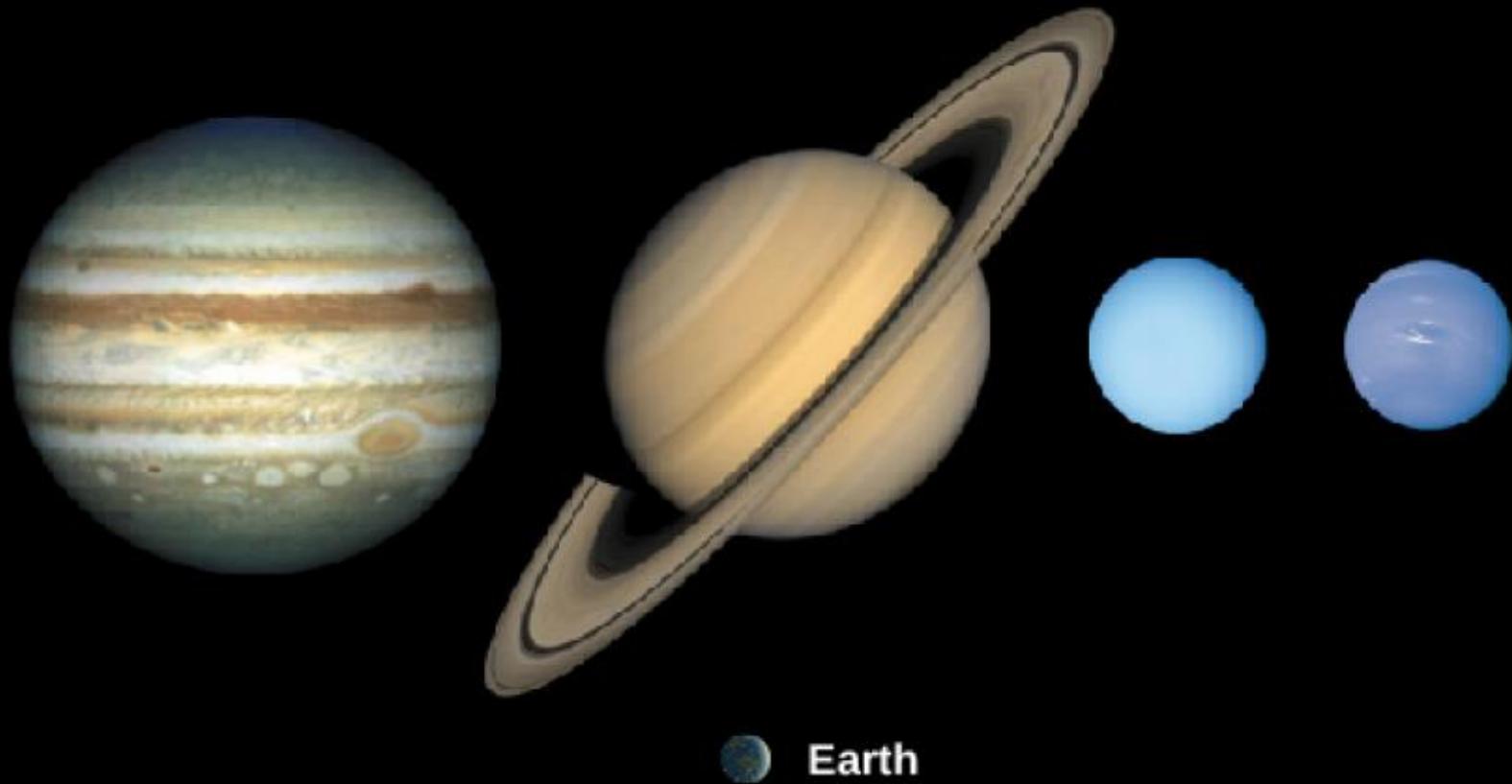
2.0



1.0



Now

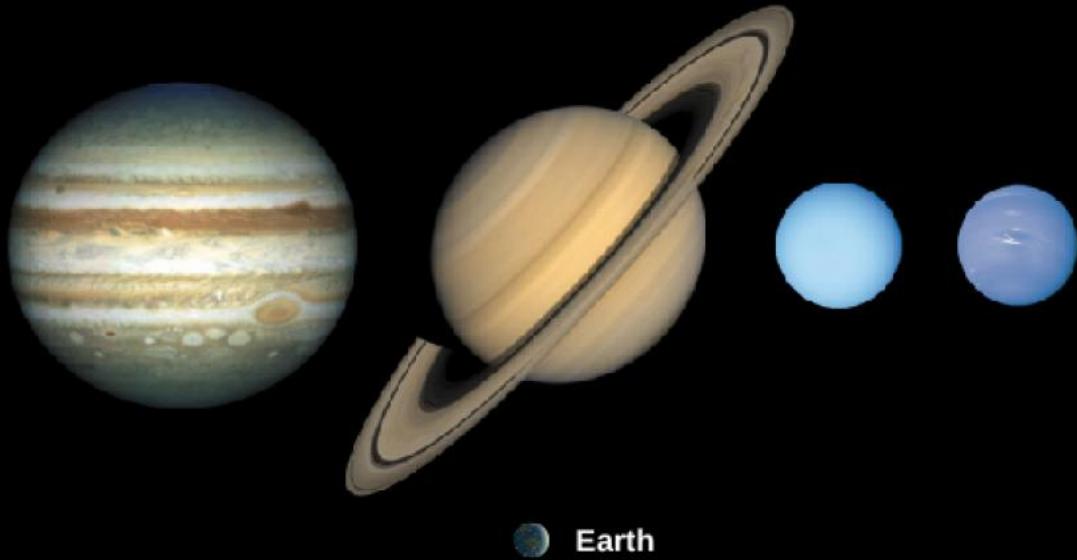


Earth

Basic Properties of the Jovian Planets

Planet	Distance (AU)	Period (years)	Diameter (km)	Mass (Earth = 1)	Density (g/cm ³)	Rotation (hours)
Jupiter	5.2	11.9	142,800	318	1.3	9.9
Saturn	9.5	29.5	120,540	95	0.7	10.7
Uranus	19.2	84.1	51,200	14	1.3	17.2
Neptune	30.0	164.8	49,500	17	1.6	16.1

Ice giants are much smaller: started with similar sized core, but could not accrete enough material



Gas giants

Jupiter, Saturn

Much more massive

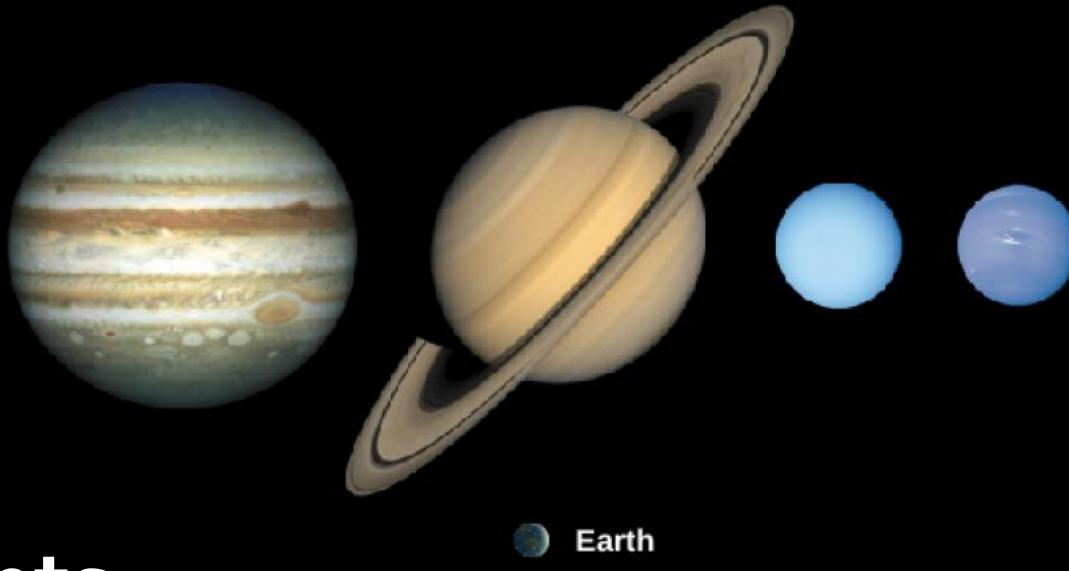
Abundances similar
to sun

Ice Giants

Uranus, Neptune

Much less massive

Similar cores as gas
giants



Gas giants

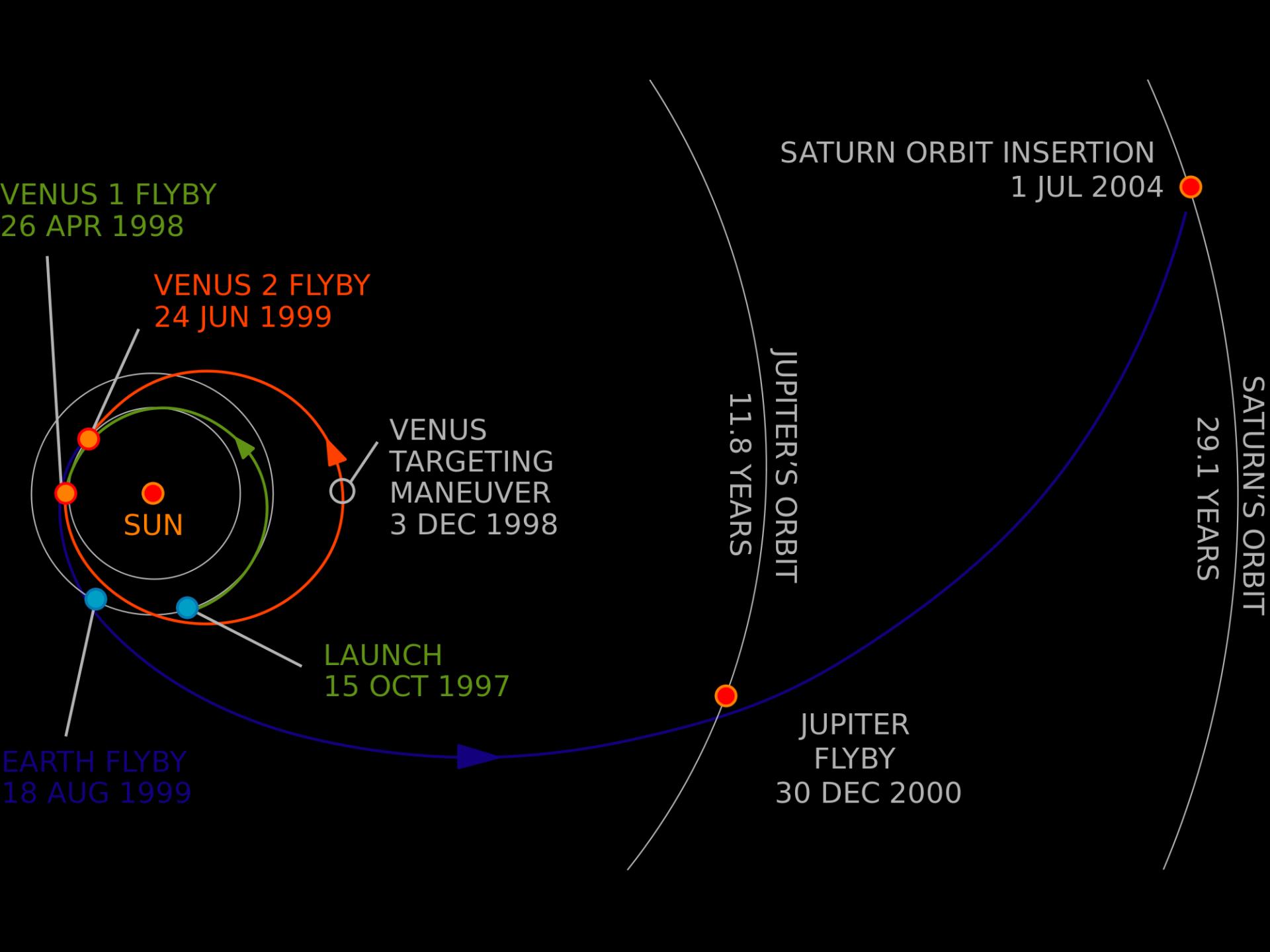
Jupiter: energy from contraction (2 cm/yr)

Ice Giants

Cold

Saturn: energy from differentiation (heavier elements sink)





Earth fly-by

2013-10-09

Launch
2011-08-05

Deep space maneuvers

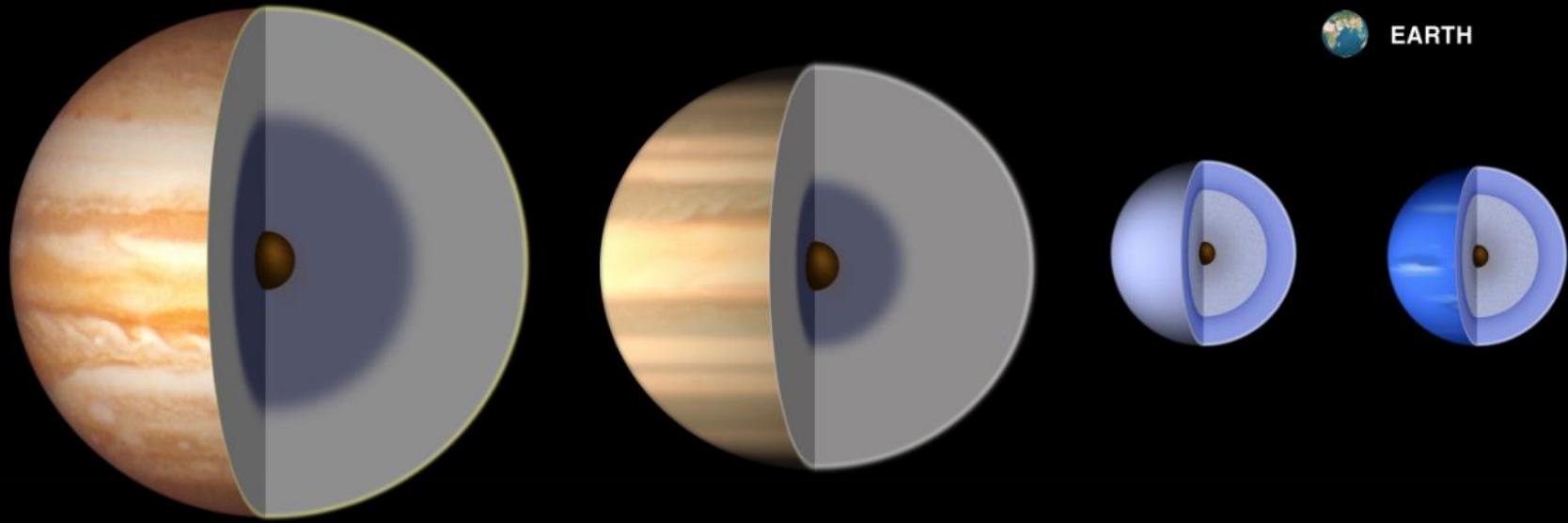
2012-08-30 & 2012-09-03

Jupiter orbital insertion

2016-07-05

Missions to the Giant Planets

Planet	Spacecraft ^[1]	Encounter Date	Type
Jupiter	Pioneer 10	December 1973	Flyby
	Pioneer 11	December 1974	Flyby
	Voyager 1	March 1979	Flyby
	Voyager 2	July 1979	Flyby
	Ulysses	February 1992	Flyby during gravity assist
	Galileo	December 1995	Orbiter and probe
	Cassini	December 2002	Flyby
	New Horizons	February 2007	Flyby during gravity assist
	Juno	July 2016	Orbiter
Saturn	Pioneer 11	September 1979	Flyby
	Voyager 1	November 1980	Flyby
	Voyager 2	August 1981	Flyby
	Cassini	July 2004 (Saturn orbit injection 2000)	Orbiter



JUPITER

SATURN

URANUS

NEPTUNE

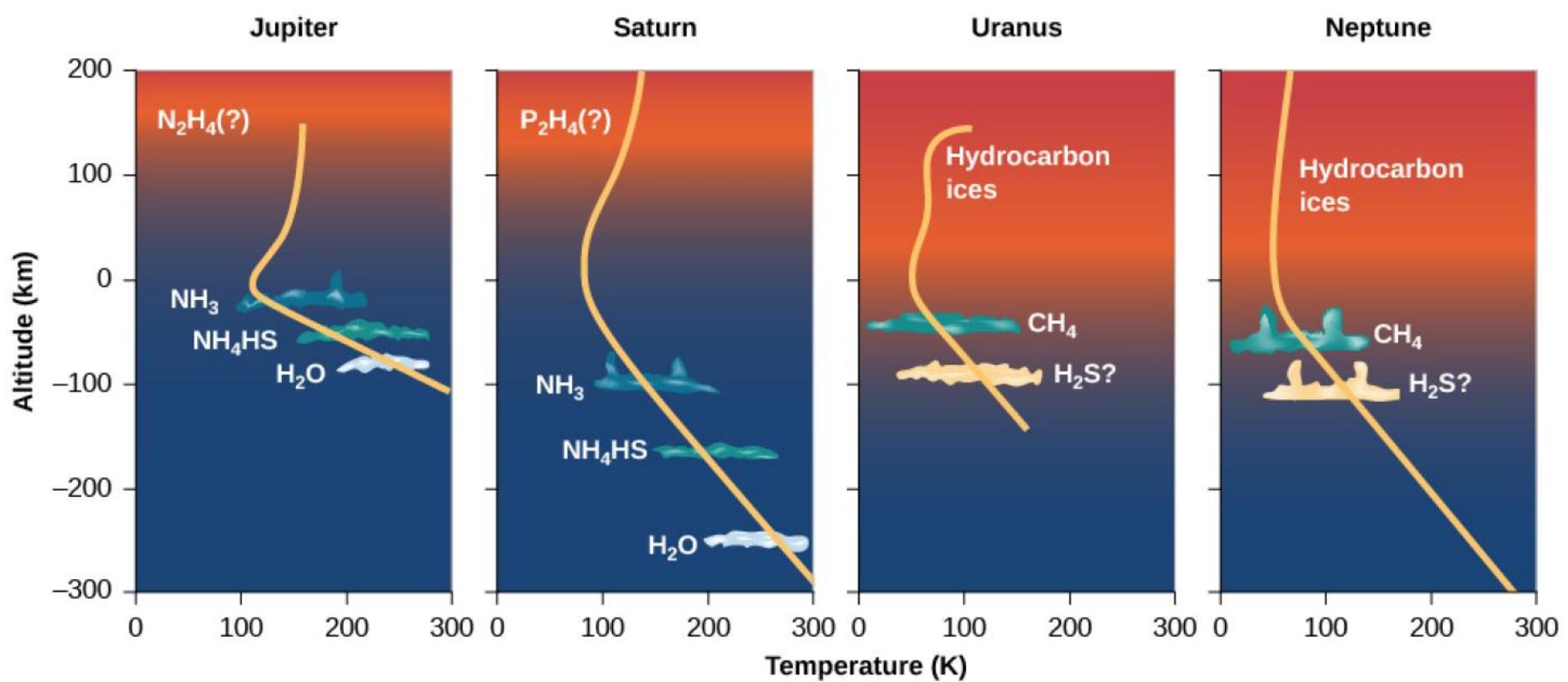
Molecular hydrogen

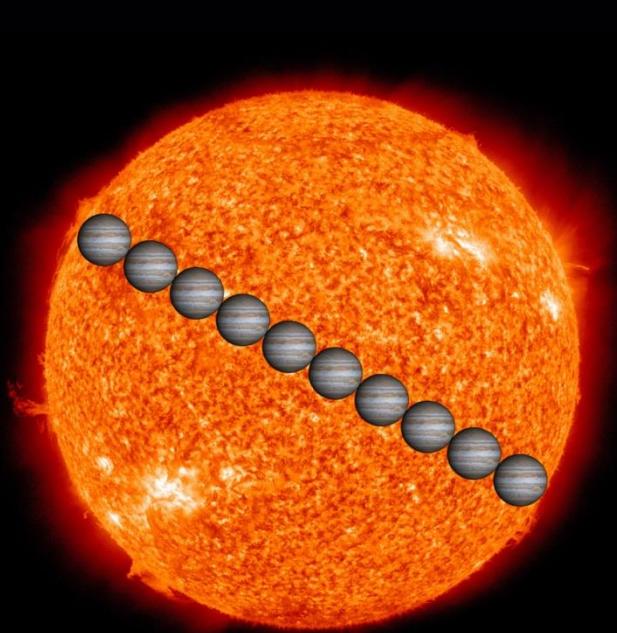
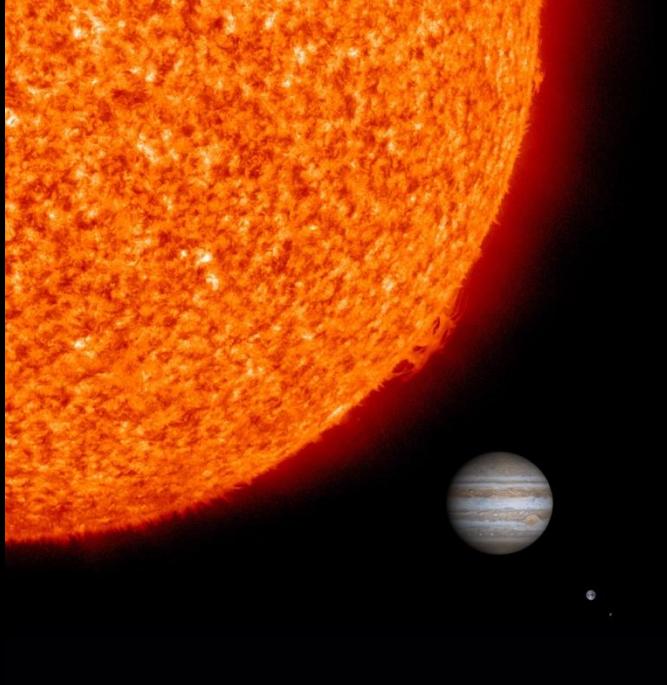
Hydrogen, helium, methane gas

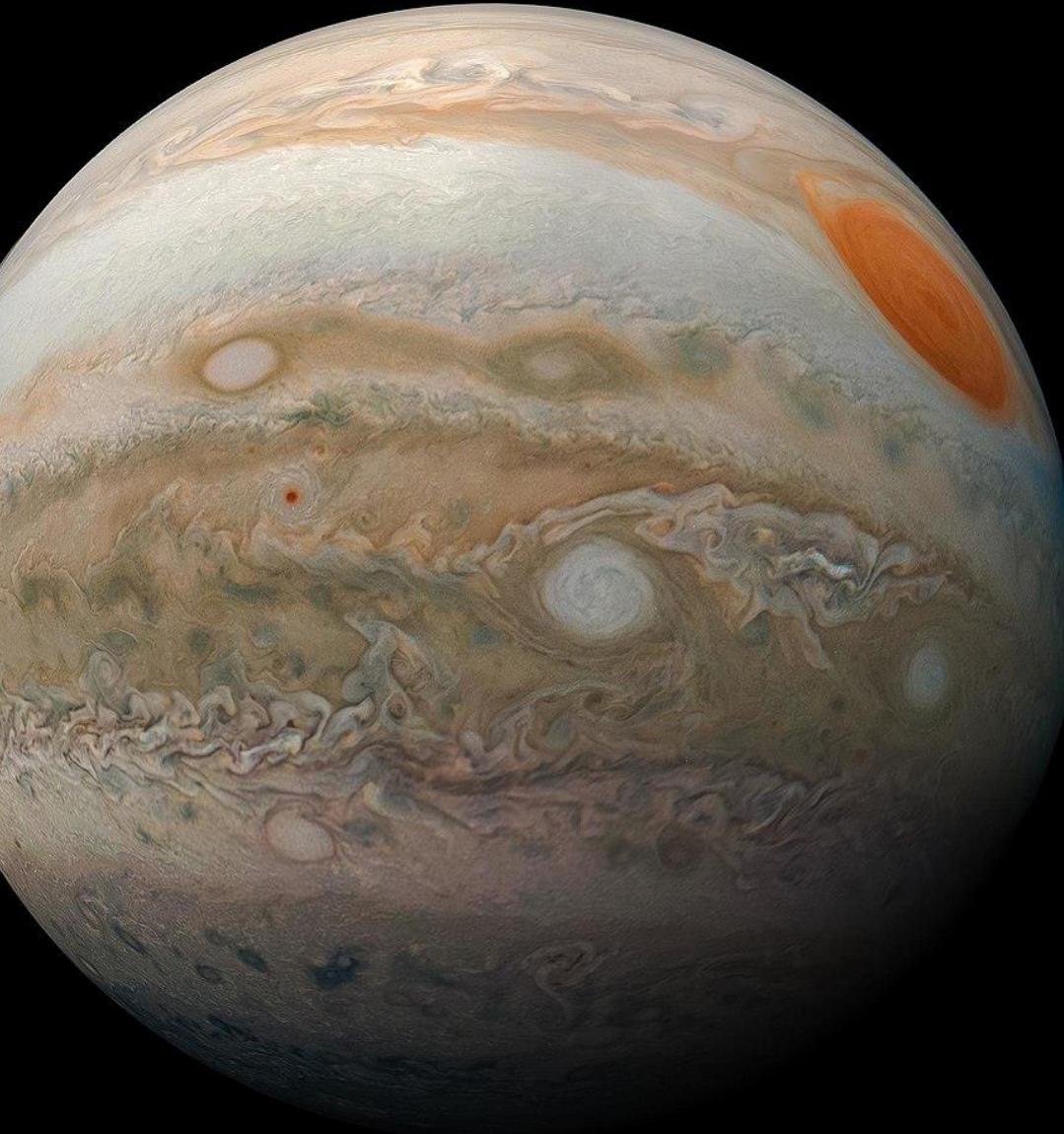
Metallic hydrogen

Mantle (water, ammonia, methane ices)

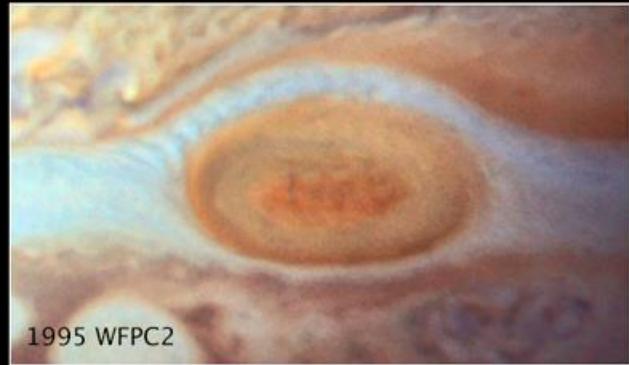
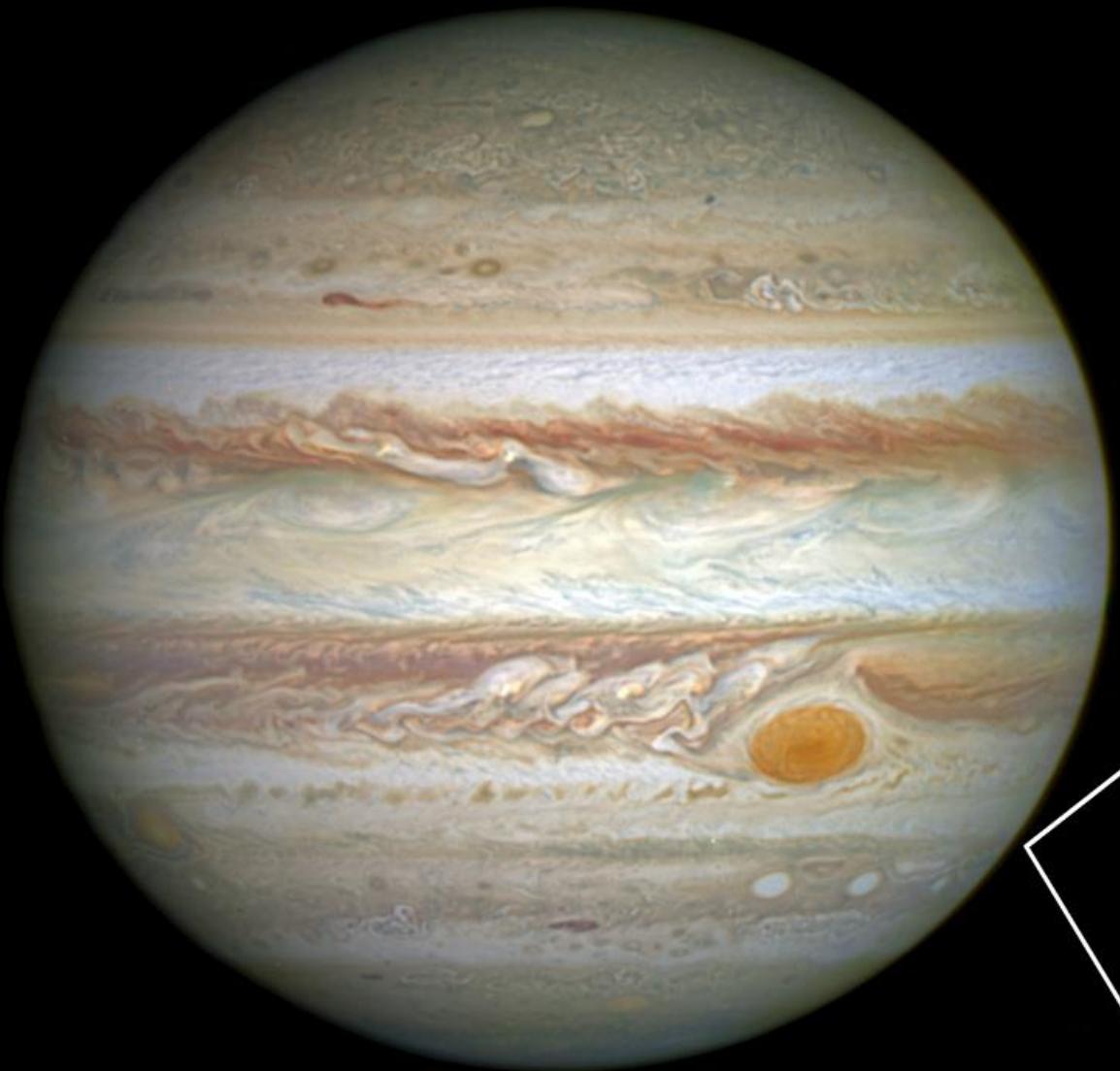
Core (rock, ice)







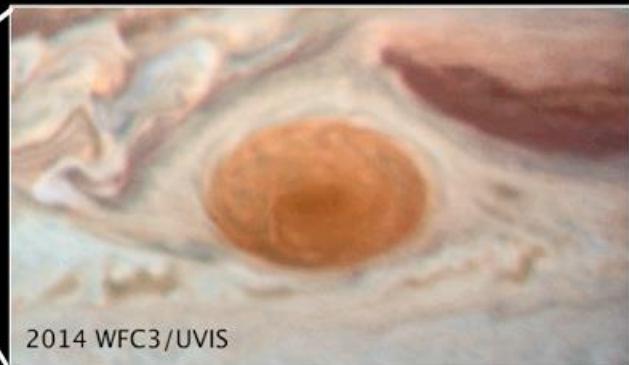
Bands of clouds
Great Red Spot:
high-pressure
storm



1995 WFPC2

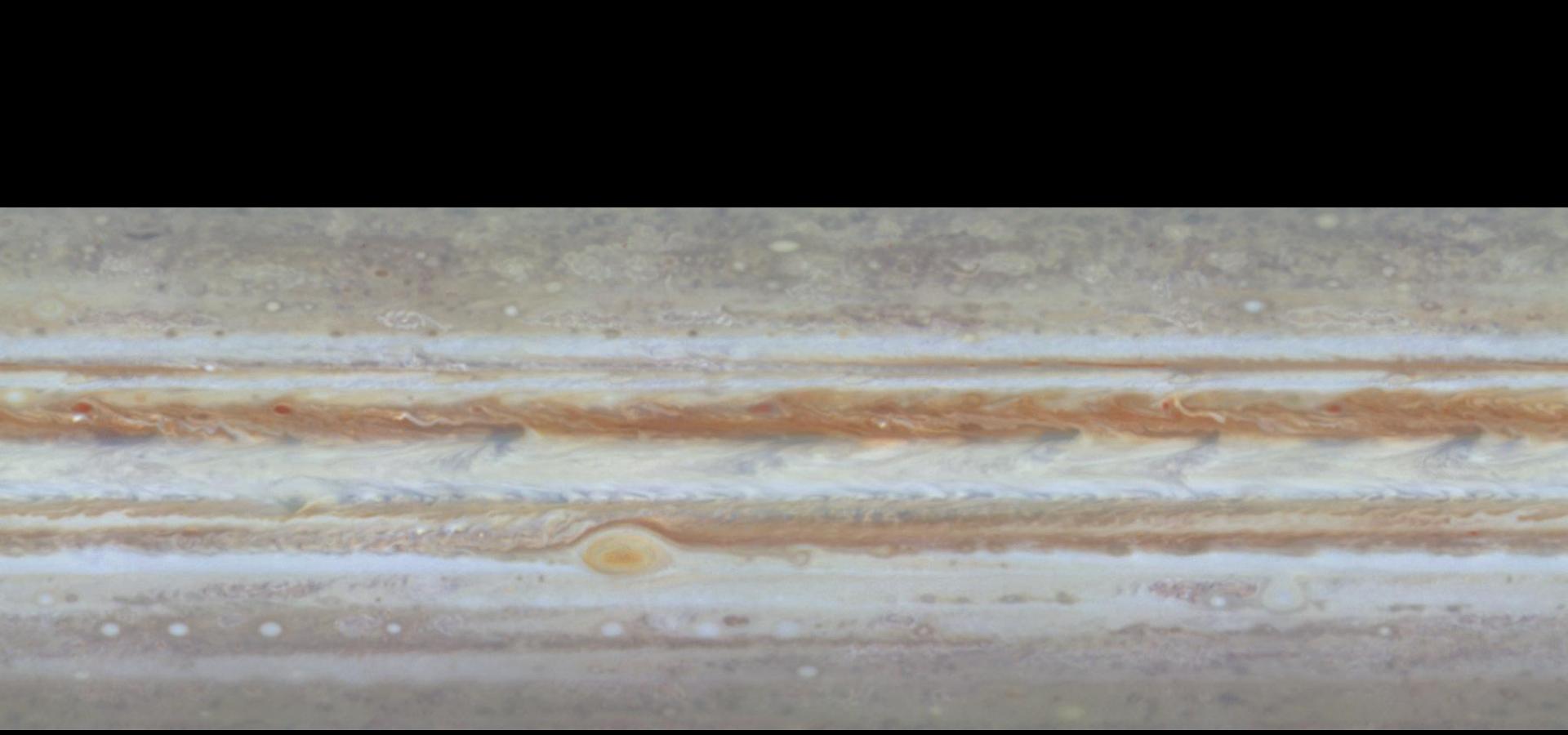


2009 WFC3/UVIS



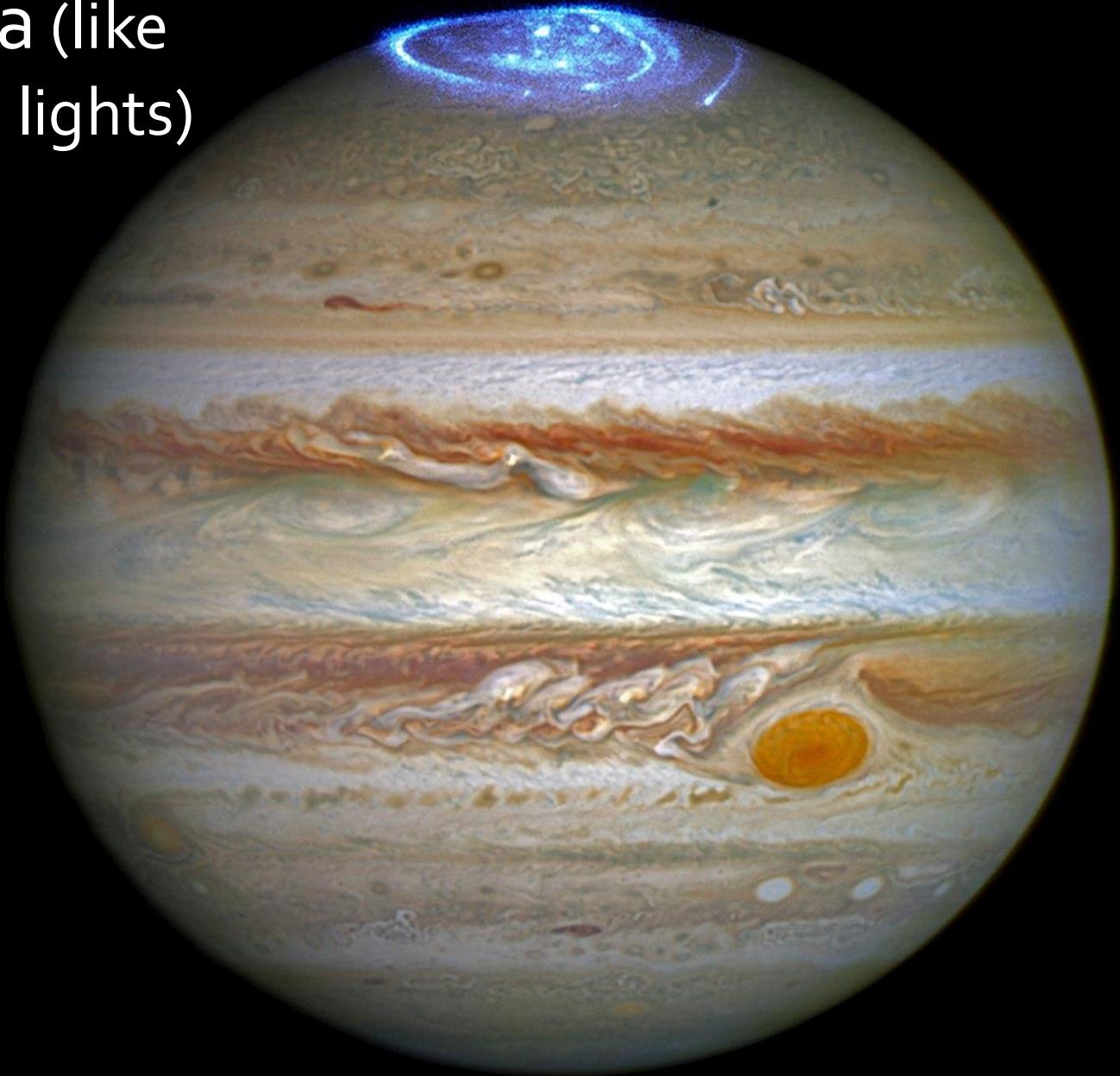
2014 WFC3/UVIS

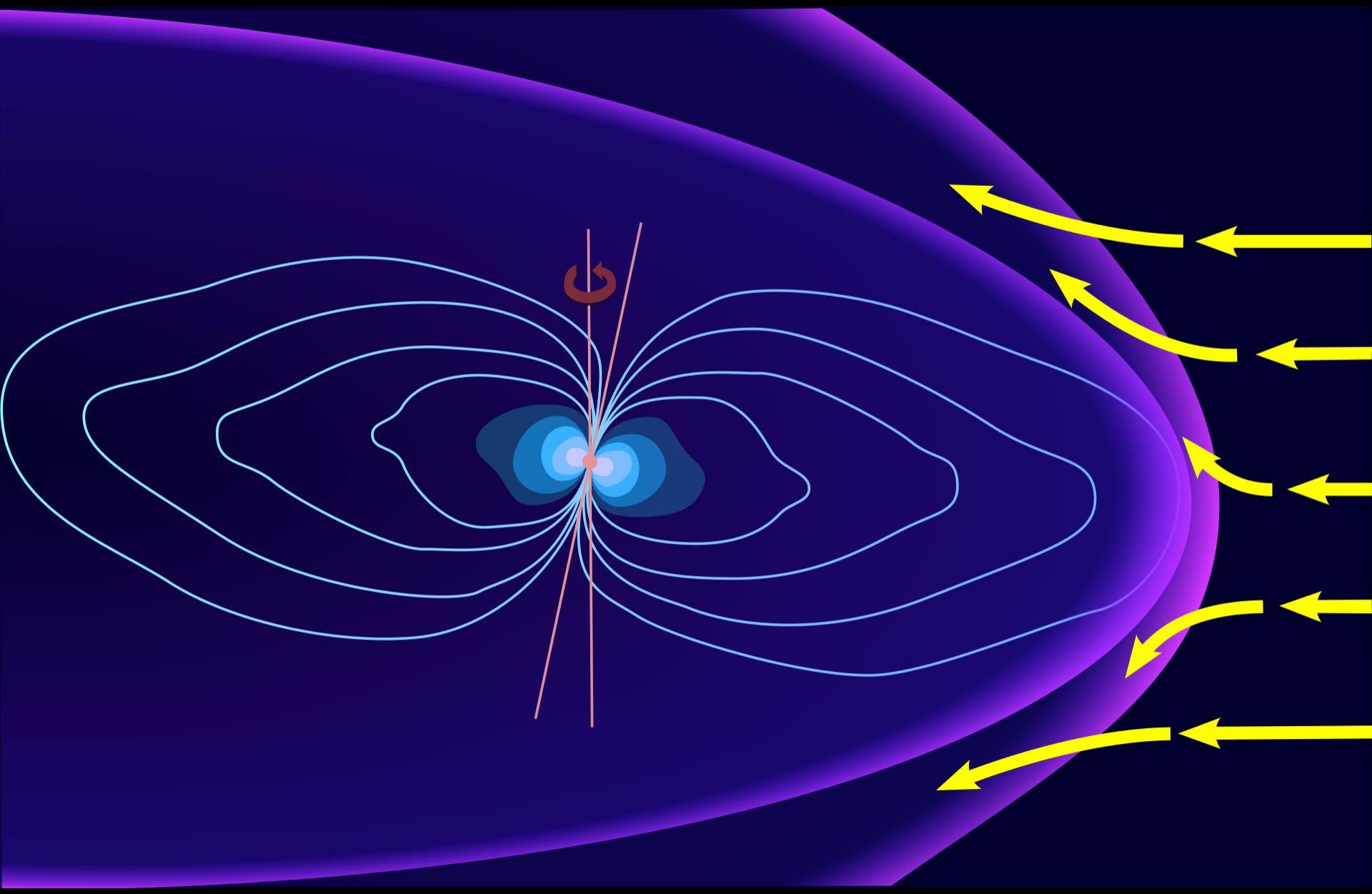
Red spot is shrinking!

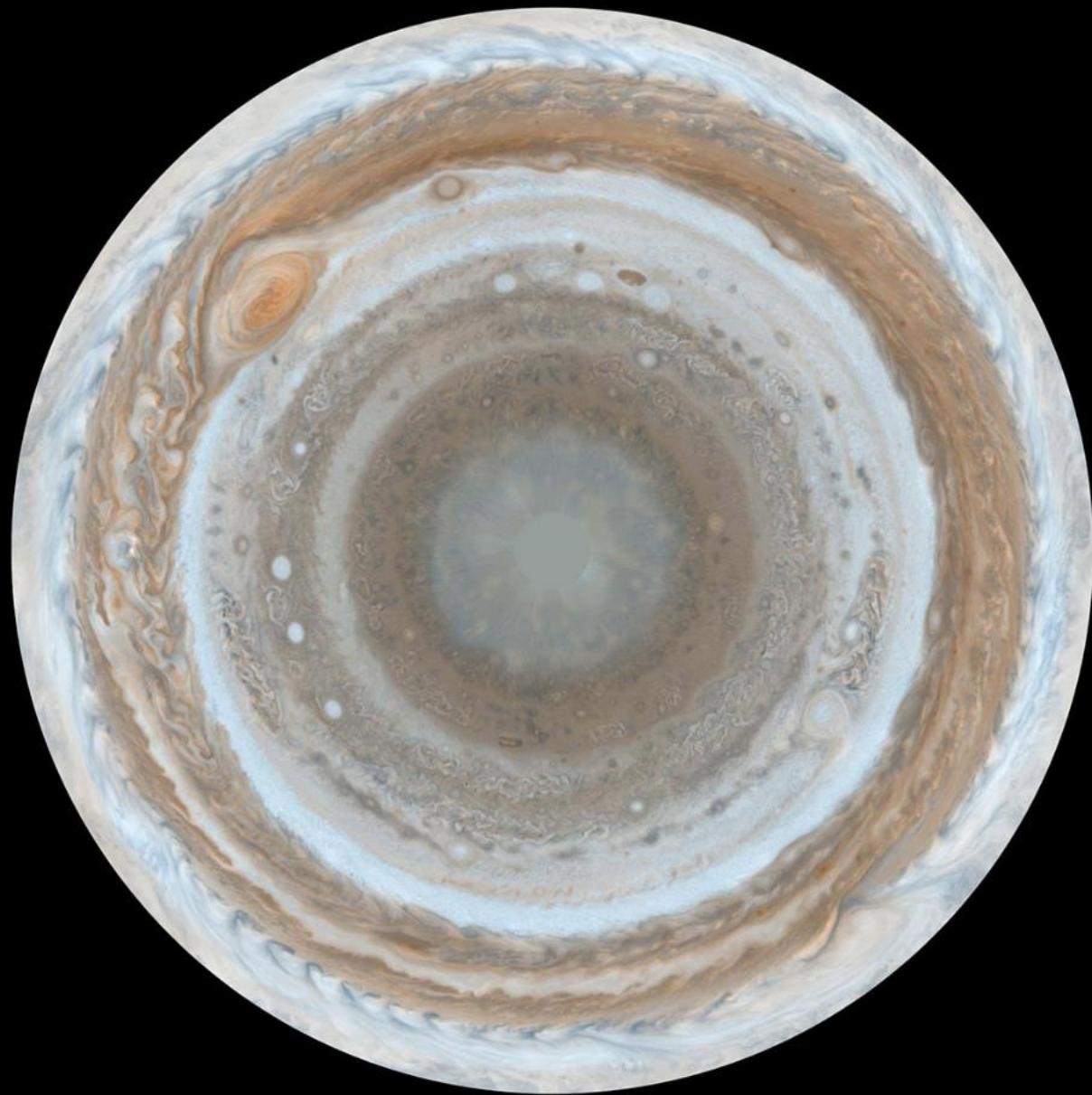


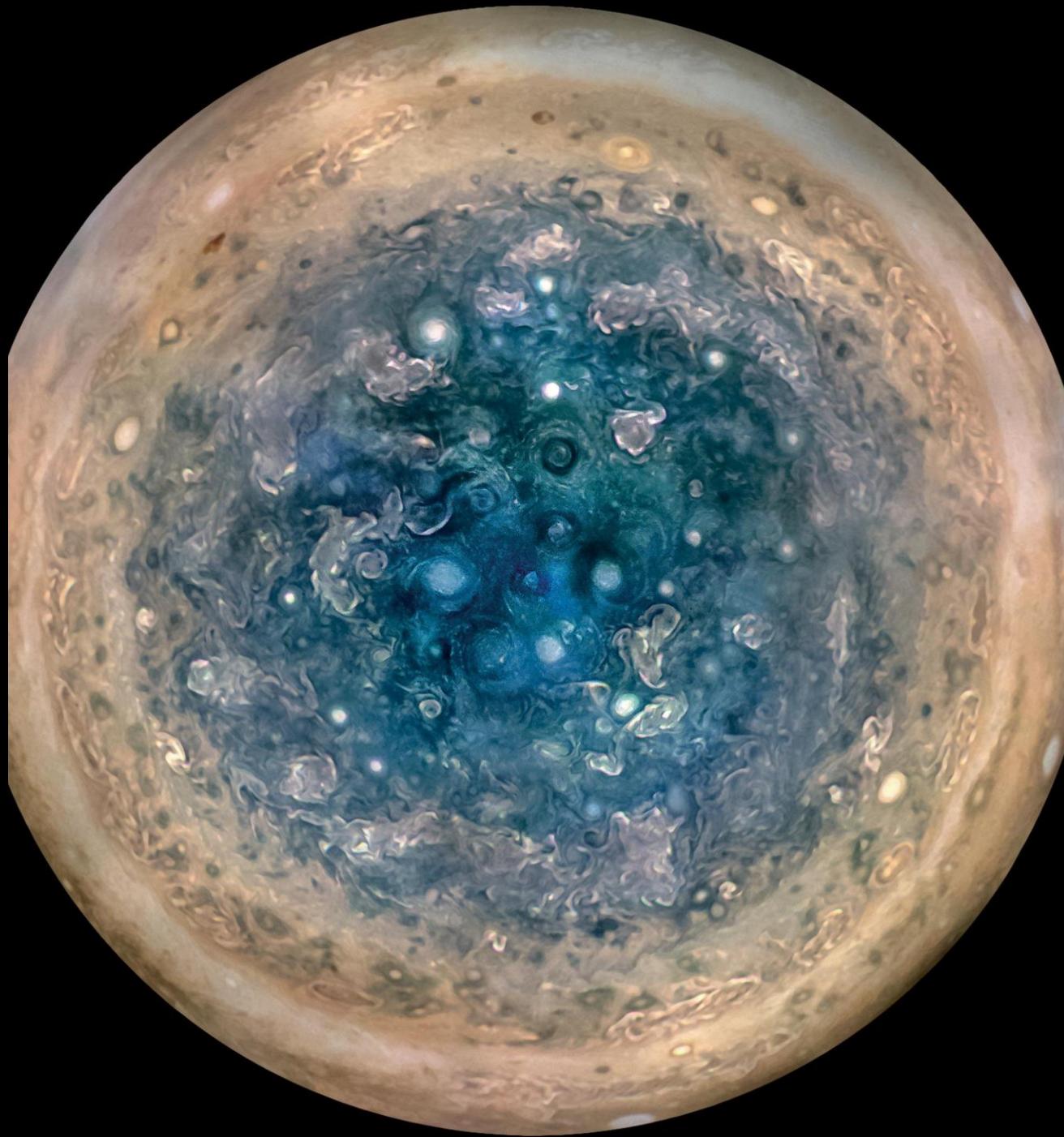
Bands rotate at different speeds
(like weather on earth)

Jovian aurora (like
Earth: Northern lights)



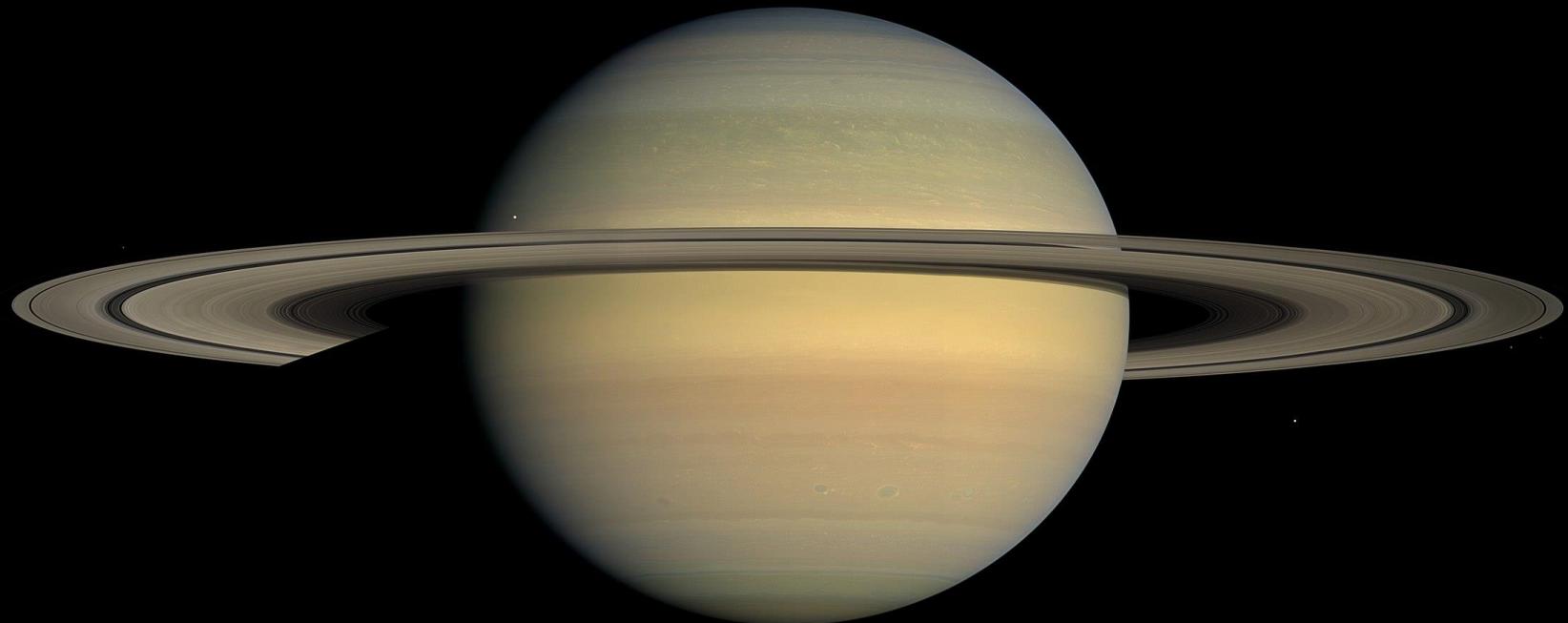


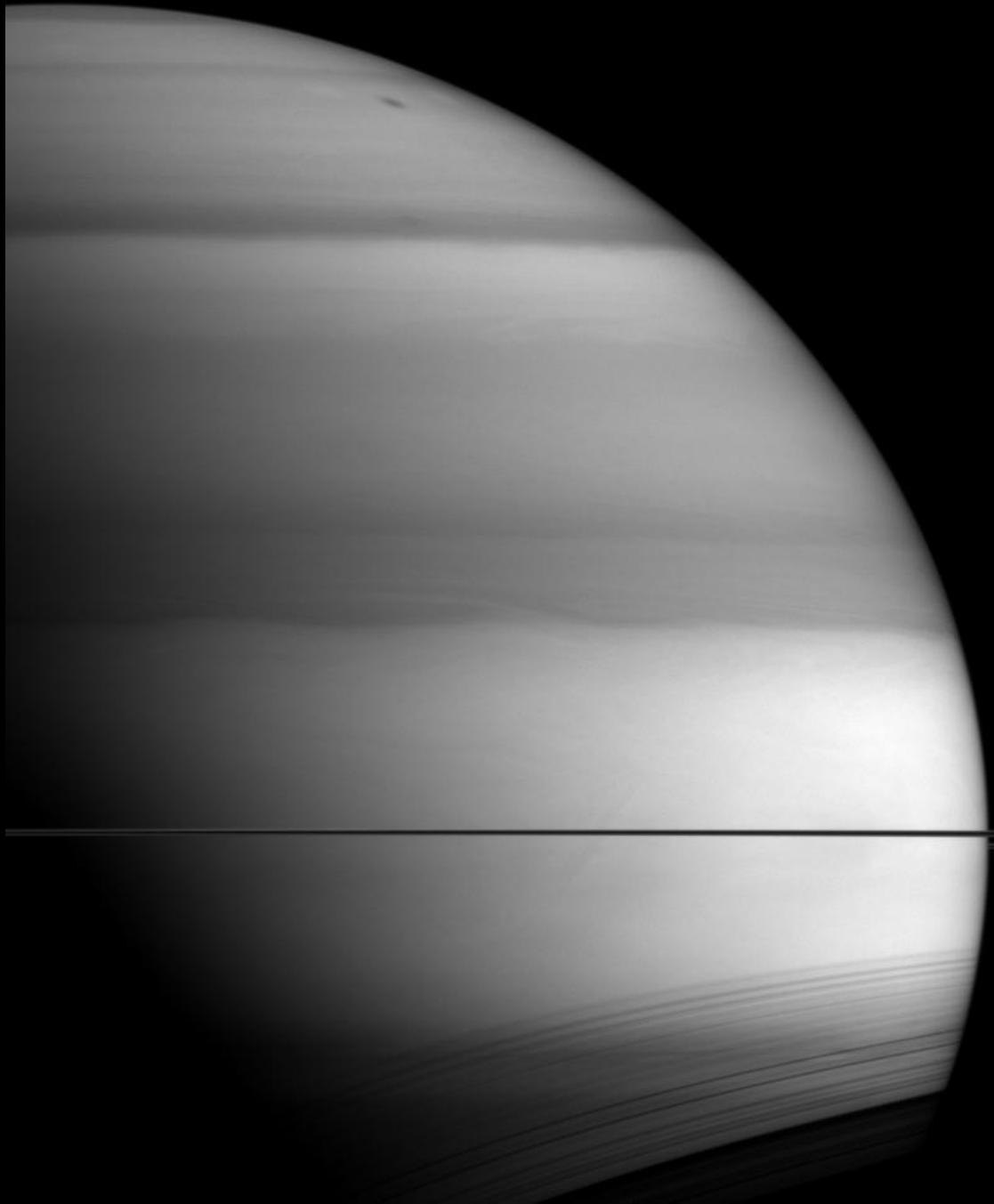


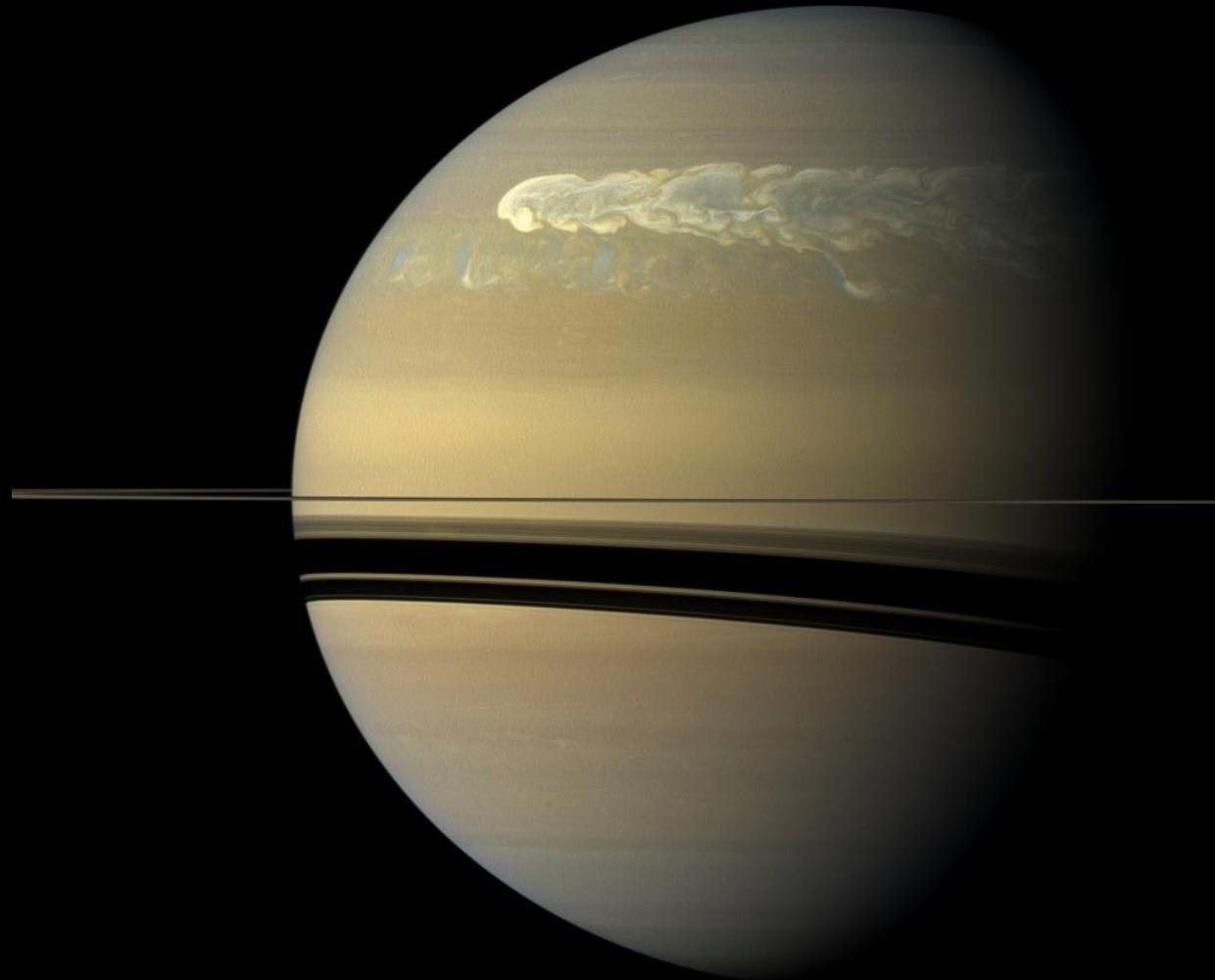


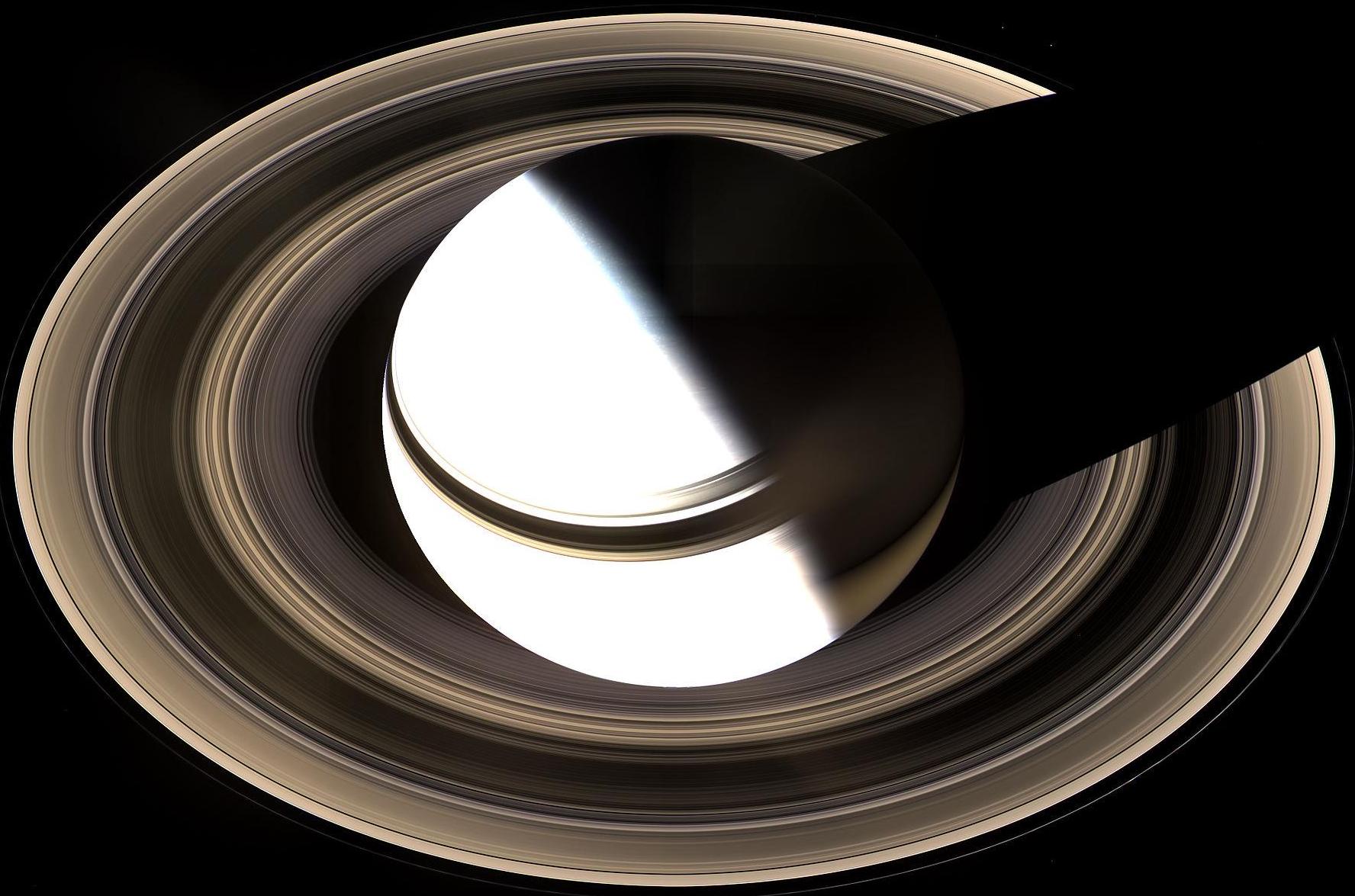


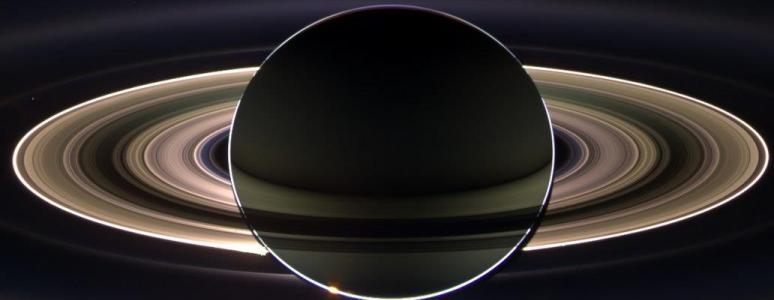
Saturn (and its rings)

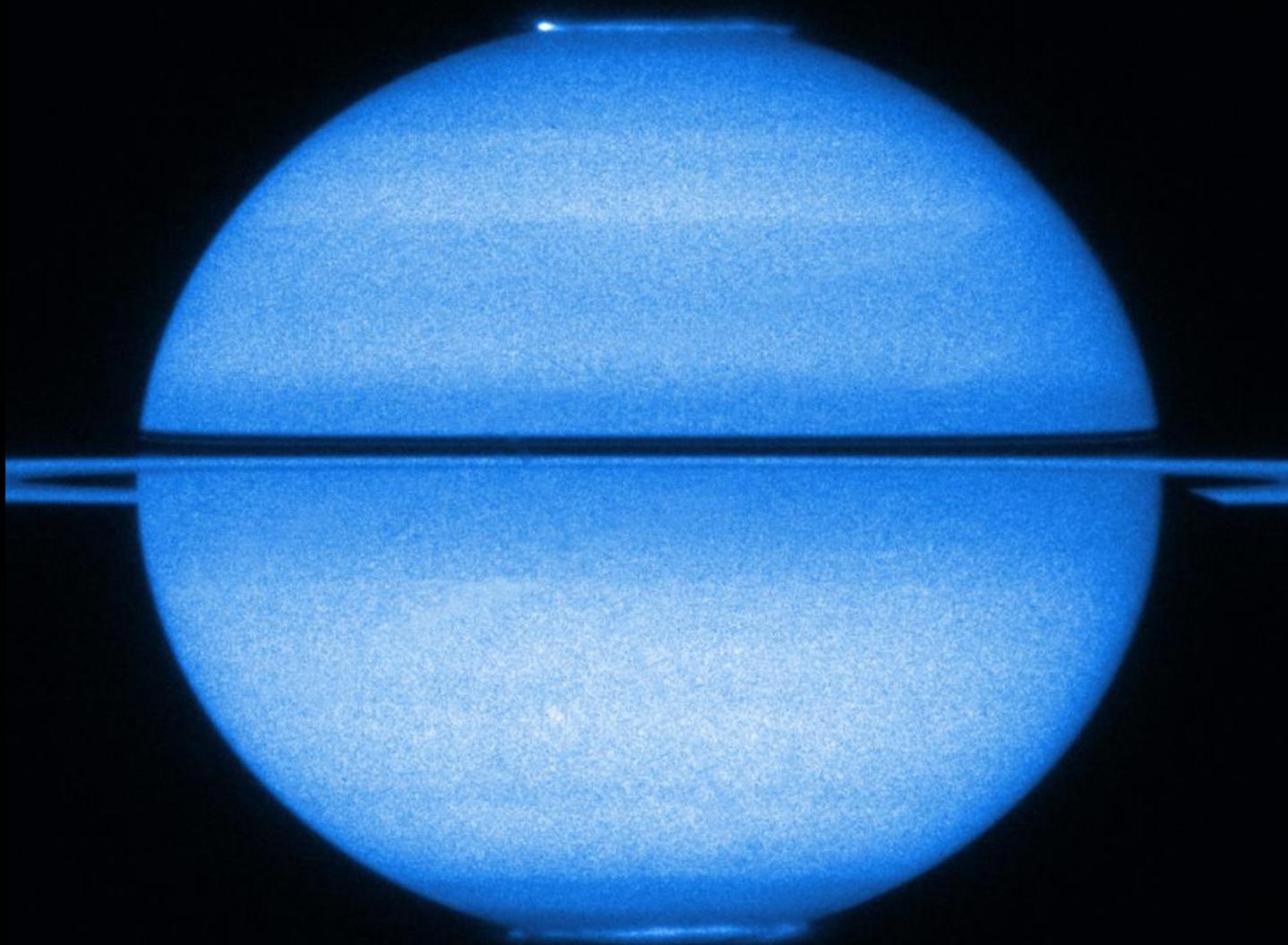




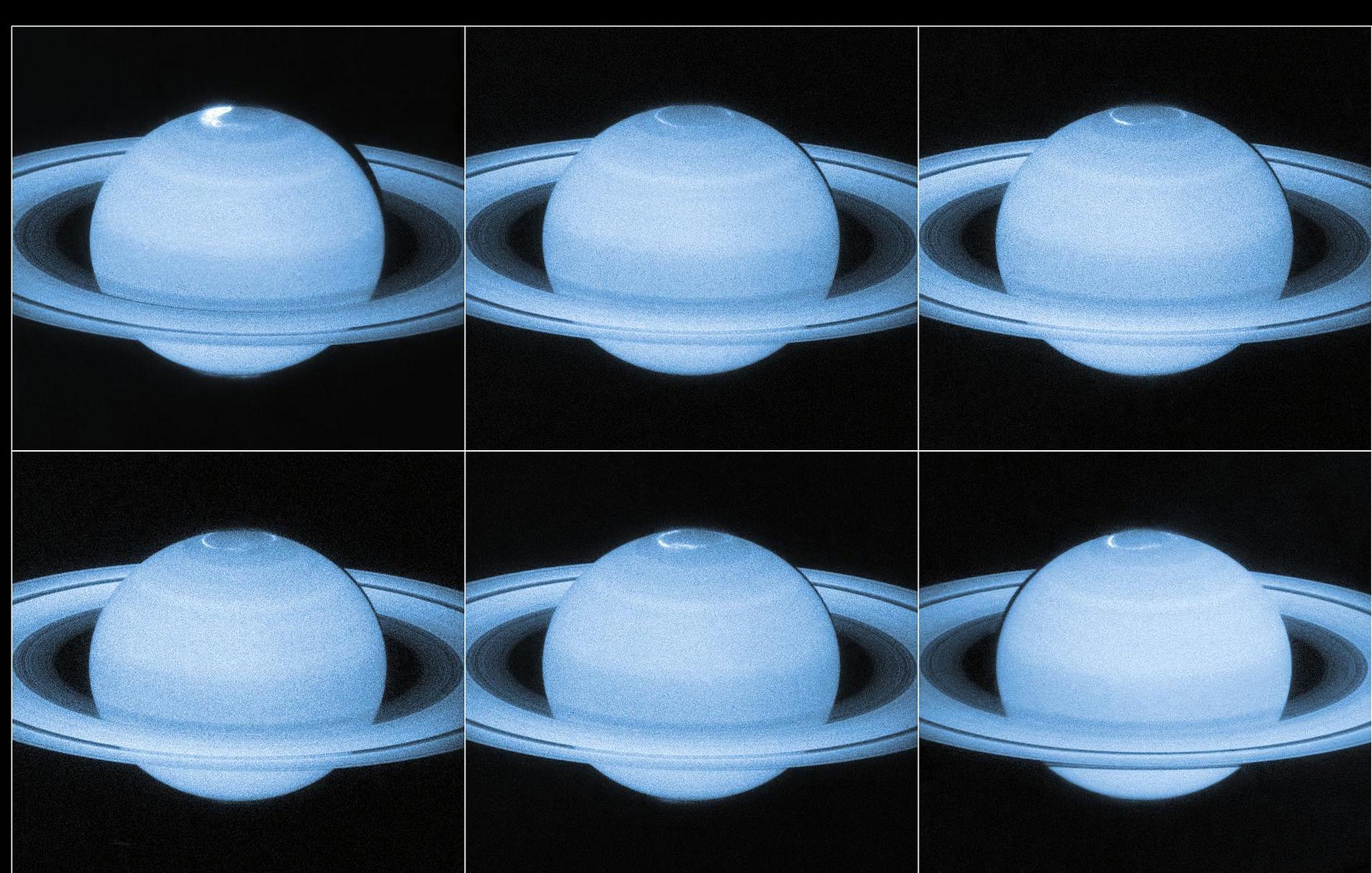


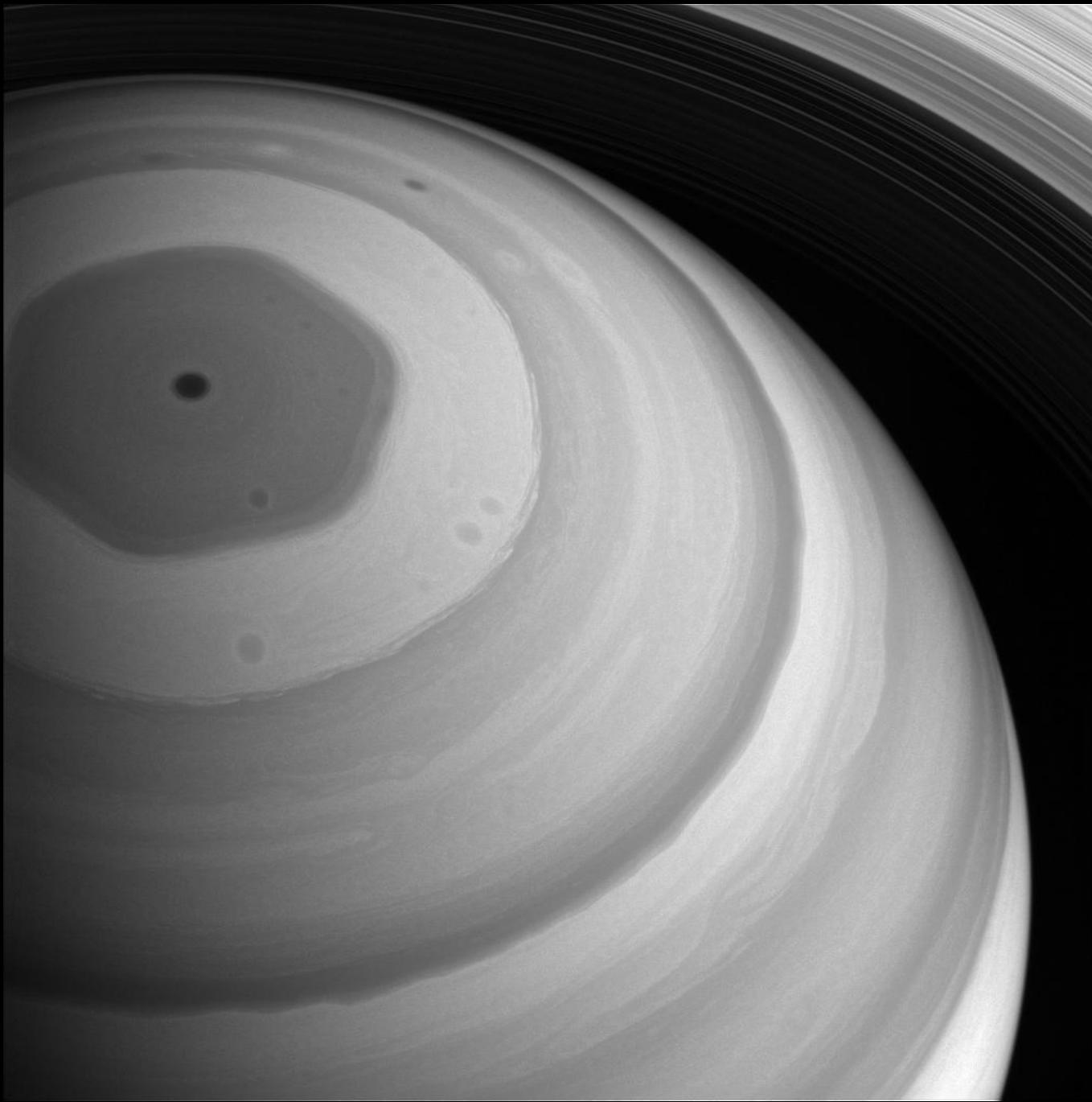


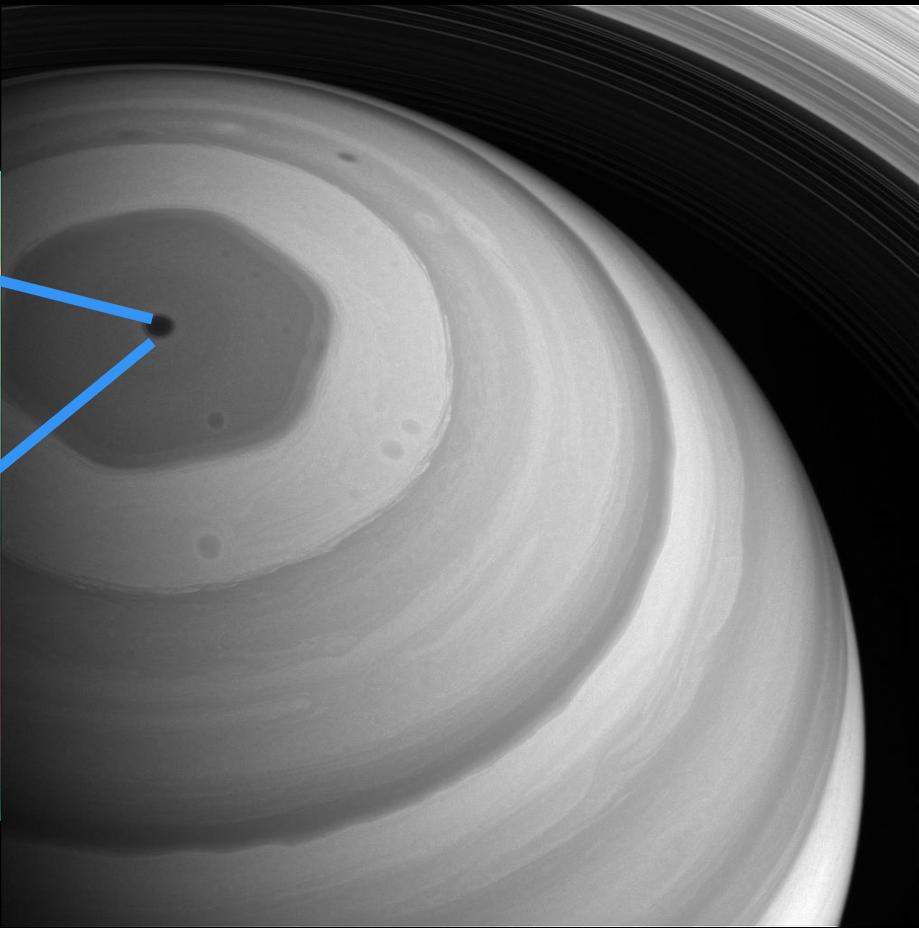
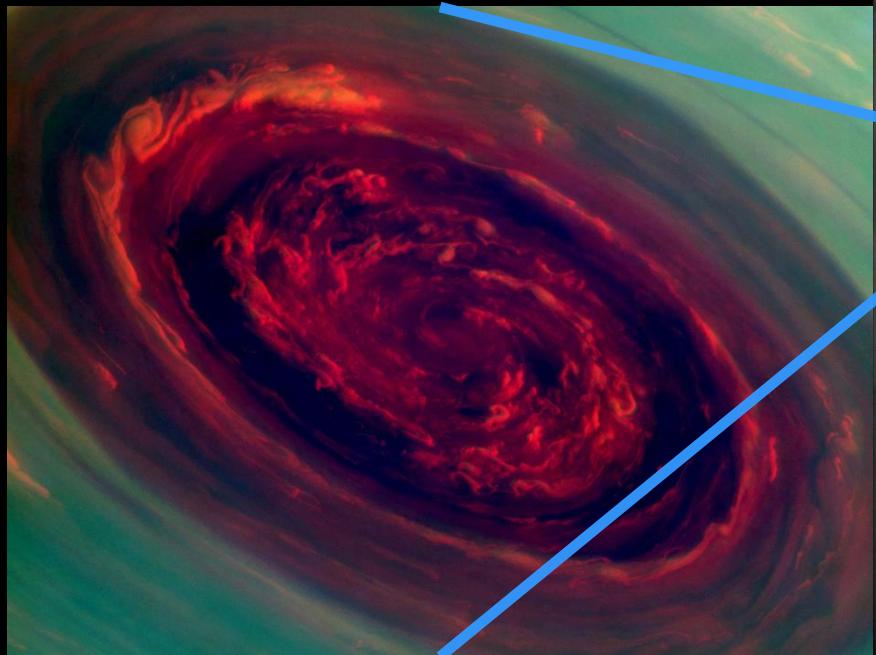


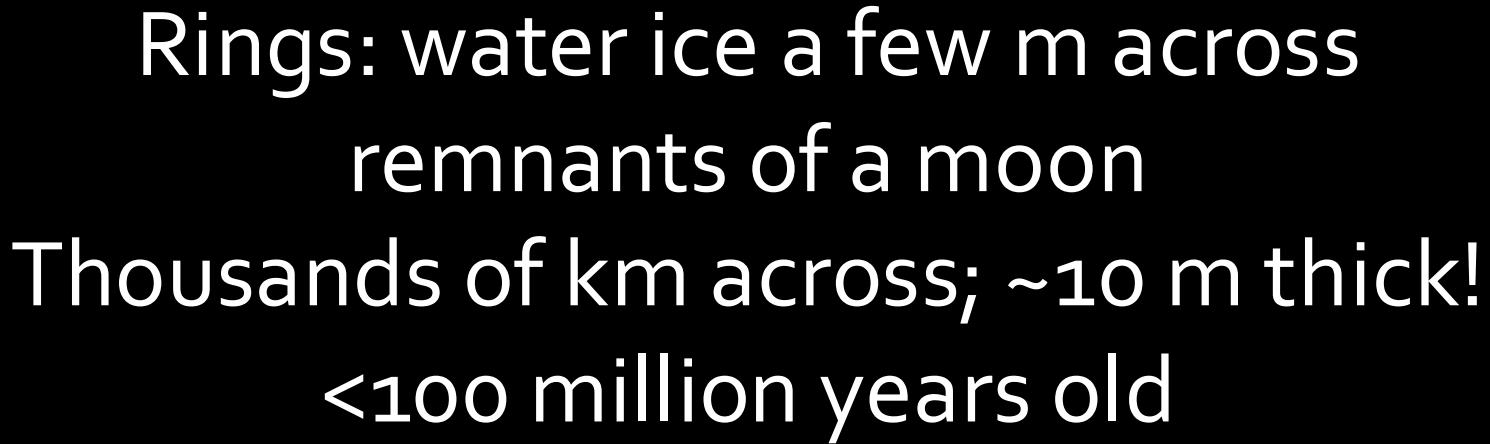


Saturn's aurora

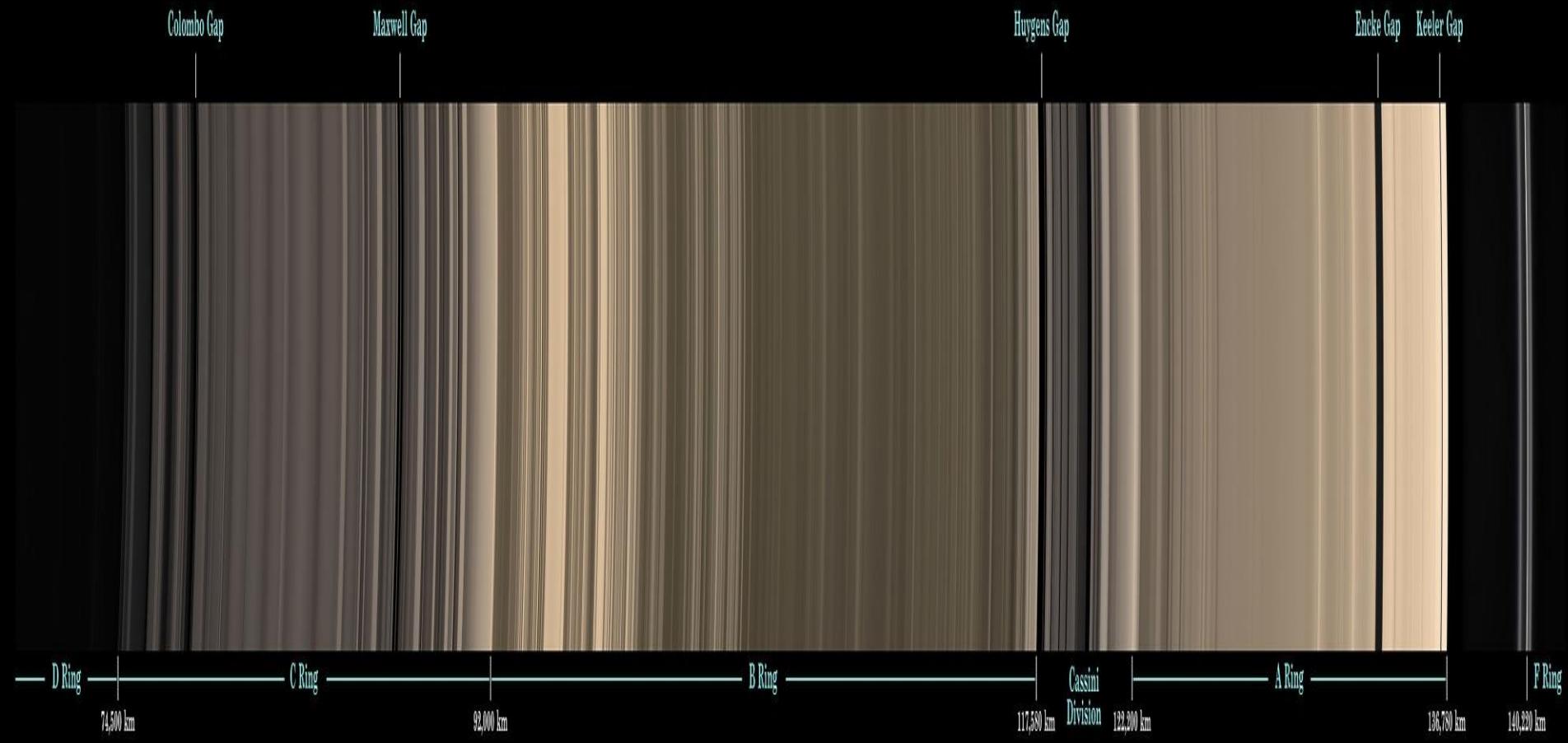


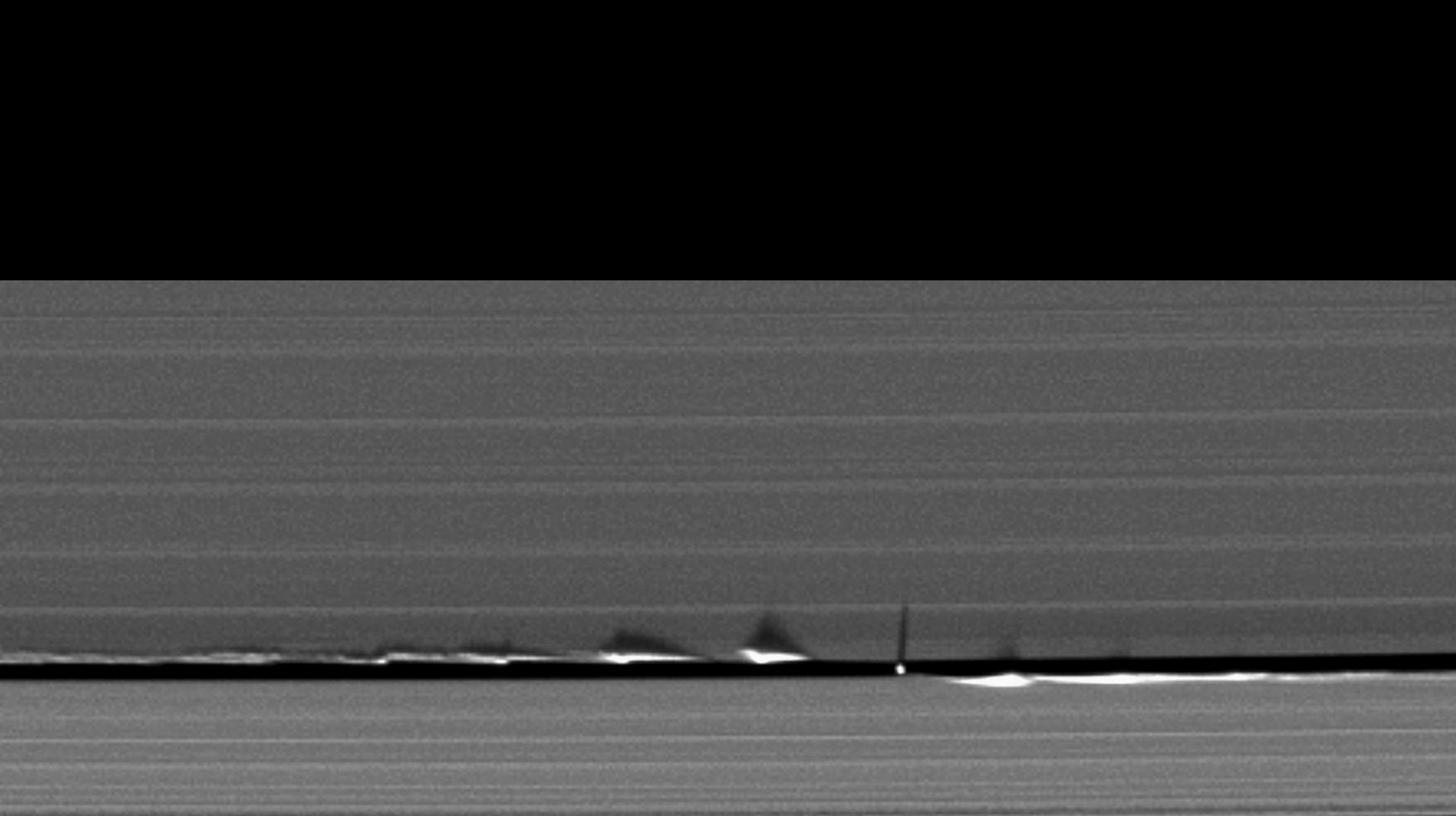


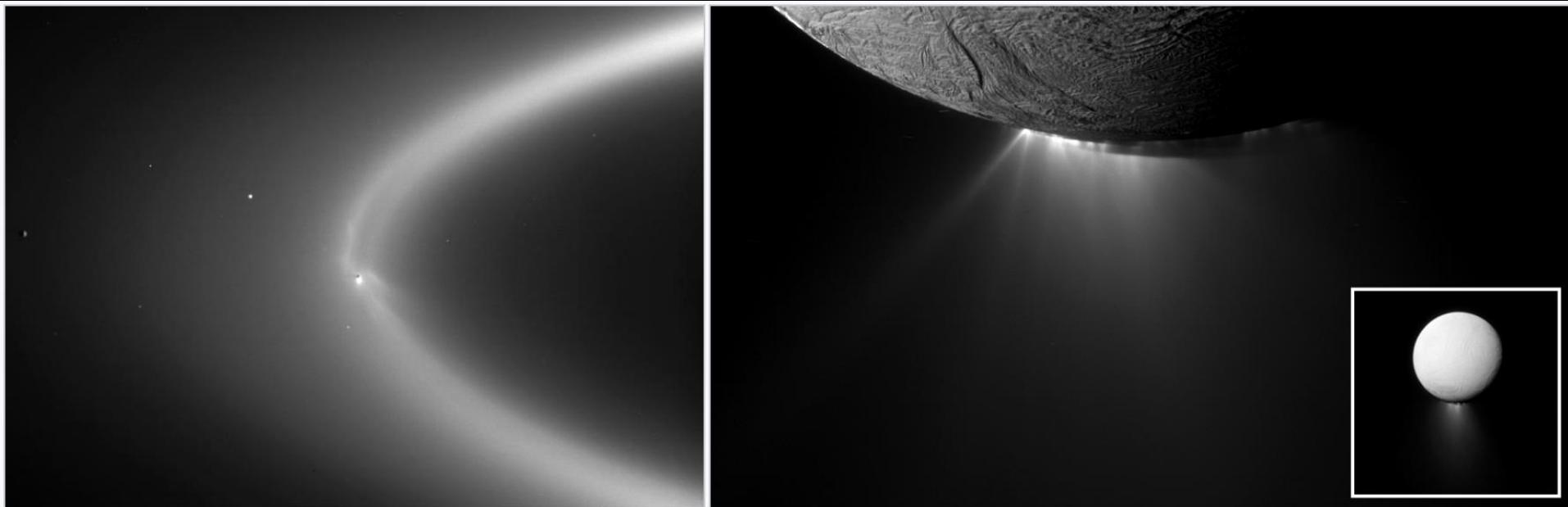




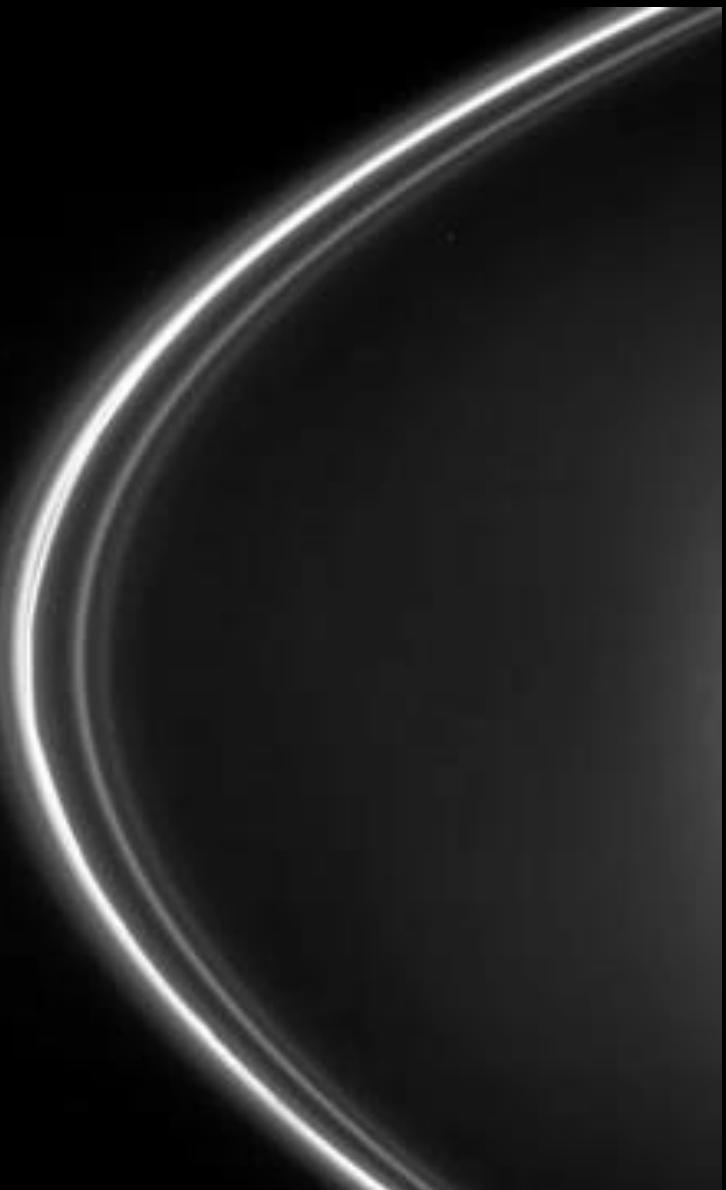
Rings: water ice a few m across
remnants of a moon
Thousands of km across; ~10 m thick!
<100 million years old

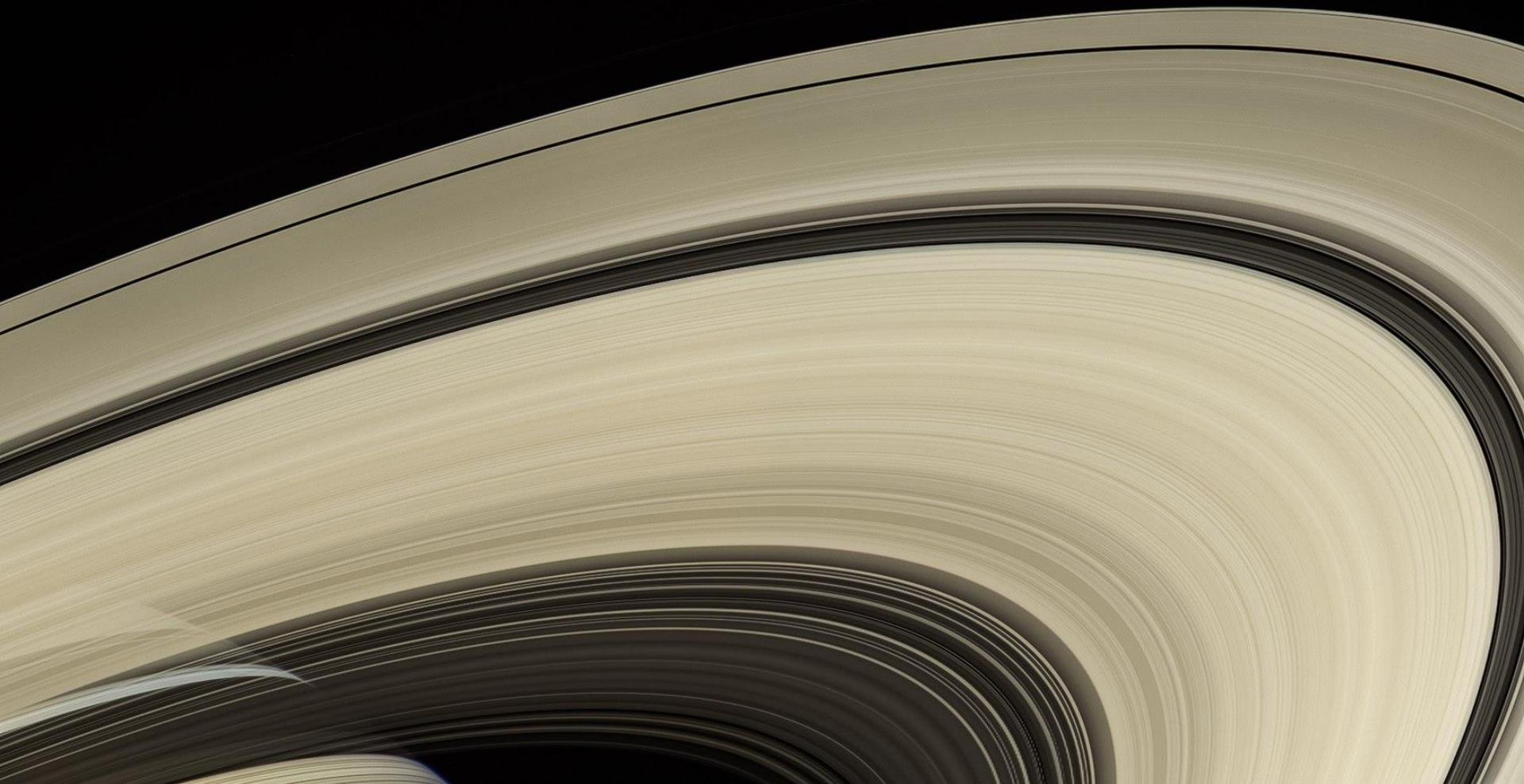






E ring: thousands of m thick
Water from geysers on the moon Enceladus

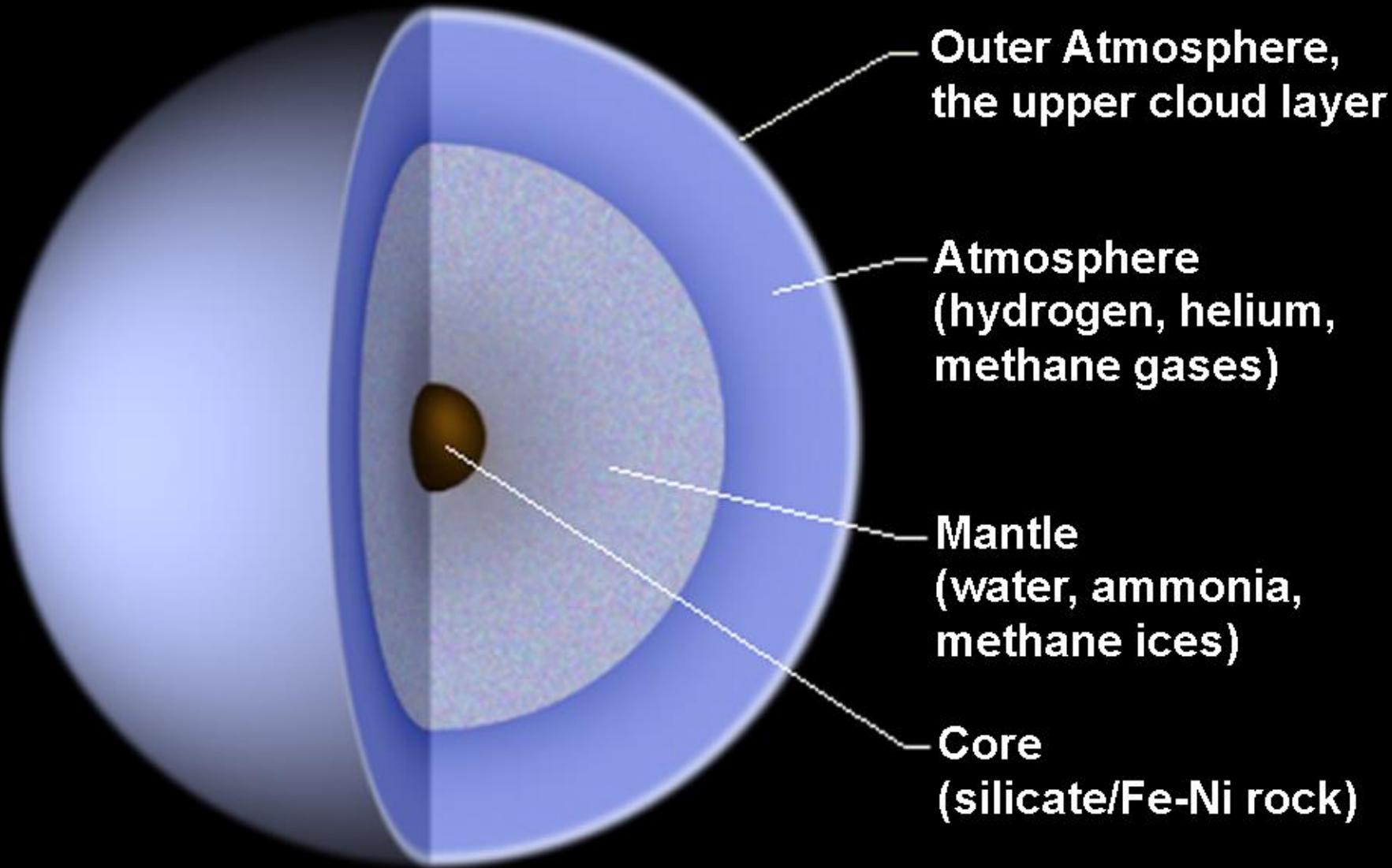




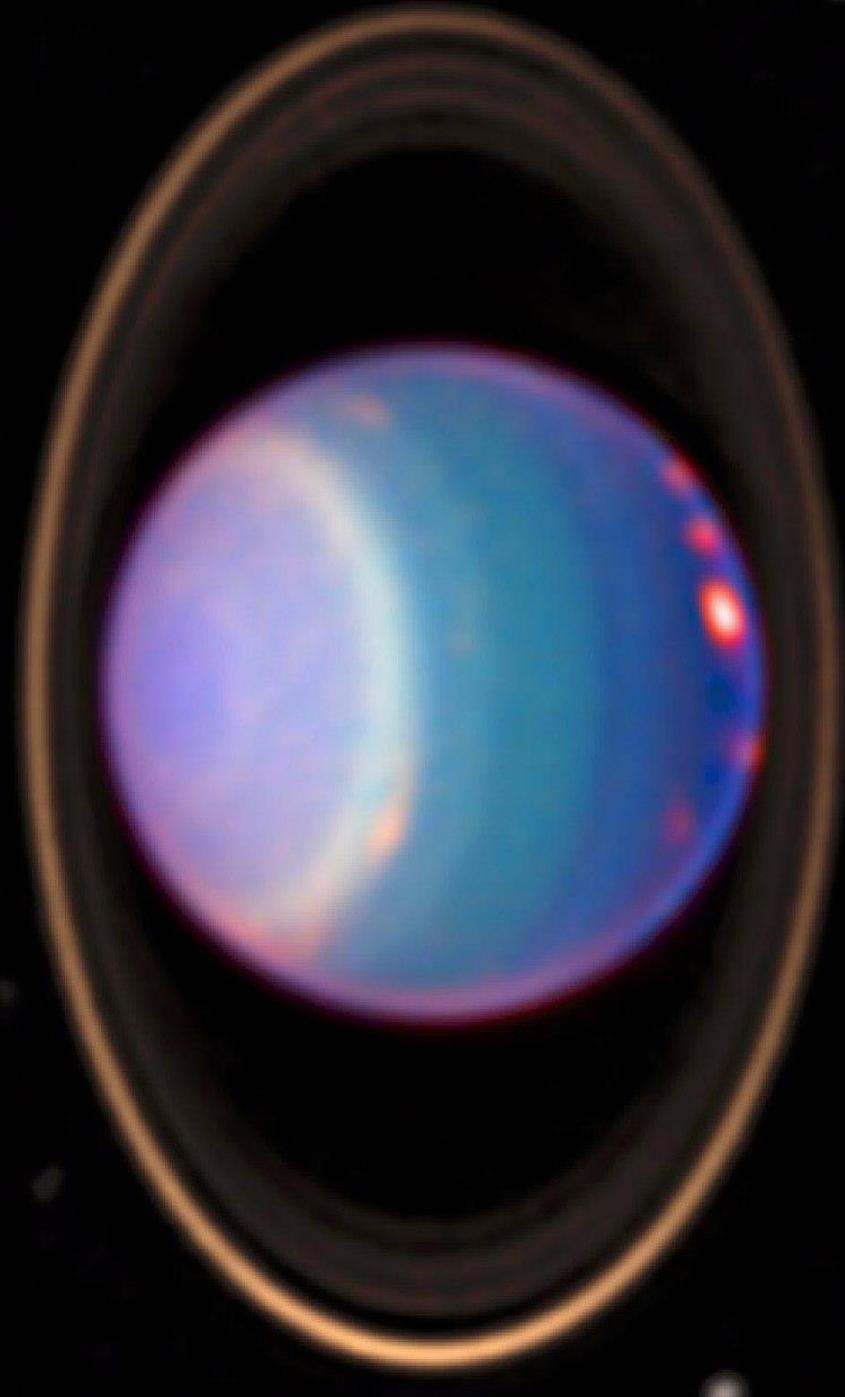


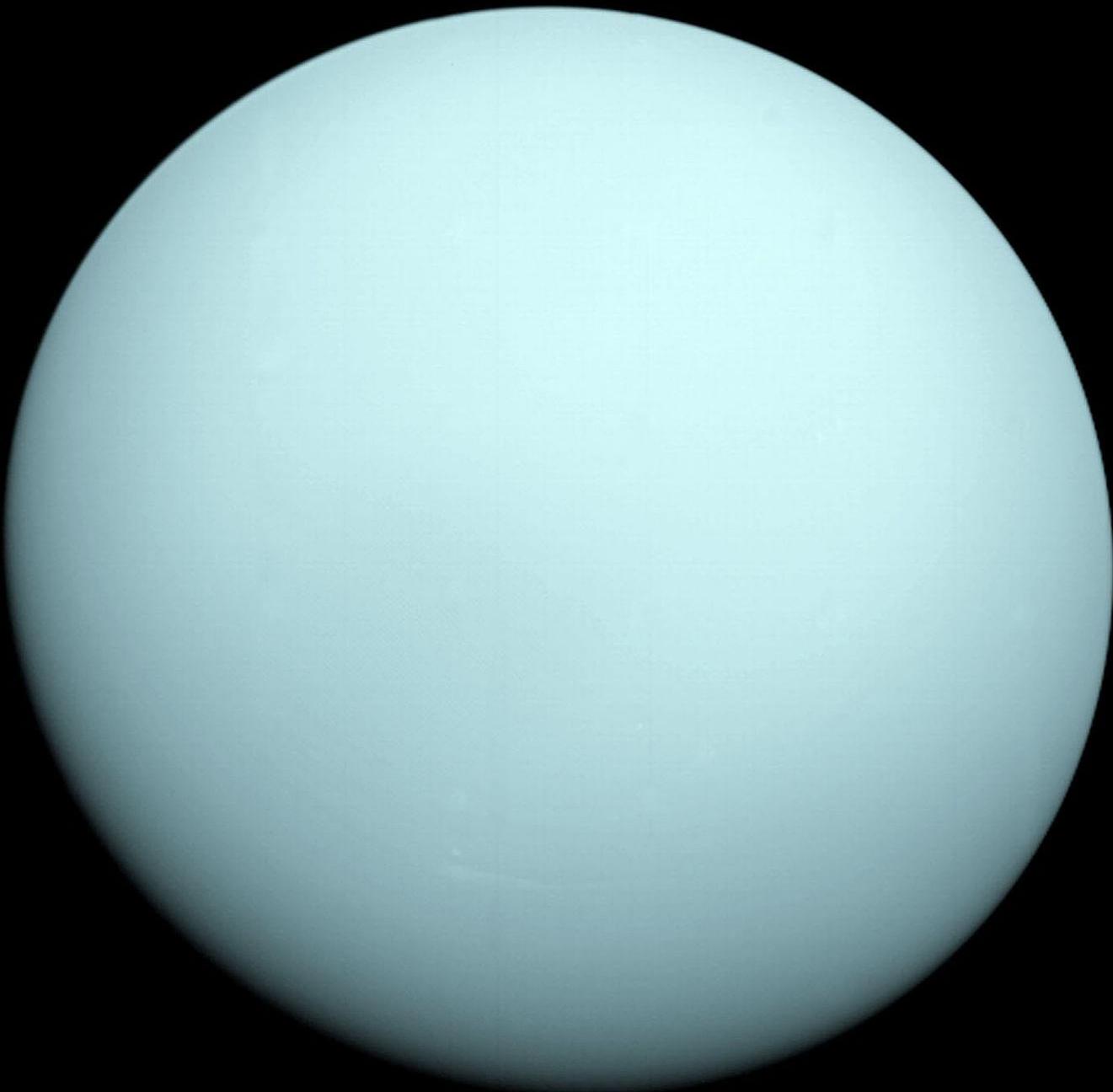
Uranus

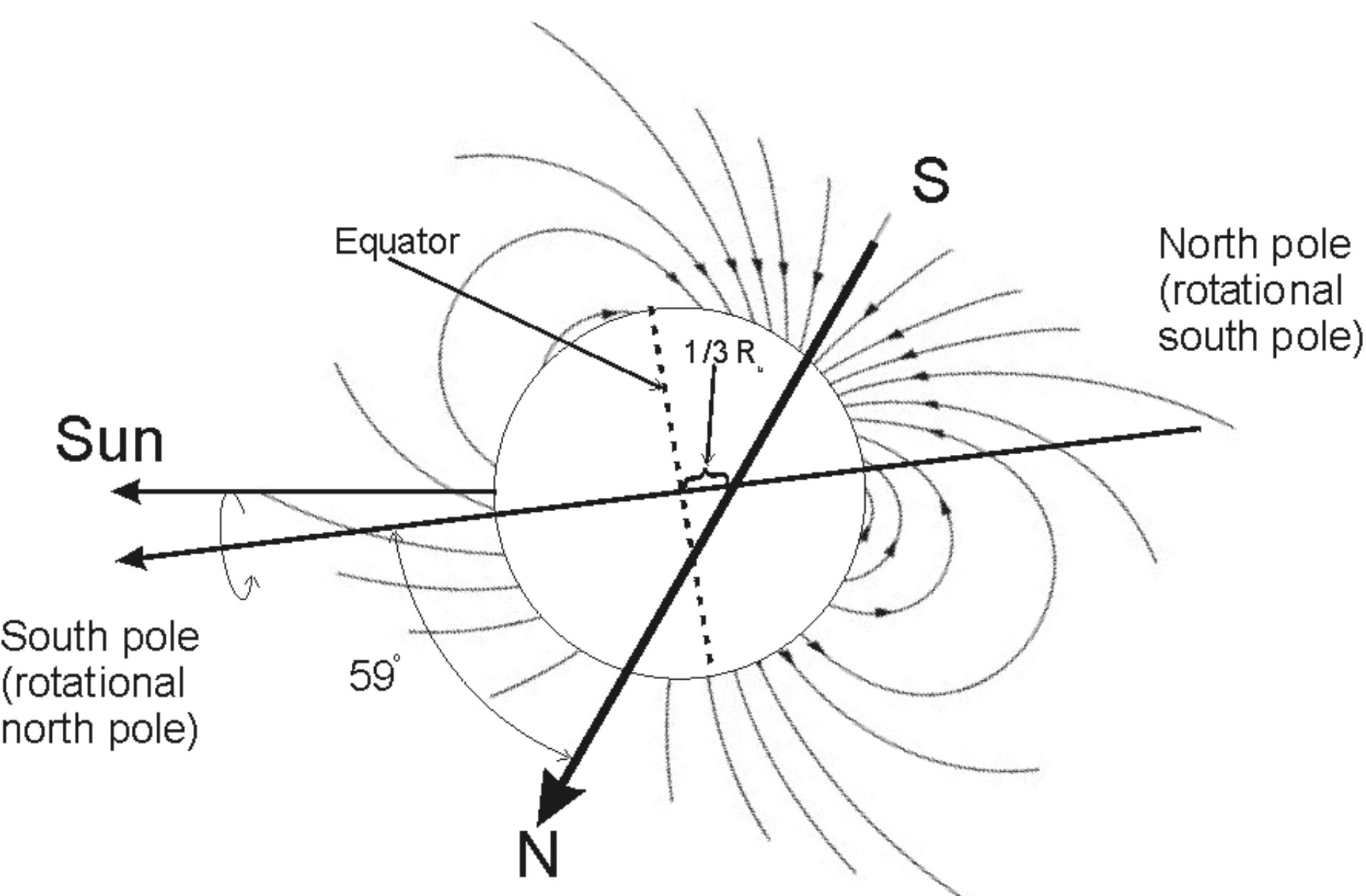




Tilted by 90 degrees!
-past collision

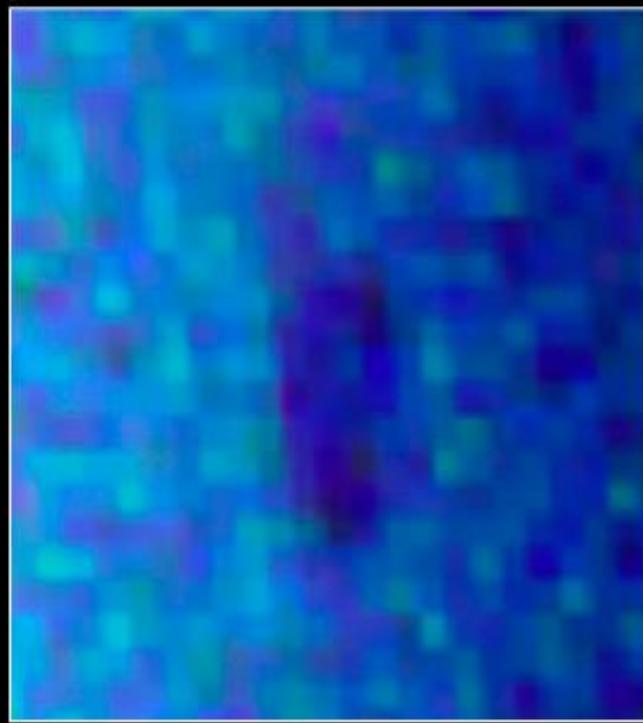
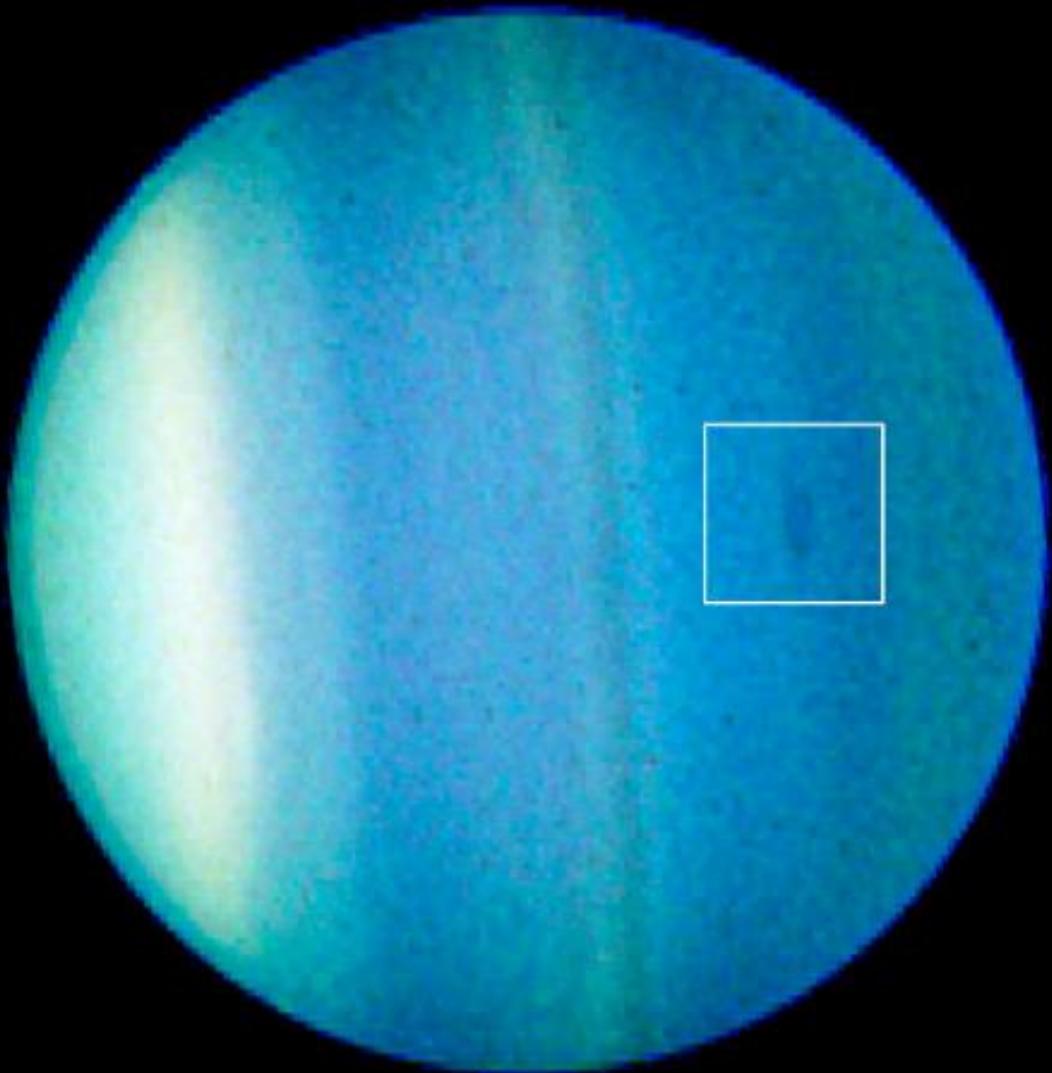






Uranus Dark Spot

Hubble Space Telescope • ACS

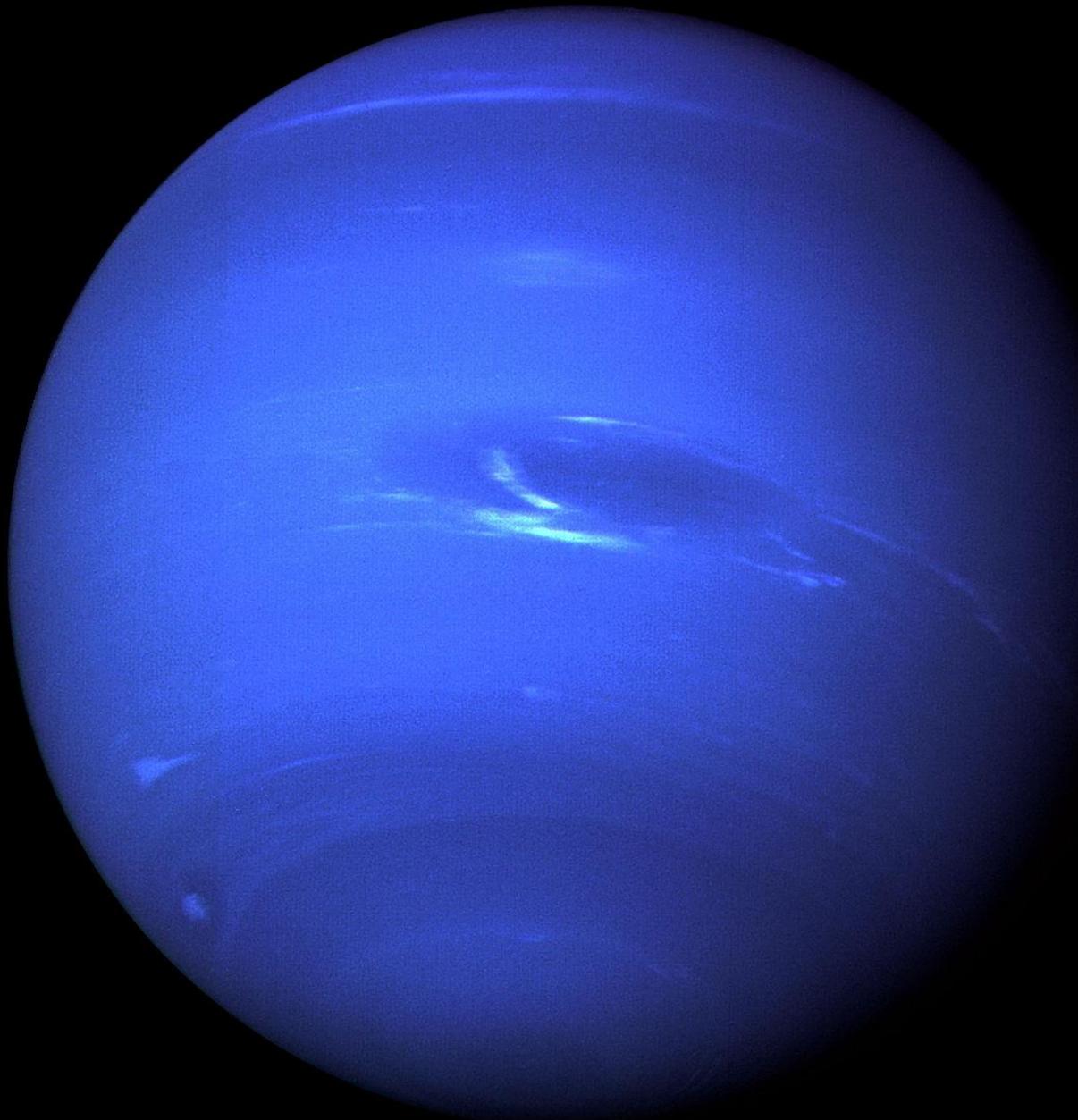


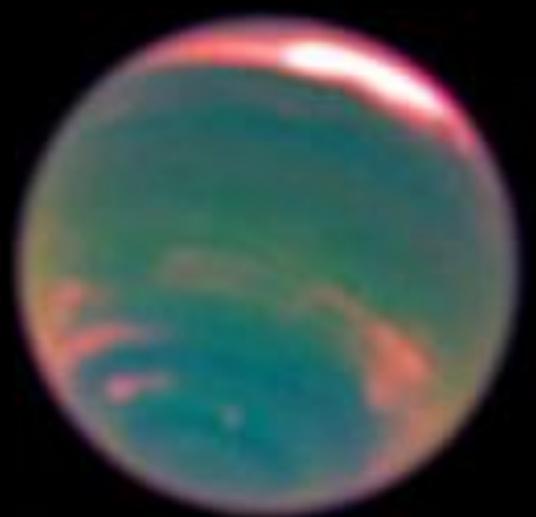
5,000 miles

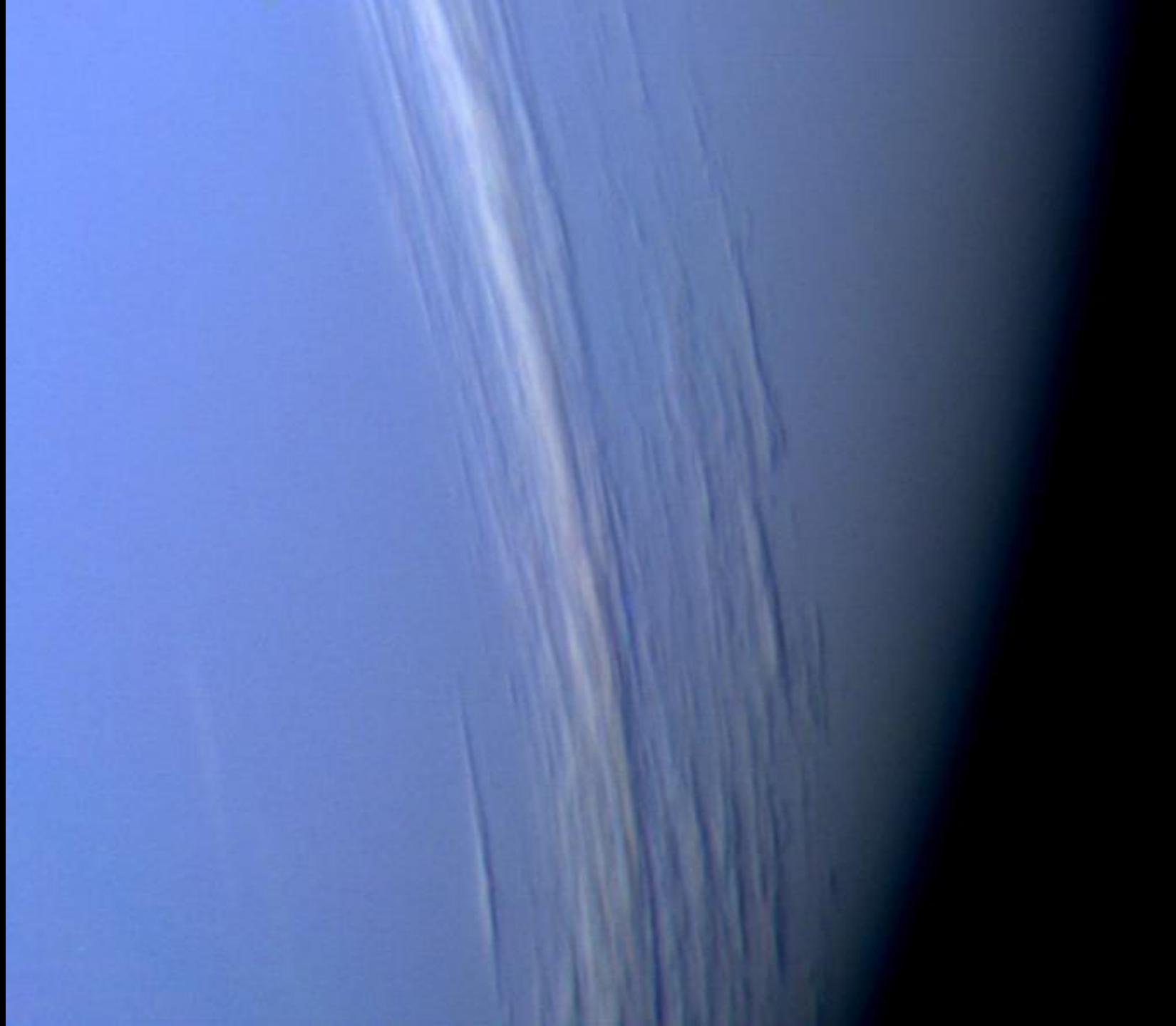
8,000 kilometers

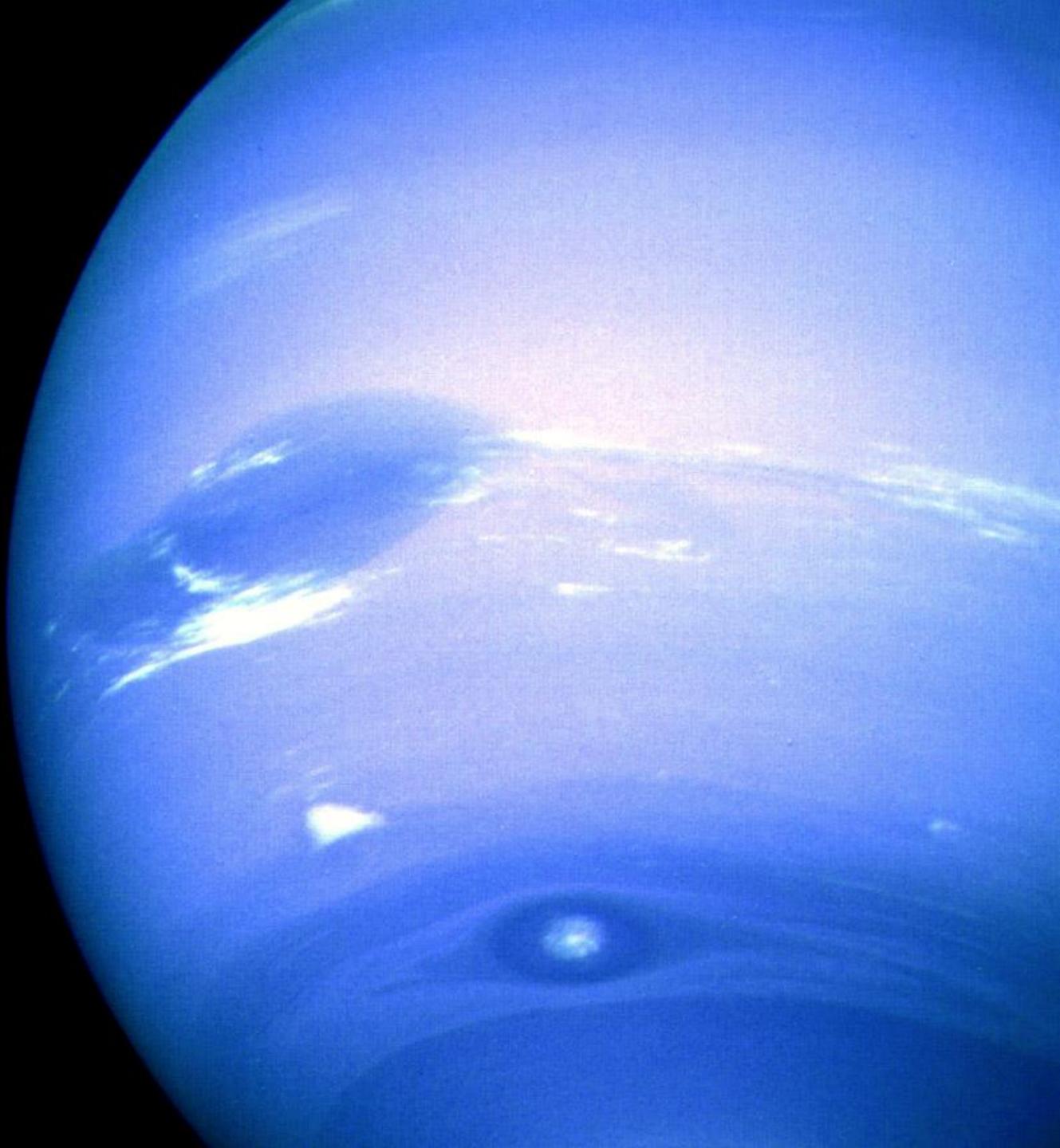


Neptune

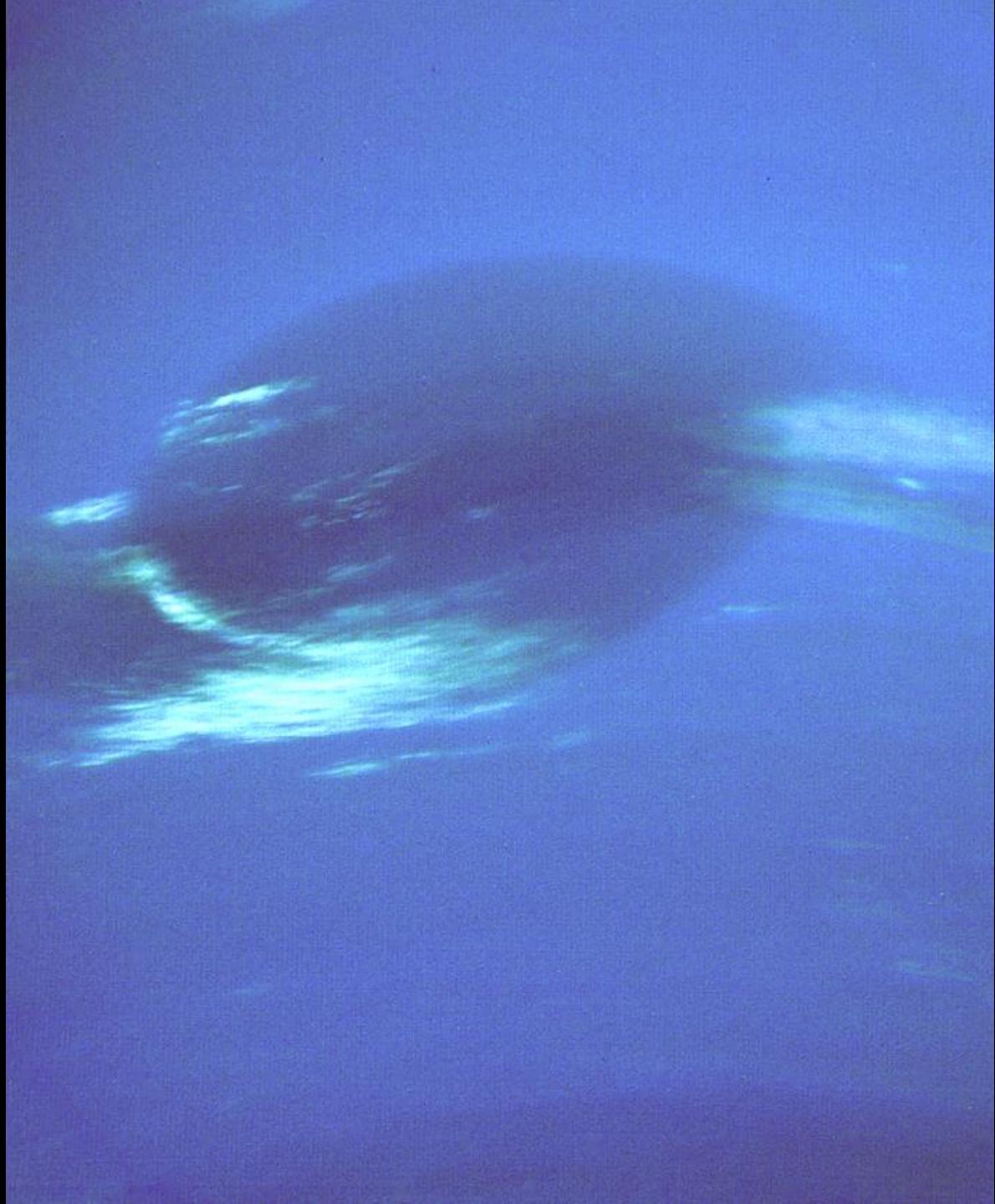


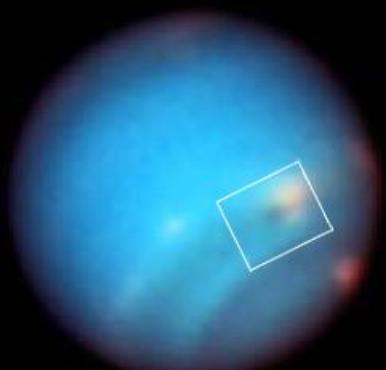




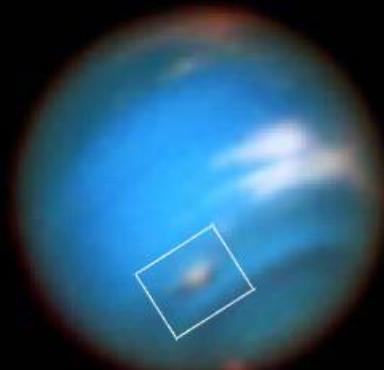




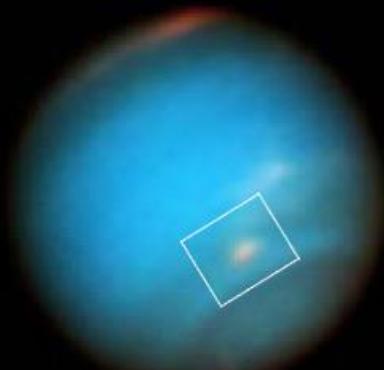




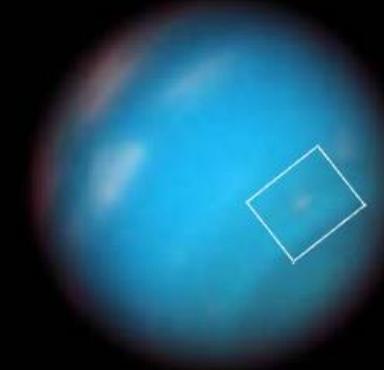
Sept. 18, 2015



May 16, 2016



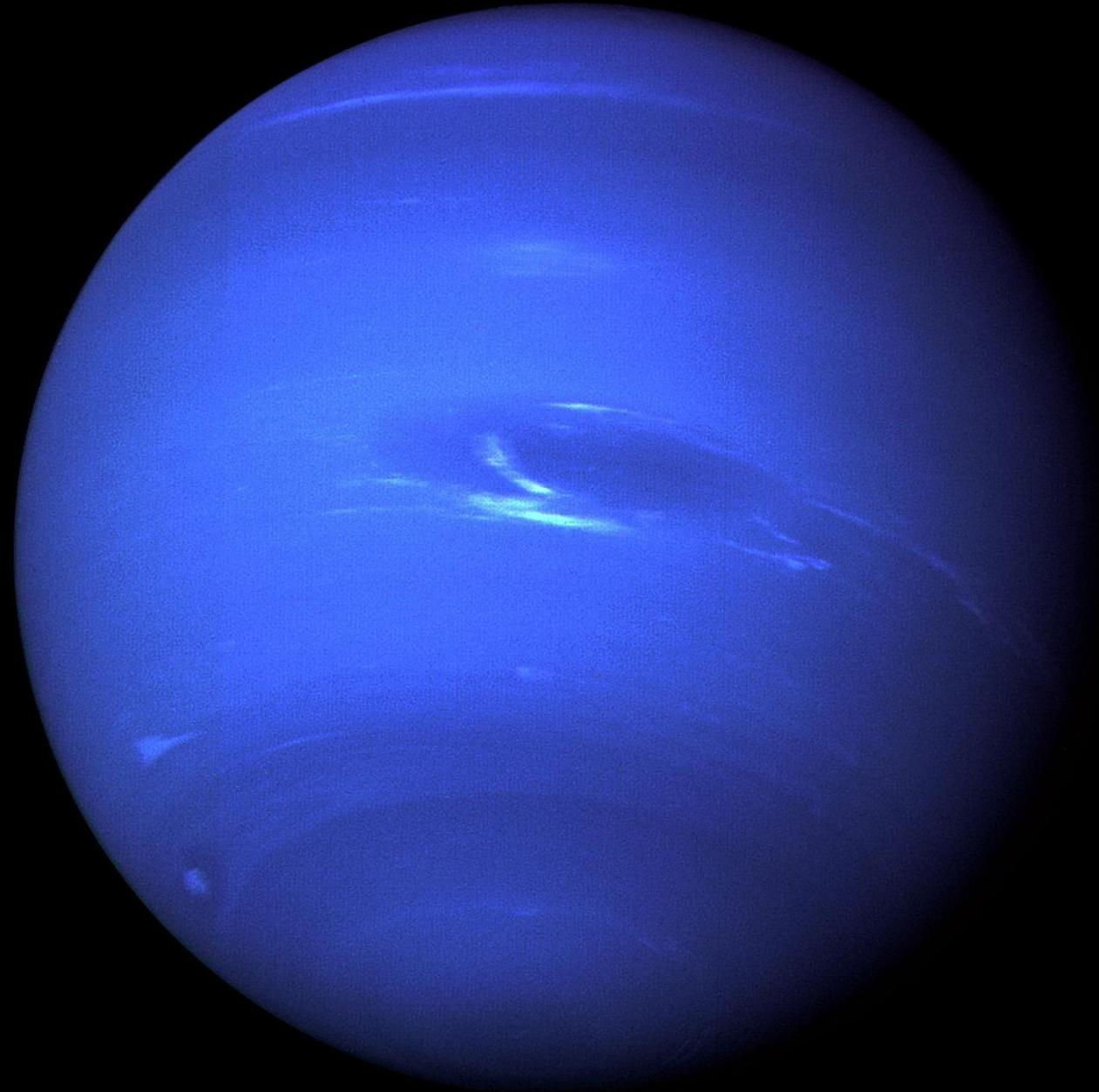
Oct. 3, 2016

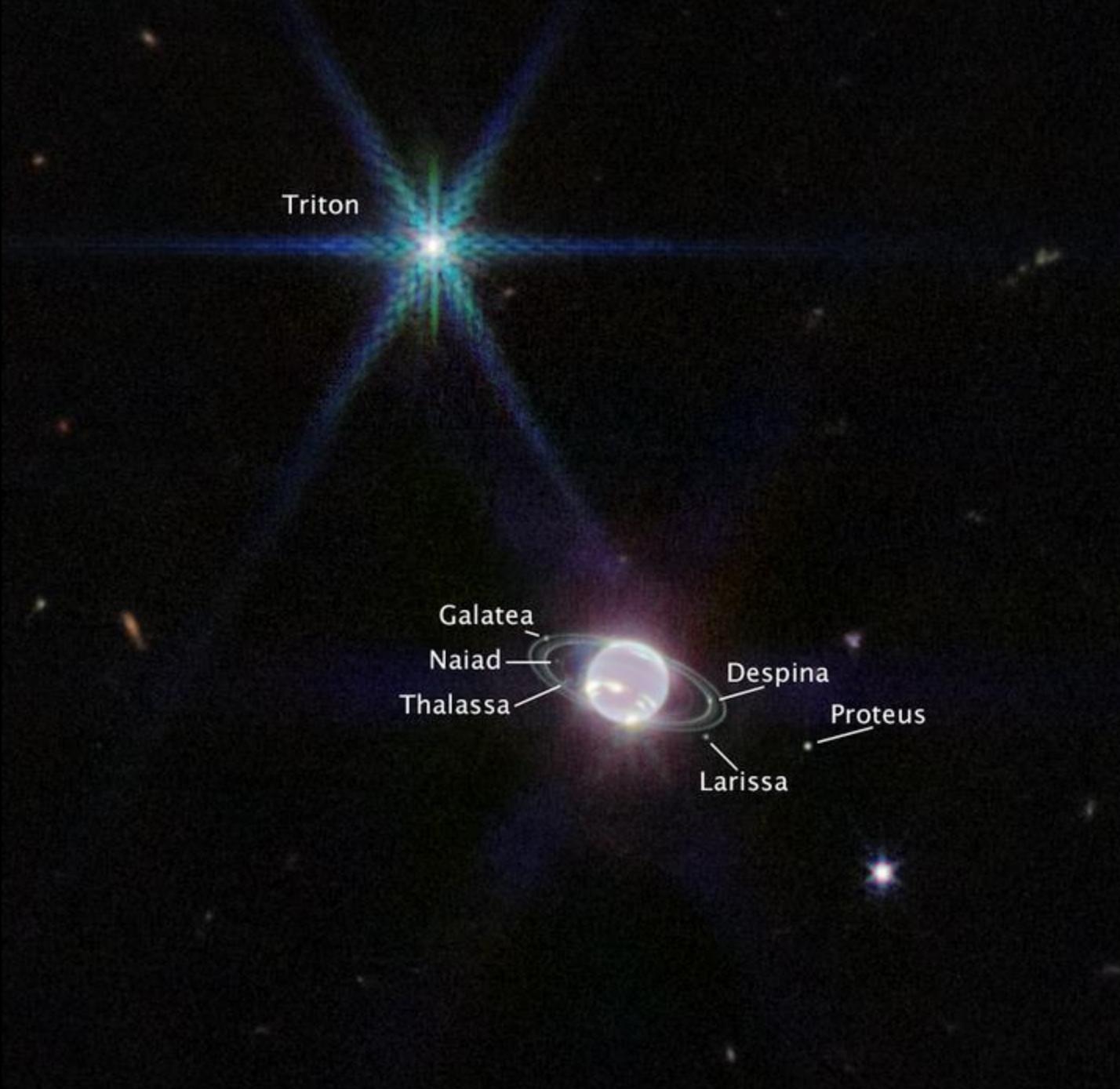


Oct. 6, 2017

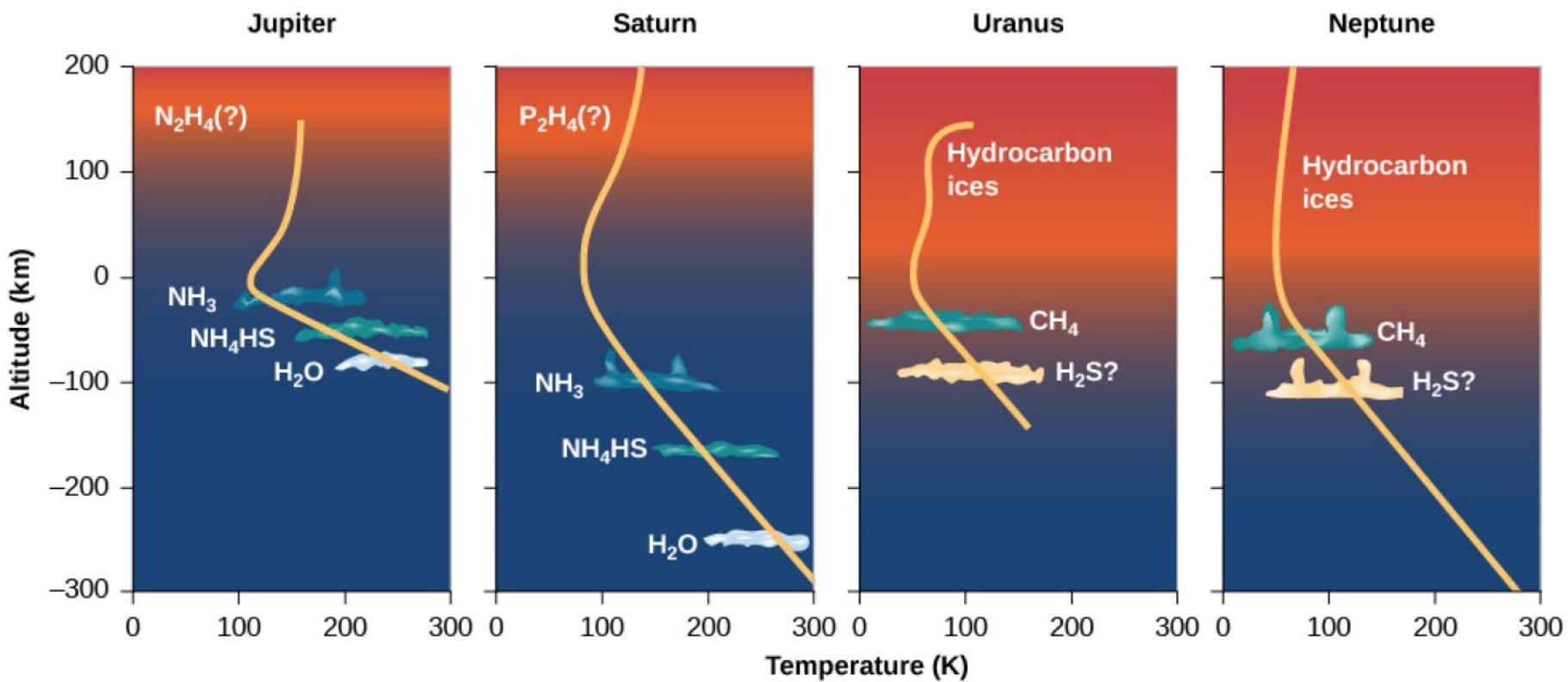
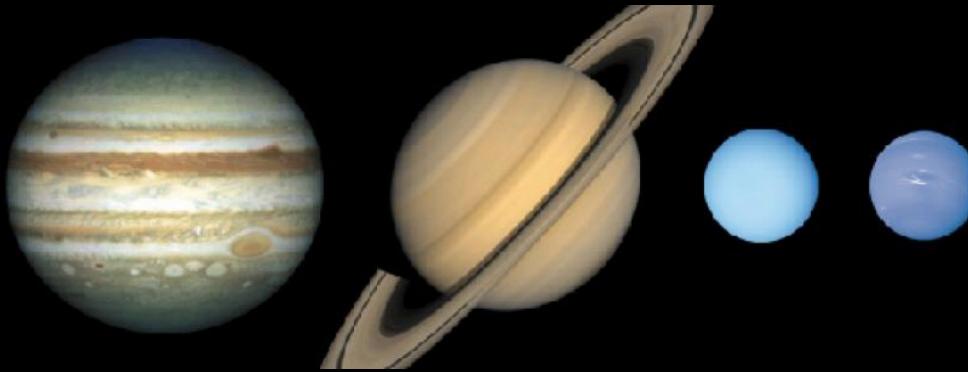








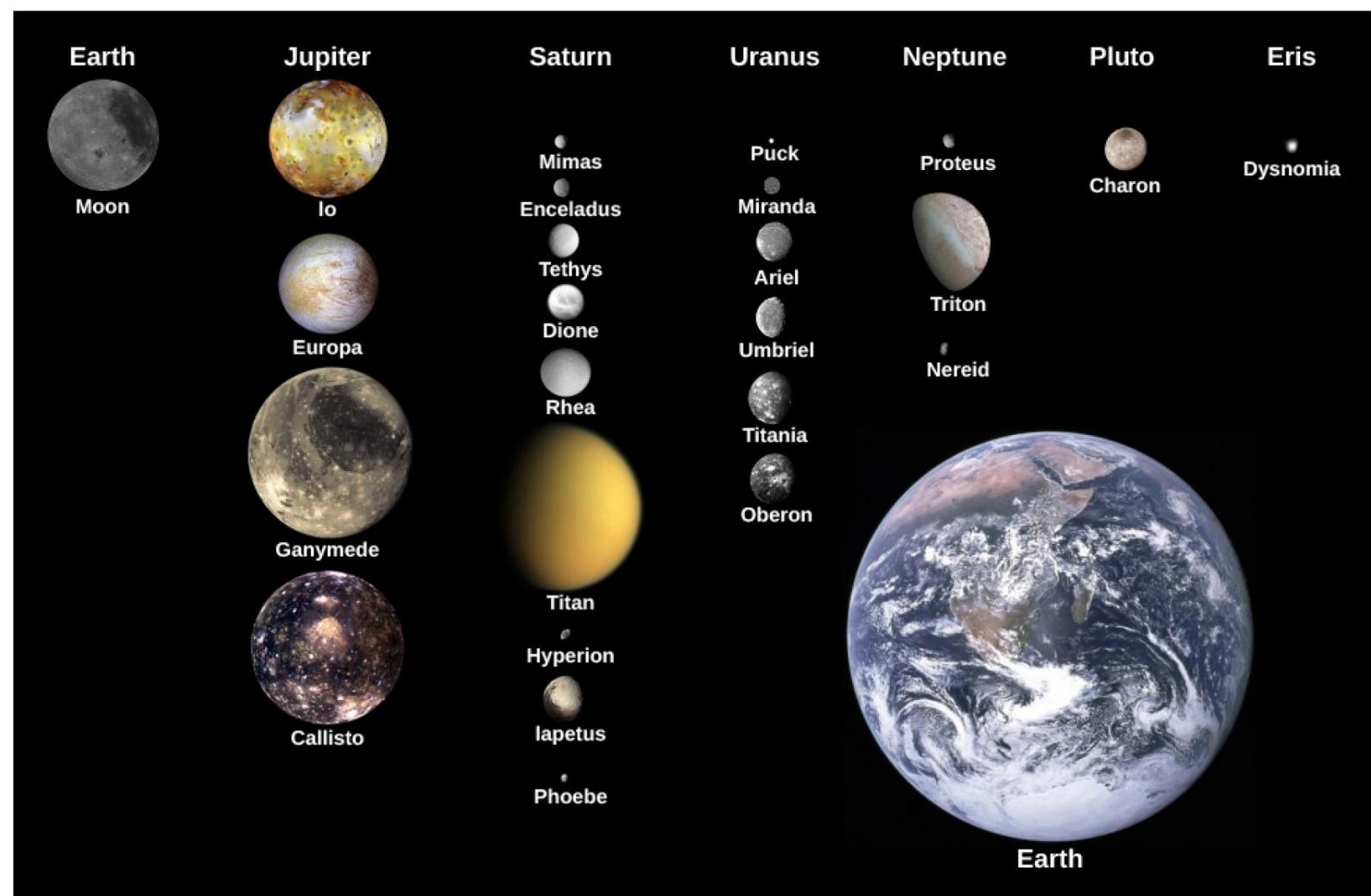
Clouds: scattering prevents detections of structure



Summary – number of moons

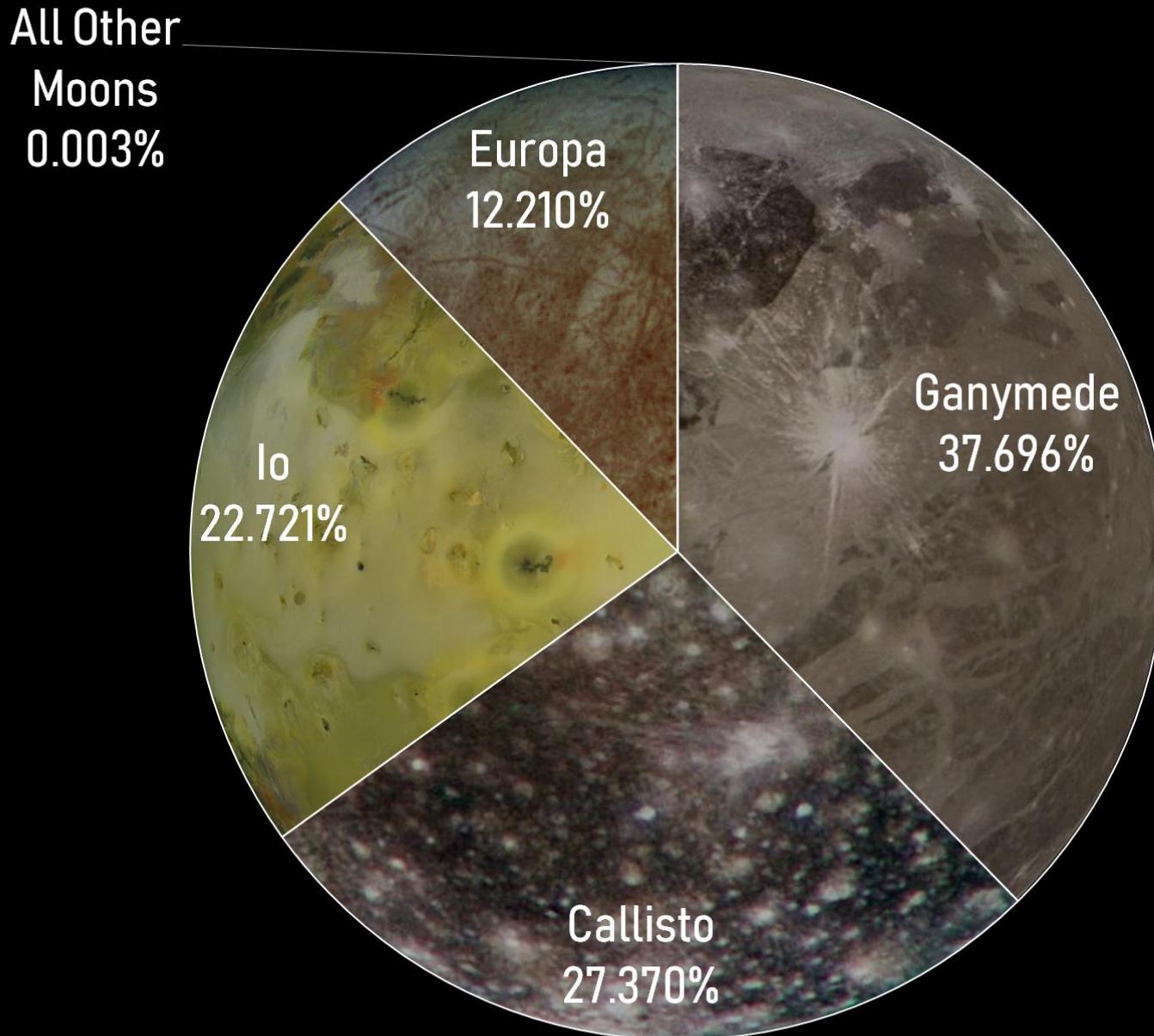
Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Number of moons	0	0	1	2	79	62	27	14

Dwarf planet	Ceres	Pluto	Haumea	Makemake	Eris
Number of moons	0	5	2	1	1

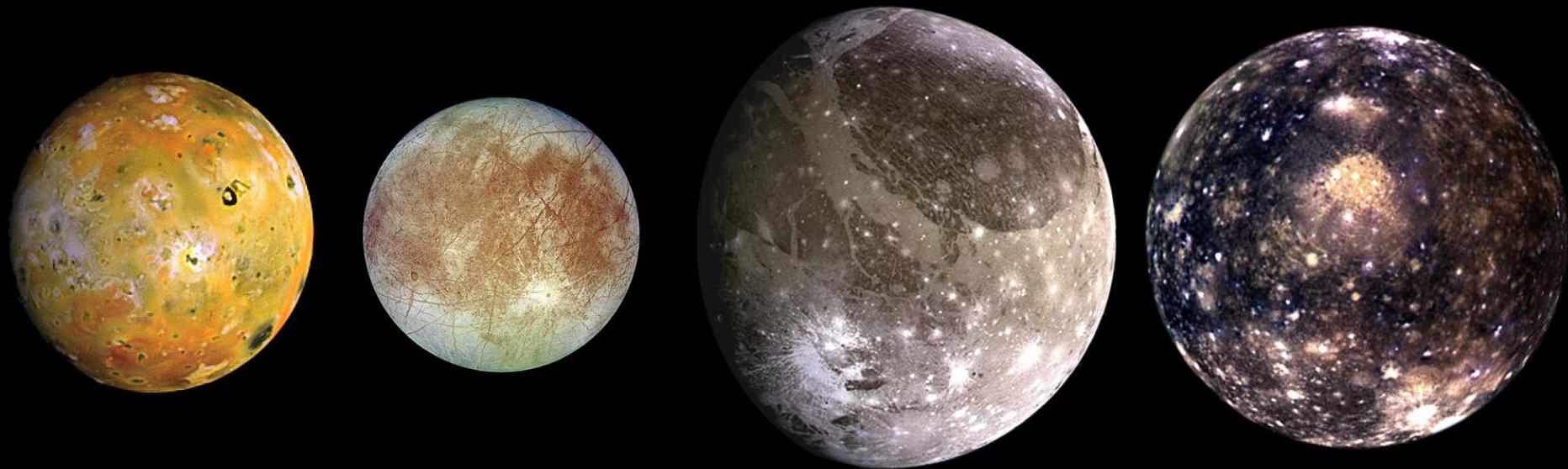


Order [note 3] ↗	Label [note 4] ↗	Name ↗	Pronunciation	Image	Abs. magn.	Diameter (km)[note 5] ↗	Mass ($\times 10^{16}$ ↗ kg)	Semi-major axis (km) ^[46]	Orbital period (d) ^{[46][note 6]}	Inclination (°) ^[46]	Eccentr. [41]	Discovery year ^[23]	Discoverer ^[23]	Group [note 7] ↗	
1	XVI	Metis	/ˈmɛtɪs/		10.5	60 × 40 × 34	≈3.6		128 852	+7h 10m 16s	2.226	0.0077	1979	Synnott (Voyager 1)	Inner
2	XV	Adrastea	/əˈdræstɪə/		12.0	20 × 16 × 14	≈0.2		129 000	+7h 15m 21s	2.217	0.0063	1979	Jewitt (Voyager 2)	Inner
3	V	Amalthea	/əˈmælθiə/ ^[47]		7.1	250 × 146 × 128 (167 ± 4.0)	208		181 366	+12h 01m 46s	2.565	0.0075	1892	Barnard	Inner
4	XIV	Thebe	/θiːbi/		9.0	116 × 98 × 84	≈43		222 452	+16h 16m 02s	2.909	0.0180	1979	Synnott (Voyager 1)	Inner
5	I	Io♦	/aɪoʊ/		-1.7	3 660.0 ×3 637.4 ×3 630.6	8 931 900		421 700	+1.7691	0.050 ^[48]	0.0041	1610	Galilei	Galilean
6	II	Europa♦	/jʊərəʊpə/ ^[49]		-1.4	3 121.6	4 800 000		671 034	+3.5512	0.471 ^[48]	0.0094	1610	Galilei	Galilean
7	III	Ganymede♦	/ɡænɪmɛd/ ^{[50][51]}		-2.1	5 262.4	14 819 000		1 070 412	+7.1546	0.204 ^[48]	0.0011	1610	Galilei	Galilean
8	IV	Callisto♦	/kəˈlistoʊ/		-1.2	4 820.6	10 759 000		1 882 709	+16.689	0.205 ^[48]	0.0074	1610	Galilei	Galilean
9	XVIII	Themisto†	/θɪˈmɪstɔʊ/		13.5	8	0.069		7 393 216	+129.87	45.762	0.2115	1975/2000	Kowal & Roemer/ Sheppard et al.	Themisto
10	XIII	Leda†	/lɛdə/		12.8	16	0.6		11 187 781	+240.82	27.562	0.1673	1974	Kowal	Himalia
11	VI	Himalia†	/hɪˈmɛliə/		8.3	170	670		11 451 971	+250.23	30.486	0.1513	1904	Perrine	Himalia
12	LXXI	S/2018 J 1†			15.9	2	0.0015		11 453 004	+250.40	30.606	0.0944	2018	Sheppard et al.	Himalia

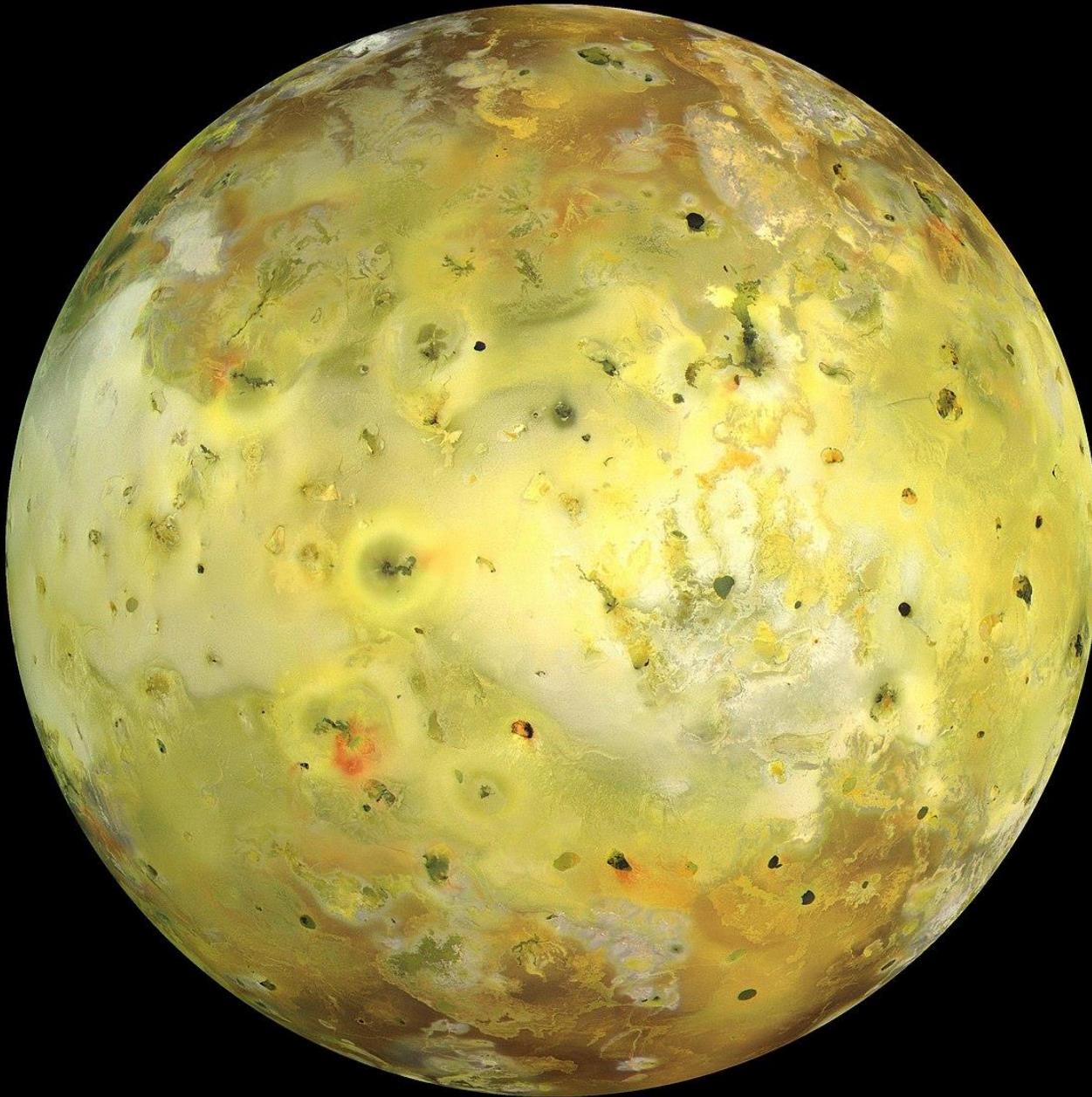
Relative Masses of Jovian Satellites

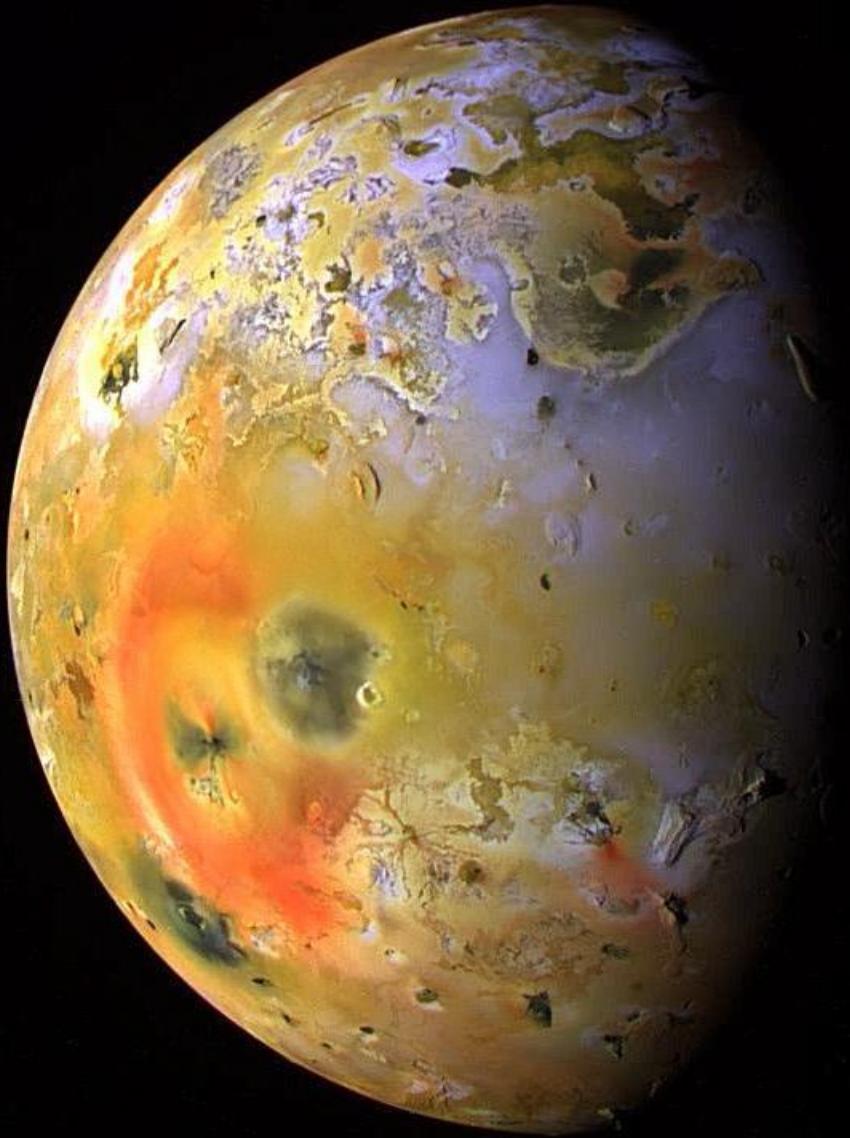


Galilean satellites of Jupiter



Io: a volcanic moon heated by tides





Io Surface Changes

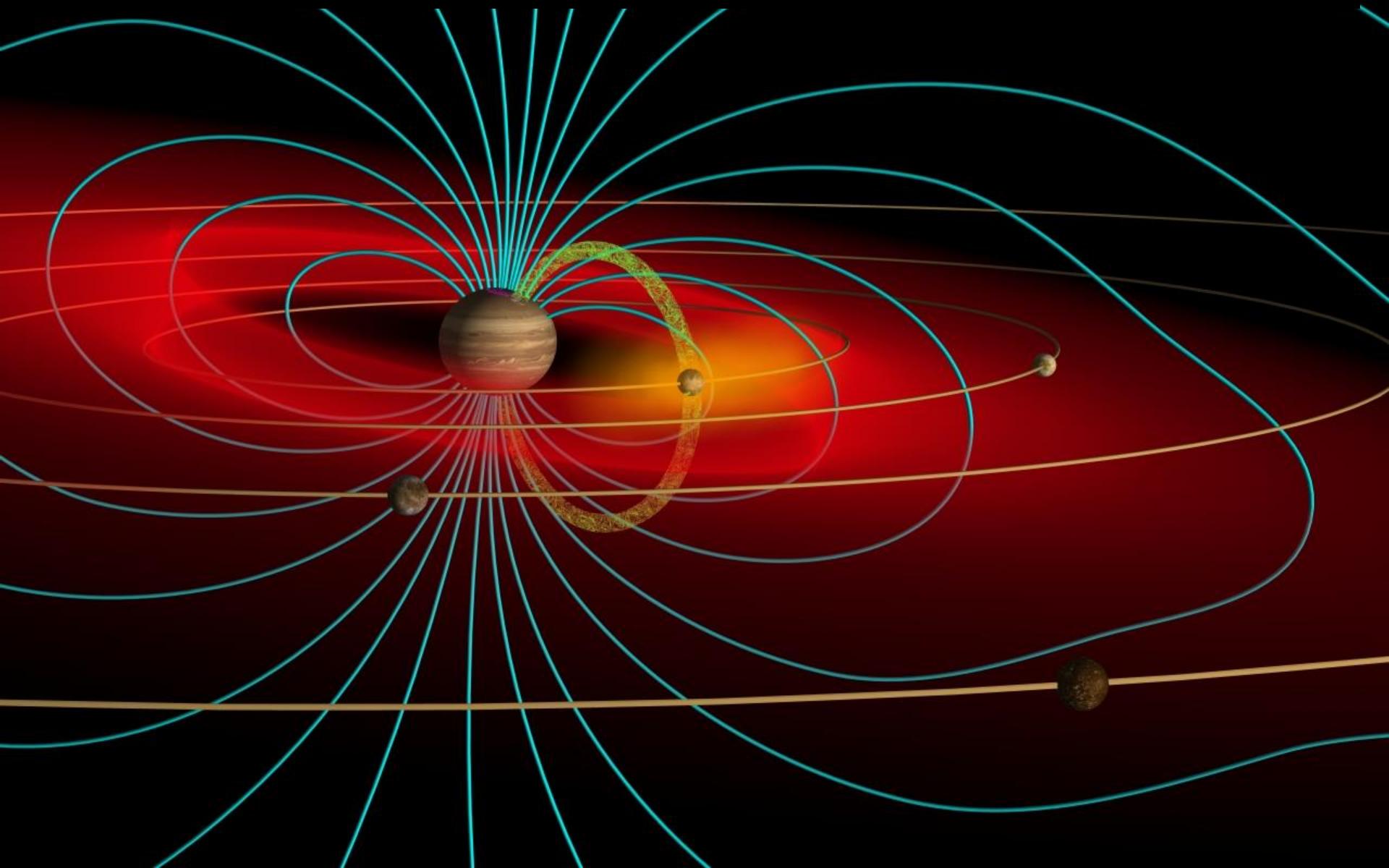
Galileo 1999



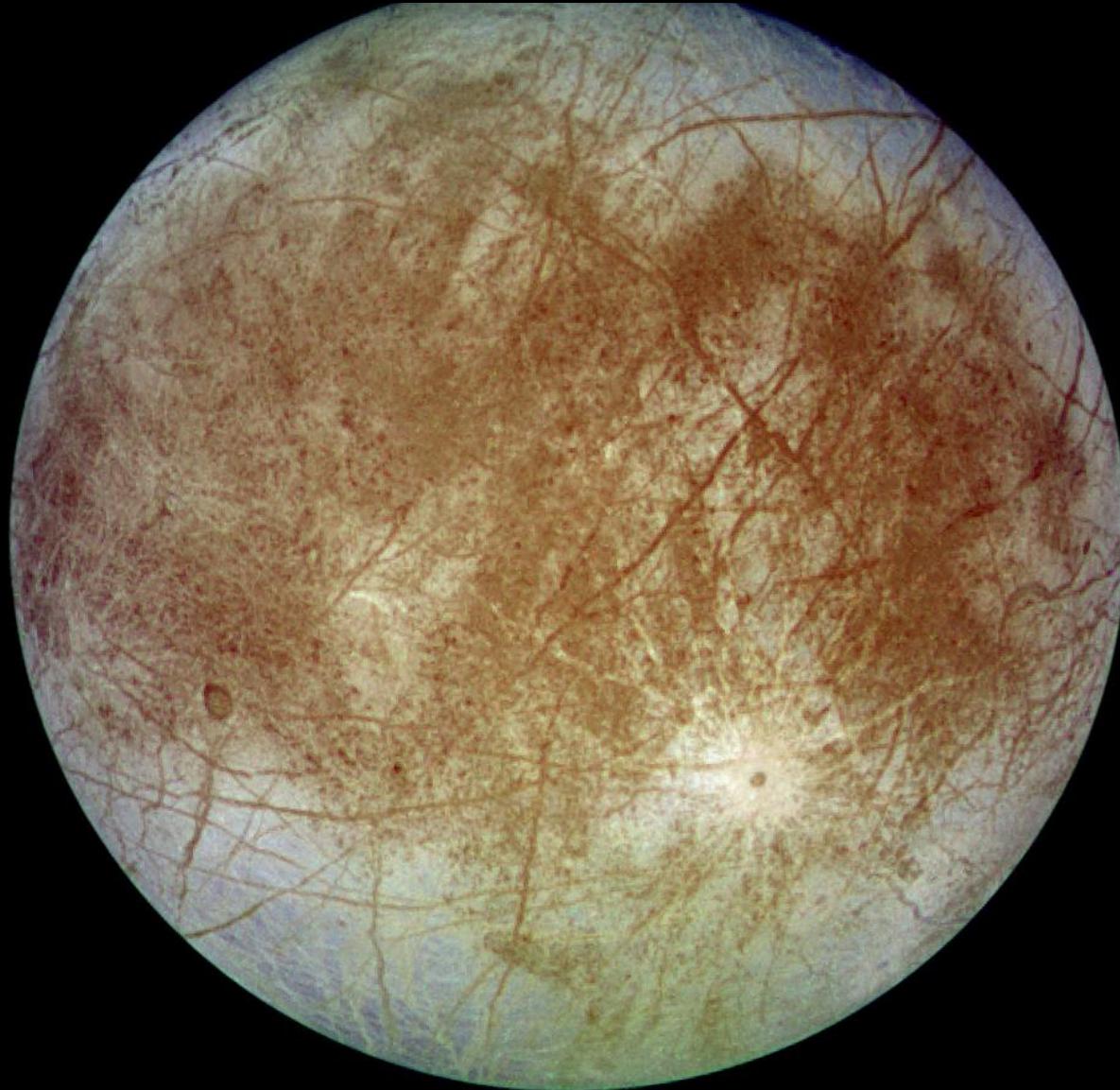
New Horizons 2007

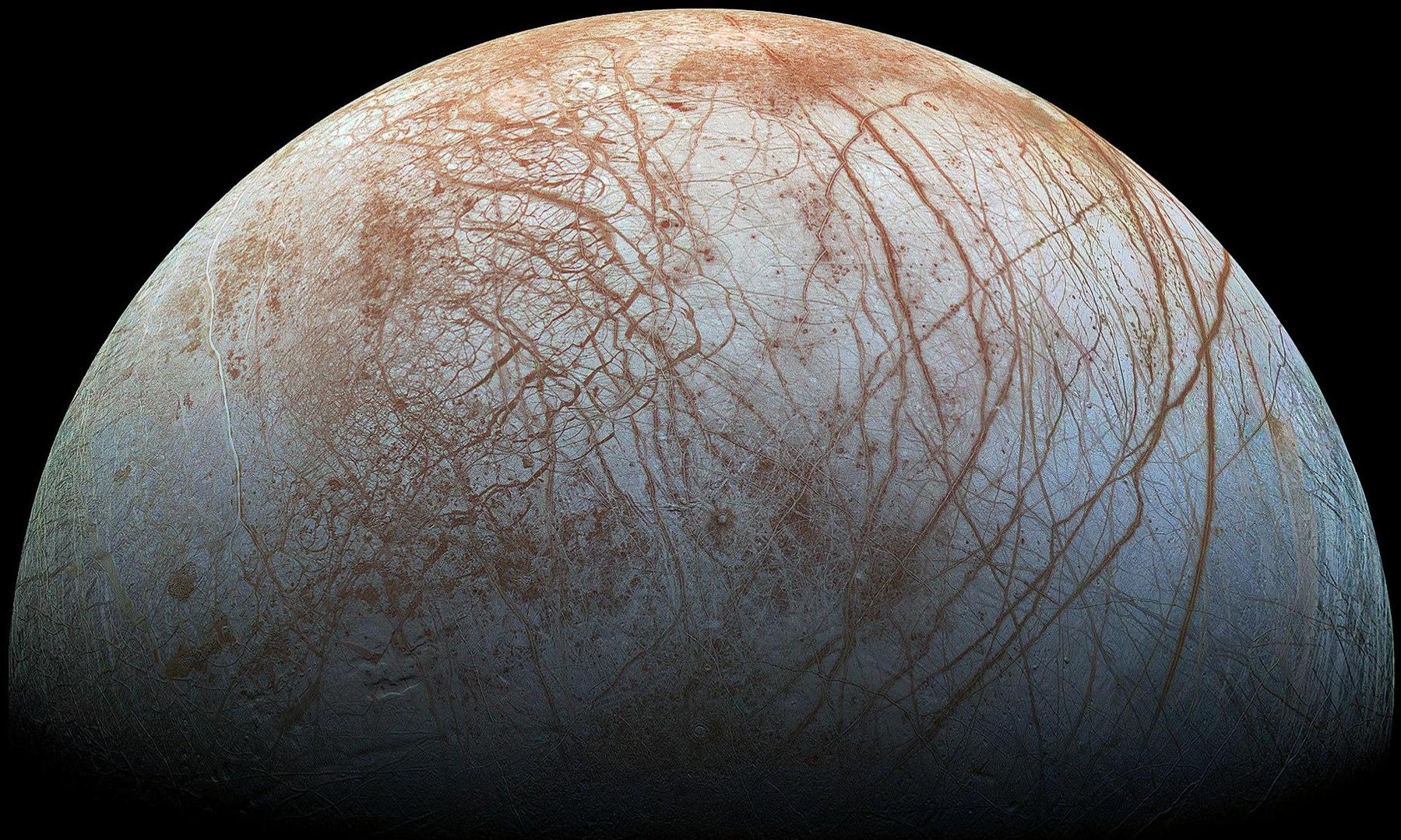


Io: cloud around Io because of
Jupiter's magnetic field

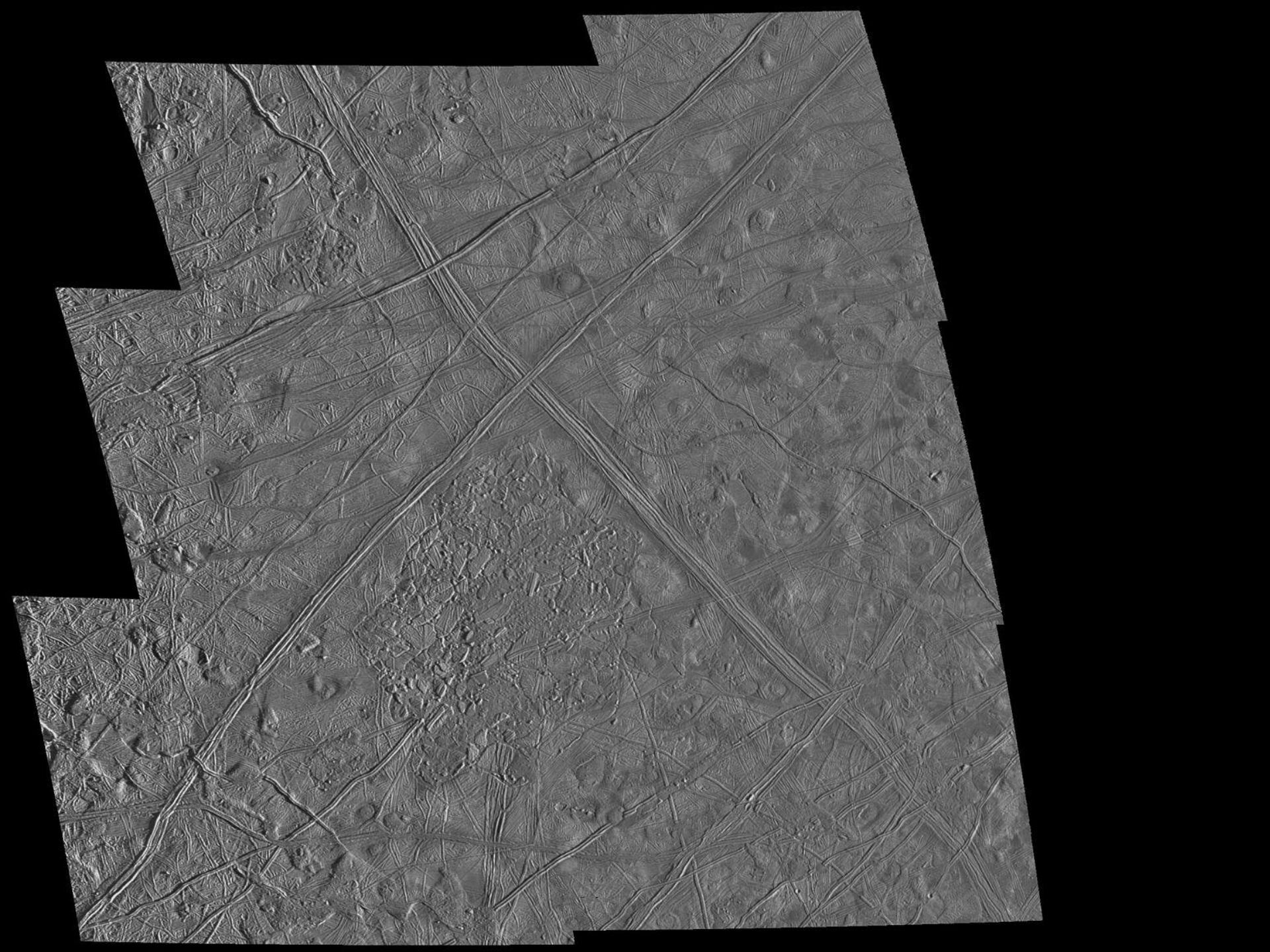


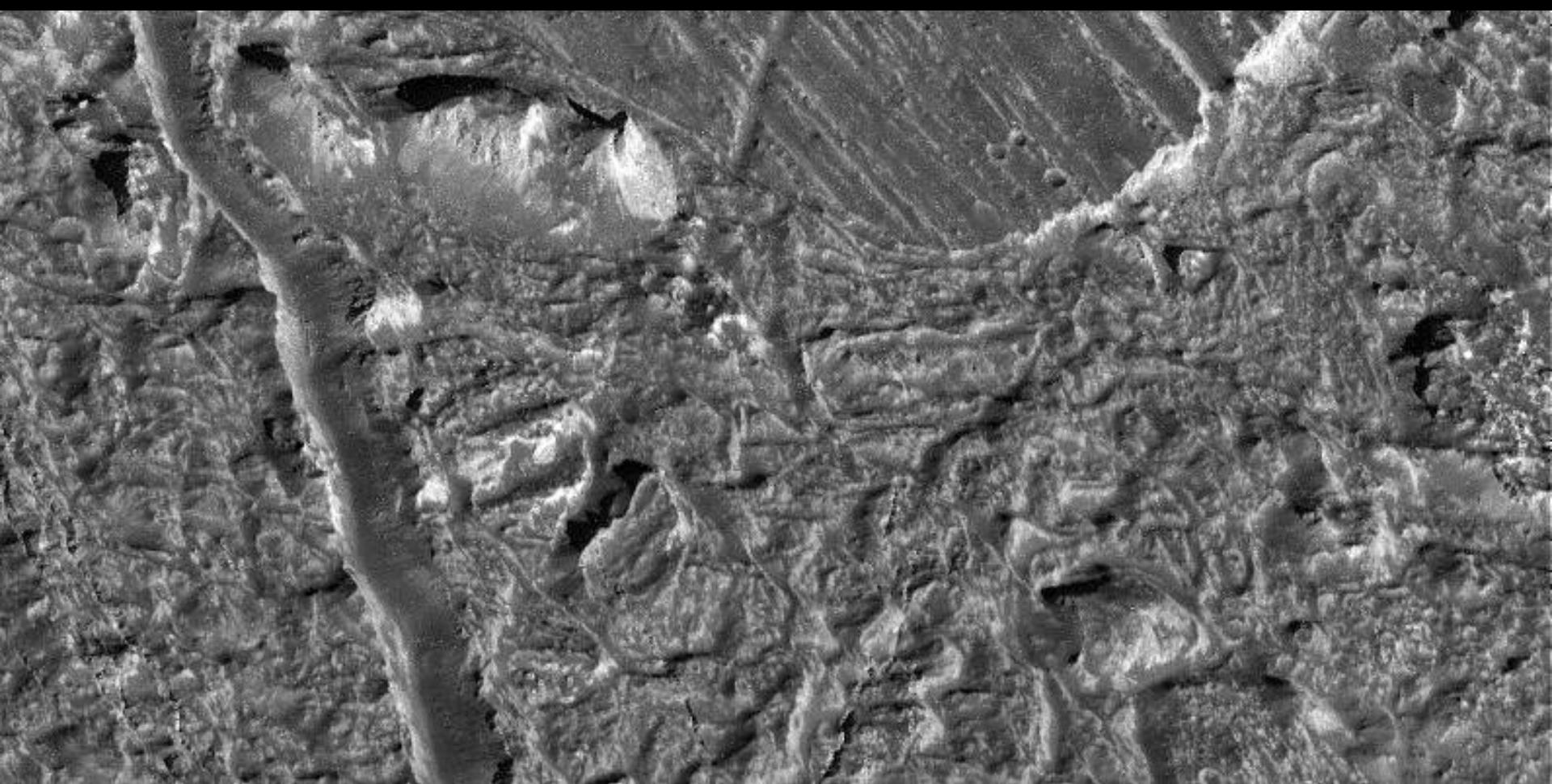
Europa: smallest of inner moons; ice world

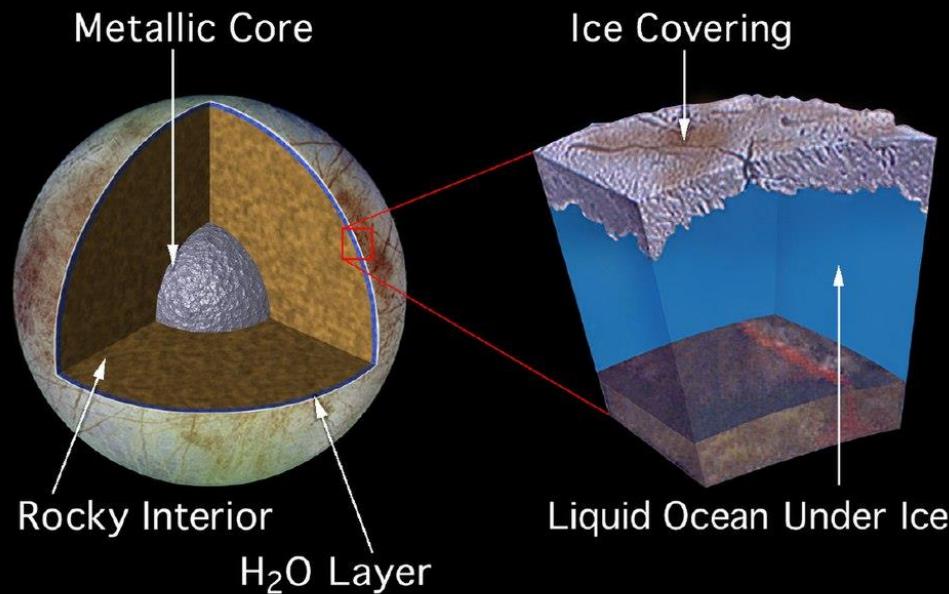
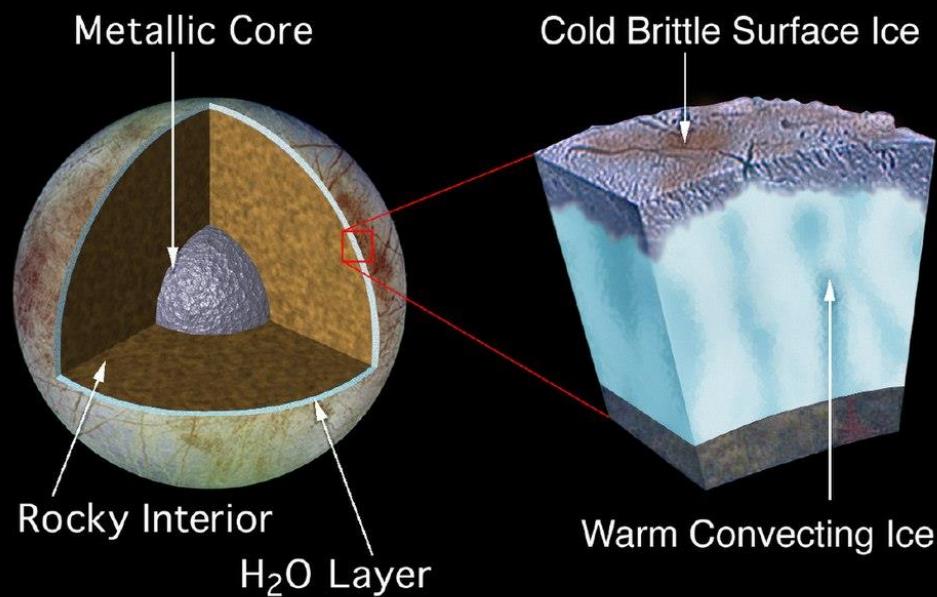


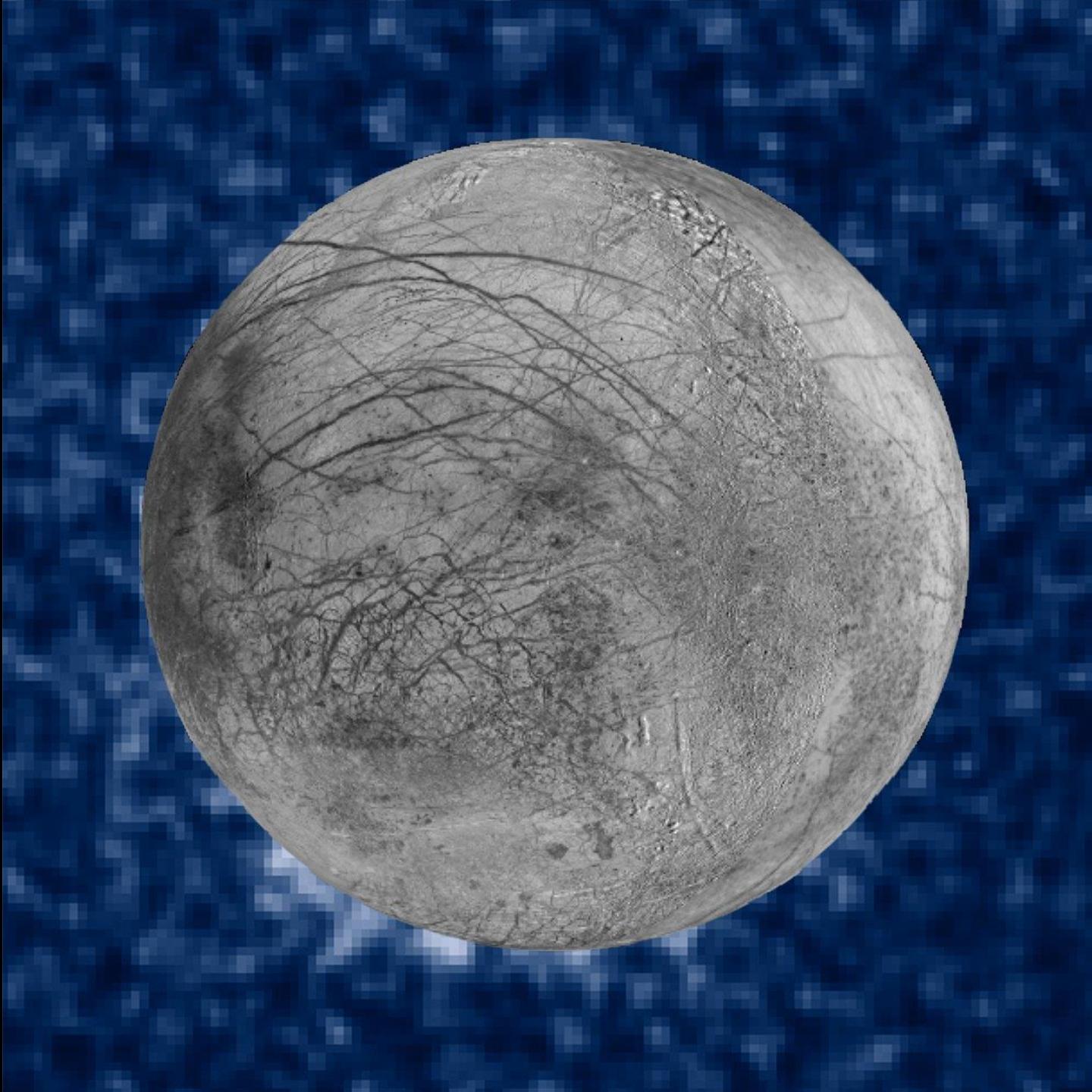


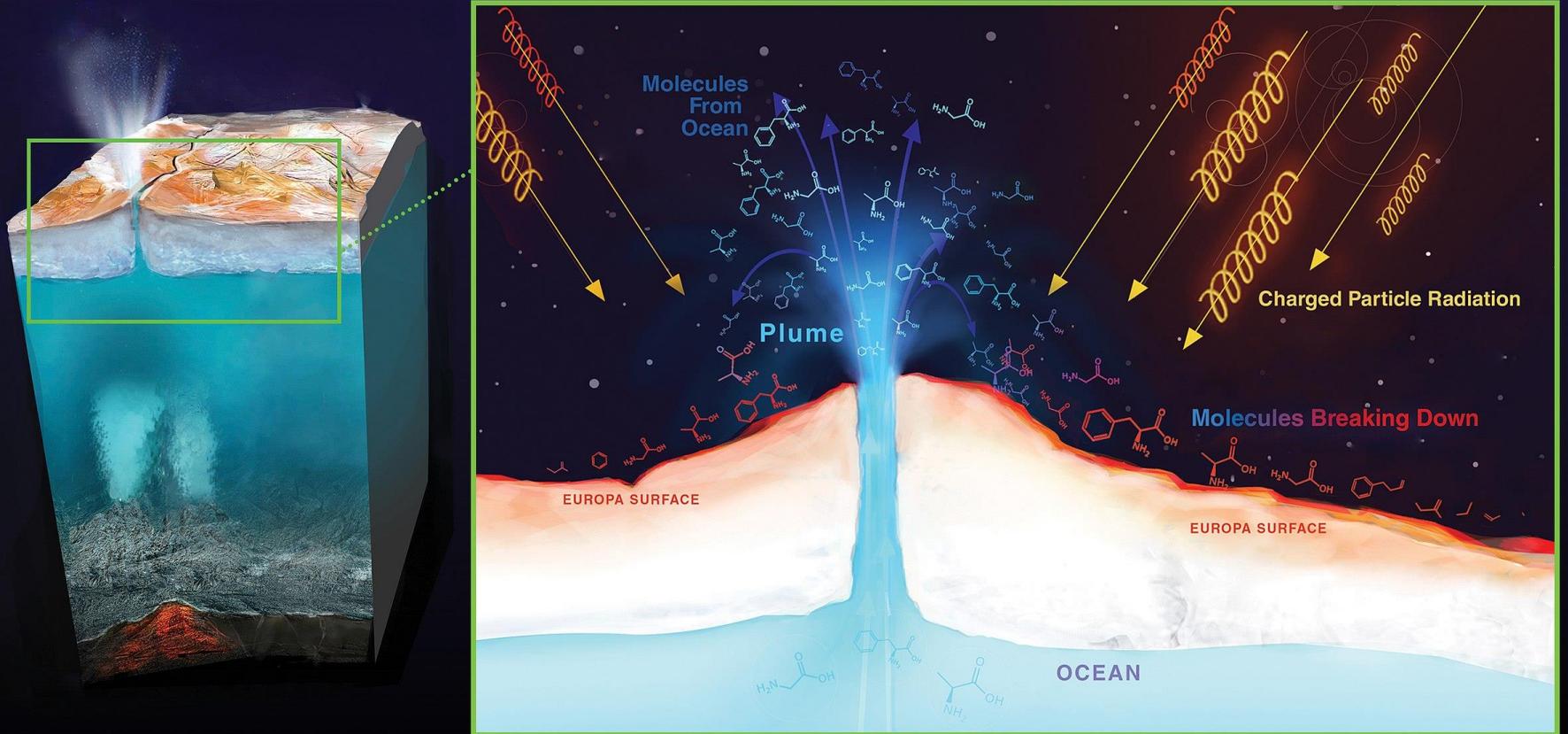






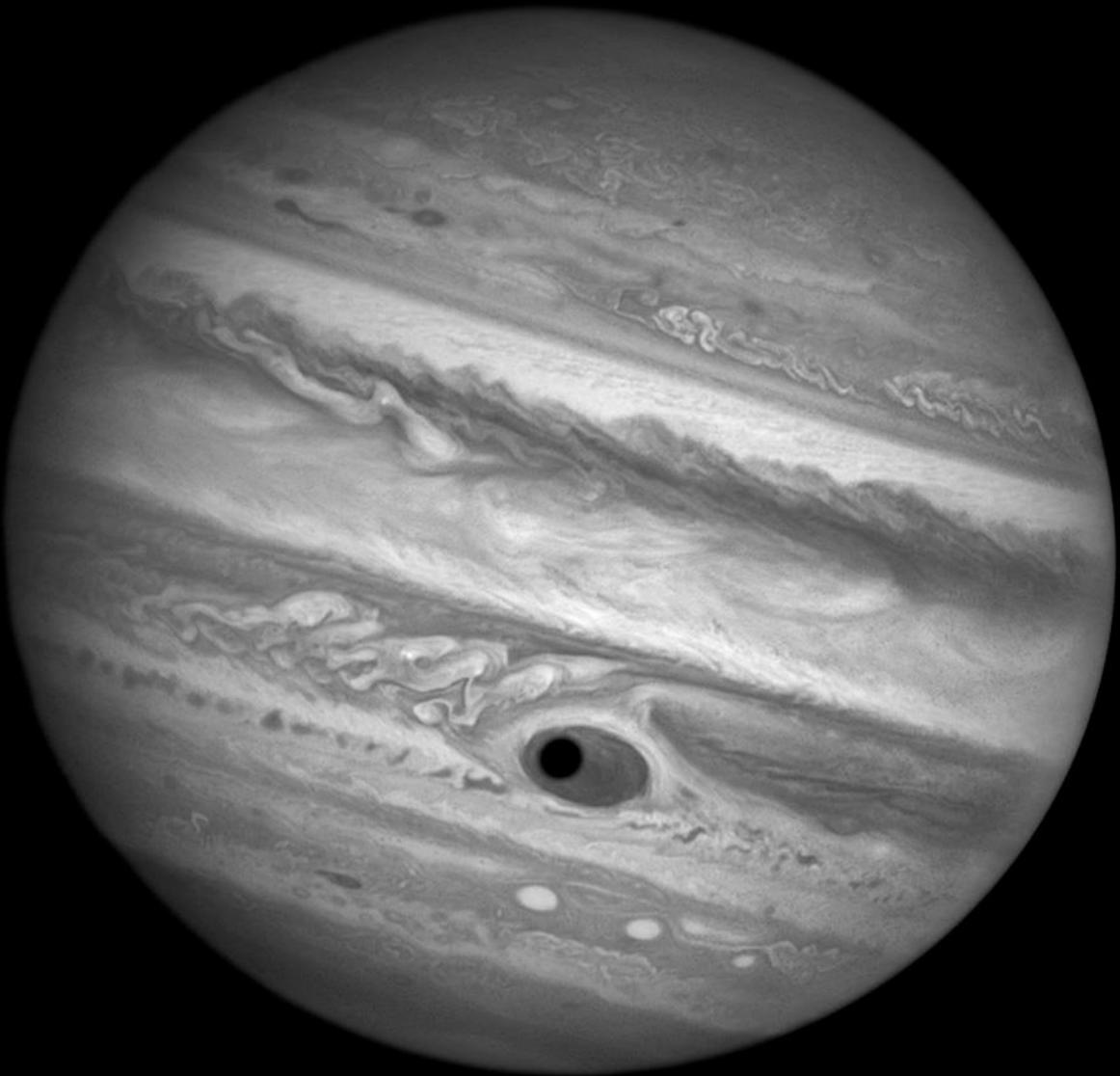


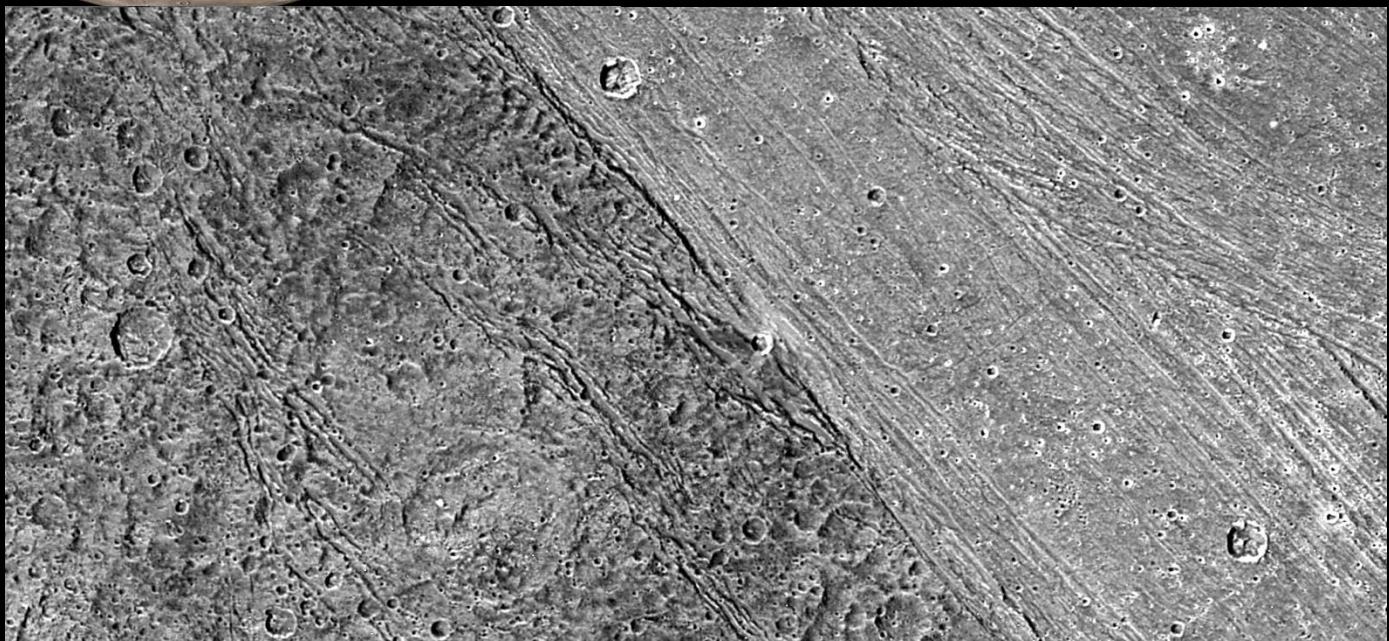


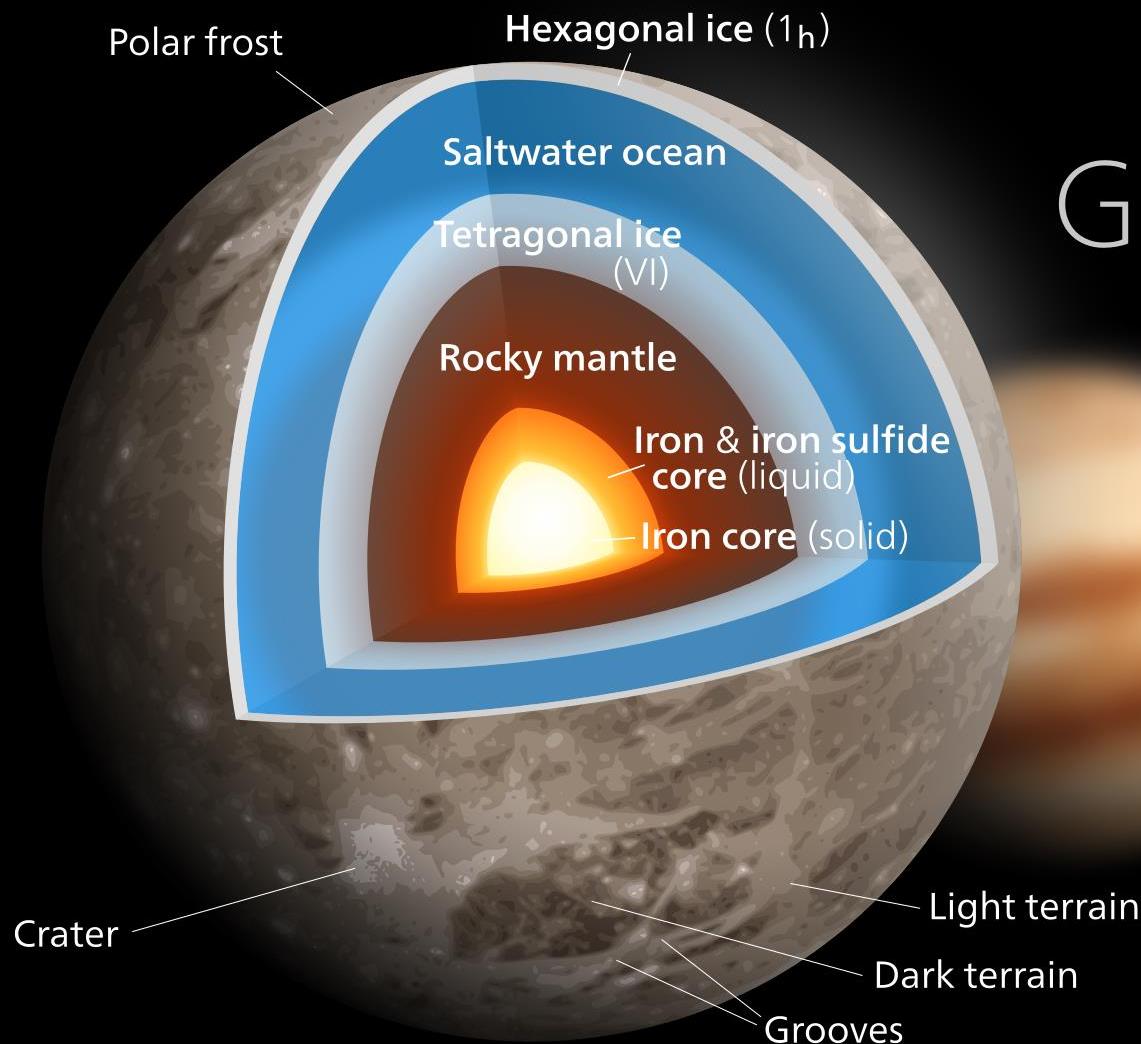


Ganymede and Callisto



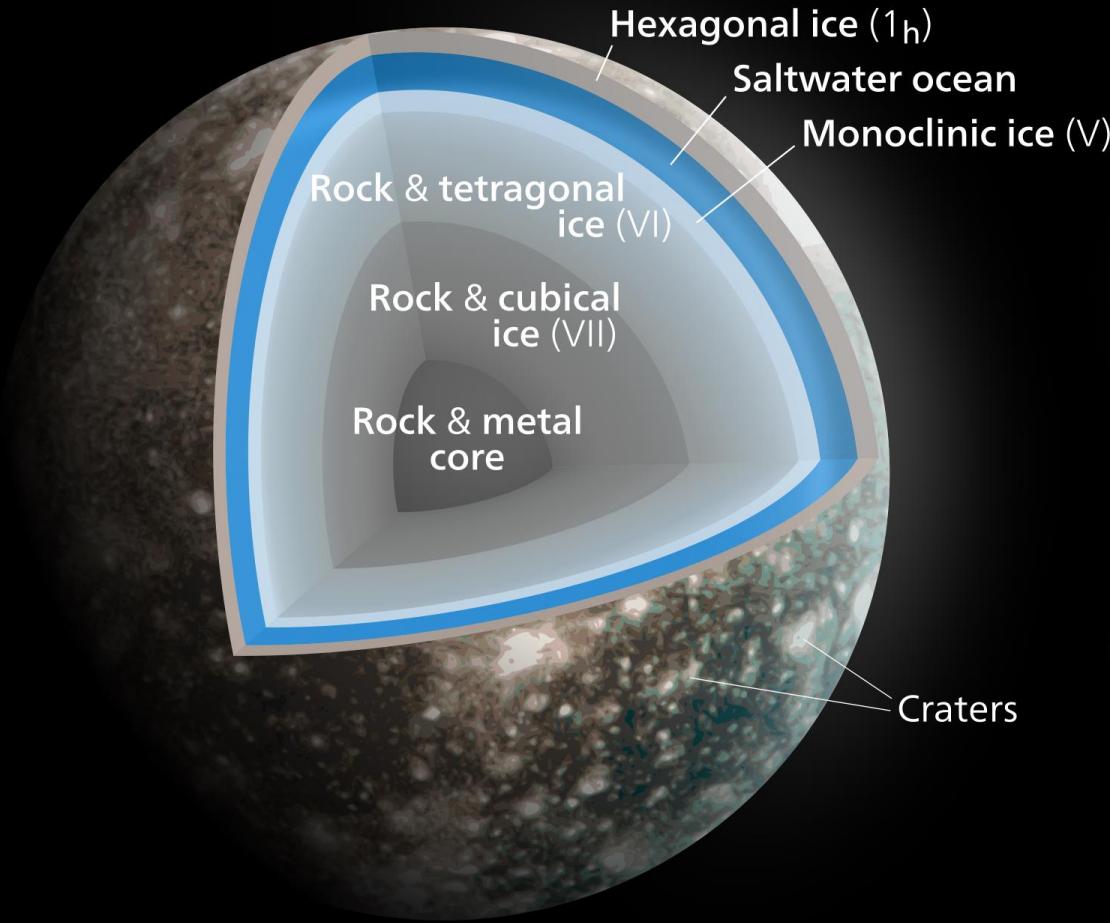






Ganymede

layers drawn to scale



Callisto

SATMOD monoclinic ice model
layers drawn to scale

Europa Clipper

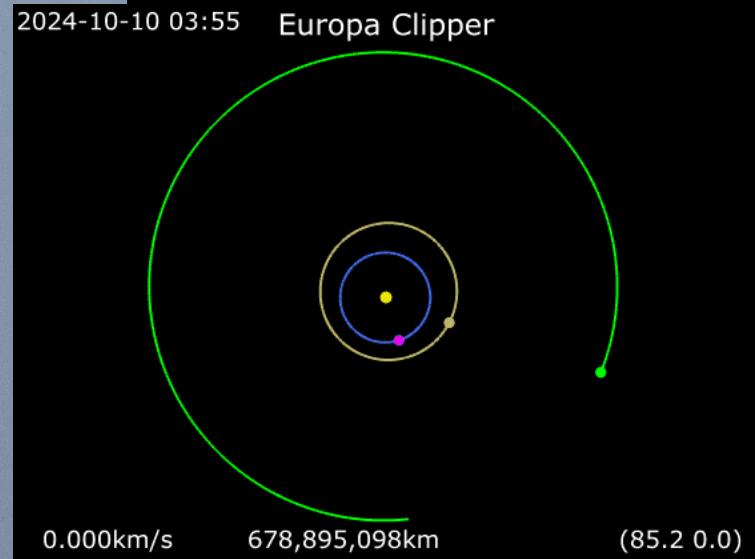
- Launched on 2024.10.14 by NASA (US)
- Arrived at Europa in 2030.04
- Cost: \$2B USD
- 9 instruments

Objectives:

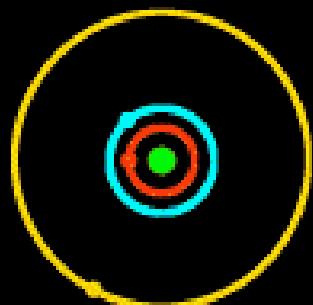
Confirm liquid water between ice and ice-ocean exchange

Composition and chemistry

Geology of surface features



2030-03-11 00:00 Europa Clipper



0.000km/s

21,461,301km

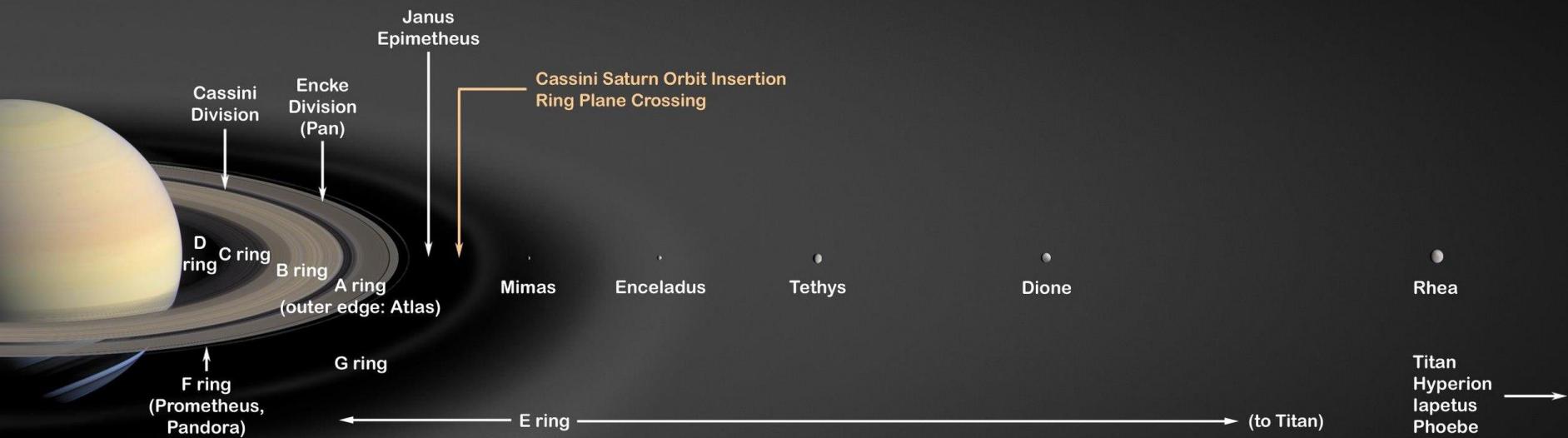
(88.4 0.0)

JUICE: Jupiter Icy Moons Explorer

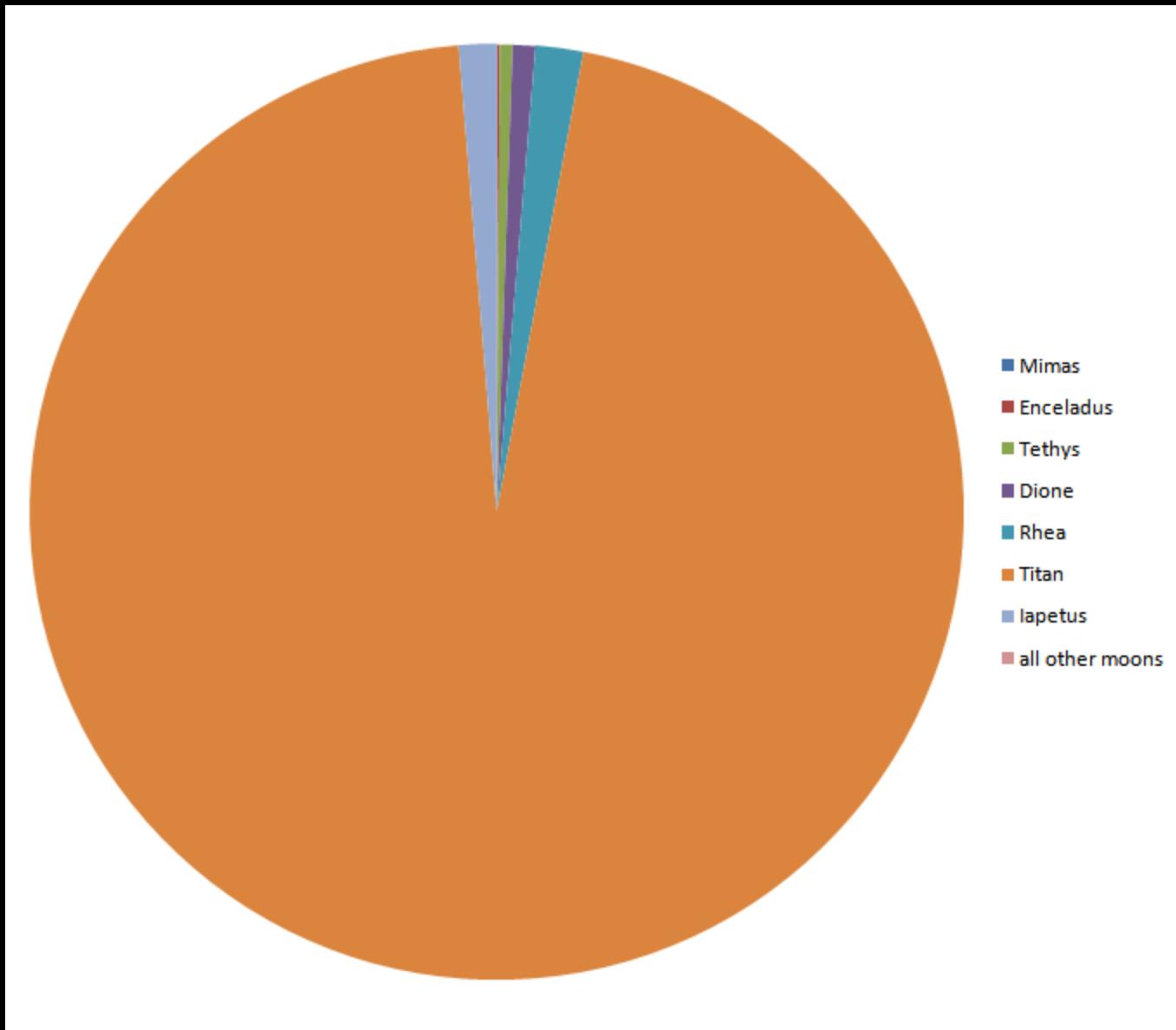
- Launched on 2023.04.14 by ESA (Europe)
- Arrive in 2031.07
- \$1.6B USD
- Will enter orbit around Ganymede
 - With flybys of Europa and Callisto

Similar science goals, but for Ganymede

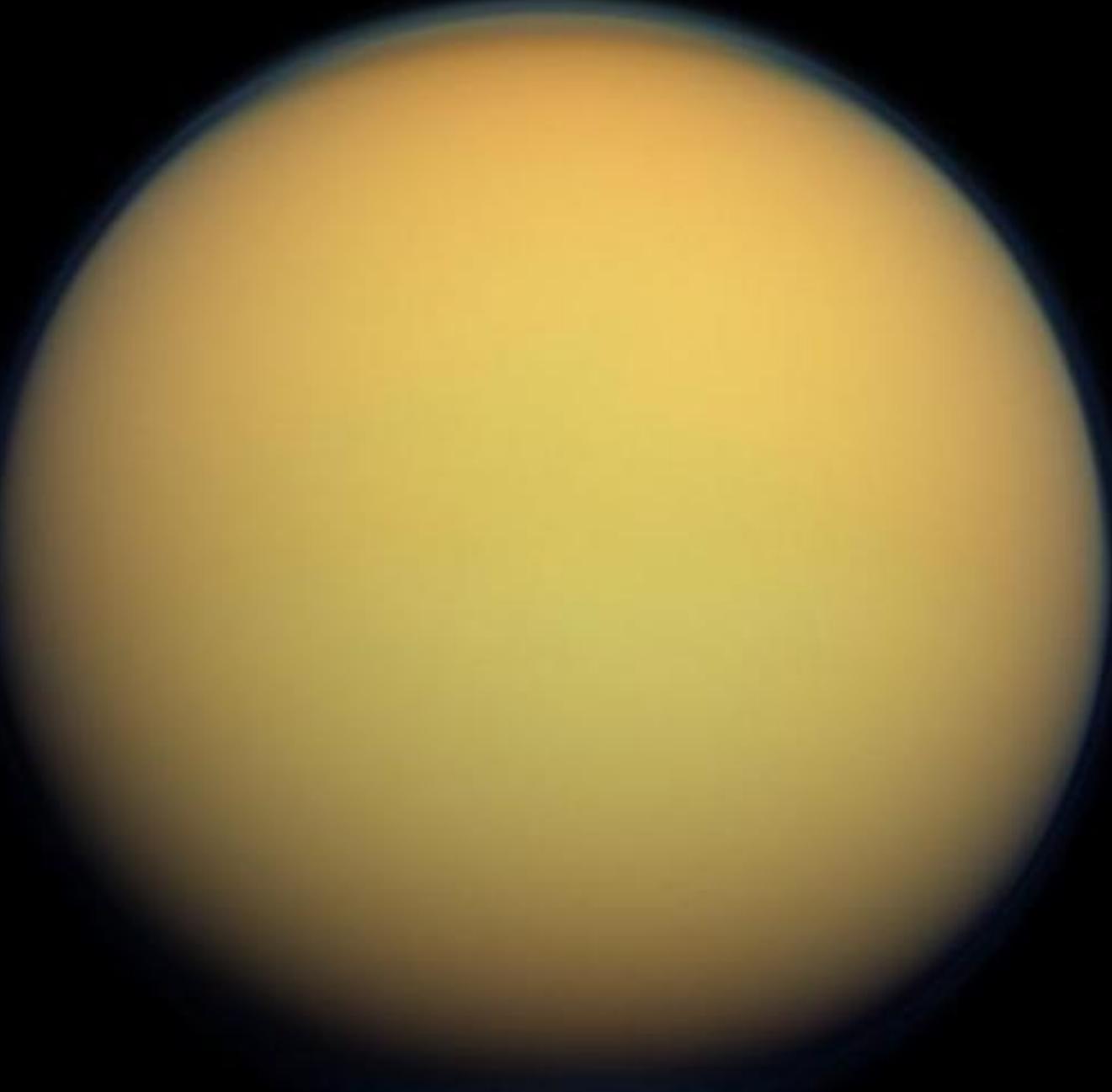
Moons of Saturn



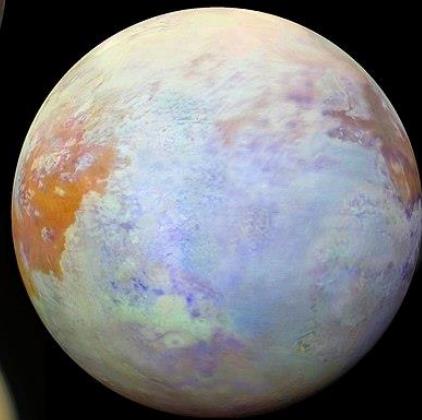
Moons of Saturn

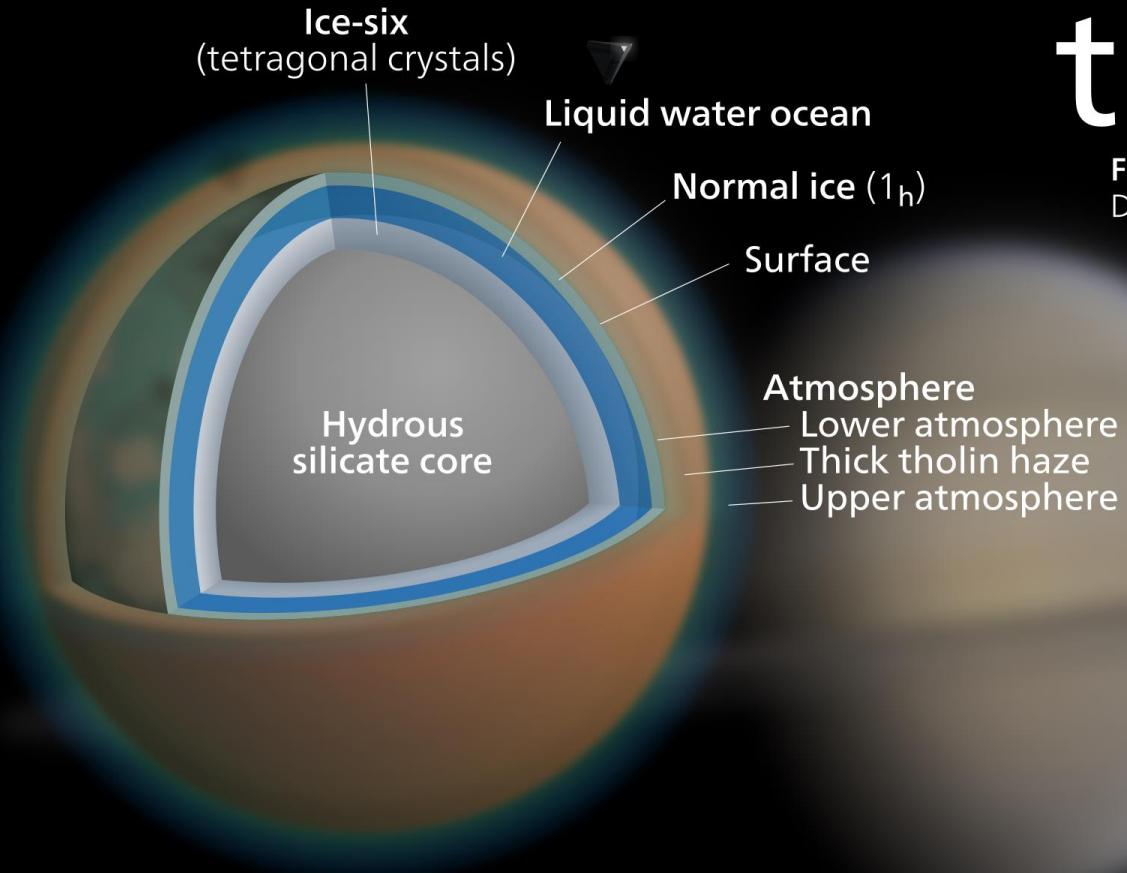


Titan: the main moon of Saturn



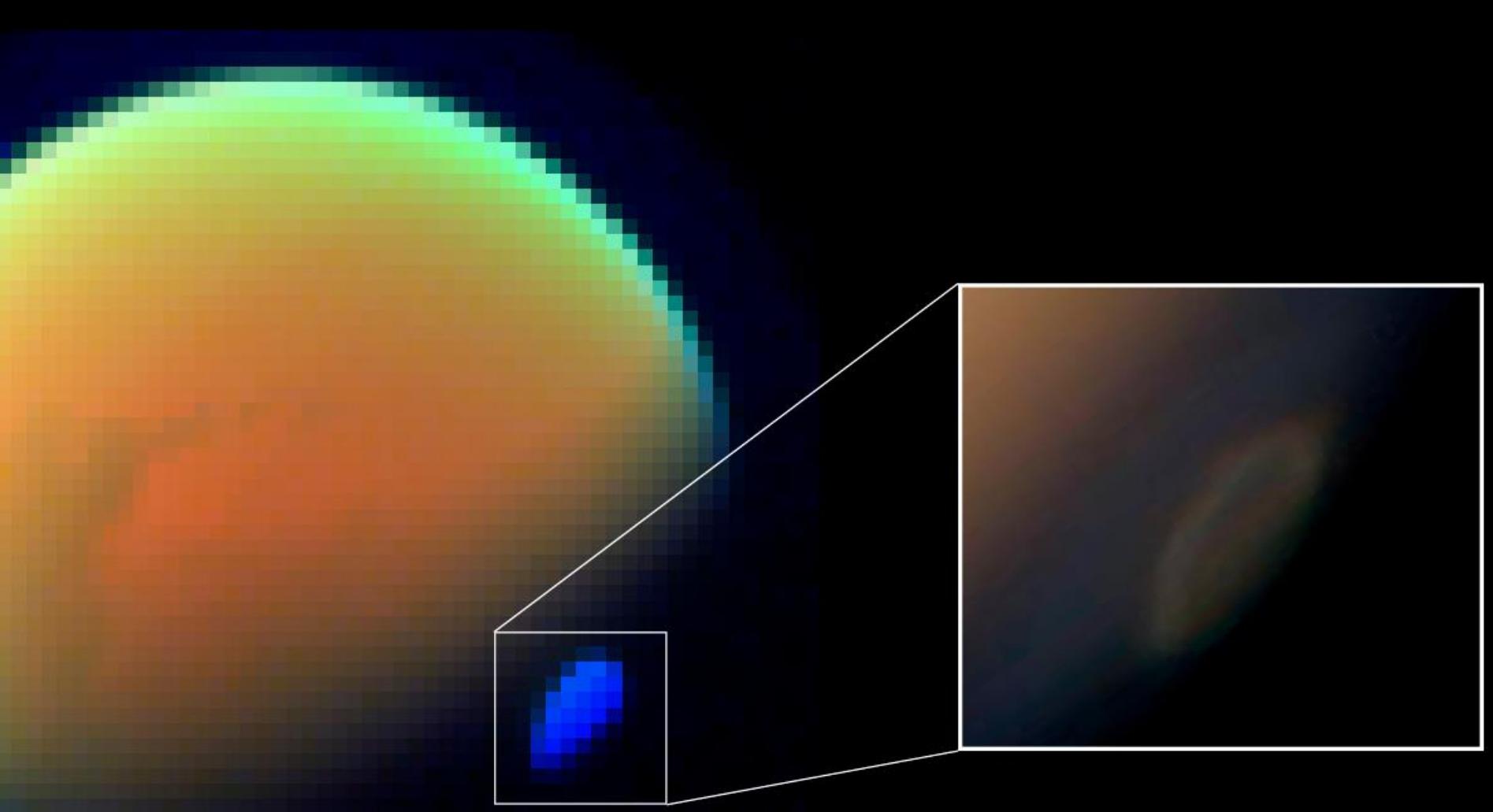


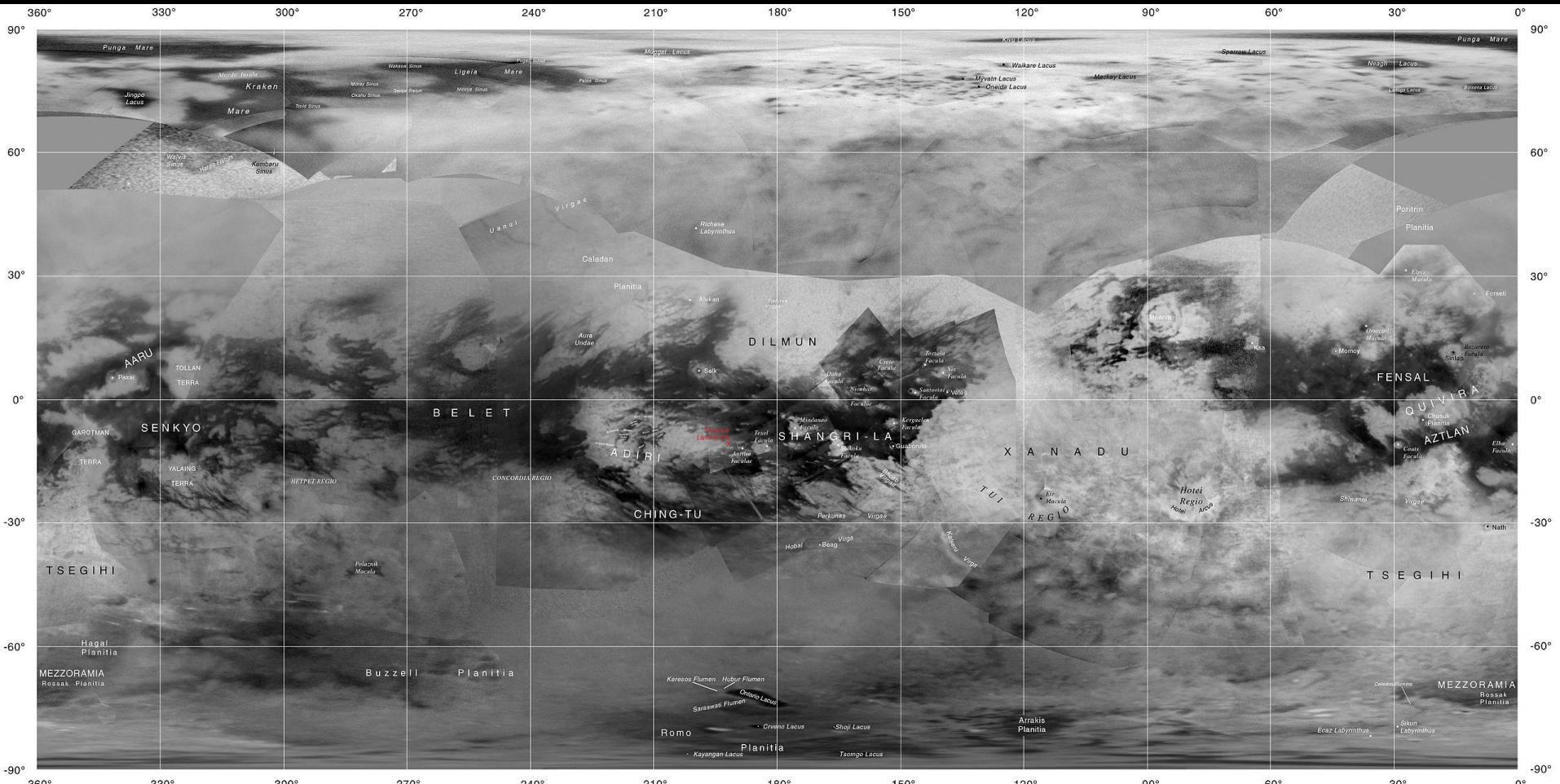


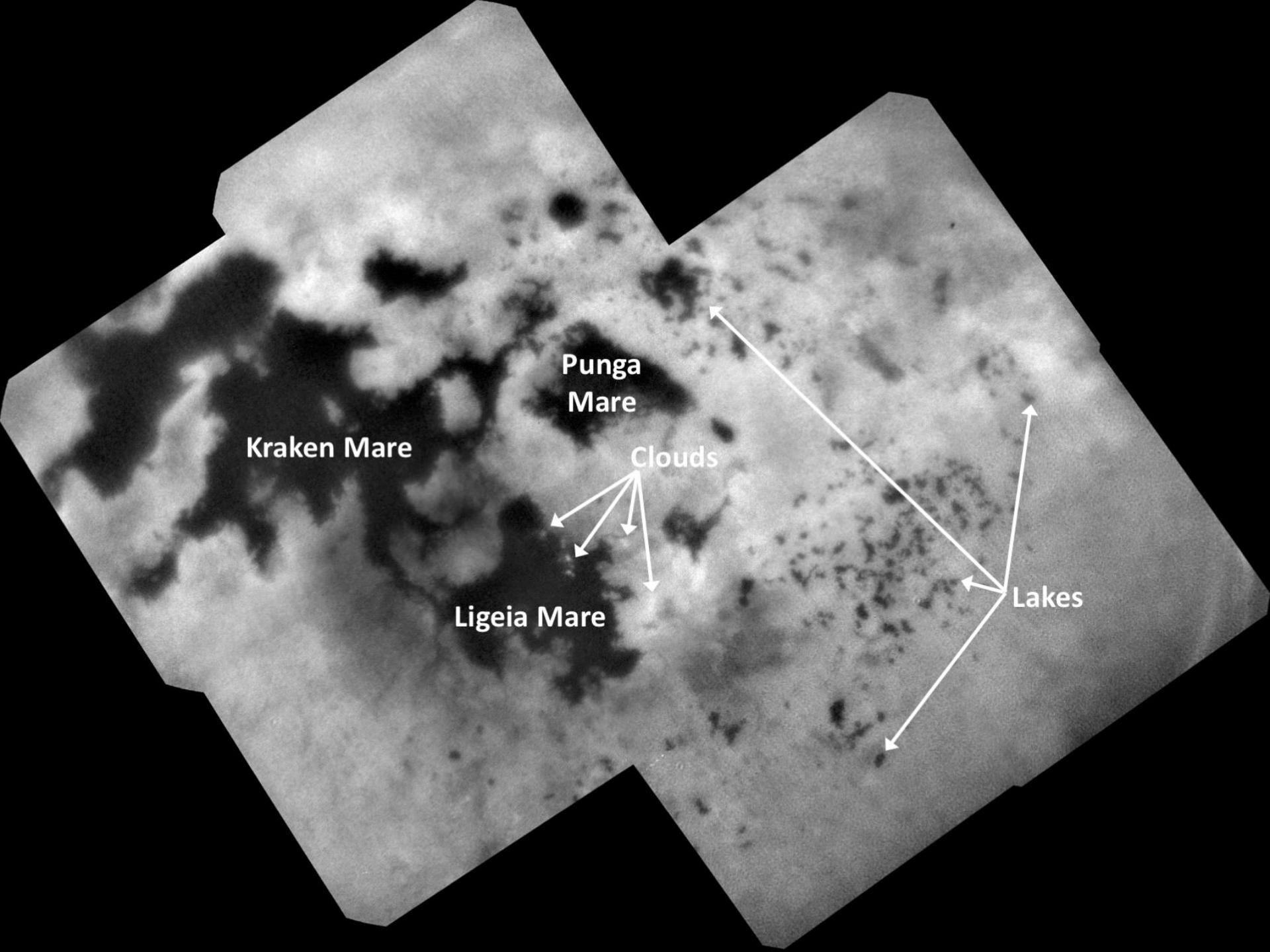


titan

Fully differentiated dense-ocean model
Drawn to scale







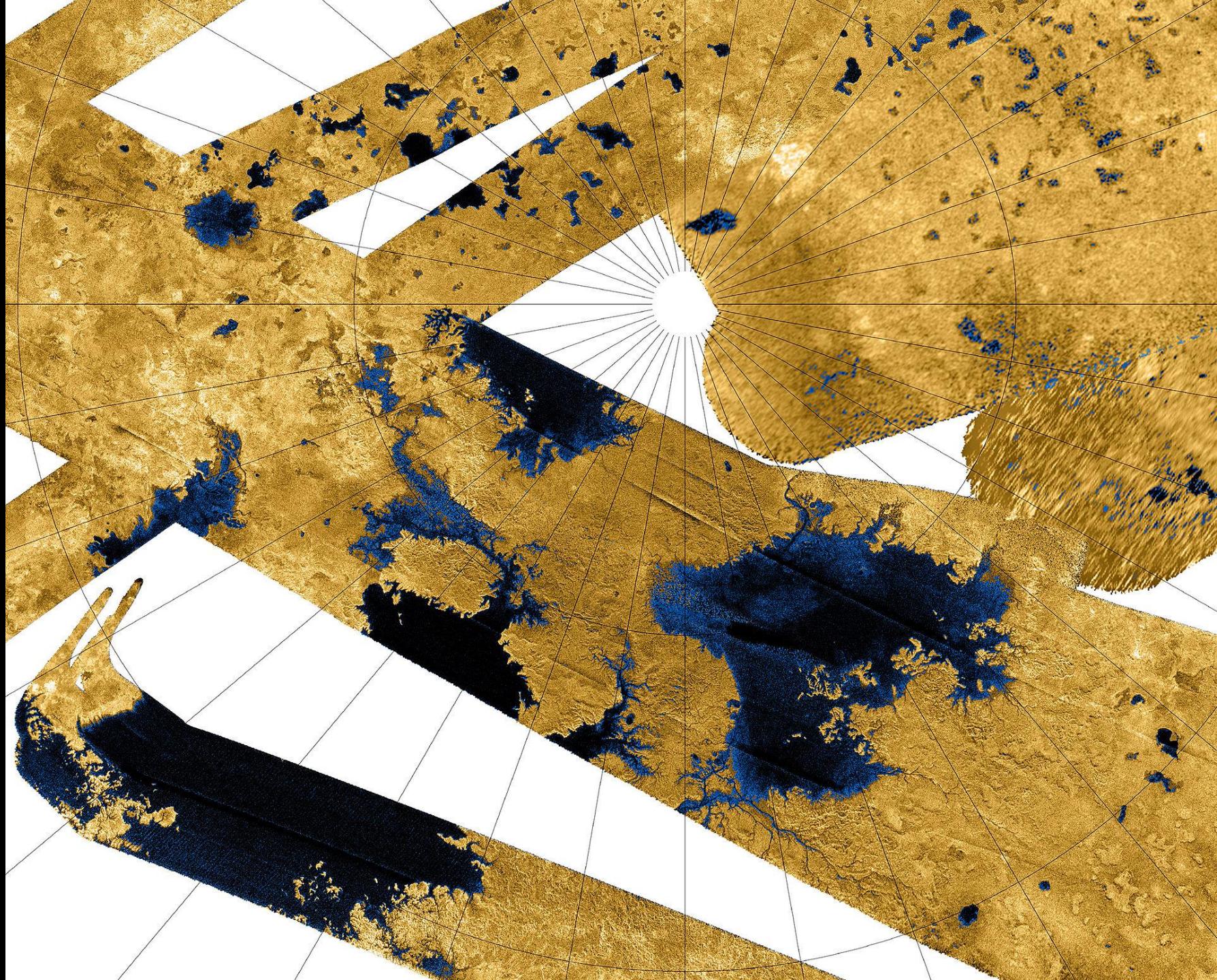
Kraken Mare

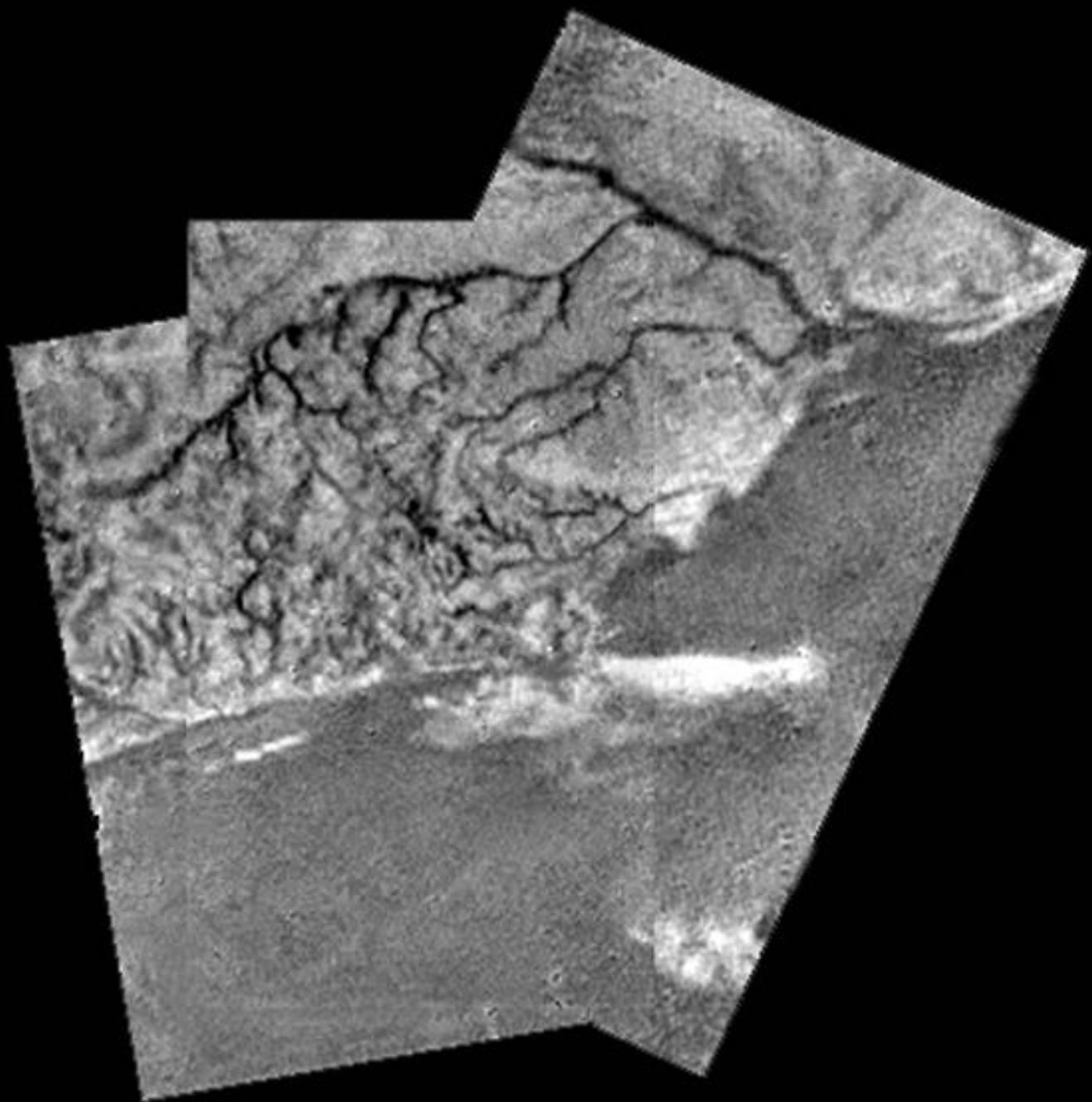
Punga
Mare

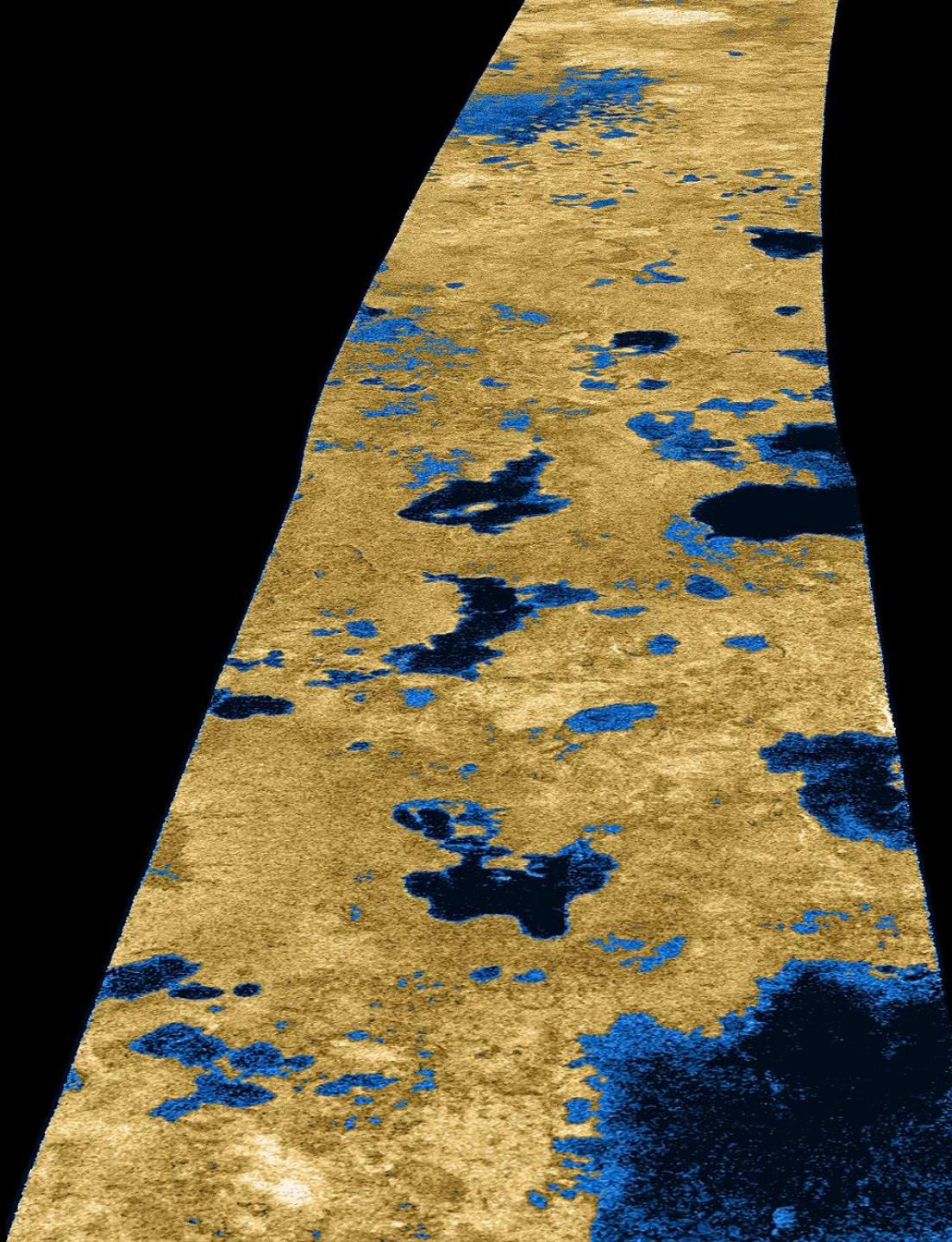
Clouds

Ligeia Mare

Lakes







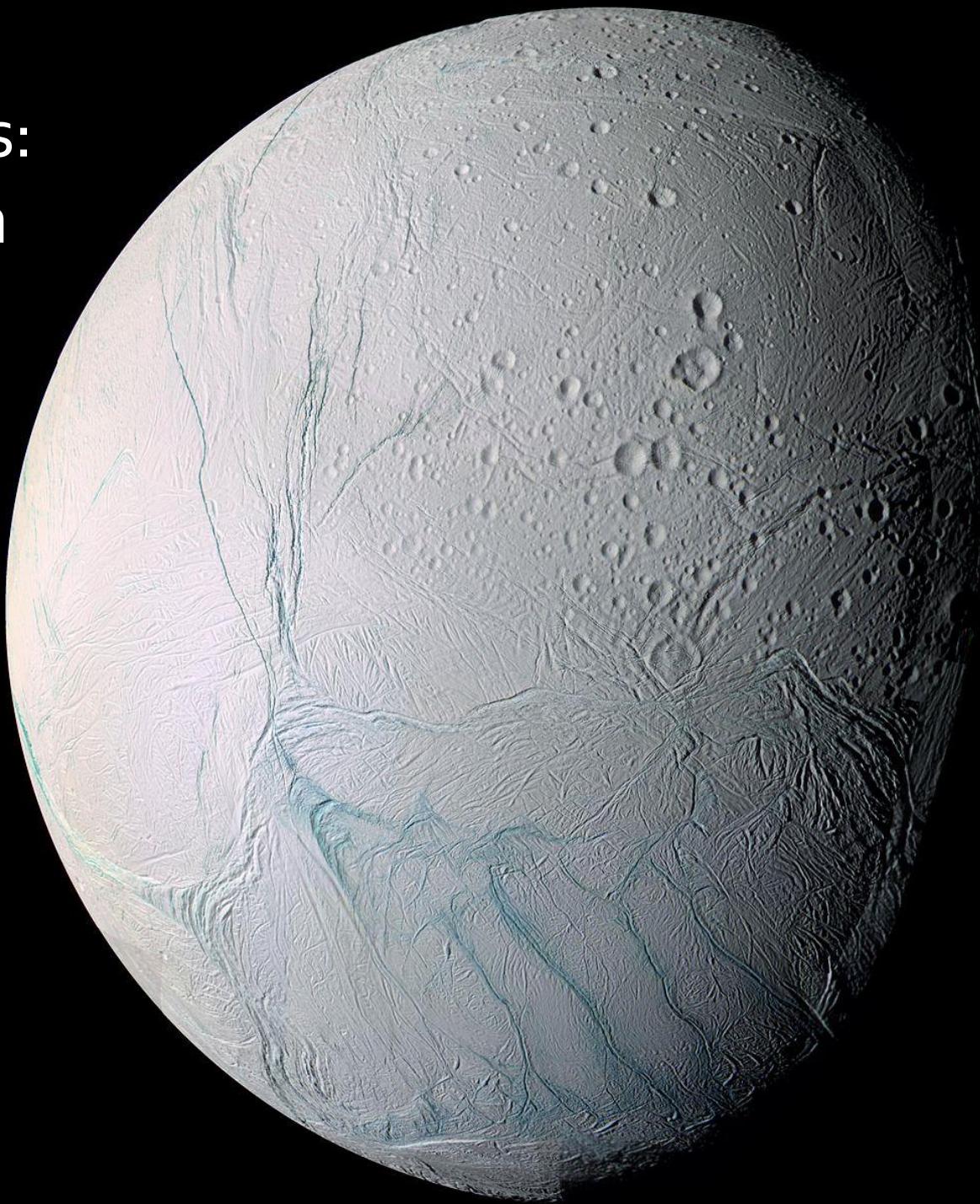


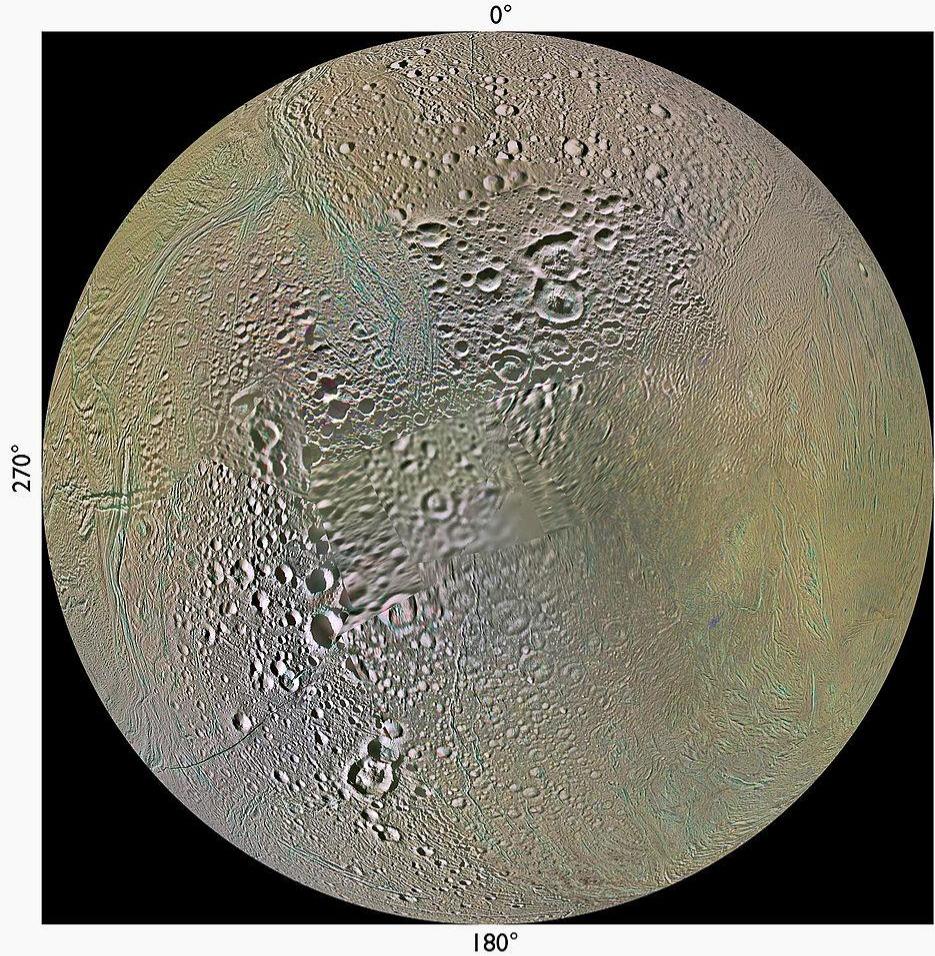




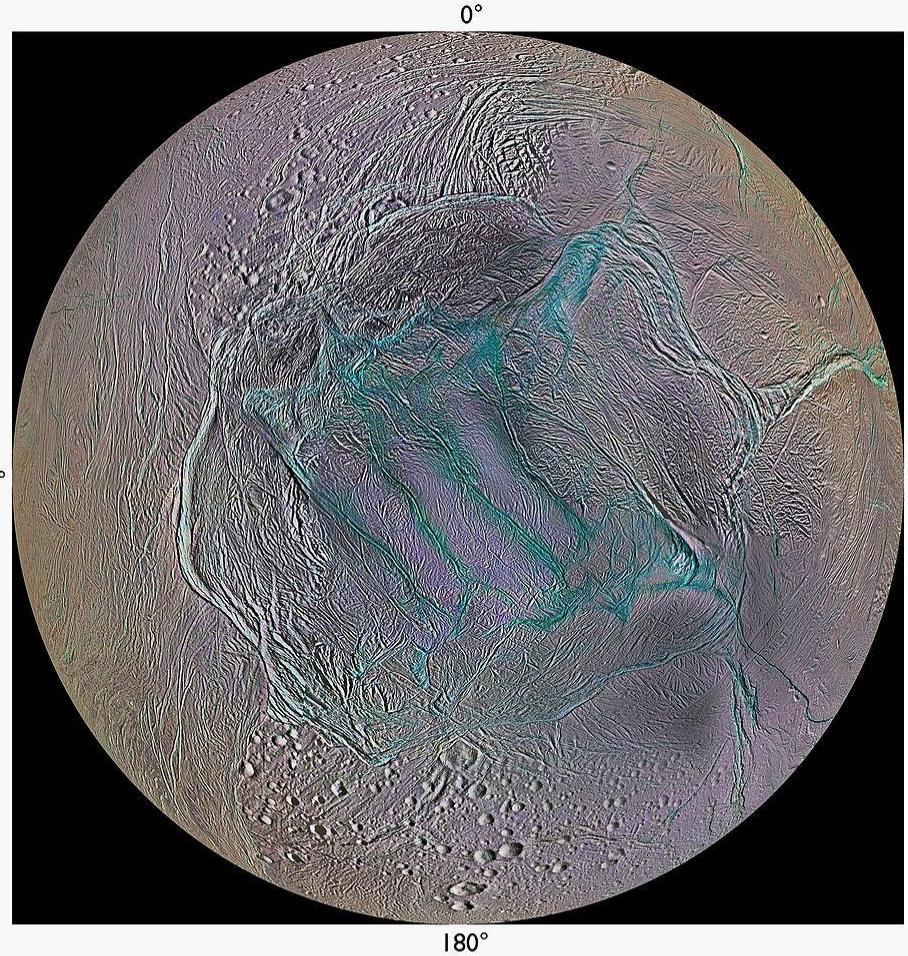
NASA/Dragonfly Mission:
drone to Titan!

Enceladus:
ice moon





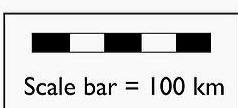
Northern Hemisphere
Orthographic map projection at 100 meters/pixel



Southern Hemisphere
Orthographic map projection at 100 meters/pixel

Global 3-Color Map of Enceladus (IR3-GRN-UV3)

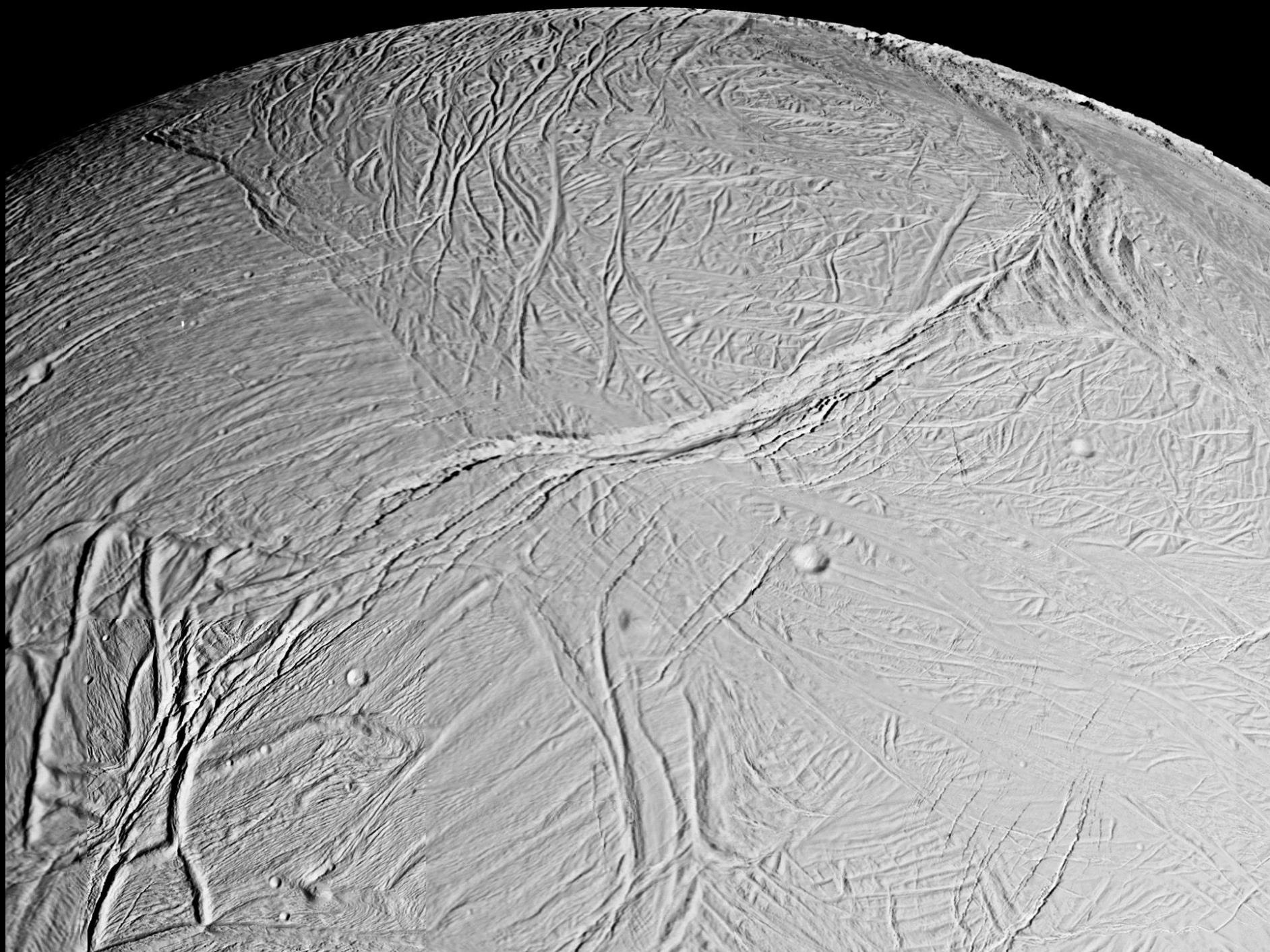
April 2014

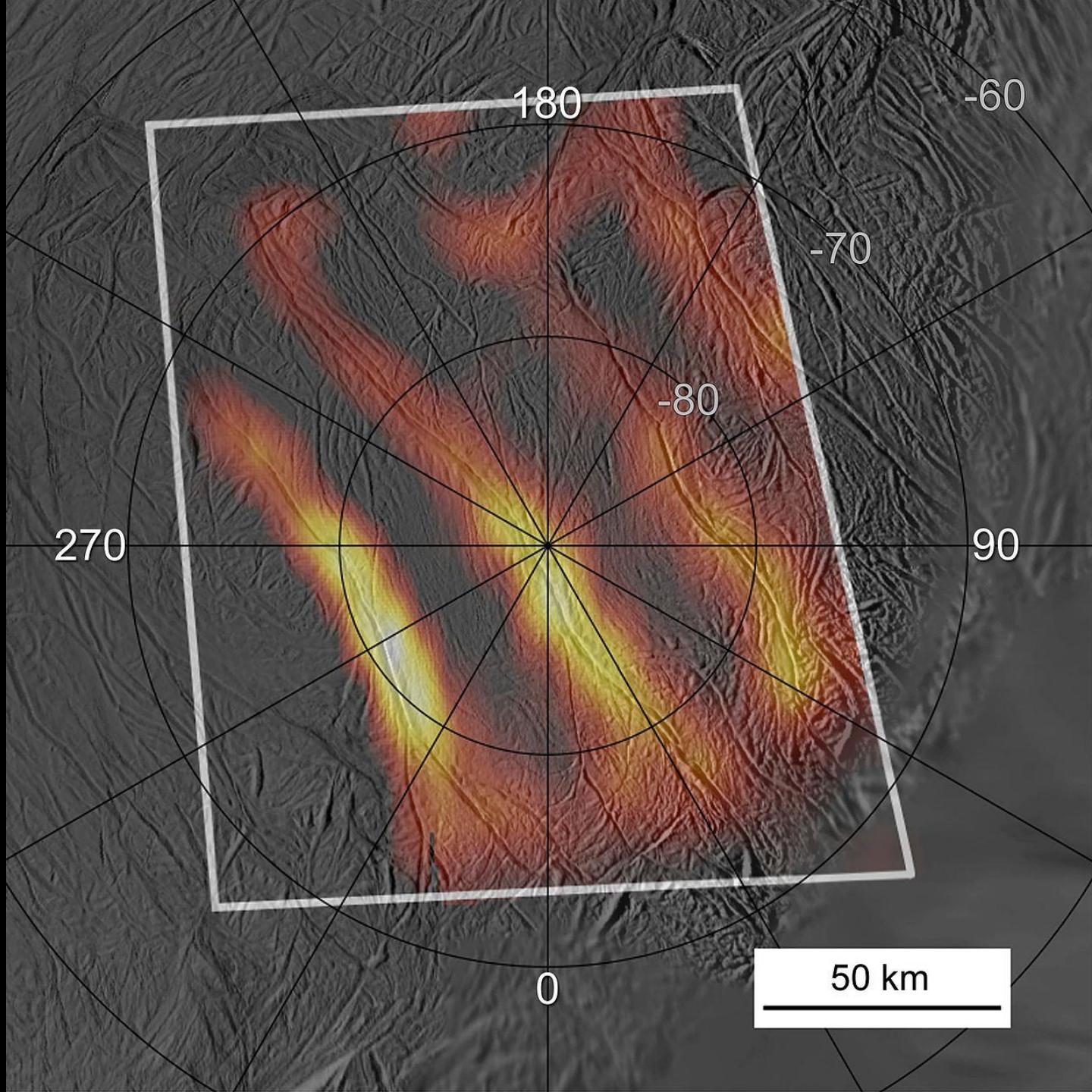


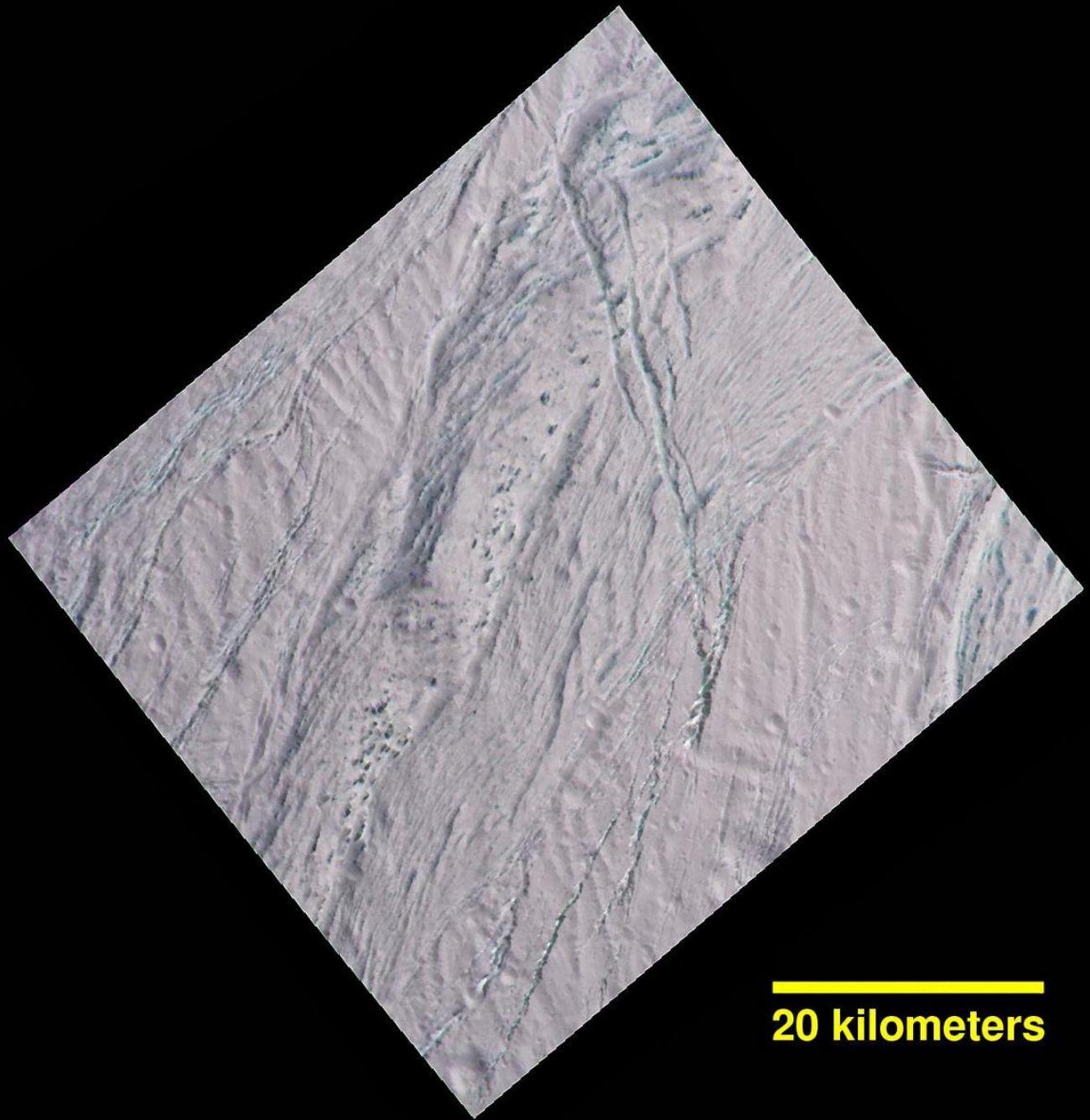
Scale bar = 100 km

Cartographic control and digital mosaic construction by Dr. Paul Schenk (LPI, Houston)
Cassini ISS images acquired 2004-2014



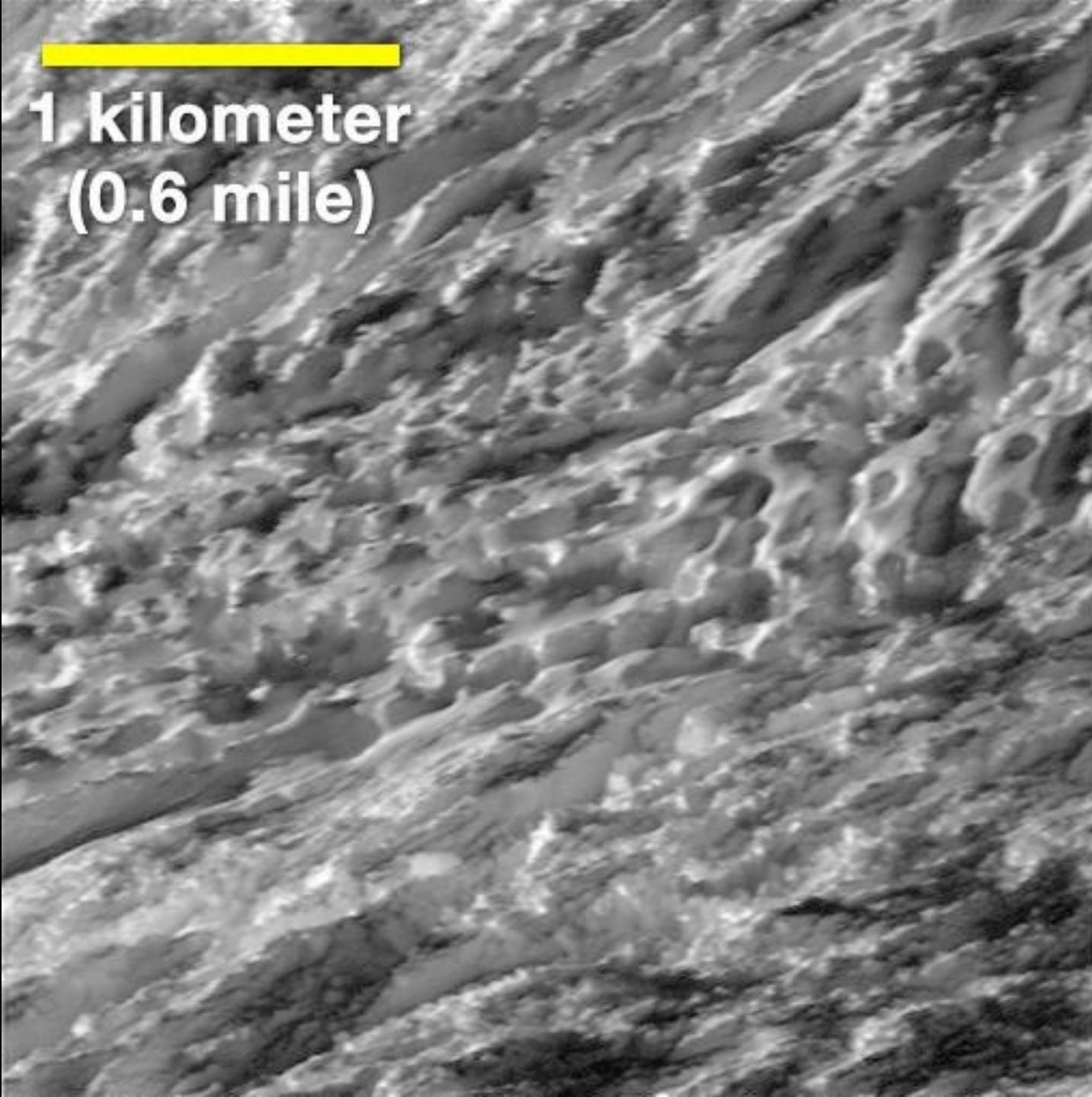




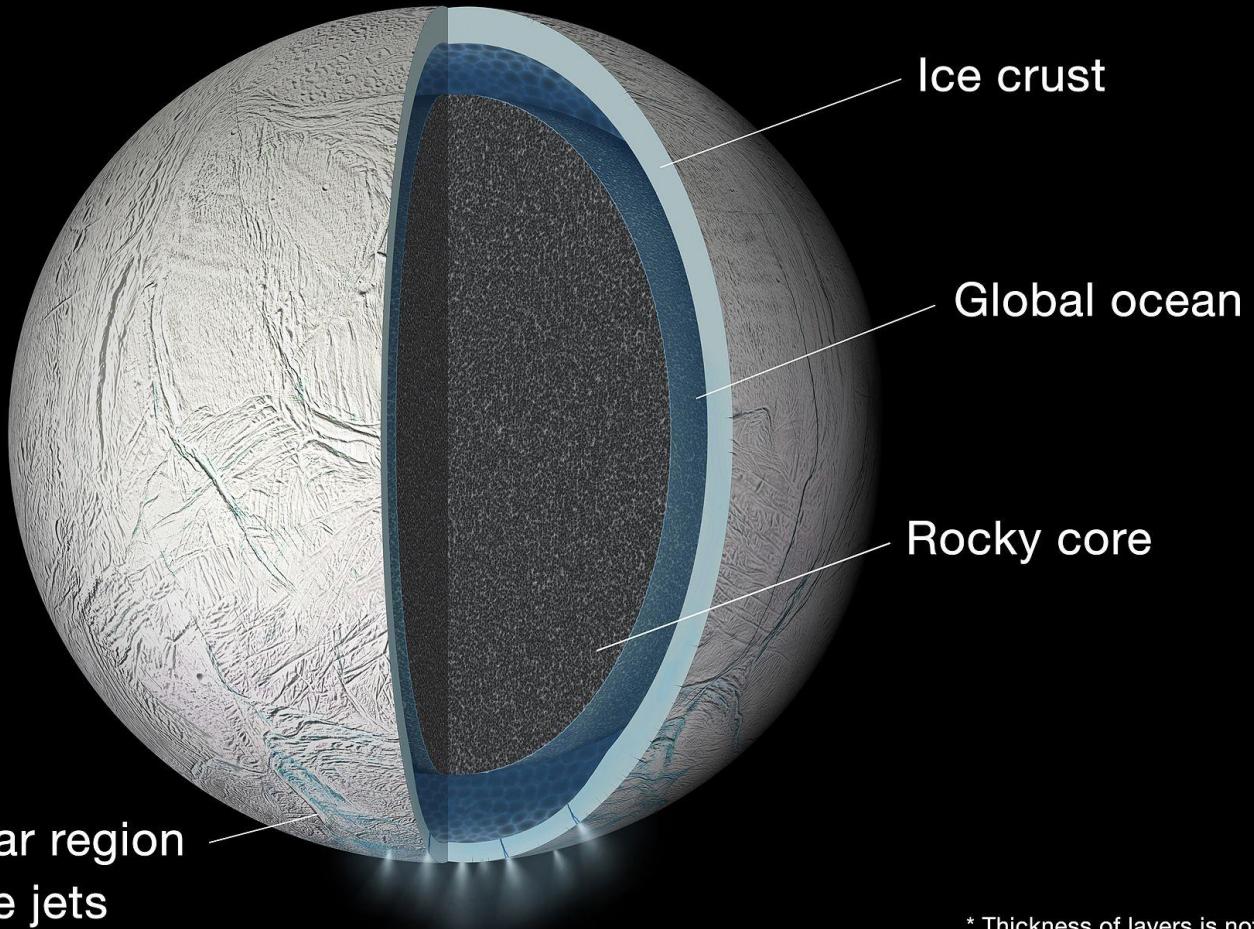


20 kilometers

**1 kilometer
(0.6 mile)**

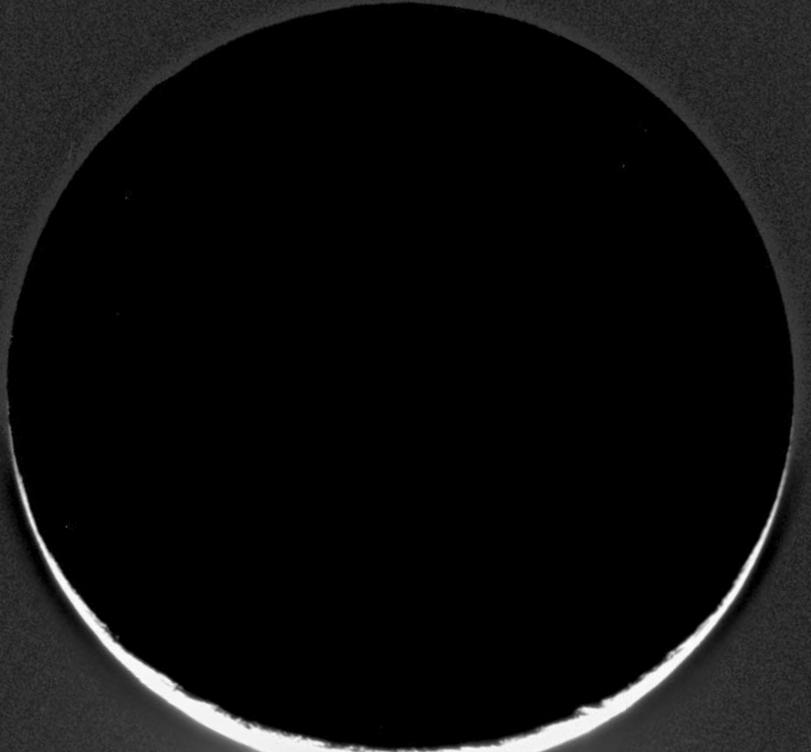


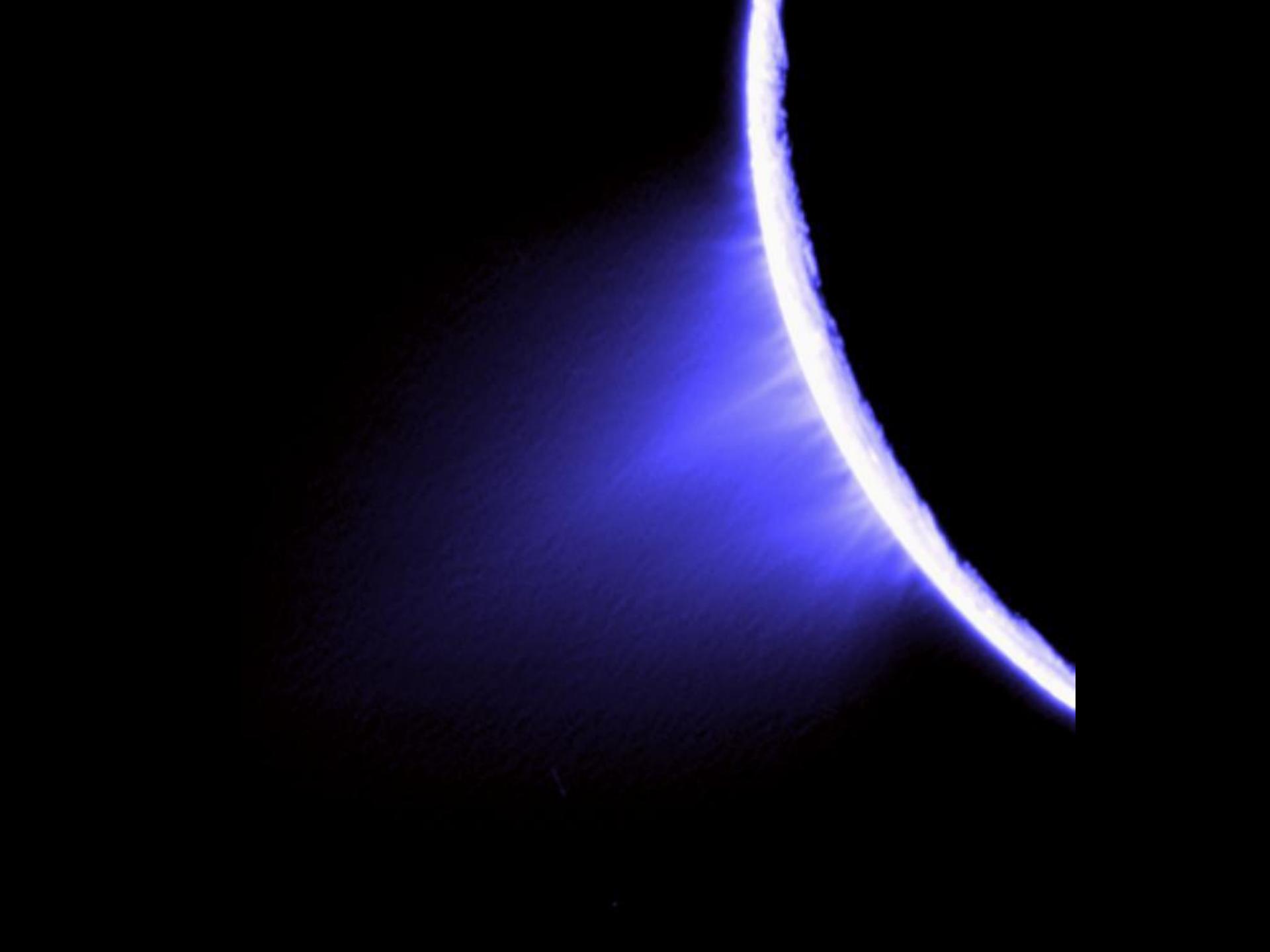
Global Ocean on Saturn's Moon ENCELADUS



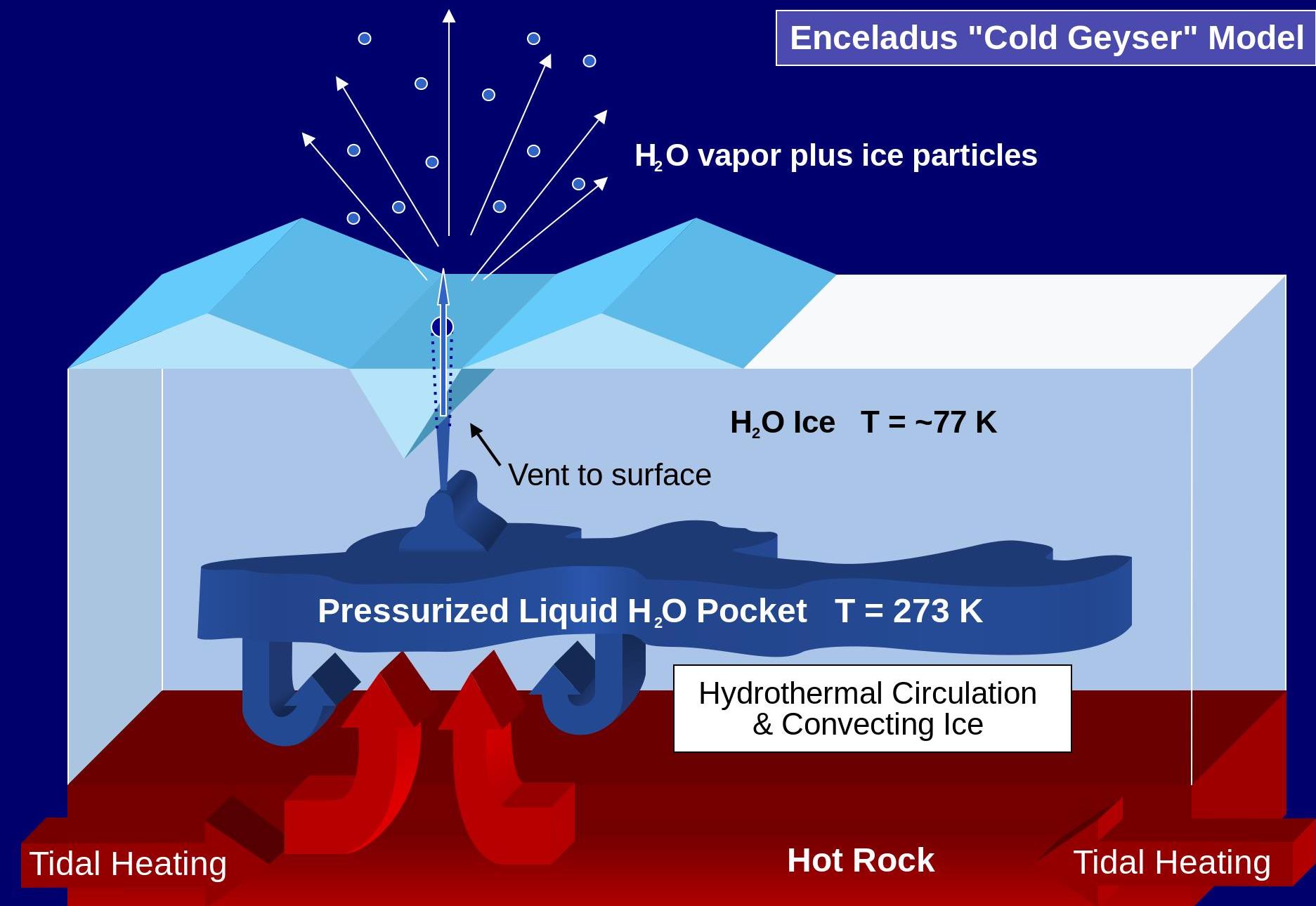
* Thickness of layers is not to scale

Enceladus: geysers!

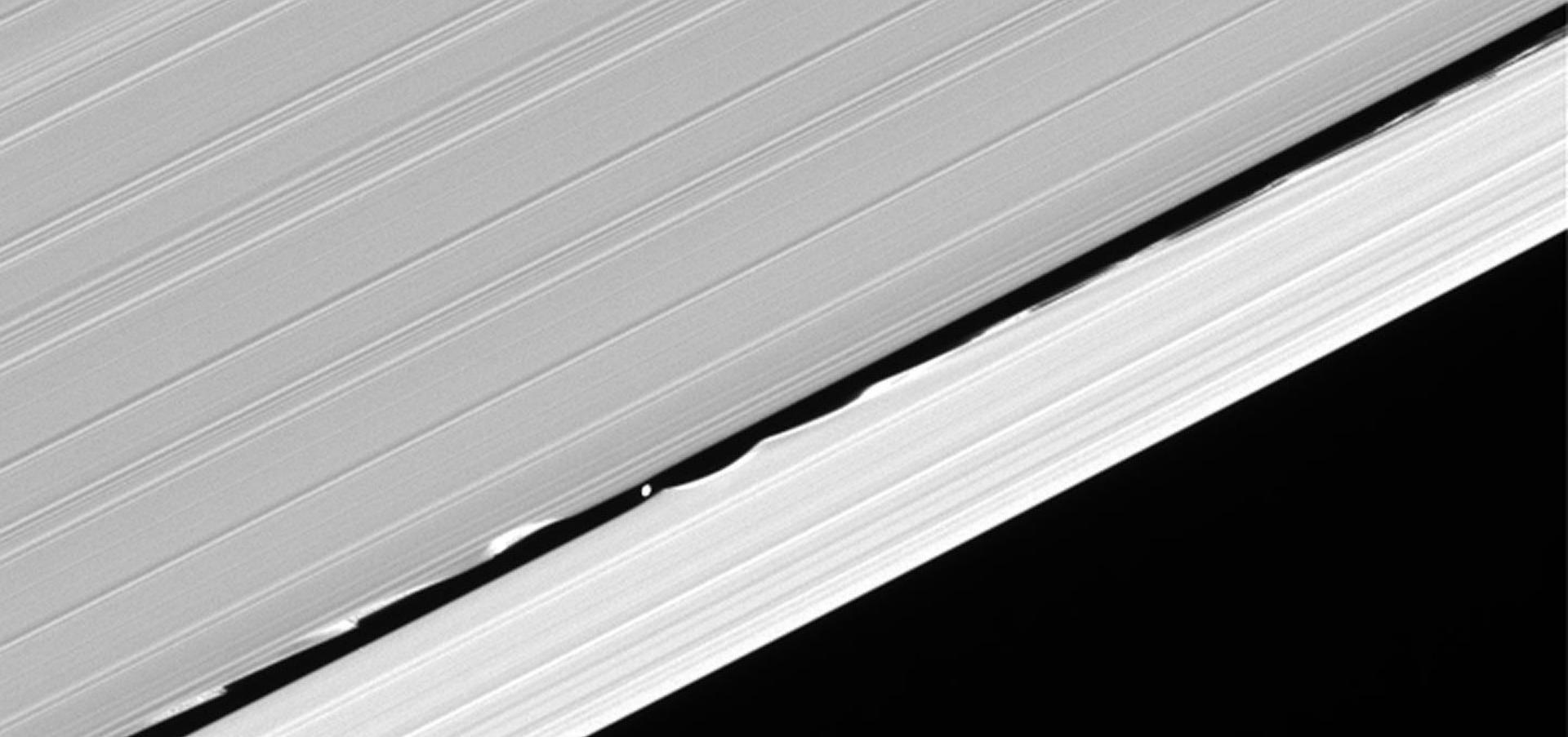




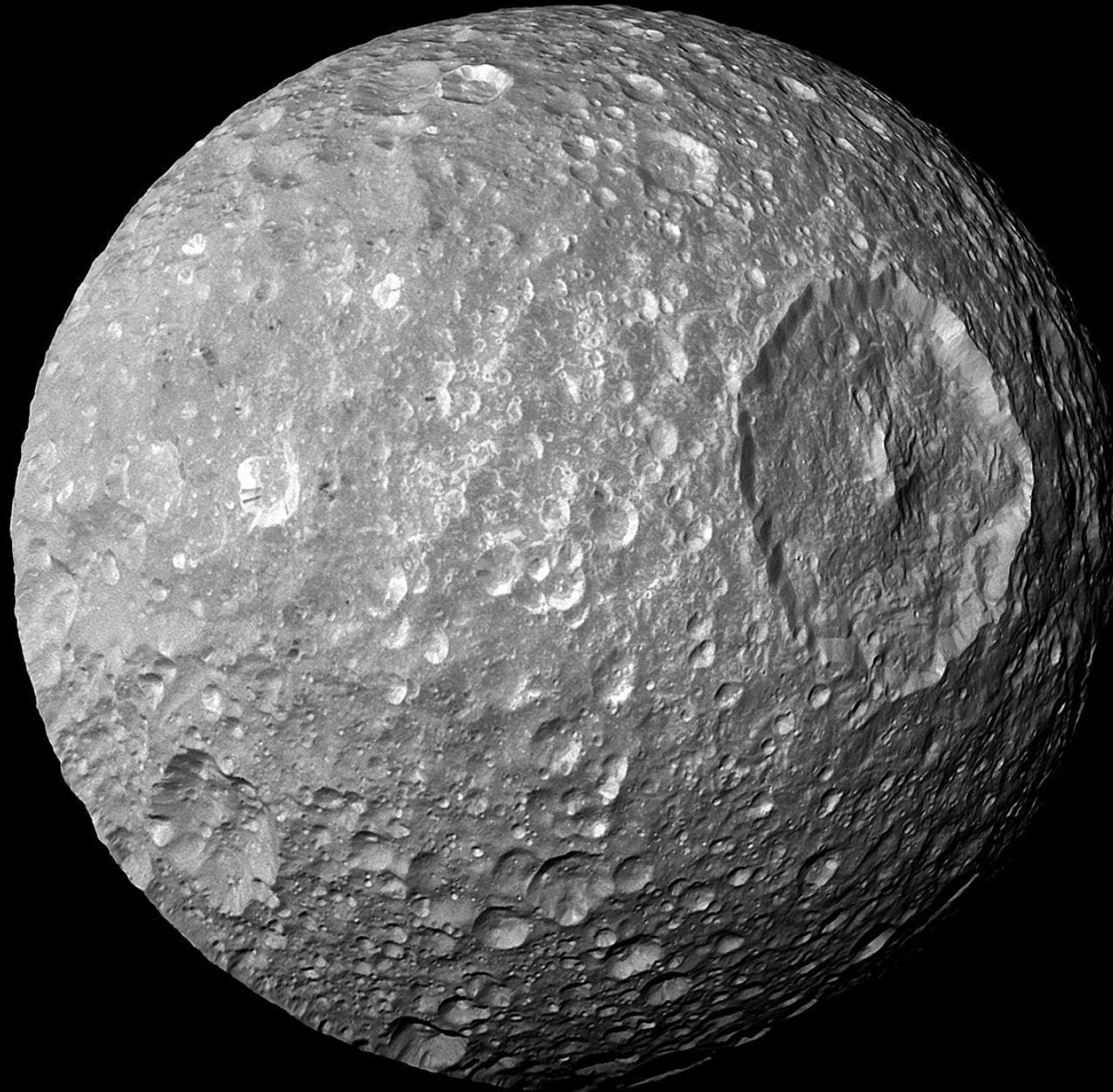
Enceladus "Cold Geyser" Model



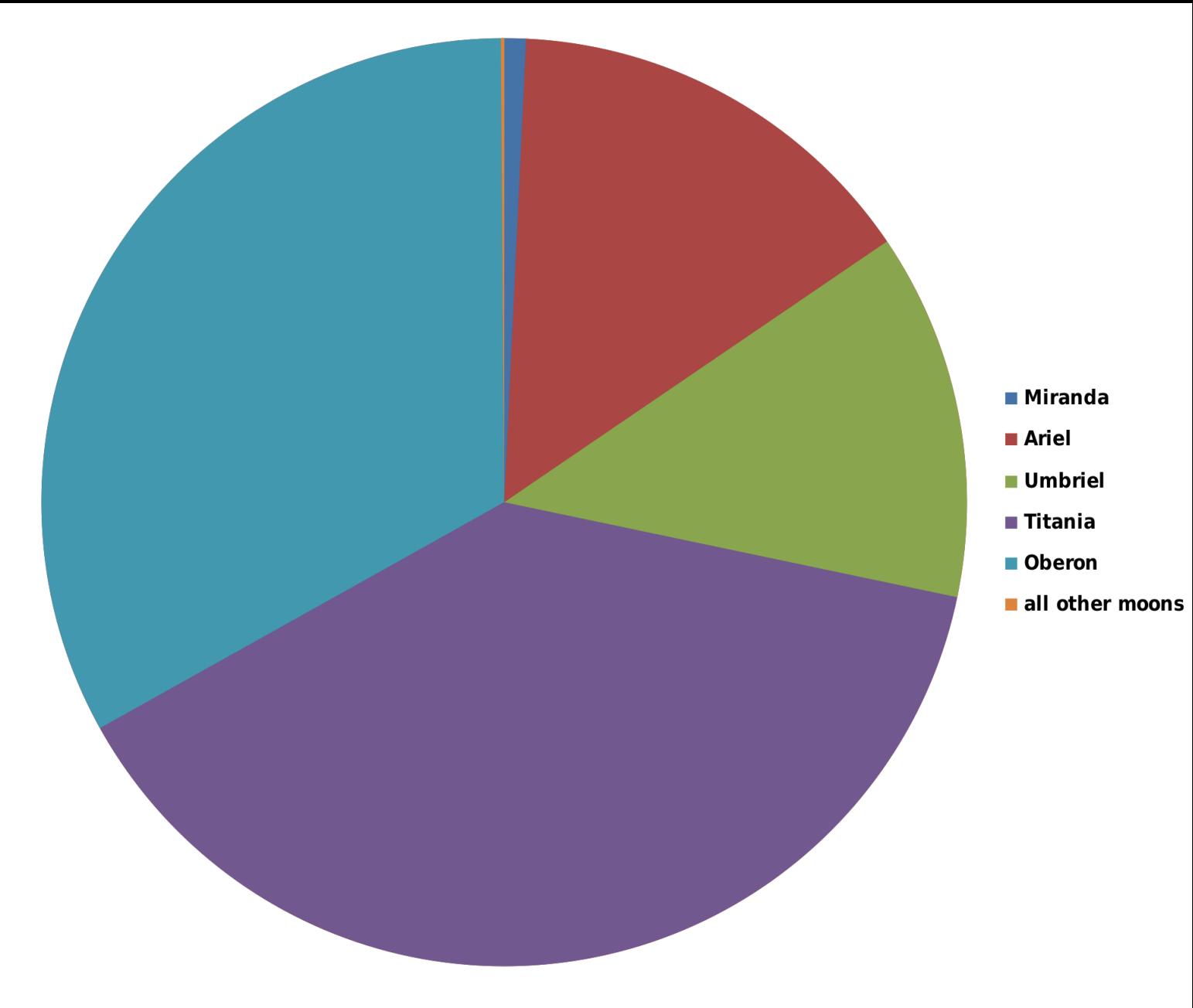
Daphnis: A shepherd moon

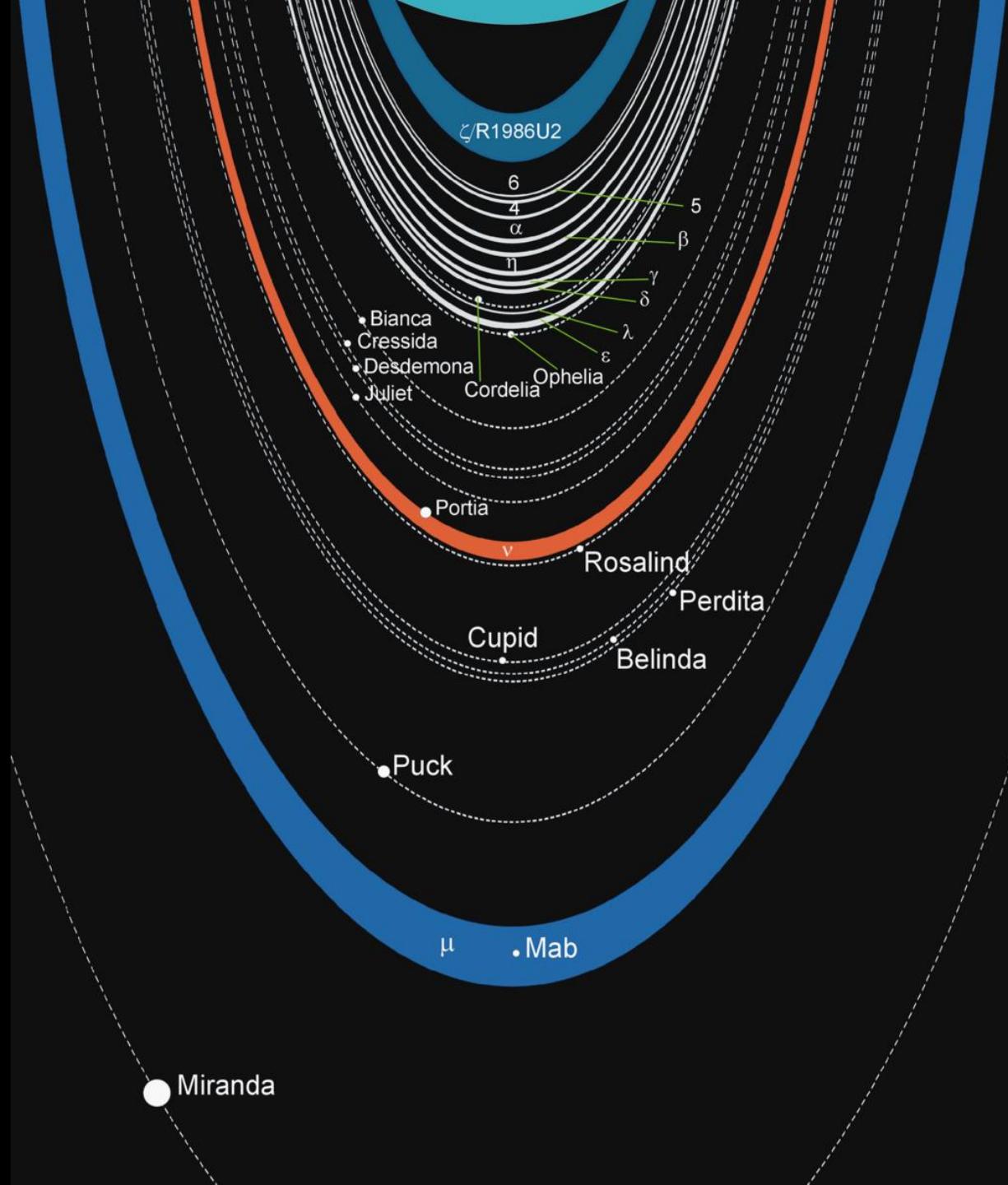


Mimas: the death star moon

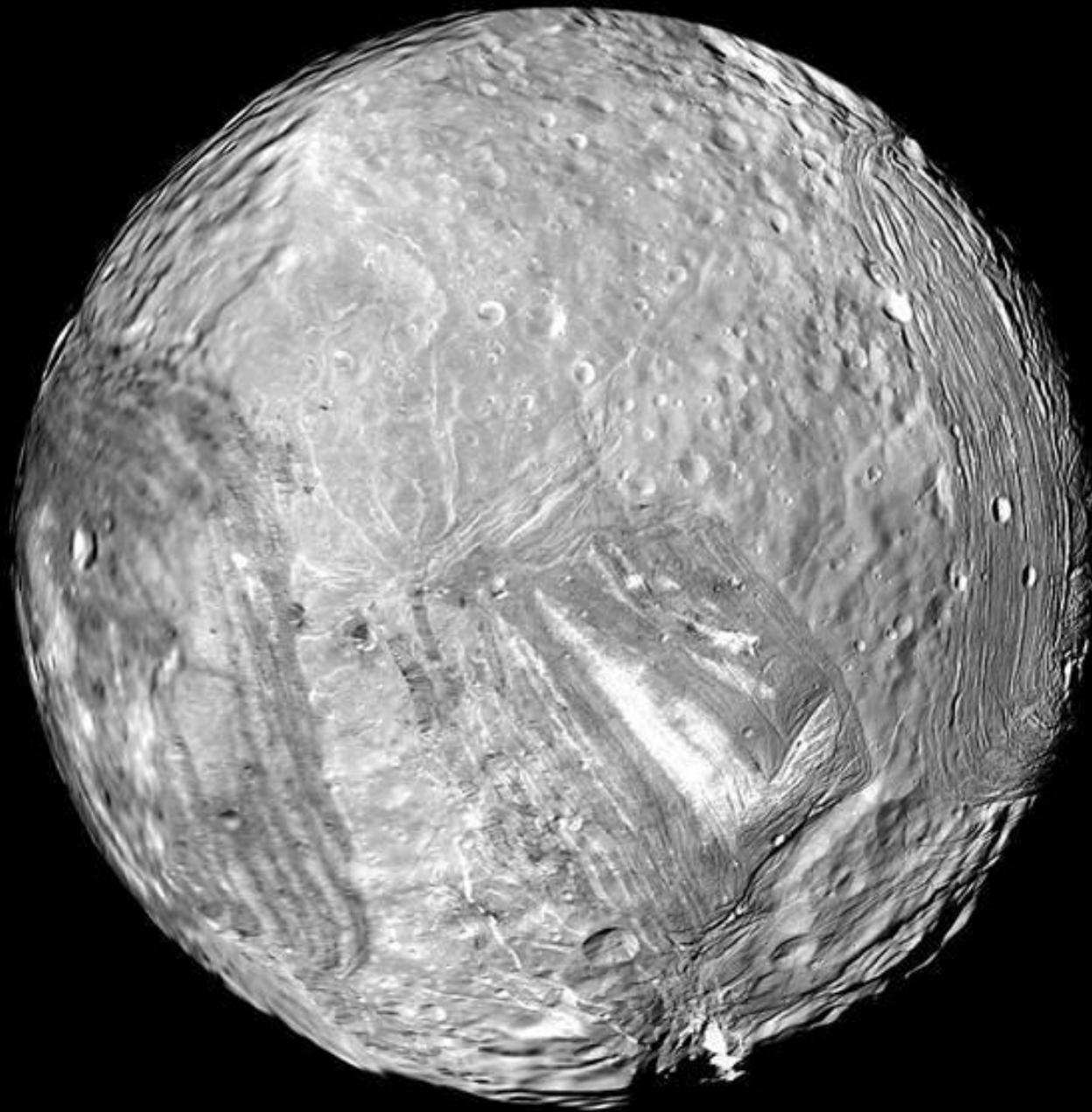


Moons of Uranus



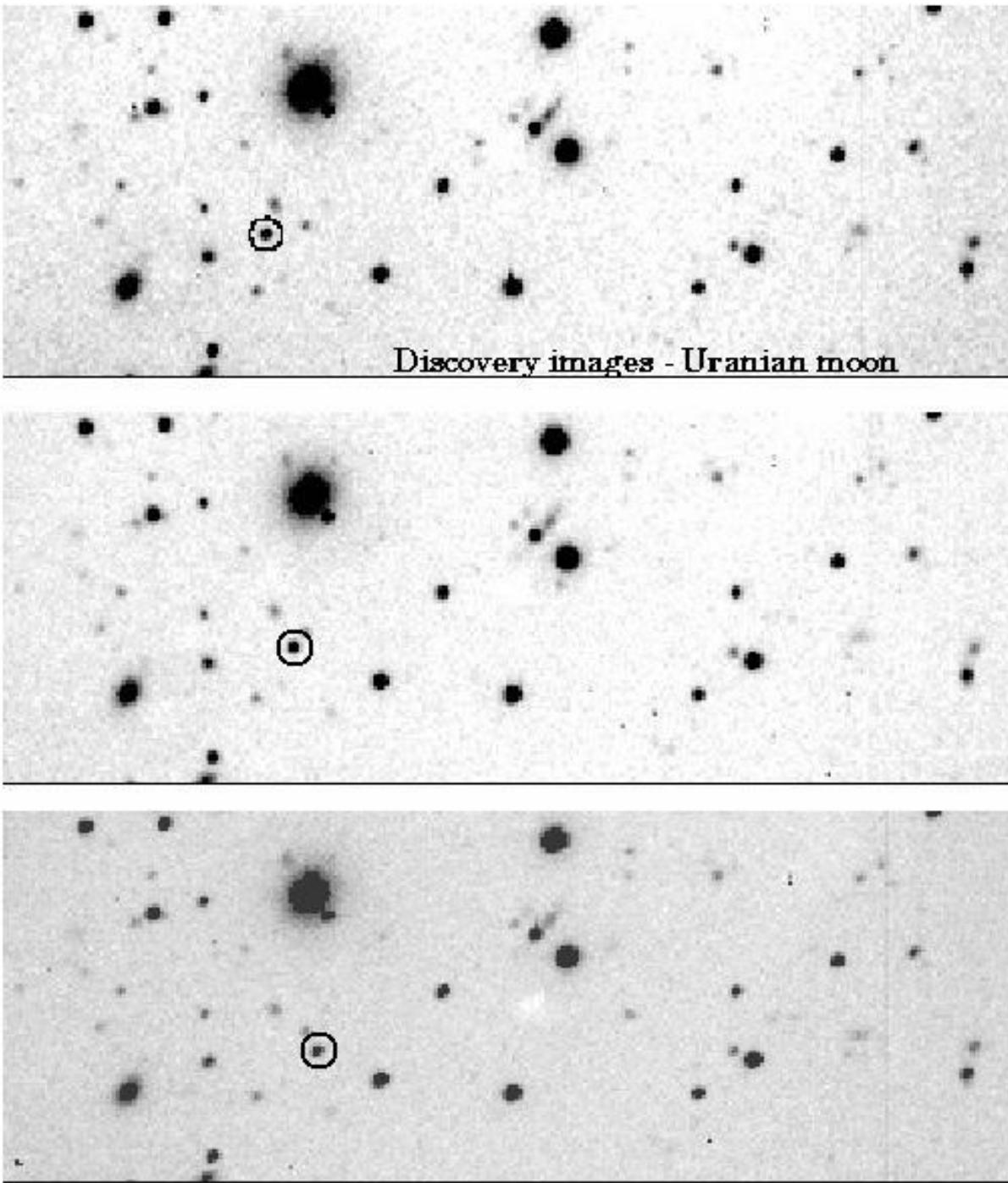


Miranda: an ice world?



Umbriel: weird ring at the top

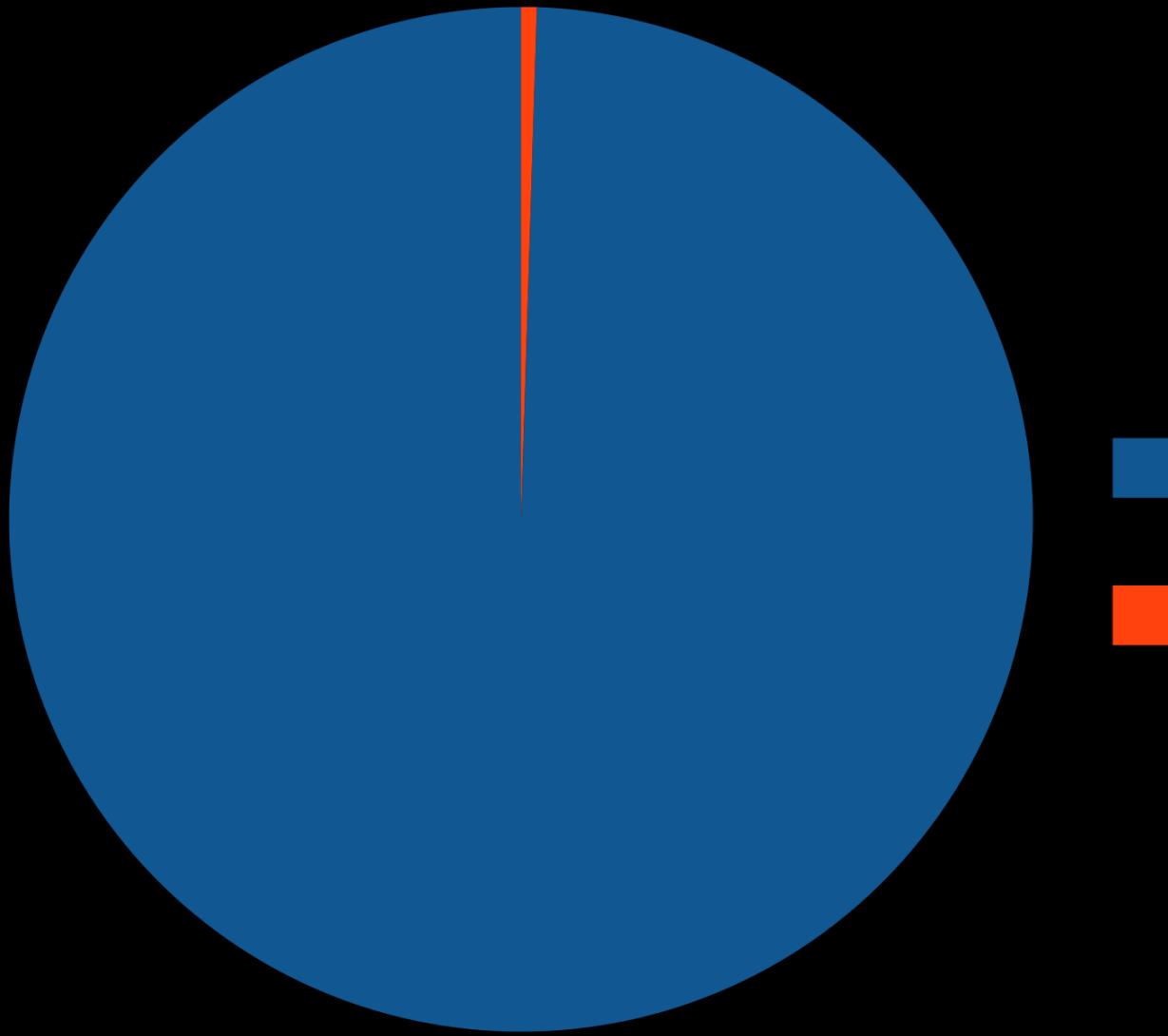




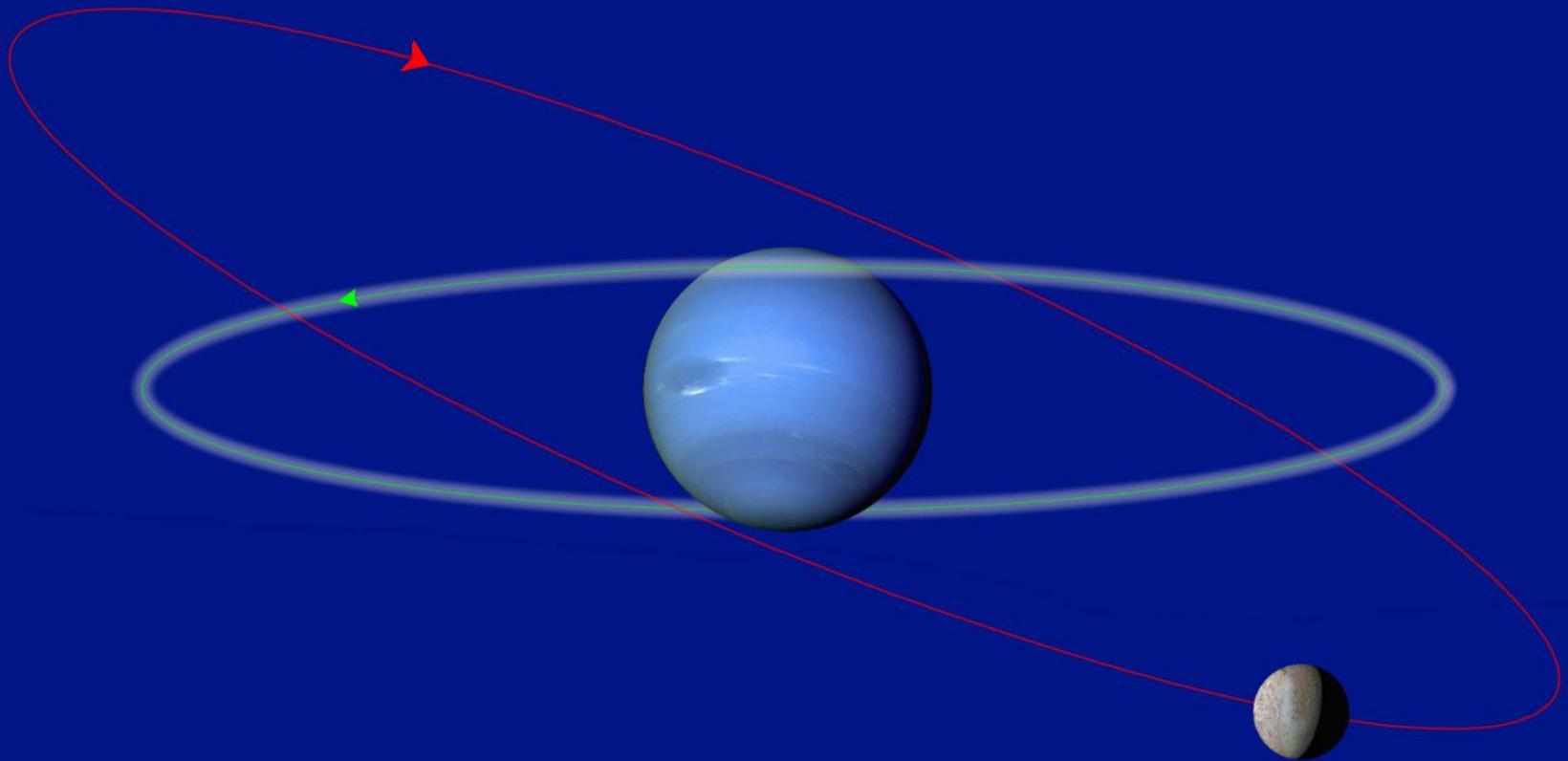
Sycorax:
example of how
the moons are
found

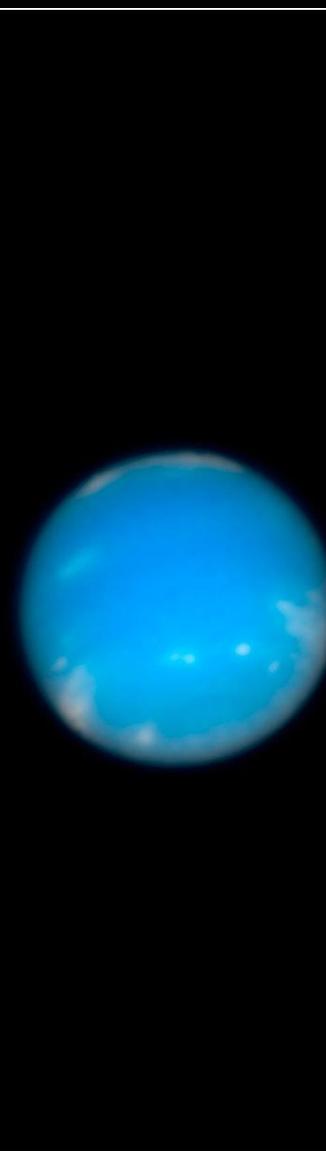
Discovery images - Uranian moon

Moons of Neptune



Triton: going in the wrong direction! captured Kuiper Belt Object?





Neptune Satellites and Ring Arcs
Hubble Space Telescope ▀ WFC3/UVIS

