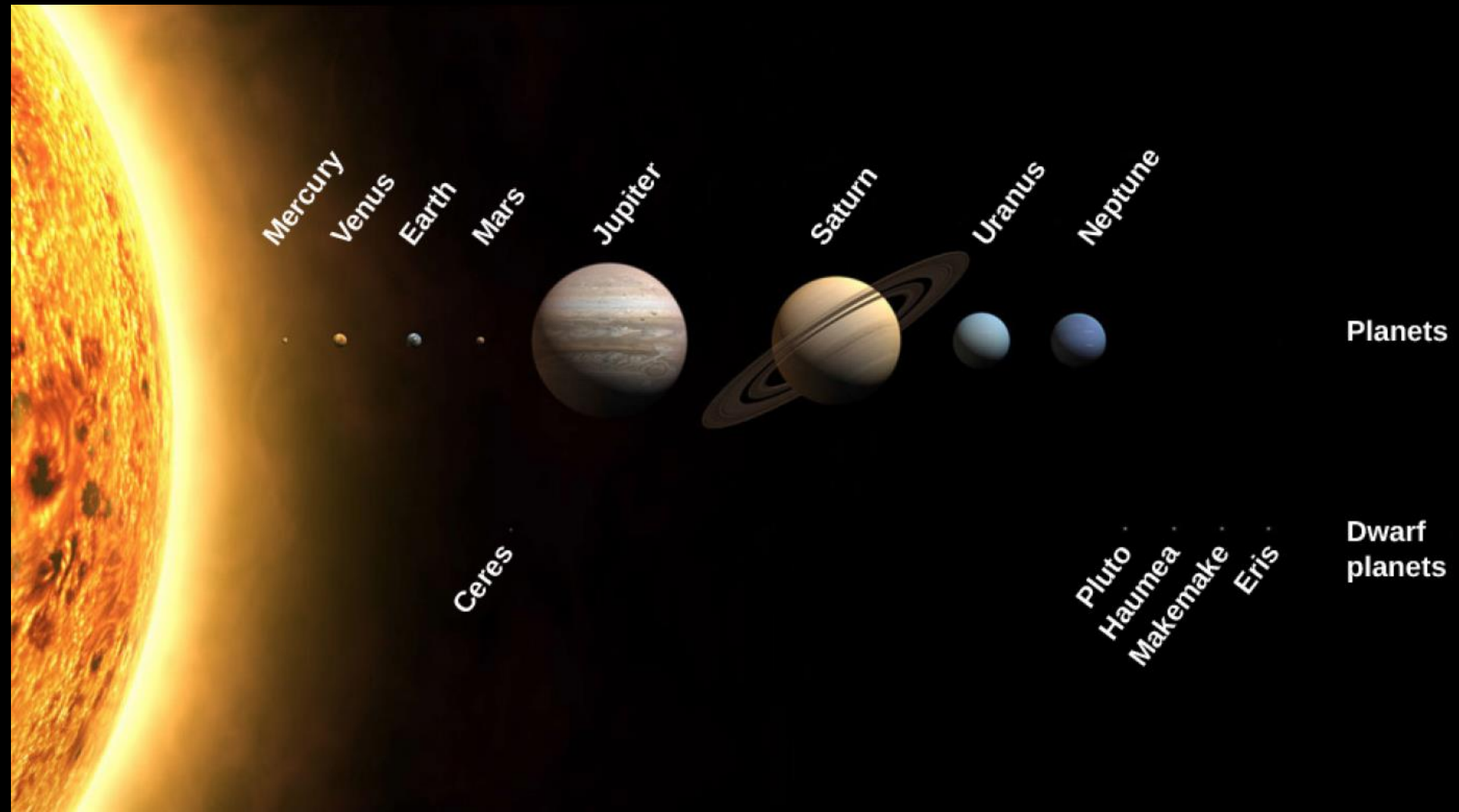
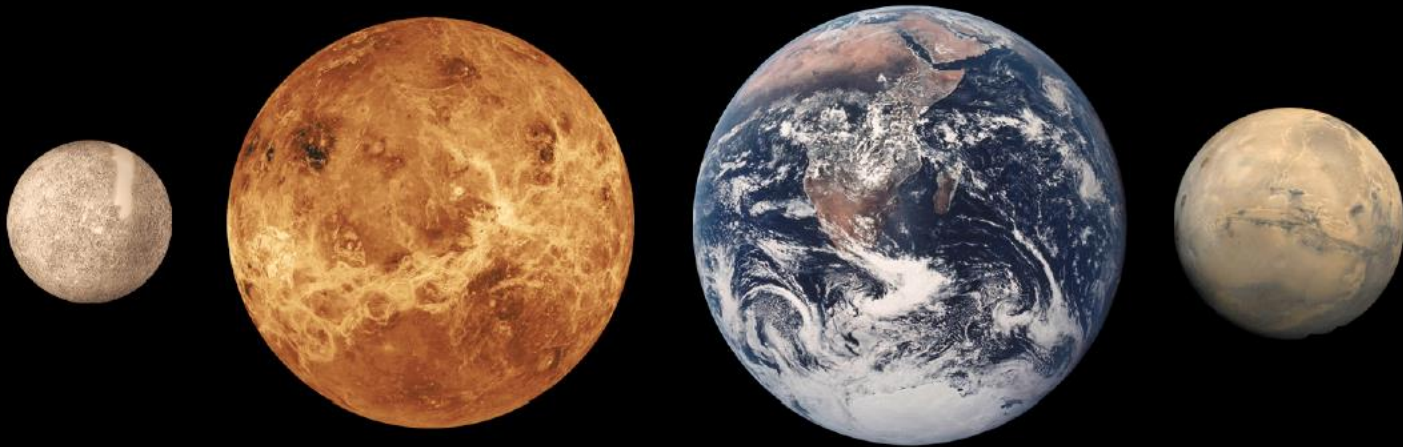


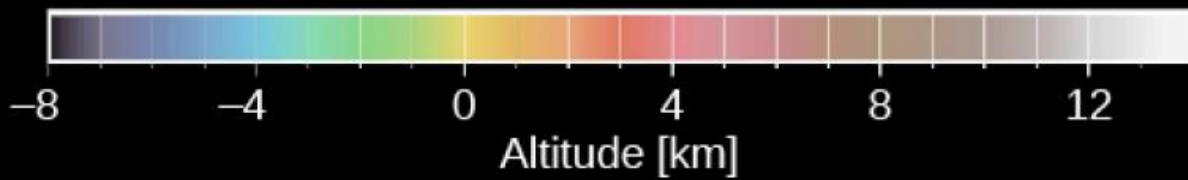
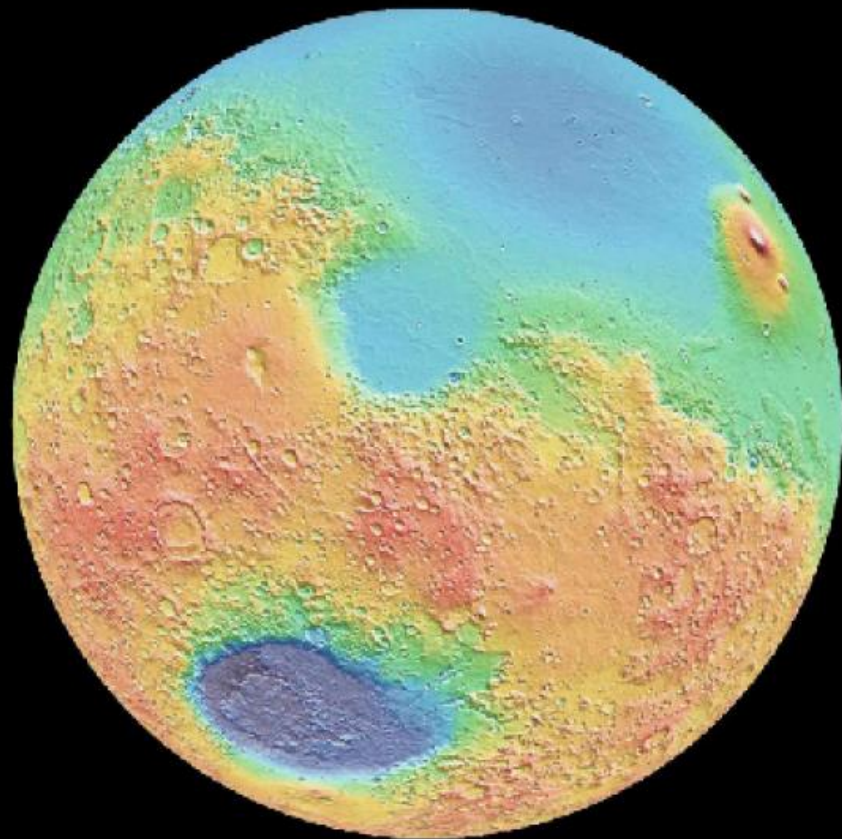
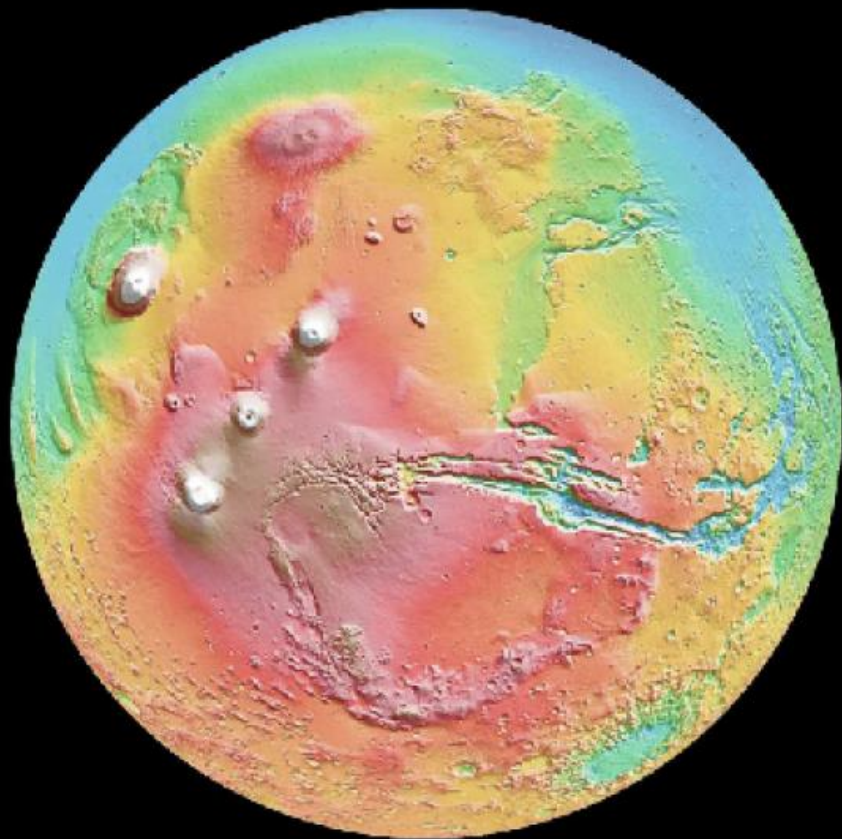
Our solar system: the giant planets and their moons



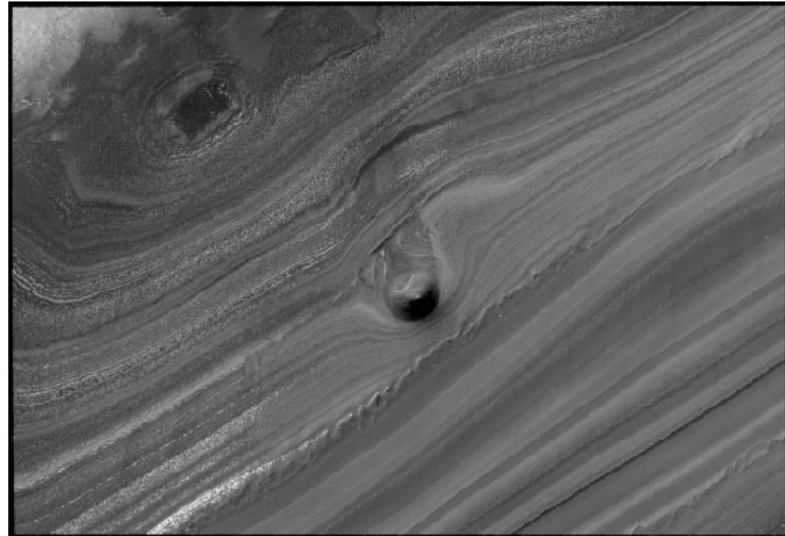
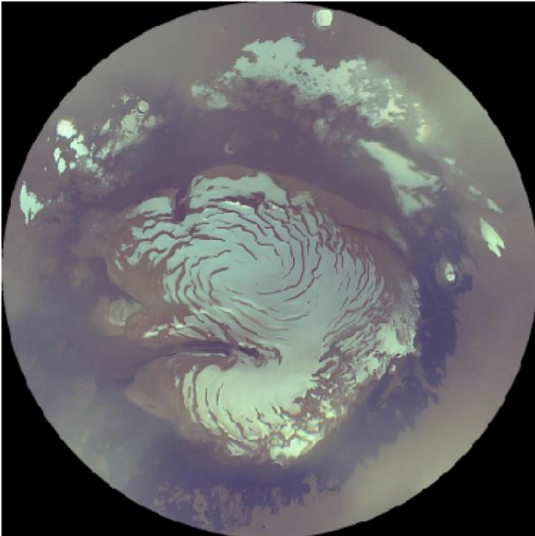
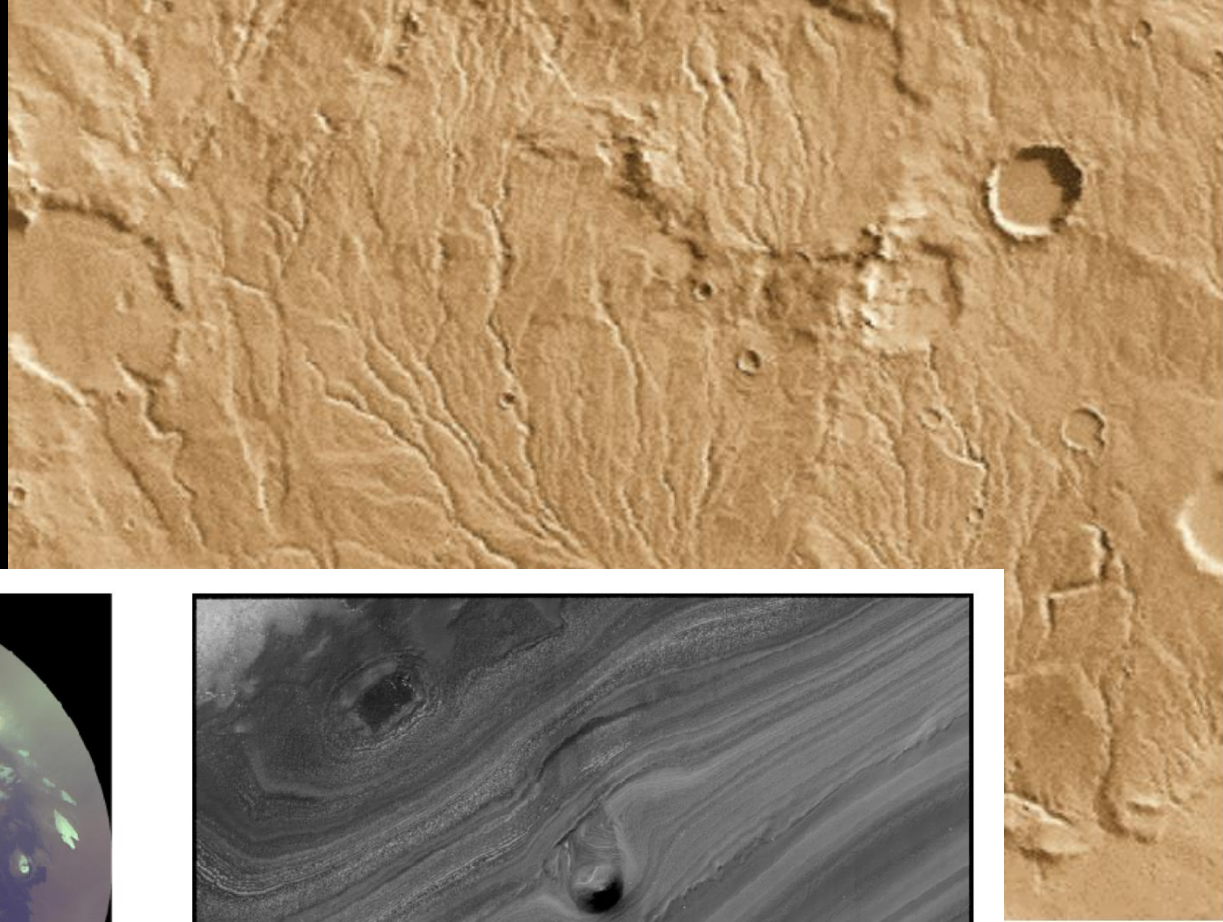
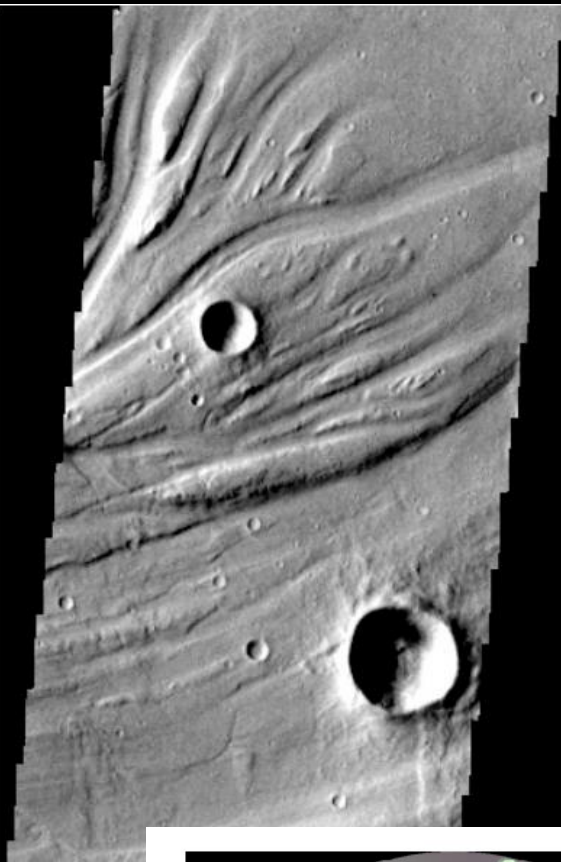
The terrestrial planets

– *rocky worlds*





Water?



HISTORY OF WATER ON MARS

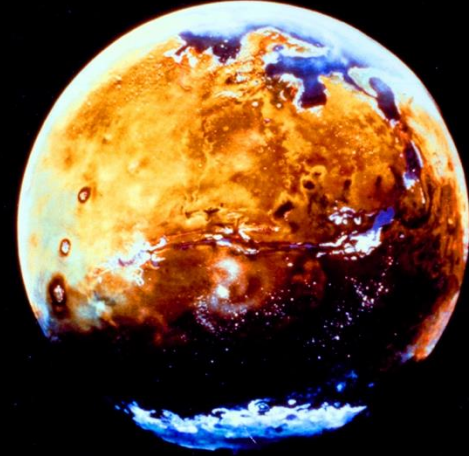
Billion years ago



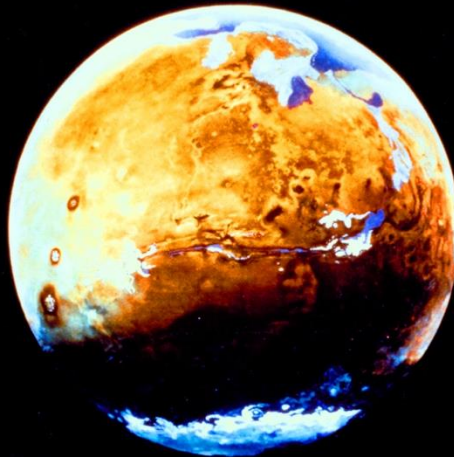
4.0



3.8



3.5



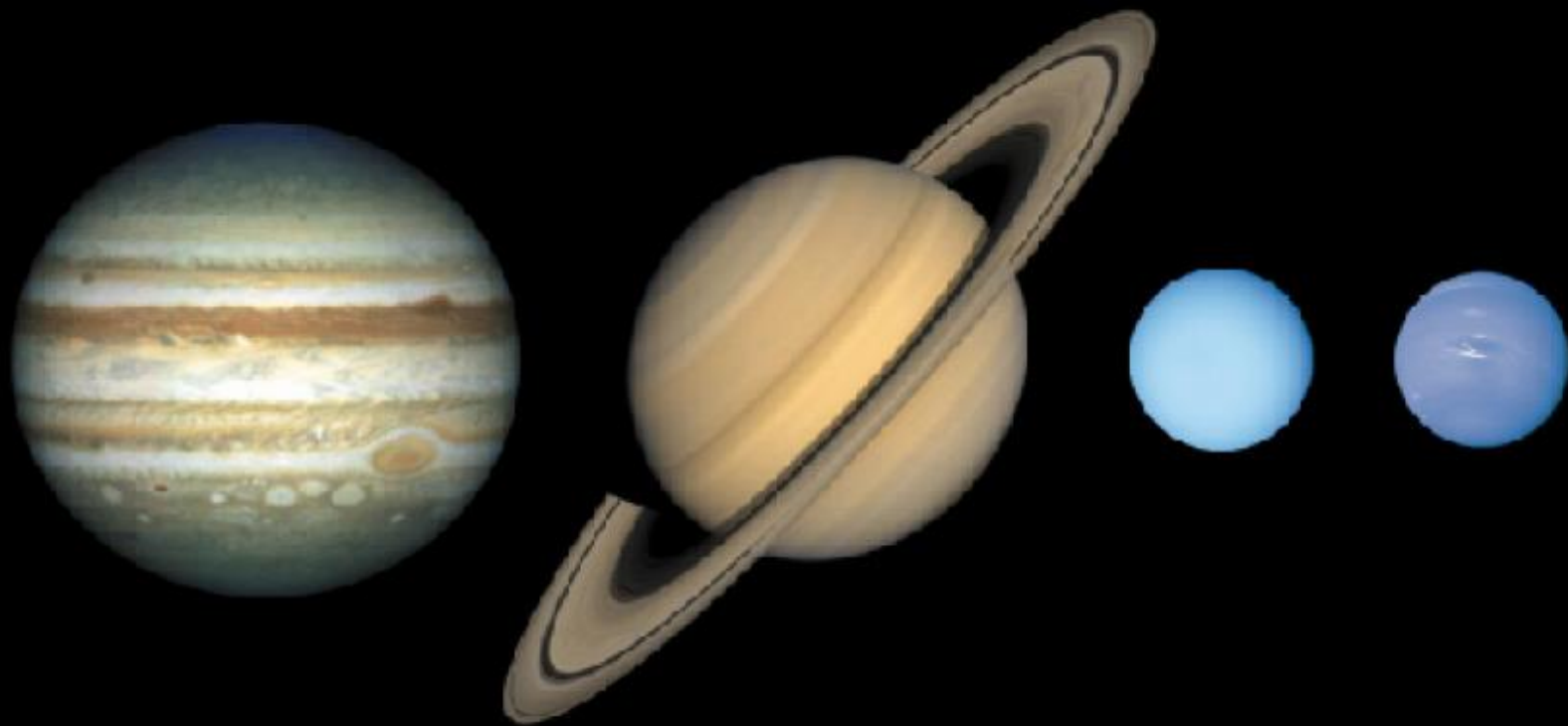
2.0



1.0



Now

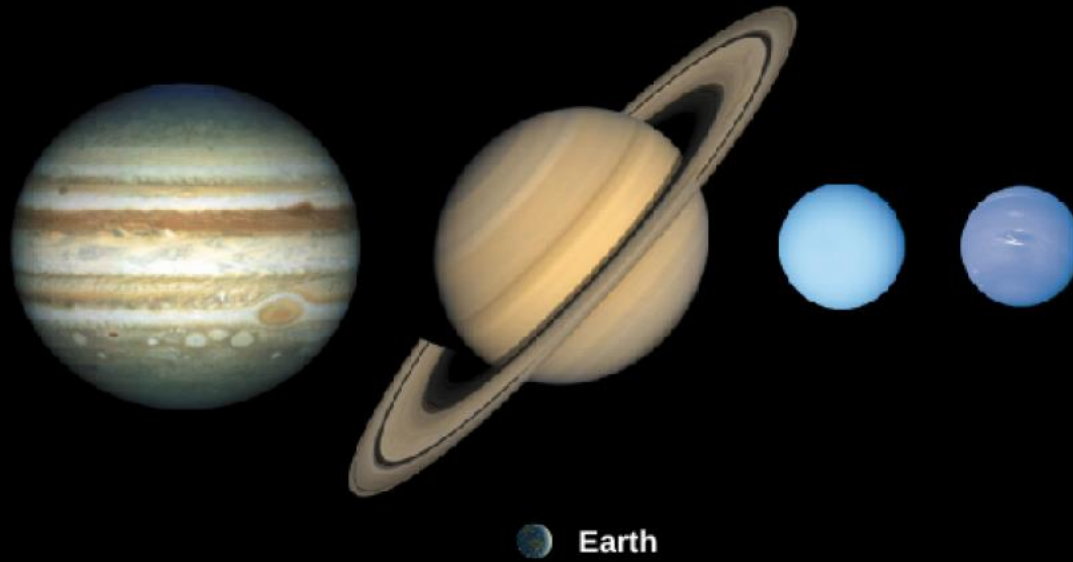


 Earth

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

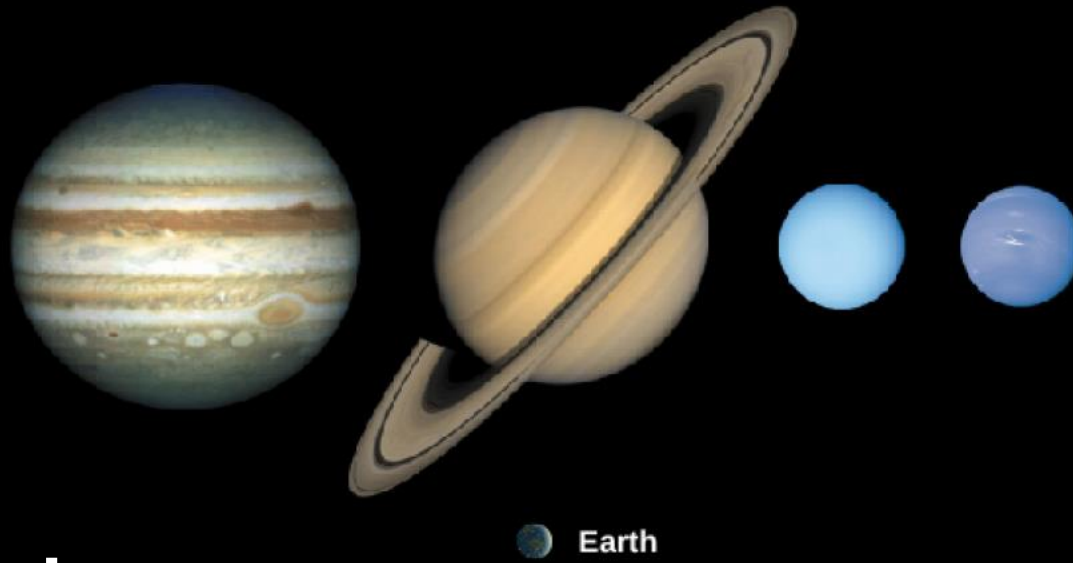
Abundances similar
to sun

Ice Giants

Uranus, Neptune

Much less massive

Similar cores as gas
giants



Gas giants

Jupiter: energy from contraction (2 cm/yr)

Saturn: energy from differentiation (heavier elements sink)

Ice Giants

Cold



VENUS 1 FLYBY
26 APR 1998

VENUS 2 FLYBY
24 JUN 1999

VENUS
TARGETING
MANEUVER
3 DEC 1998

LAUNCH
15 OCT 1997

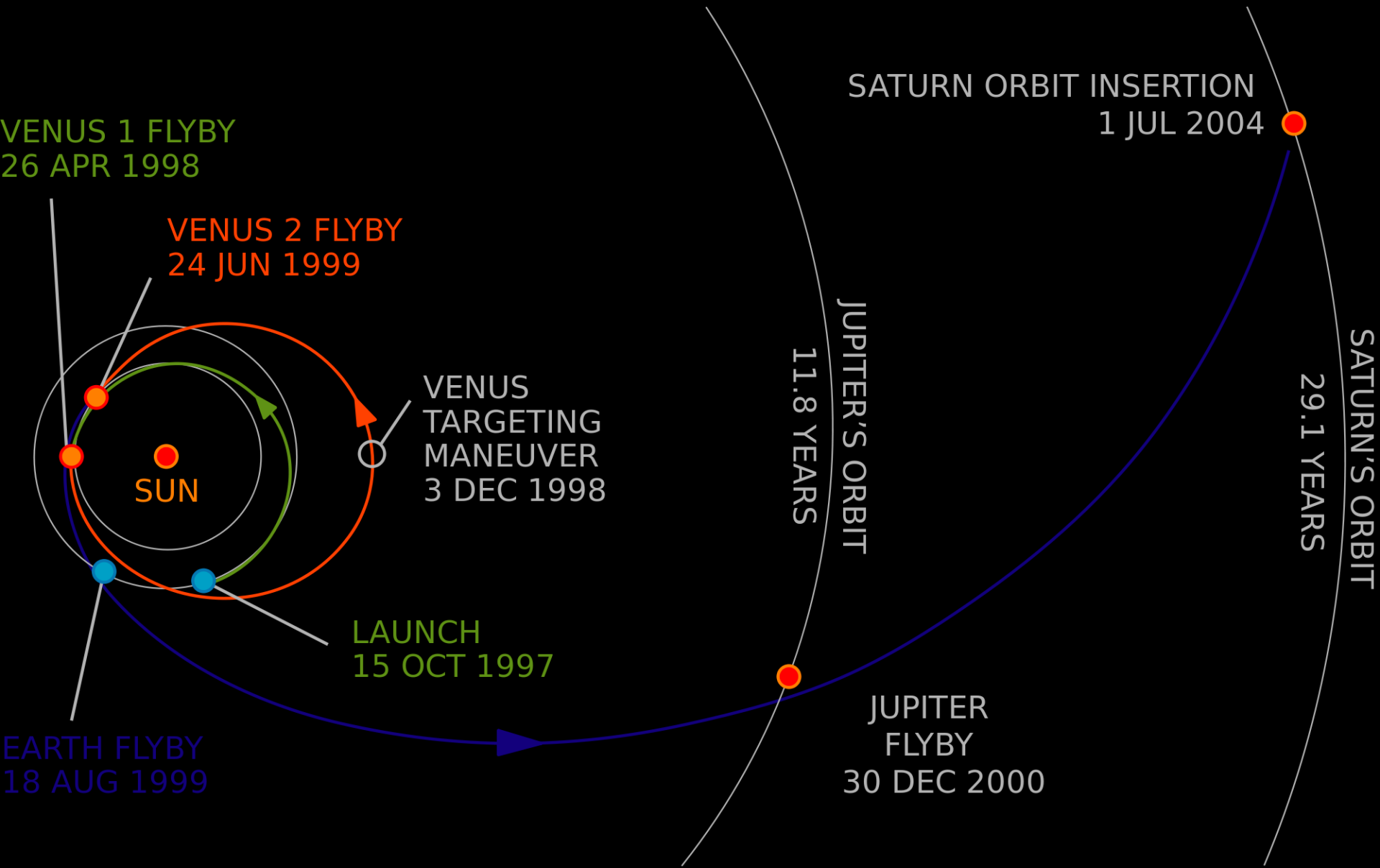
EARTH FLYBY
18 AUG 1999

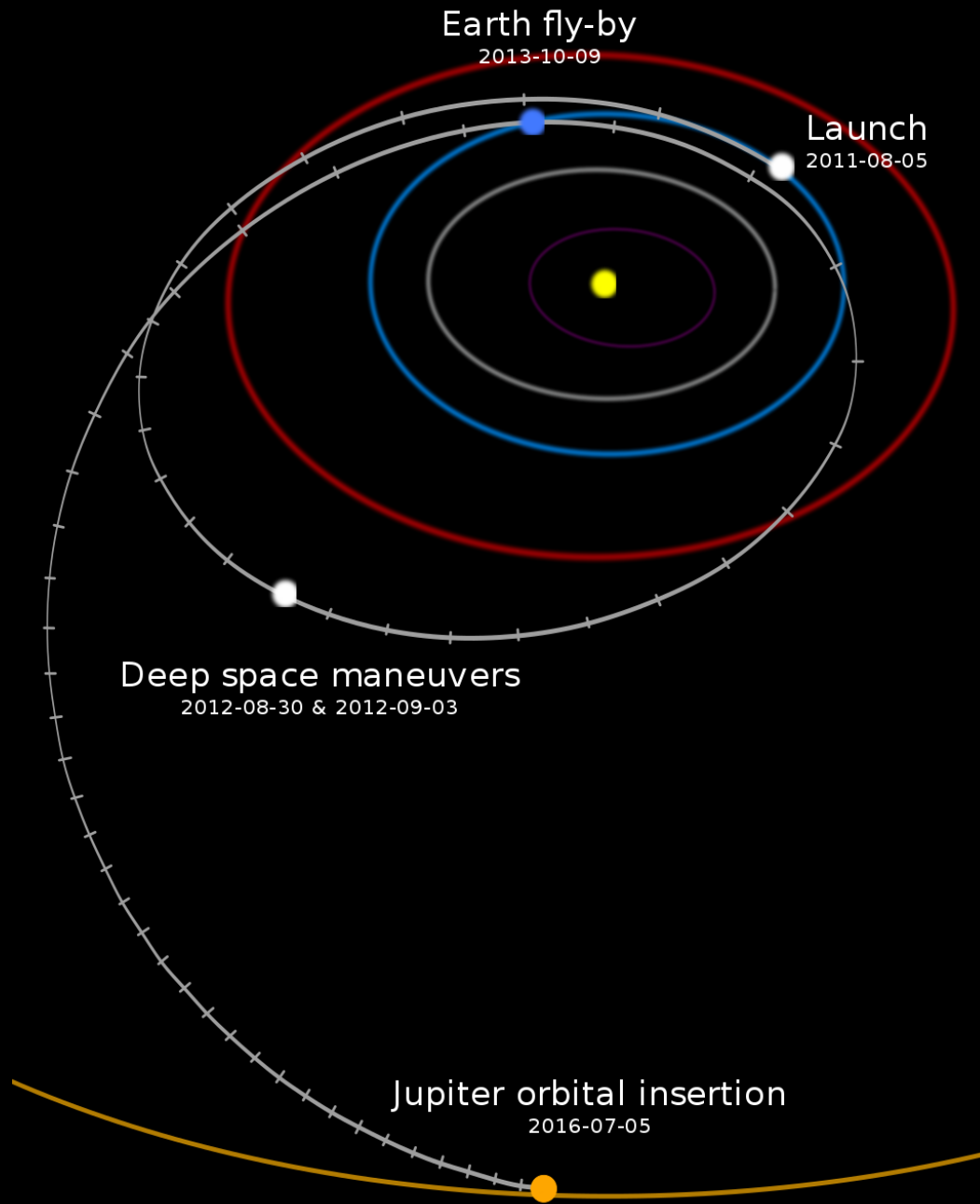
SATURN ORBIT INSERTION
1 JUL 2004

JUPITER'S ORBIT
11.8 YEARS

JUPITER
FLYBY
30 DEC 2000

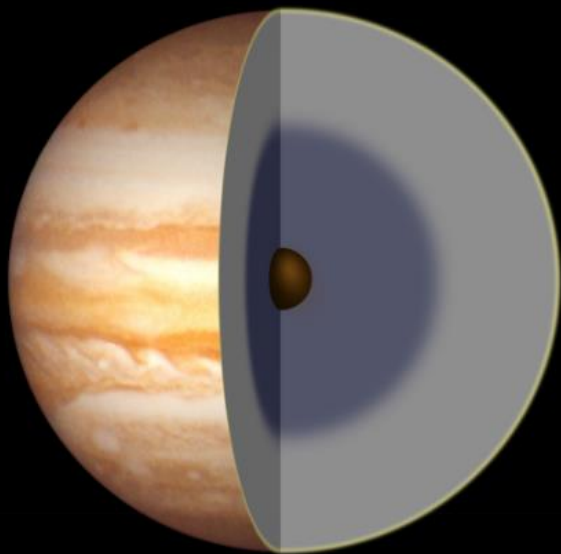
SATURN'S ORBIT
29.1 YEARS



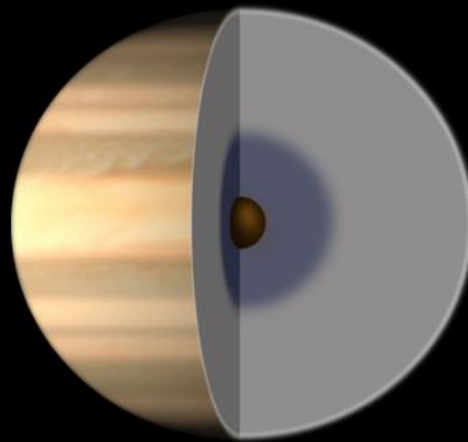


Missions to the Giant Planets

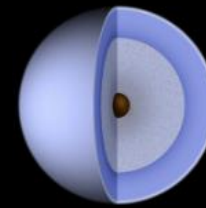
Planet	Spacecraft ^[1]	Encounter Date	Type
Jupiter	Pioneer 10	December 1973	Flyby
	Pioneer 11	December 1974	Flyby
	Voyager 1	March 1979	Flyby
	Voyager 2	July 1979	Flyby
	Ulysses	February 1992	Flyby during gravity assist
	Galileo	December 1995	Orbiter and probe
	Cassini	December 2002	Flyby
	New Horizons	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



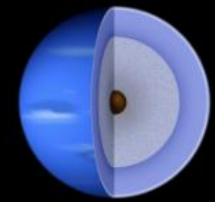
JUPITER



SATURN



URANUS



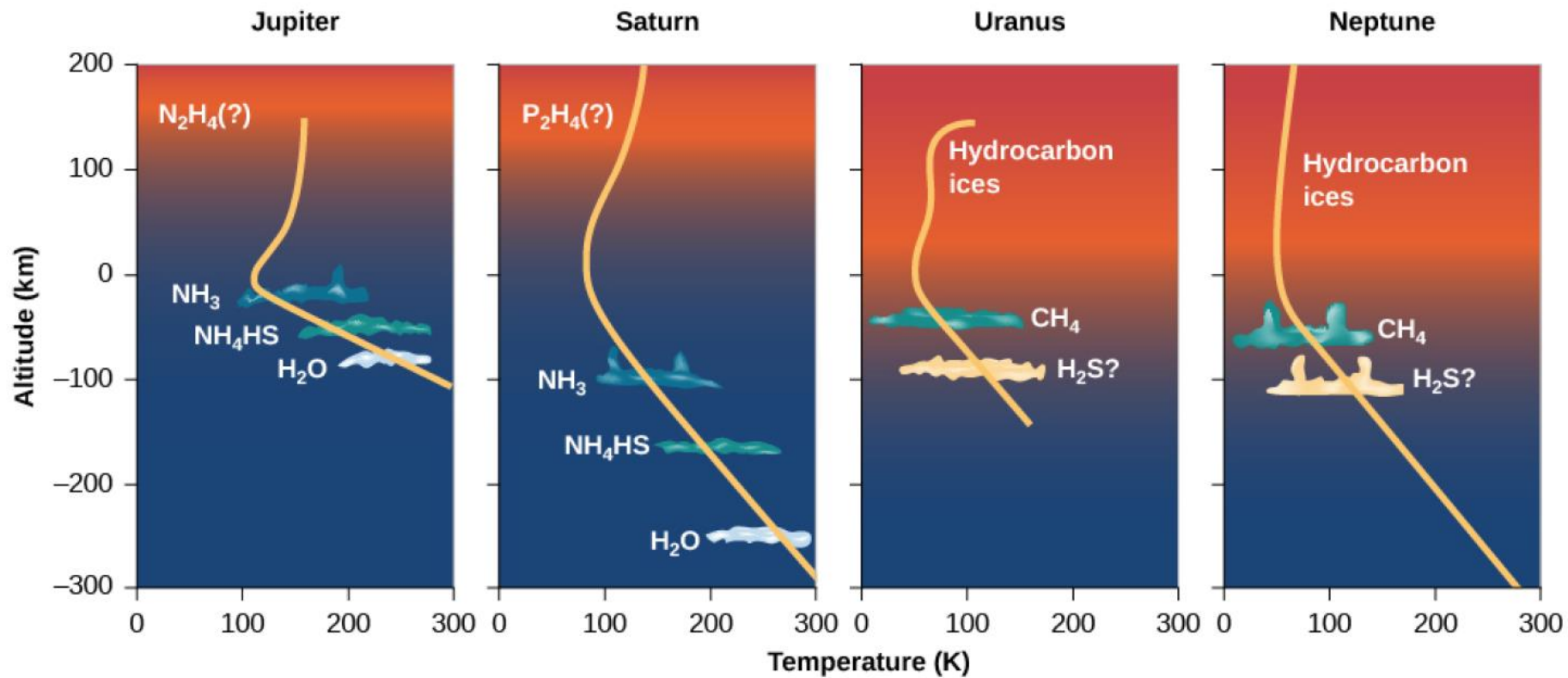
NEPTUNE

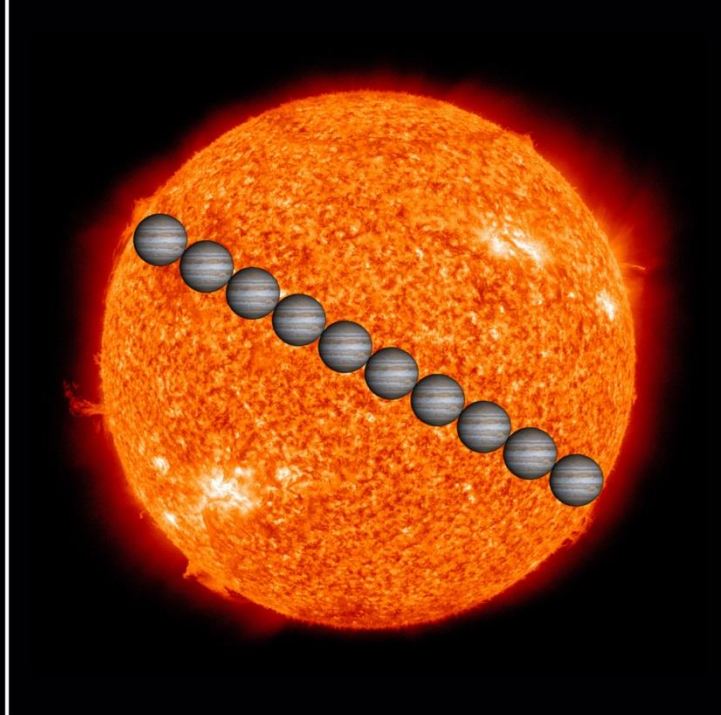
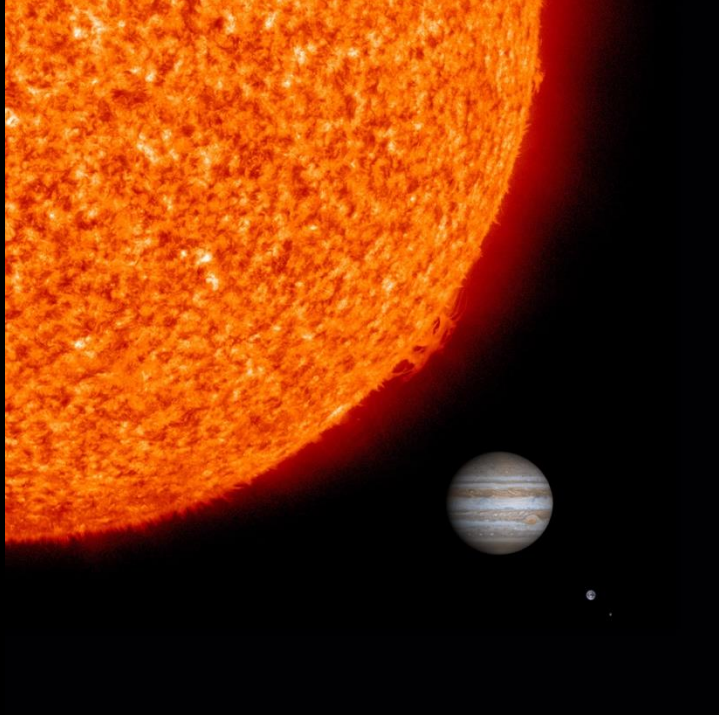


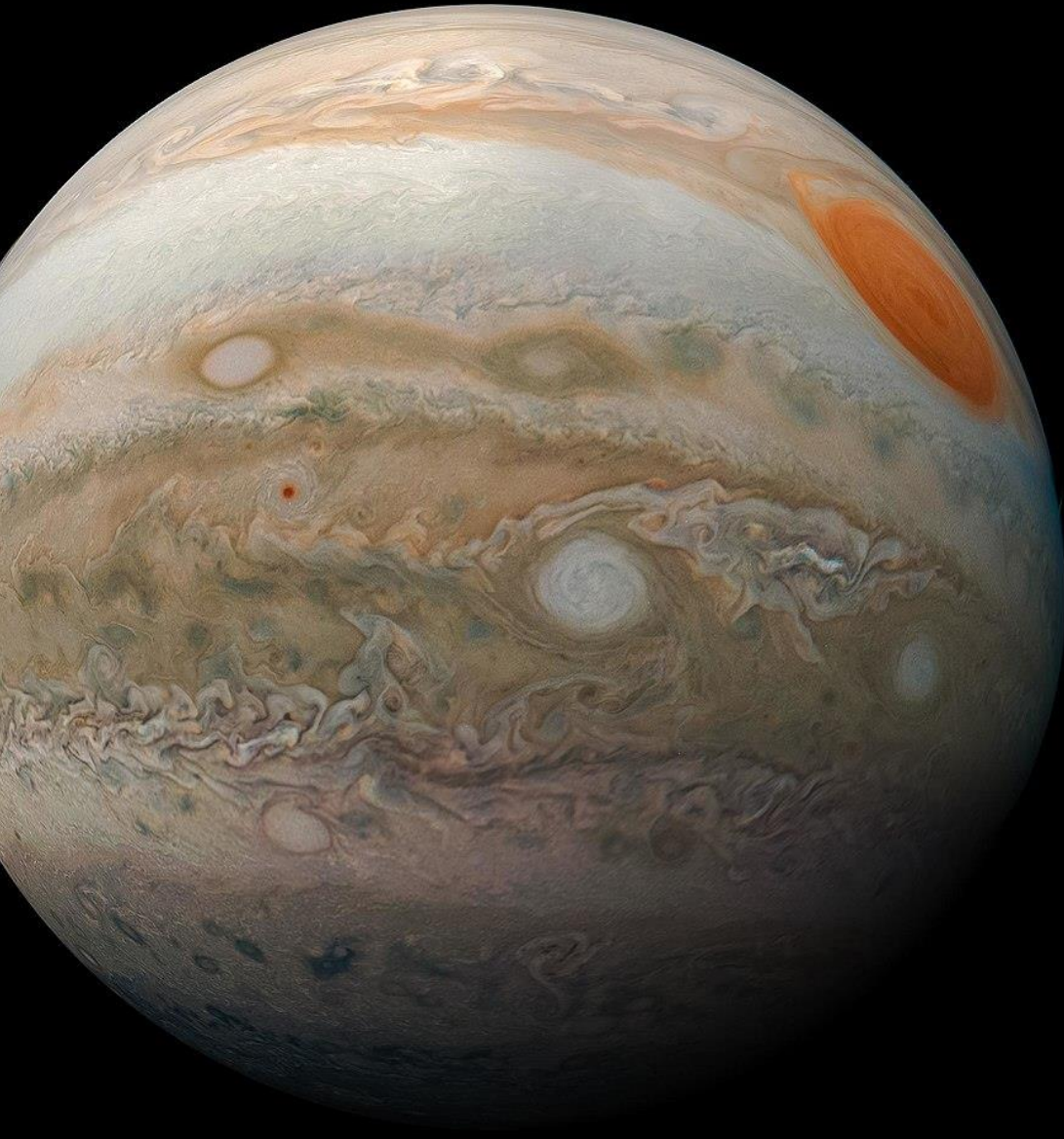
EARTH

■ Molecular hydrogen
■ Metallic hydrogen

■ Hydrogen, helium, methane gas
■ Mantle (water, ammonia, methane ices)
■ Core (rock, ice)

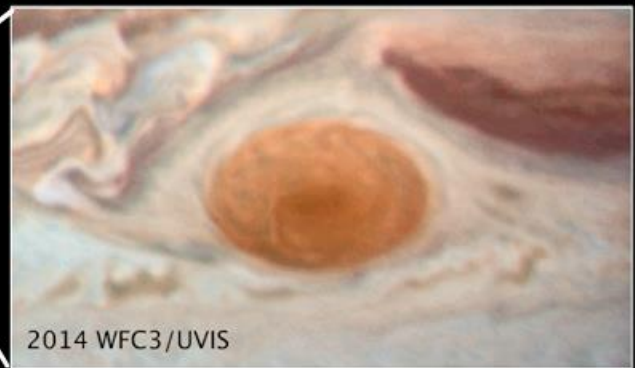
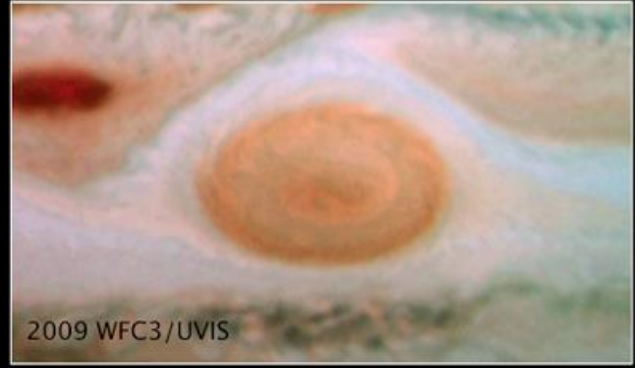
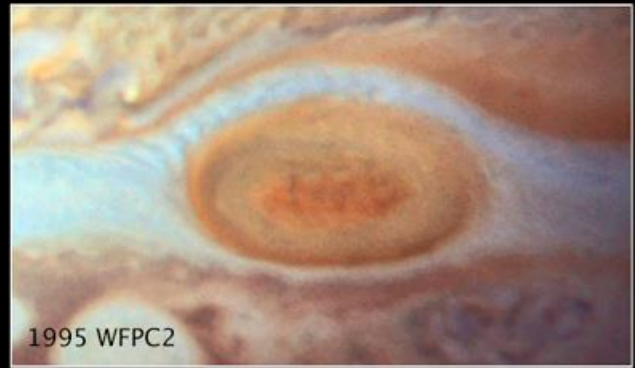




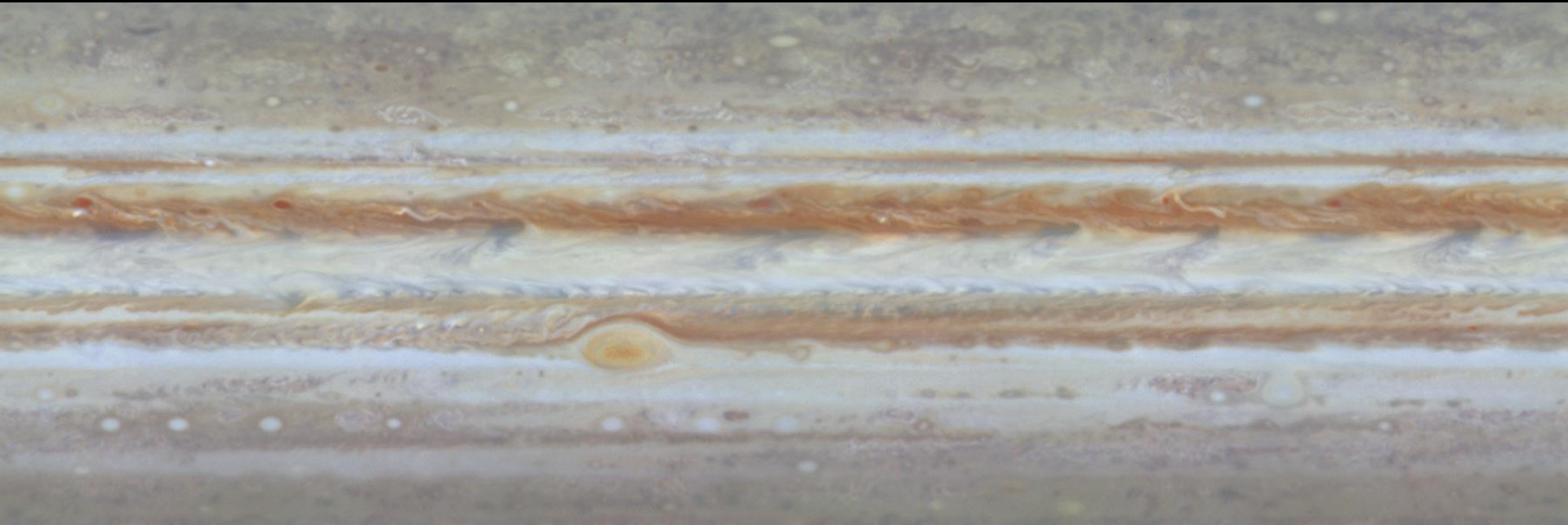


Bands of clouds

Great Red Spot:
high-pressure
storm

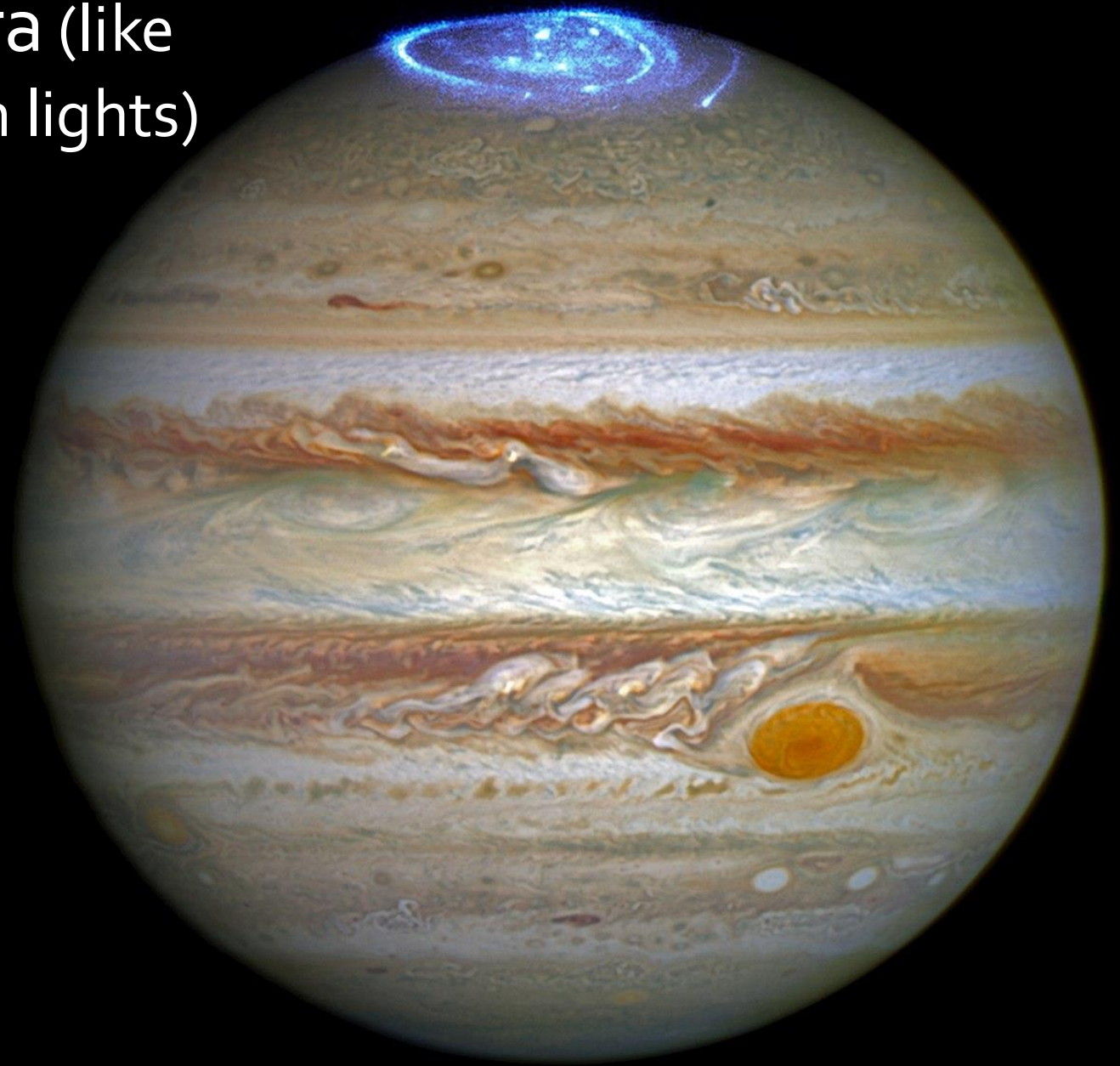


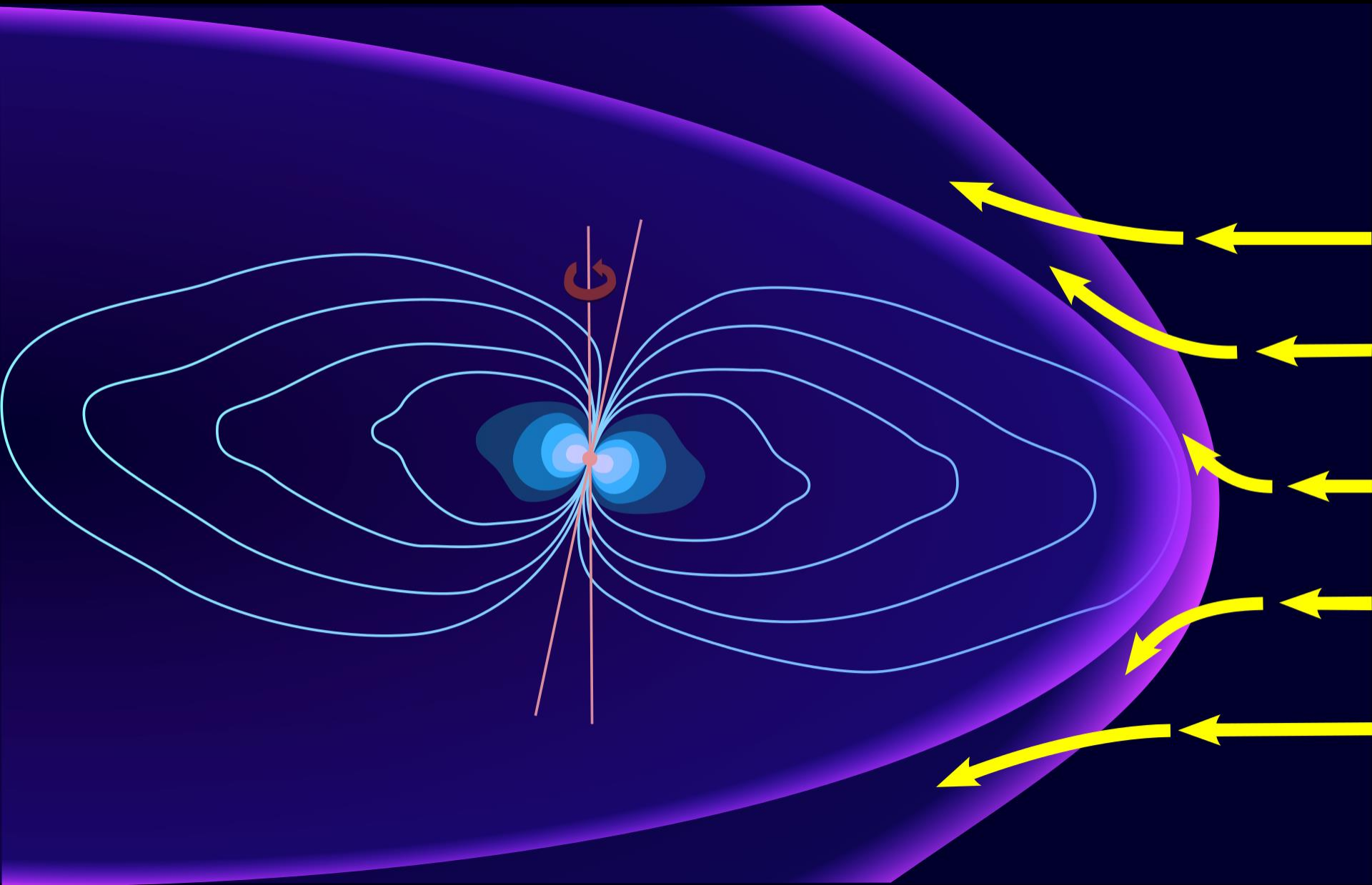
Red spot is shrinking!

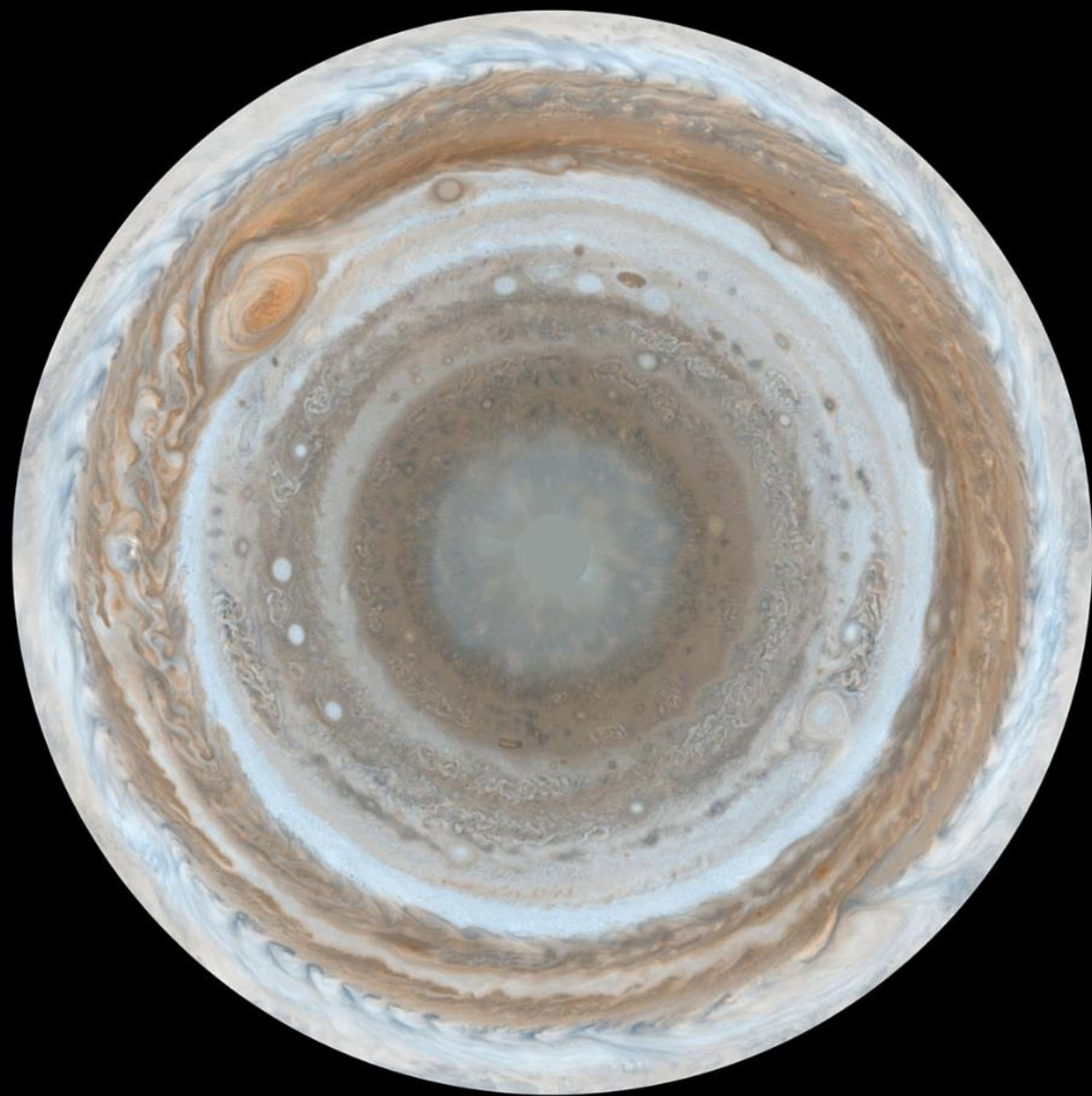


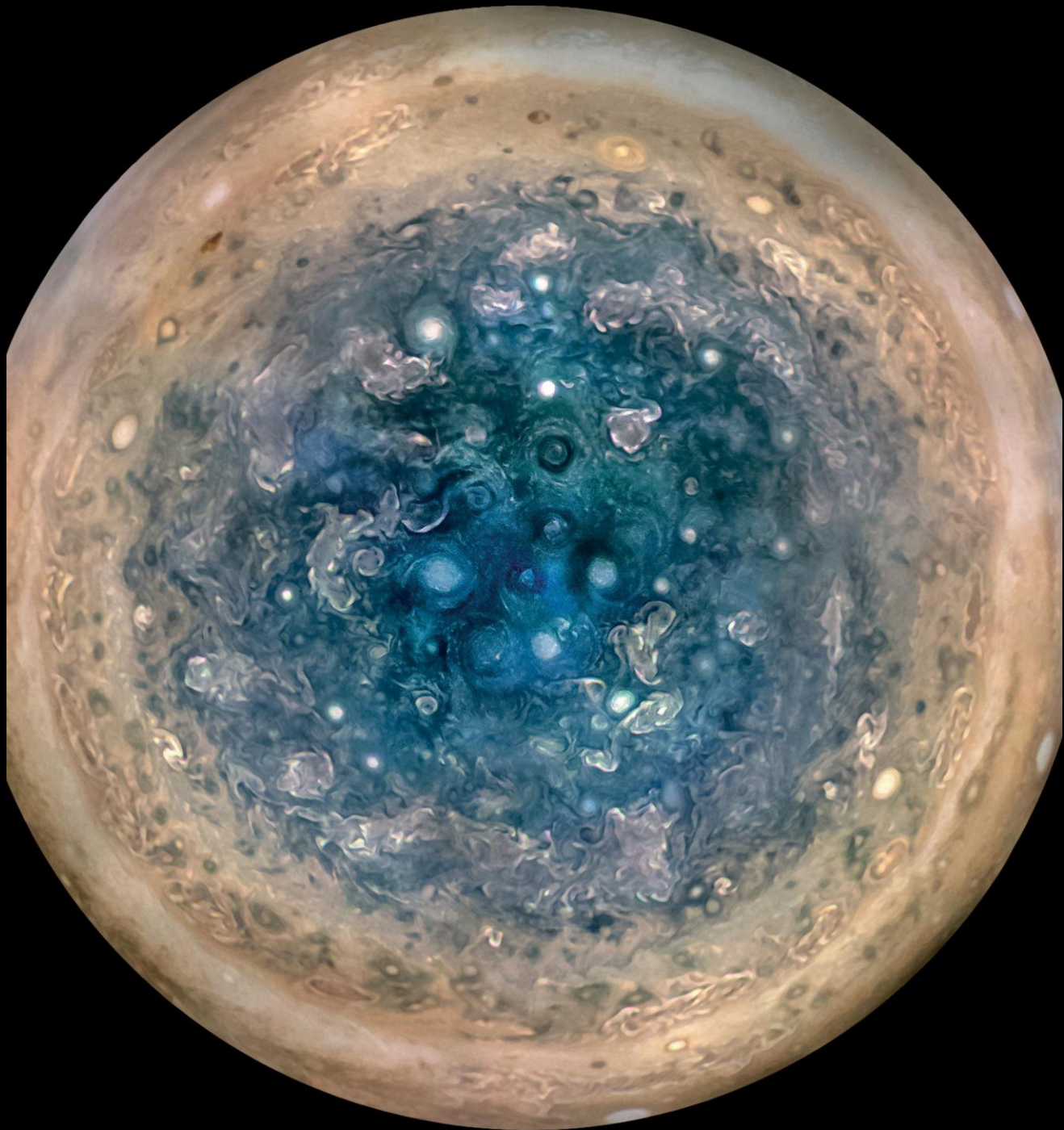
Bands rotate at different speeds
(like weather on earth)

Jovian aurora (like
Earth: Northern lights)



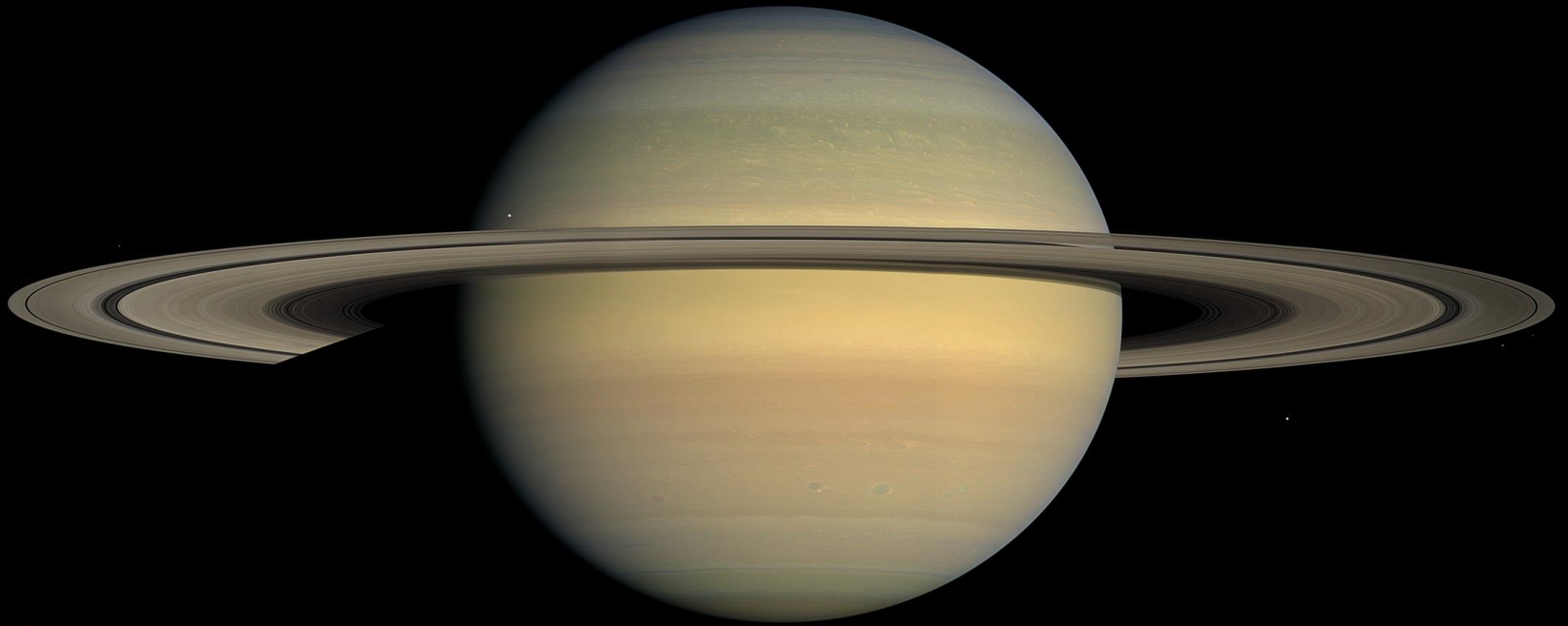


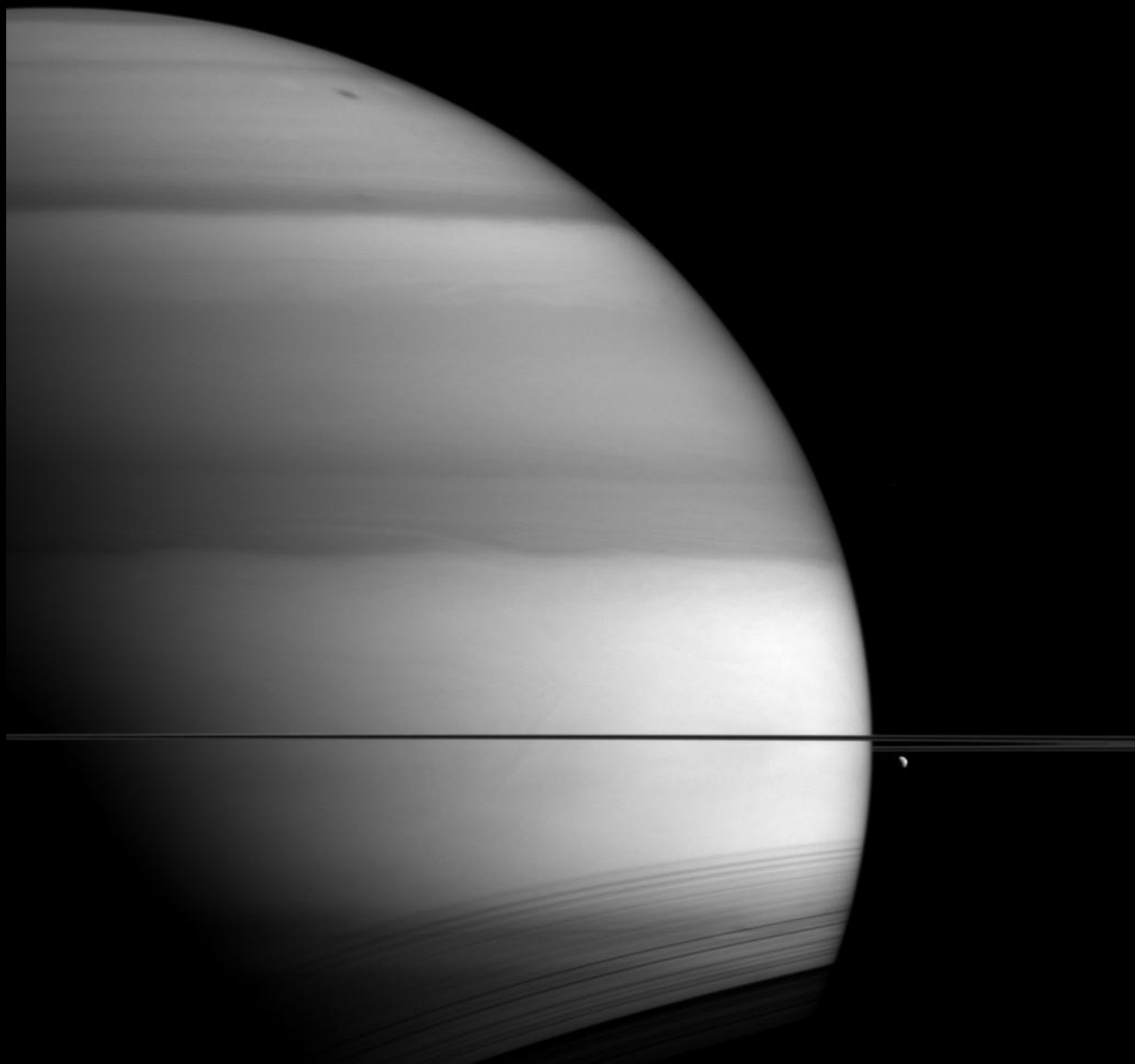


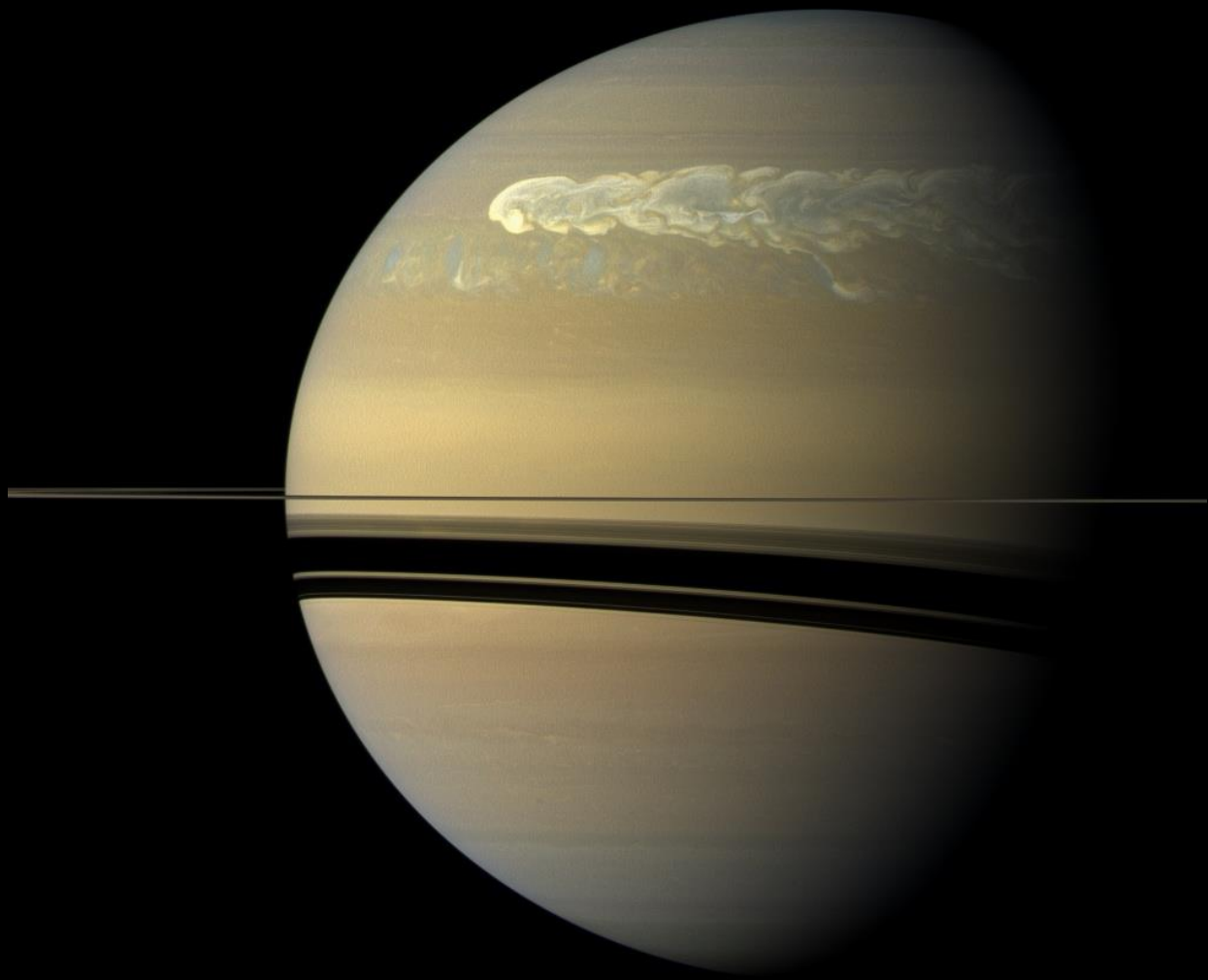


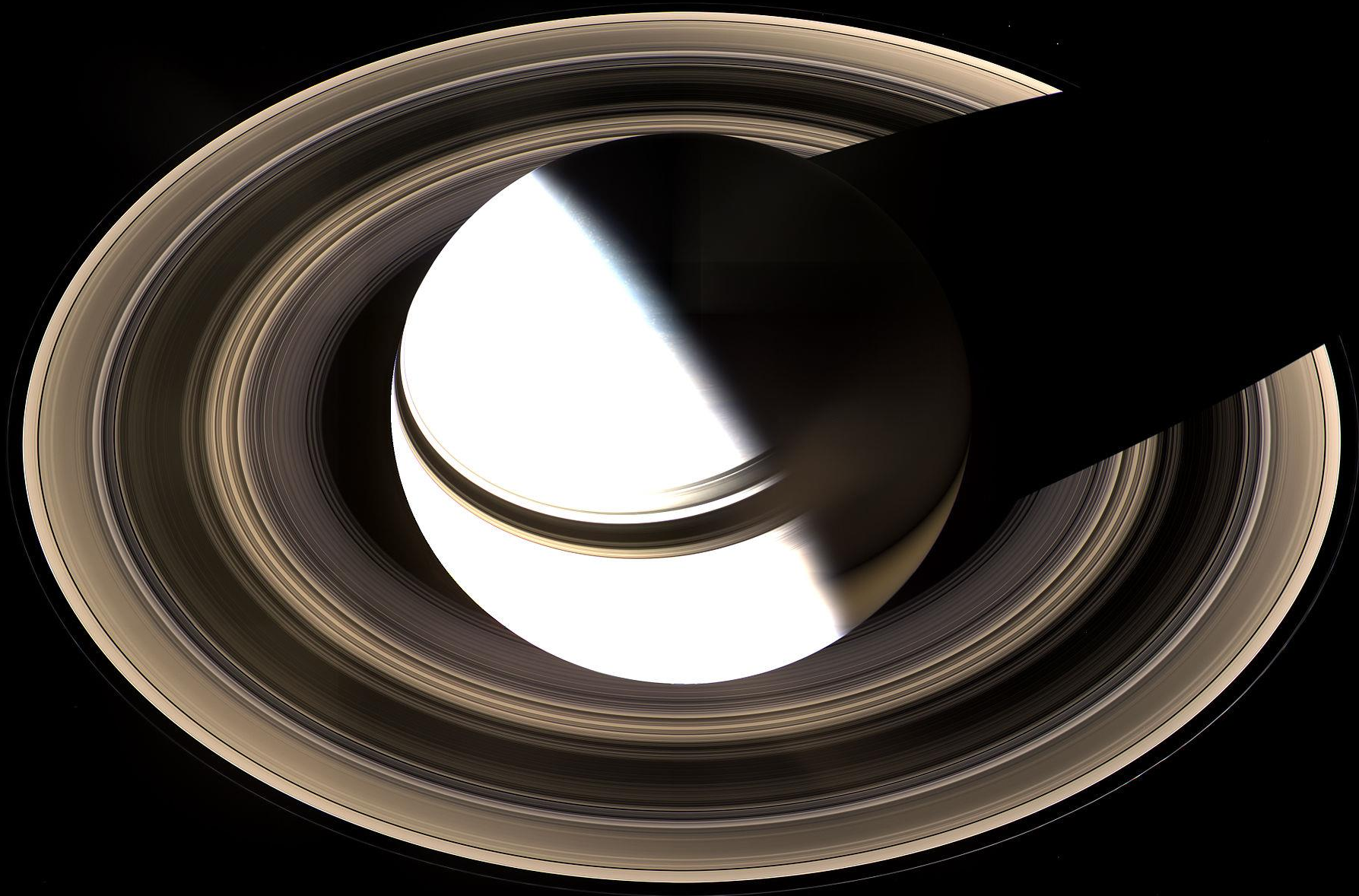


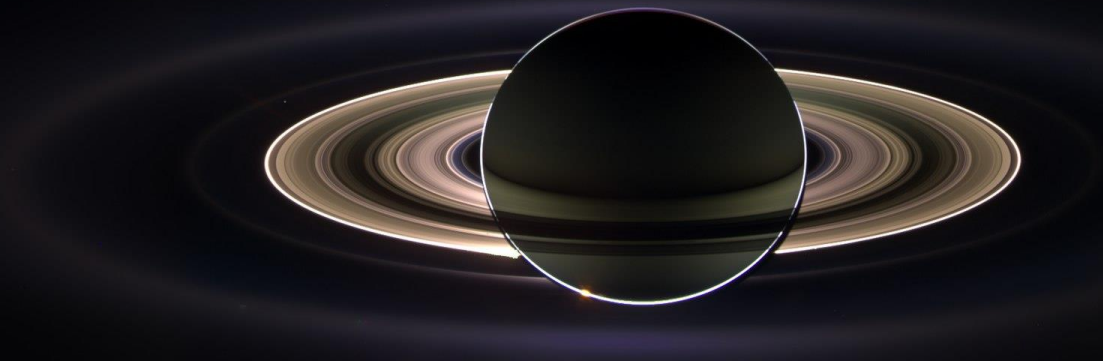
Saturn (and its rings)

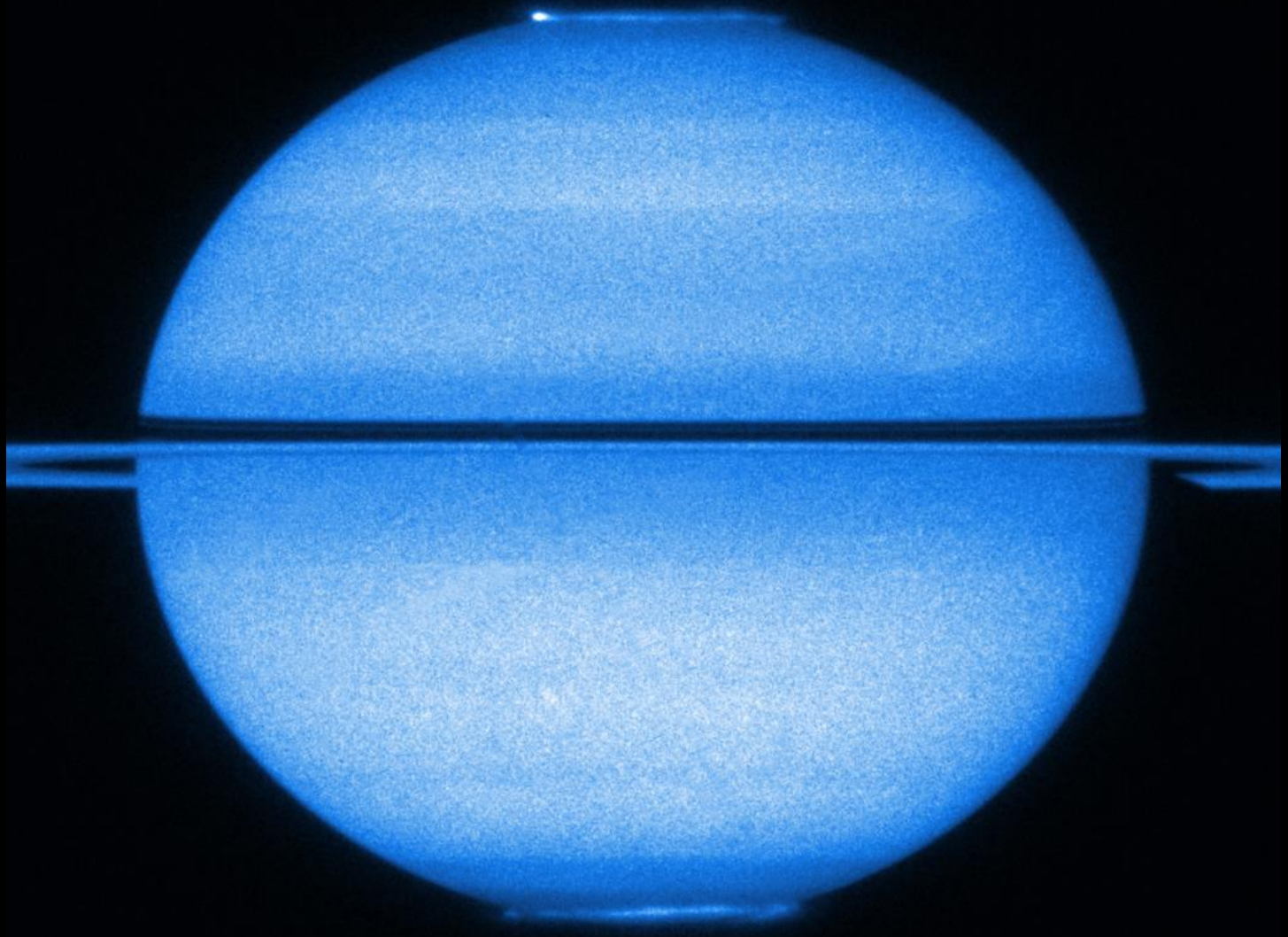




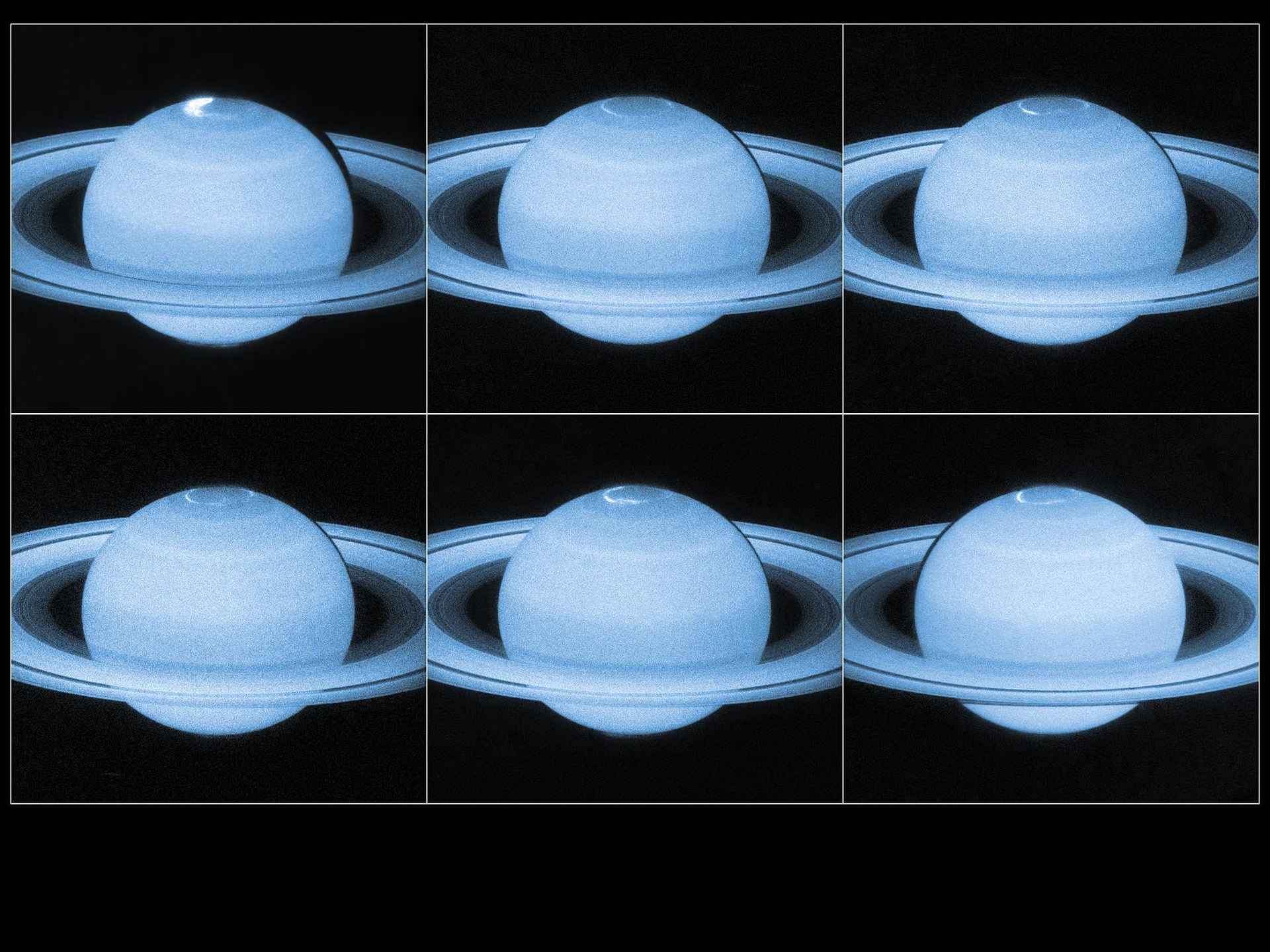


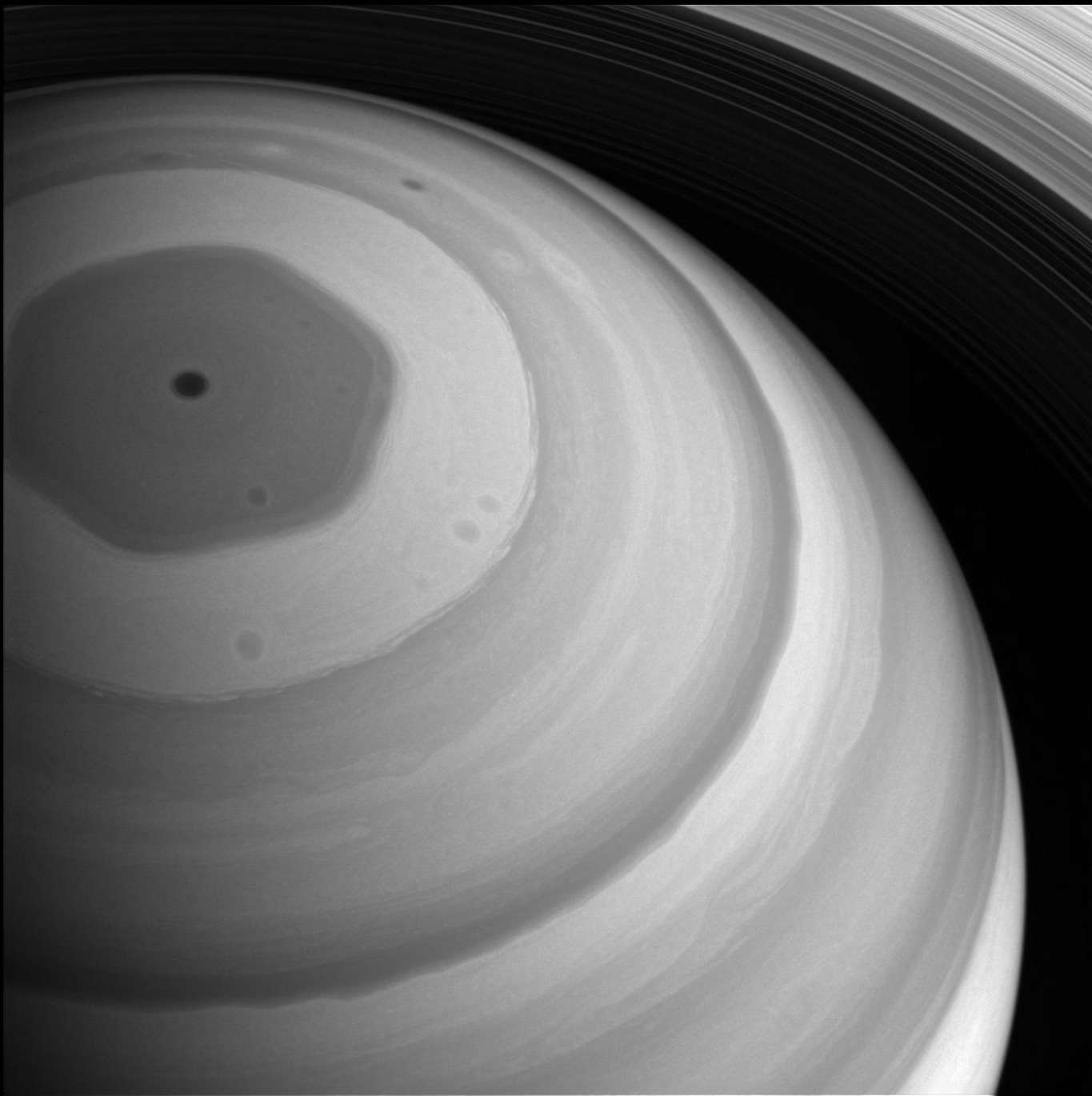


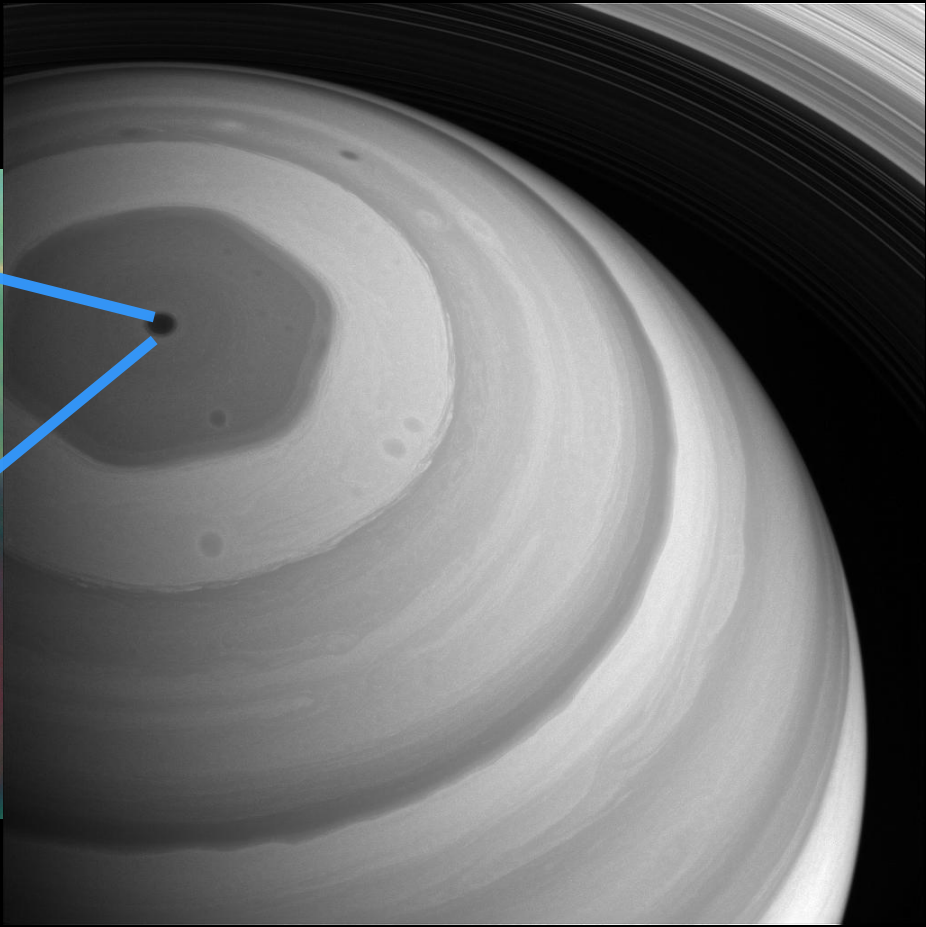
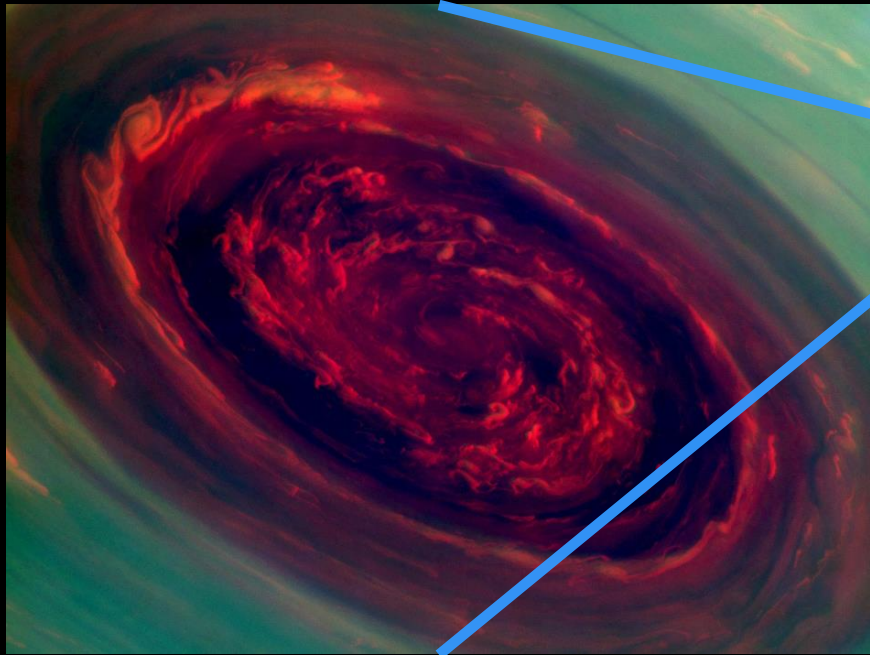




Saturn's aurora









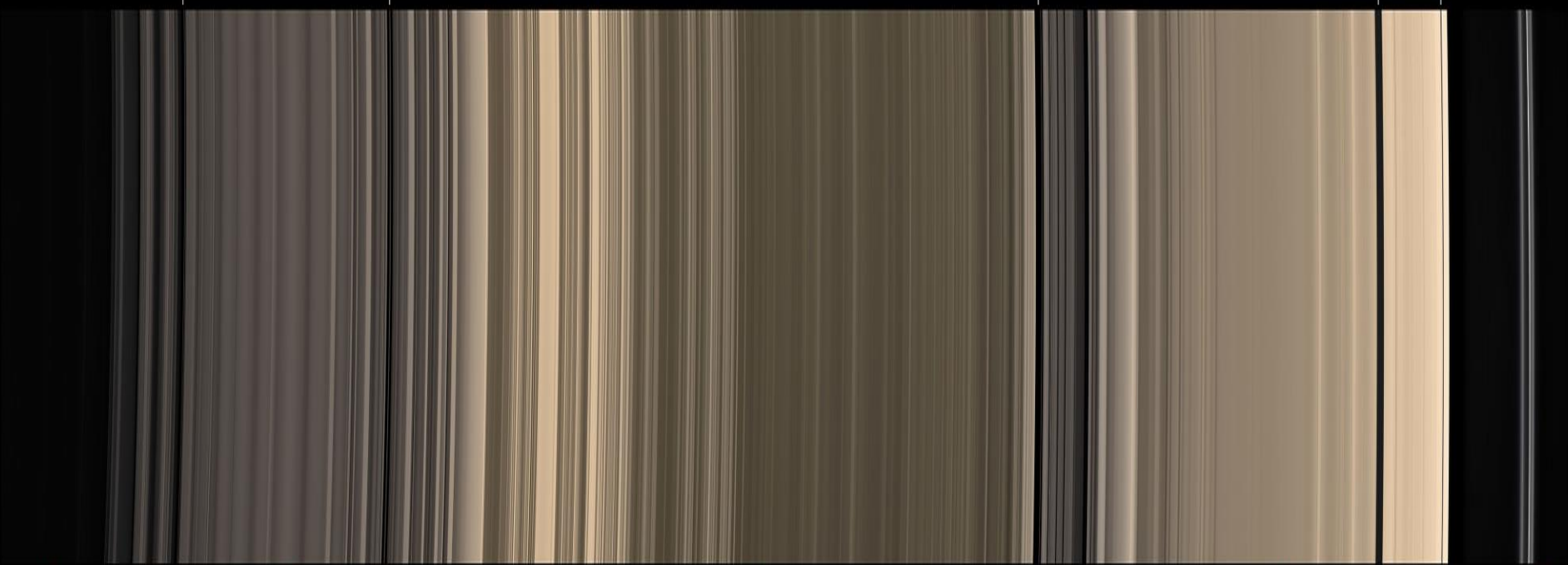
Rings: water ice a few m across
remnants of a moon
Thousands of km across; ~10 m thick!
<100 million years old

Colombo Gap

Maxwell Gap

Huygens Gap

Encke Gap Keeler Gap



D Ring

C Ring

B Ring

Cassini Division

A Ring

F Ring

74,500 km

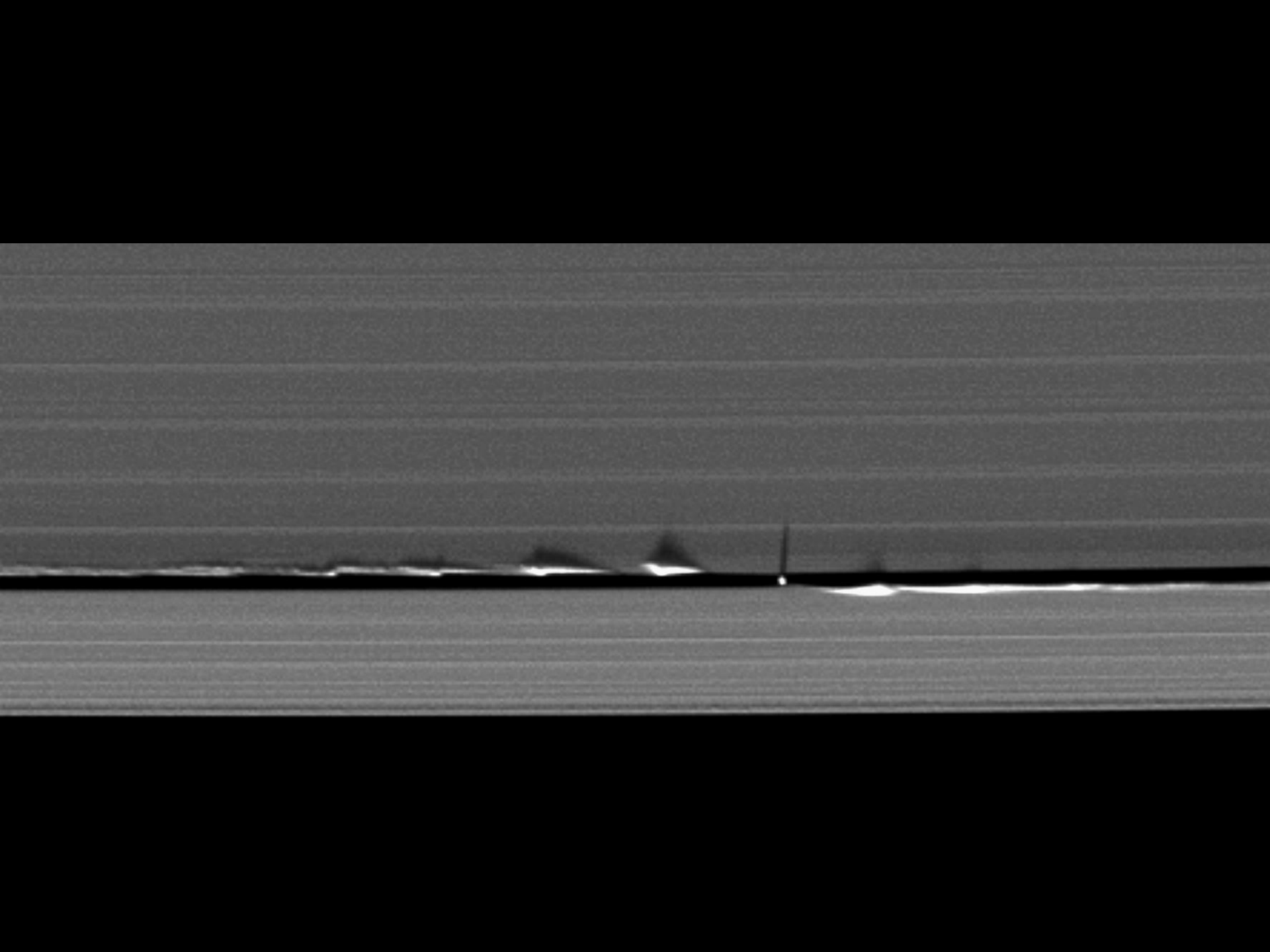
92,000 km

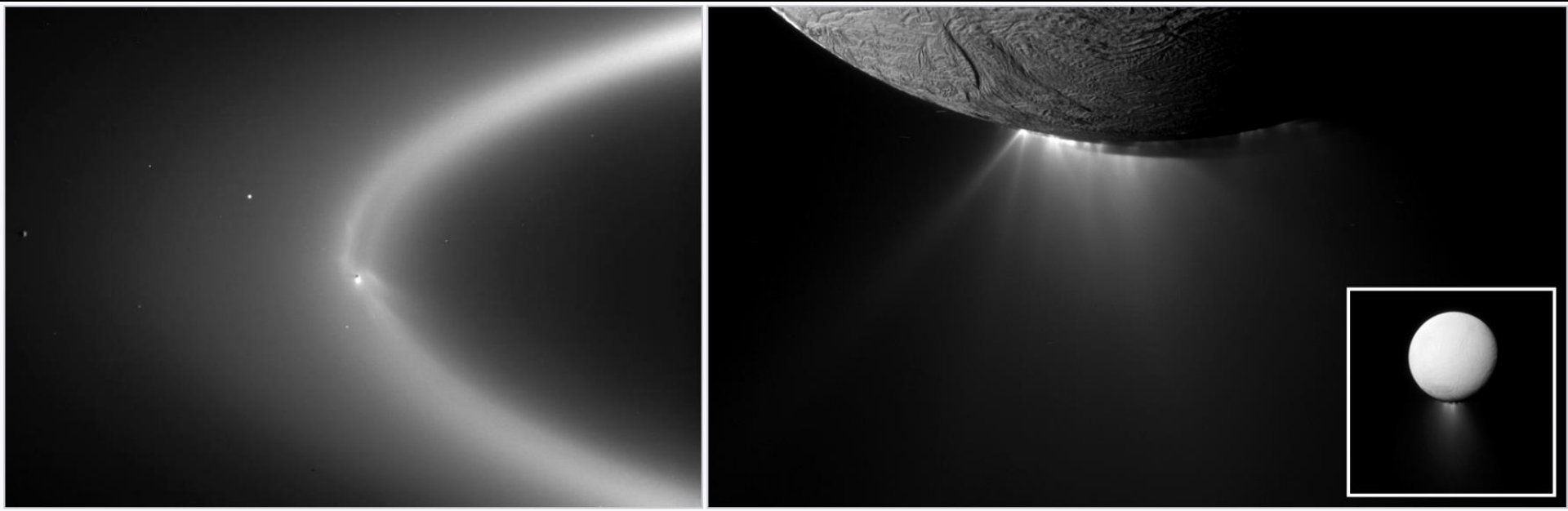
117,500 km

122,300 km

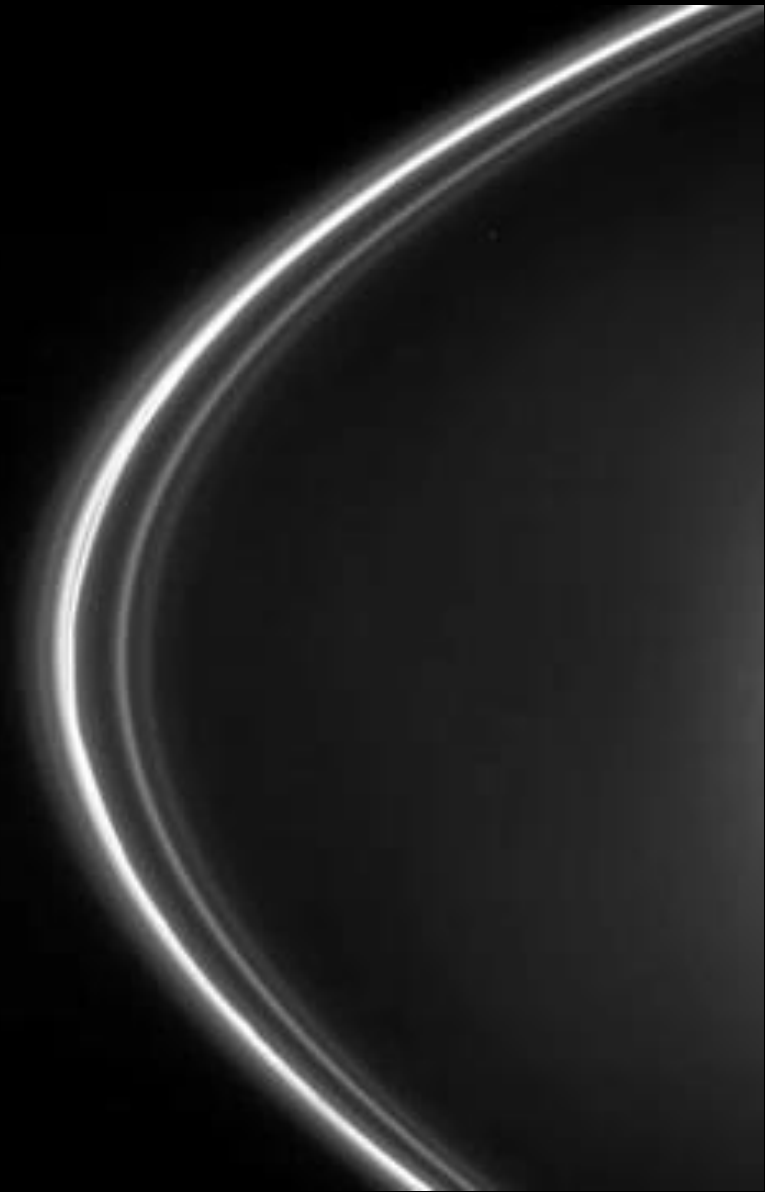
138,750 km

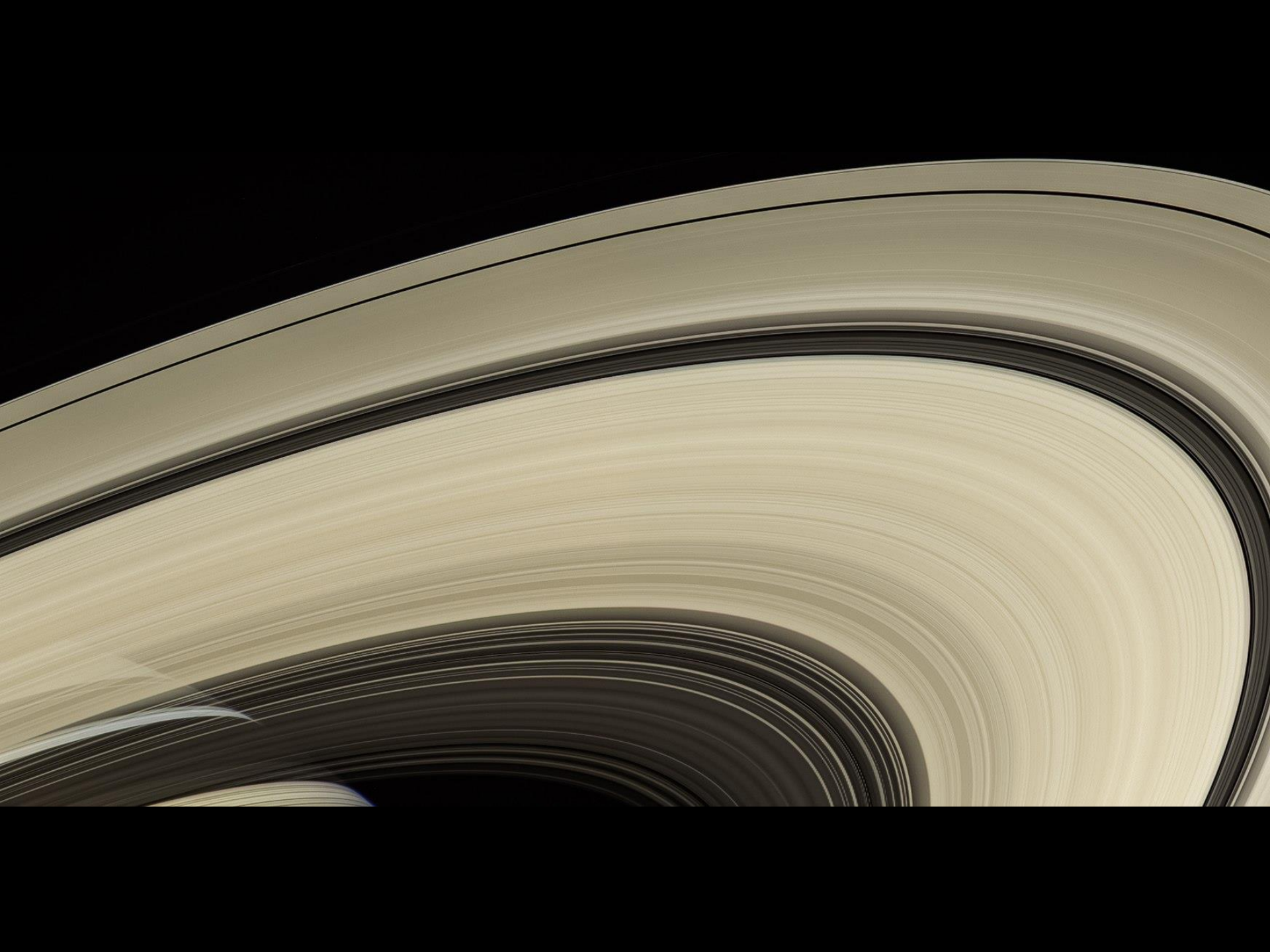
149,220 km





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

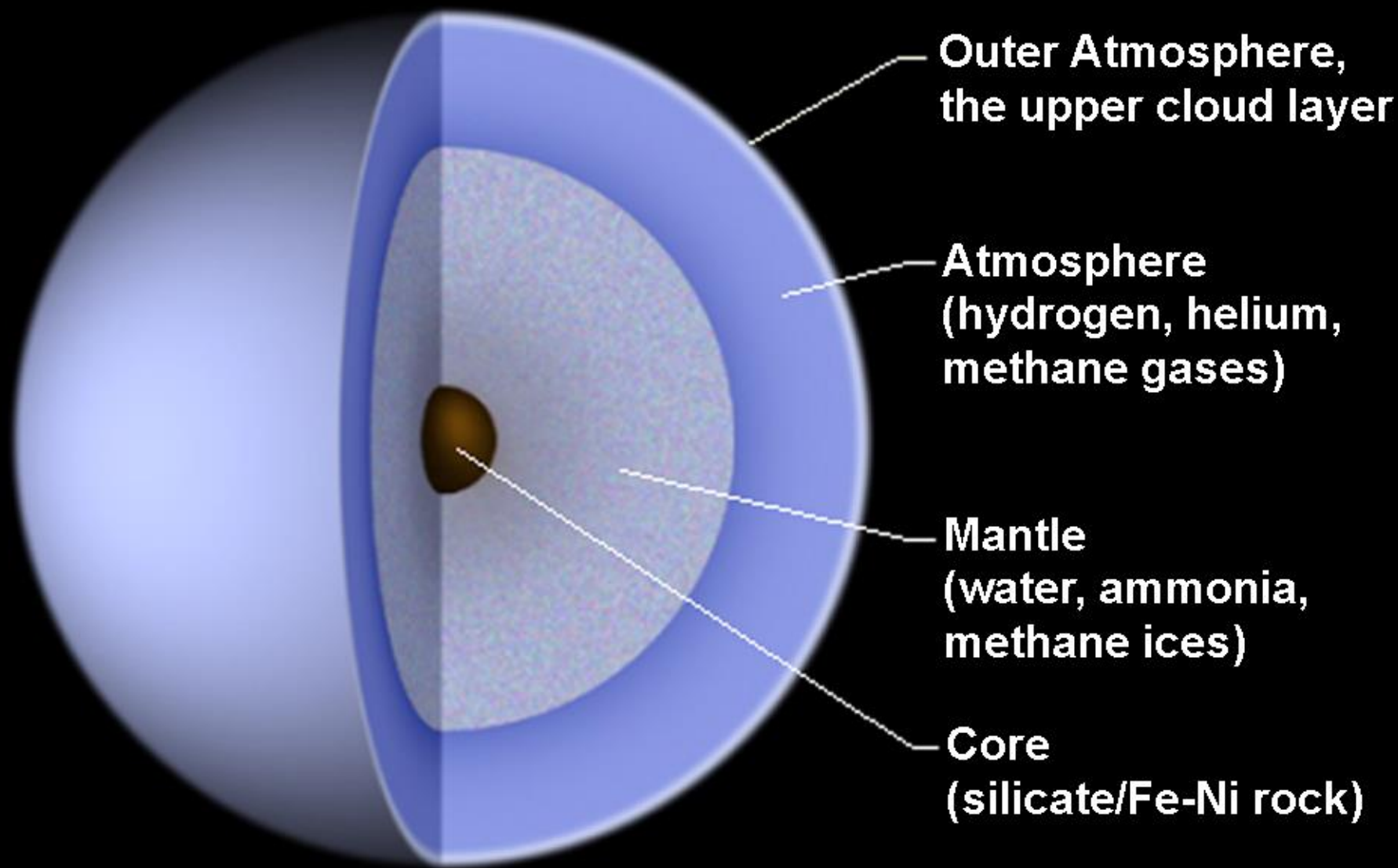




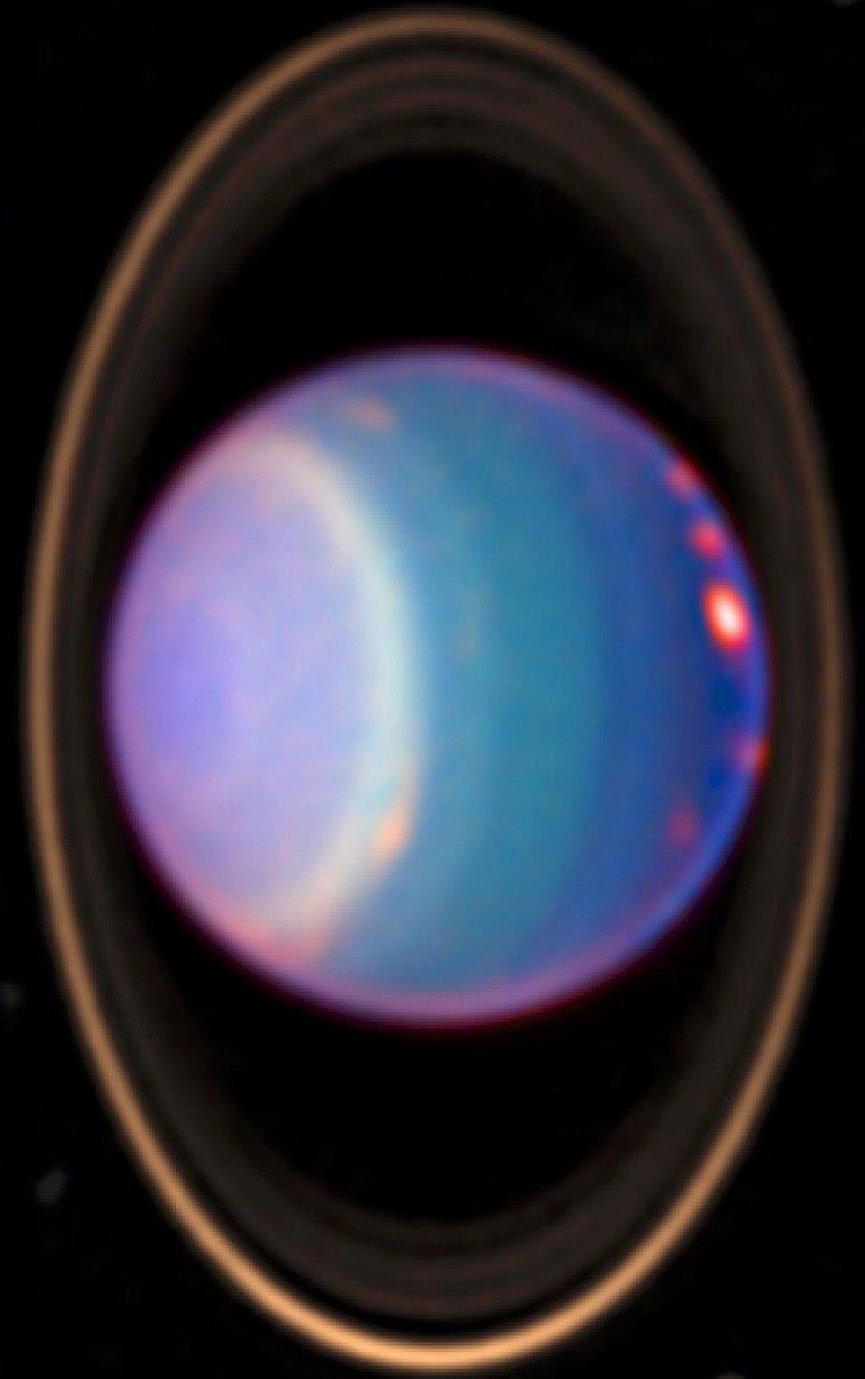


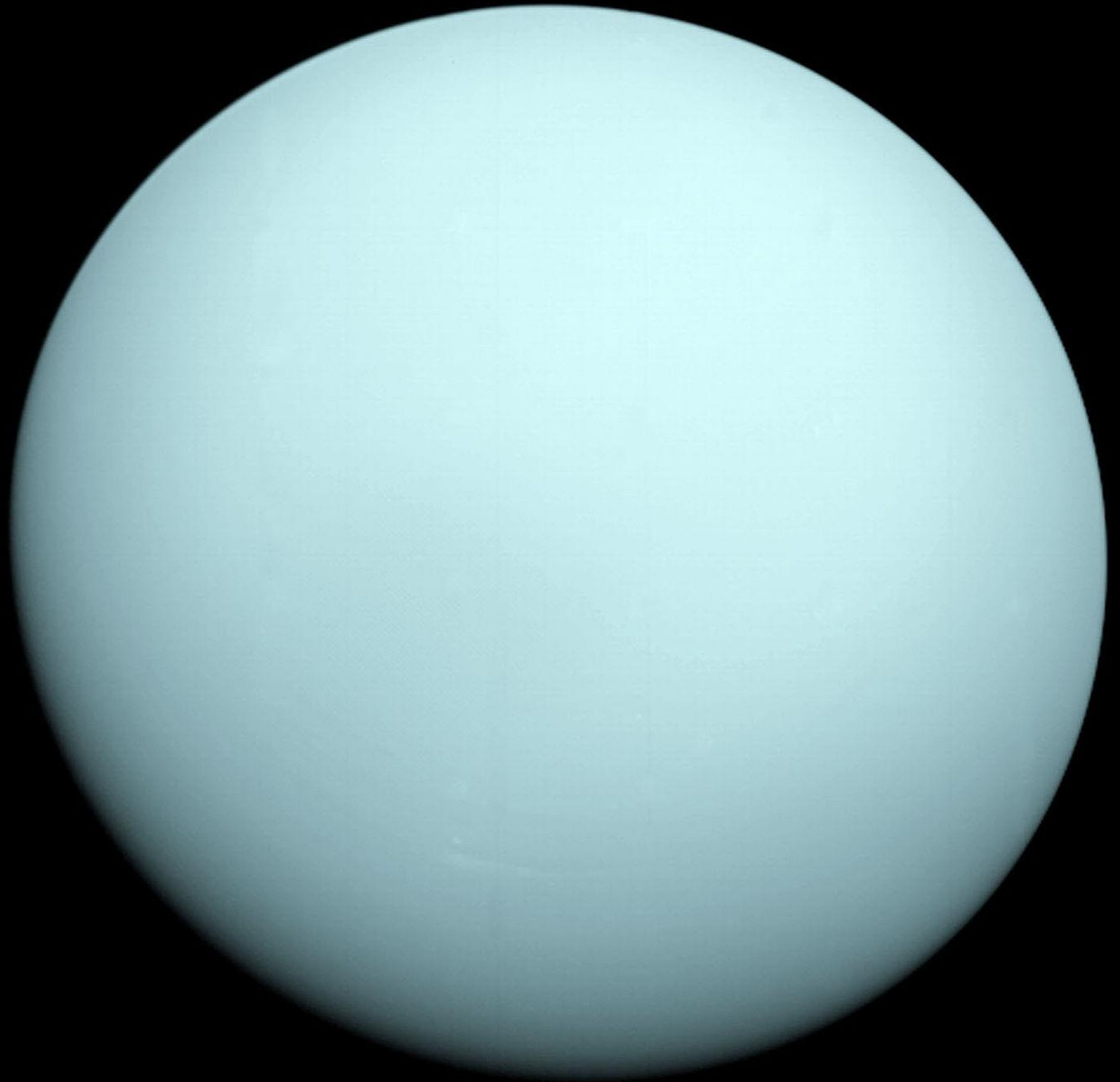
Uranus

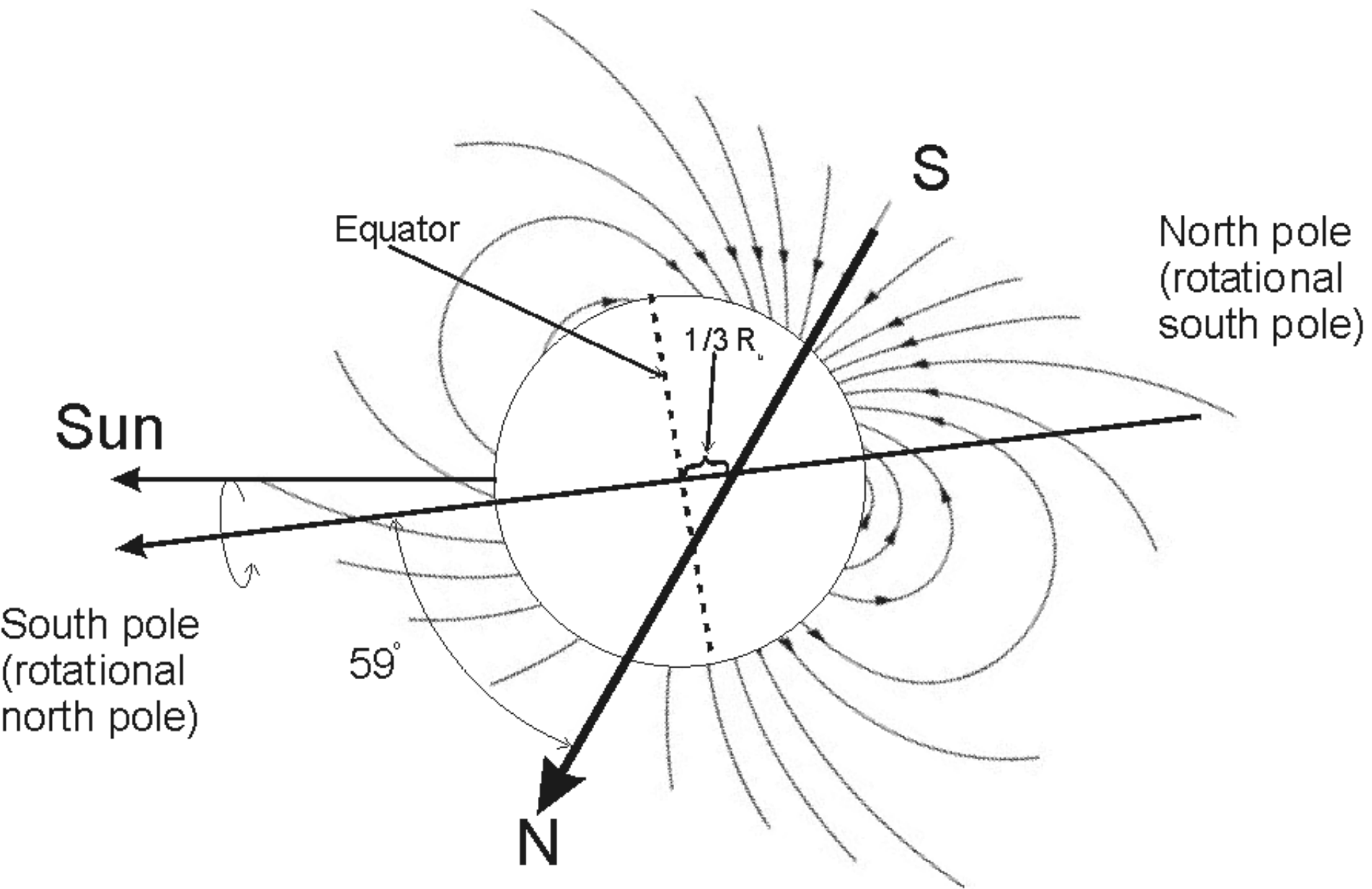




Tilted by 90 degrees!
-past collision

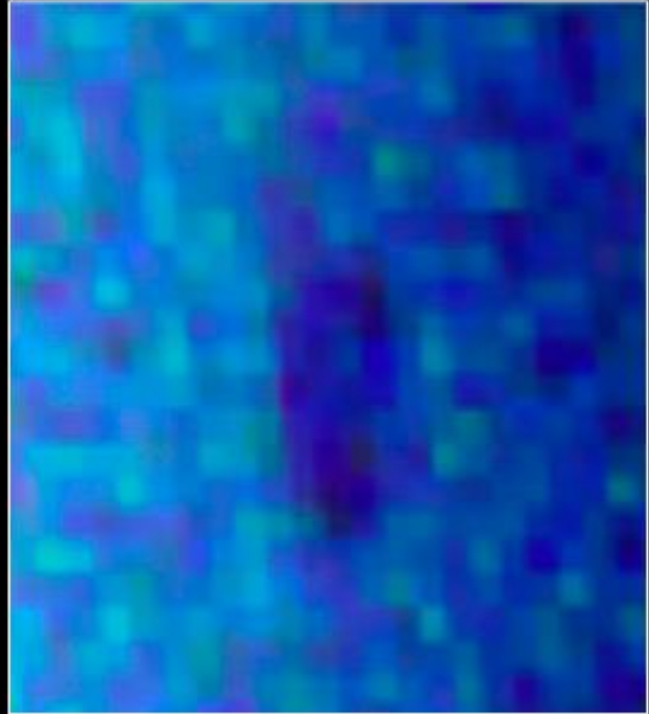
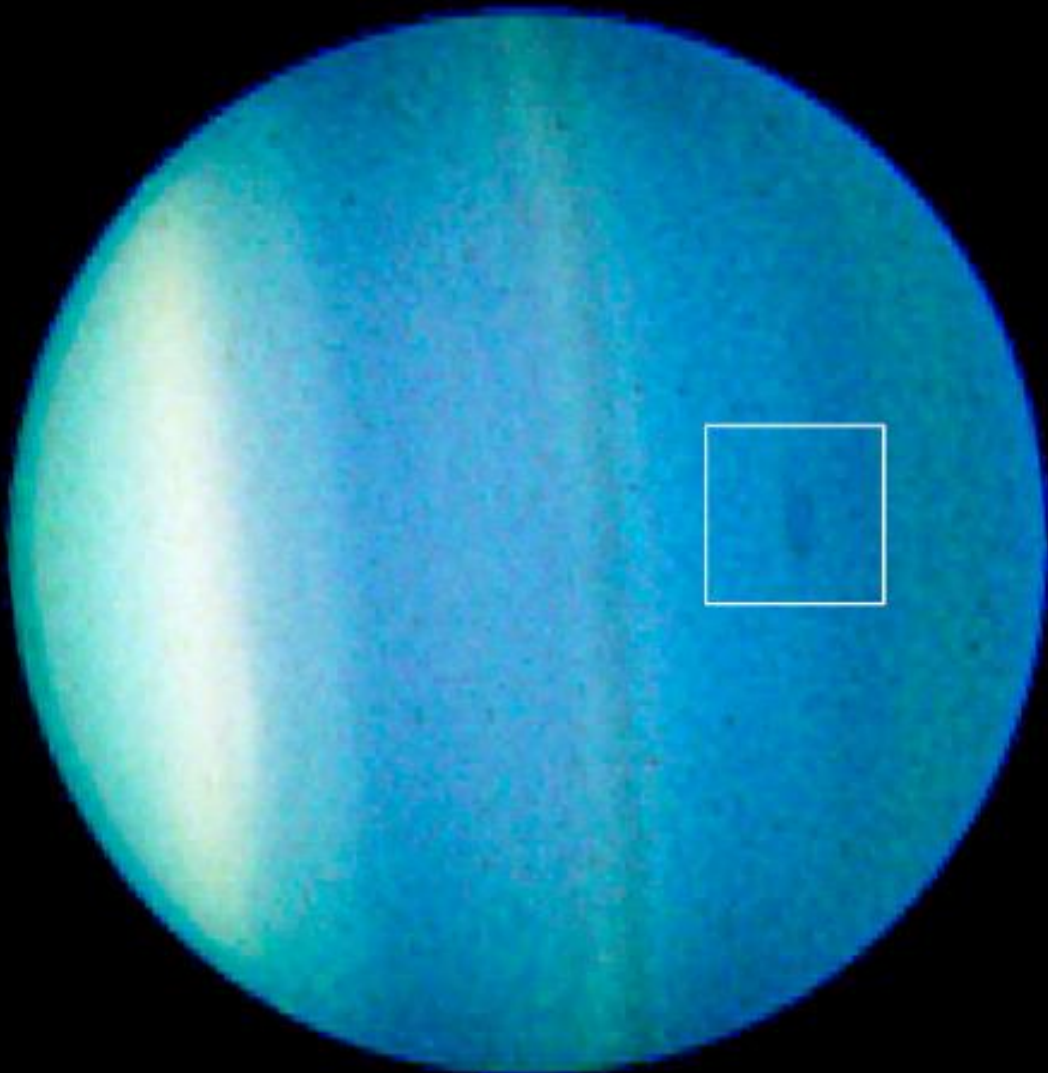






Uranus Dark Spot

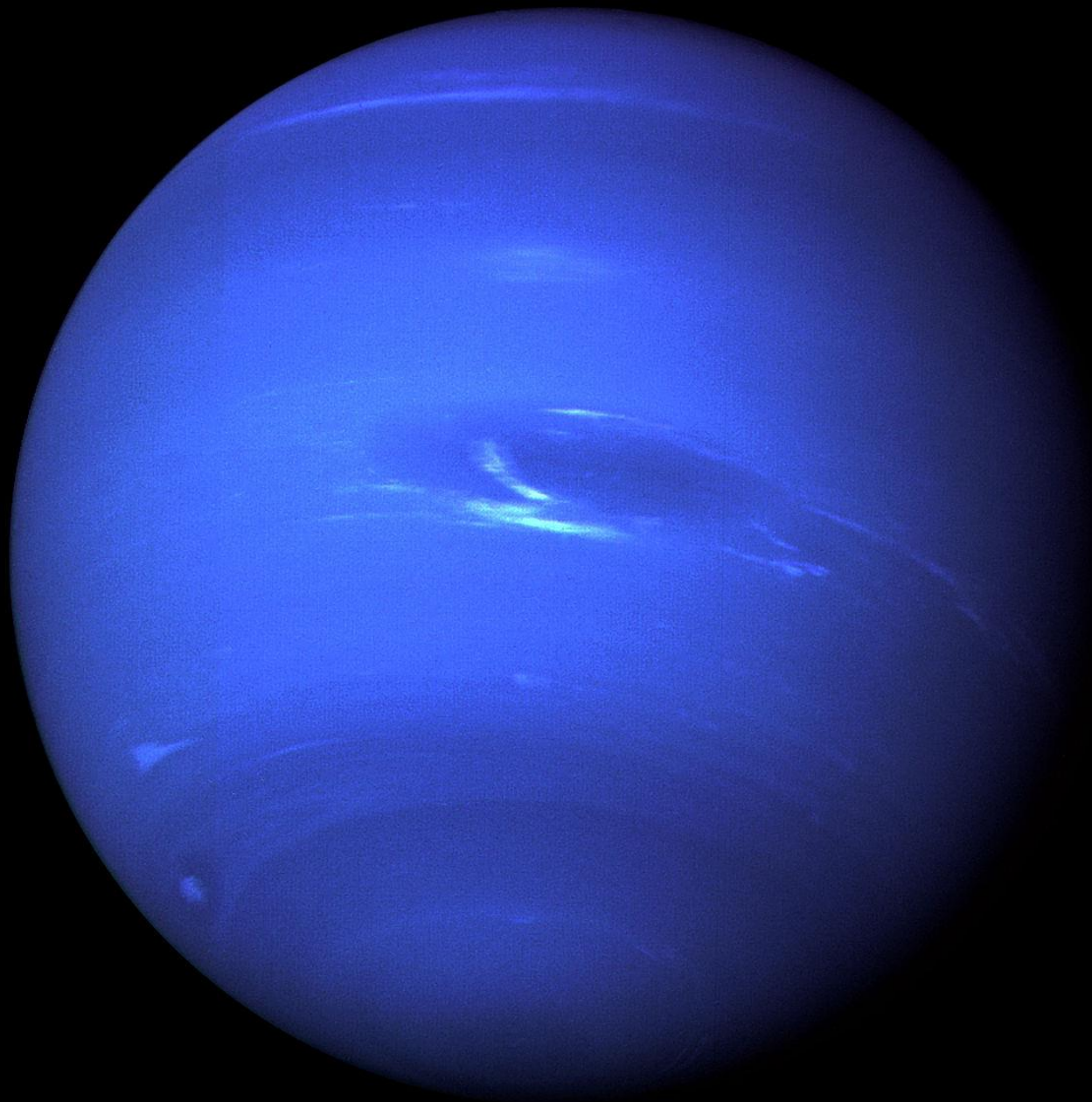
Hubble Space Telescope ■ ACS

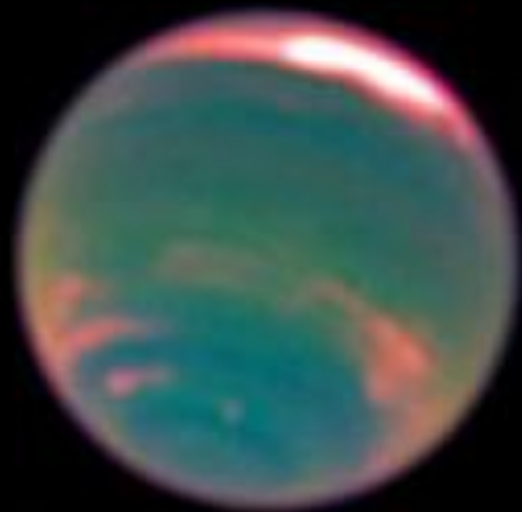


5,000 miles
8,000 kilometers

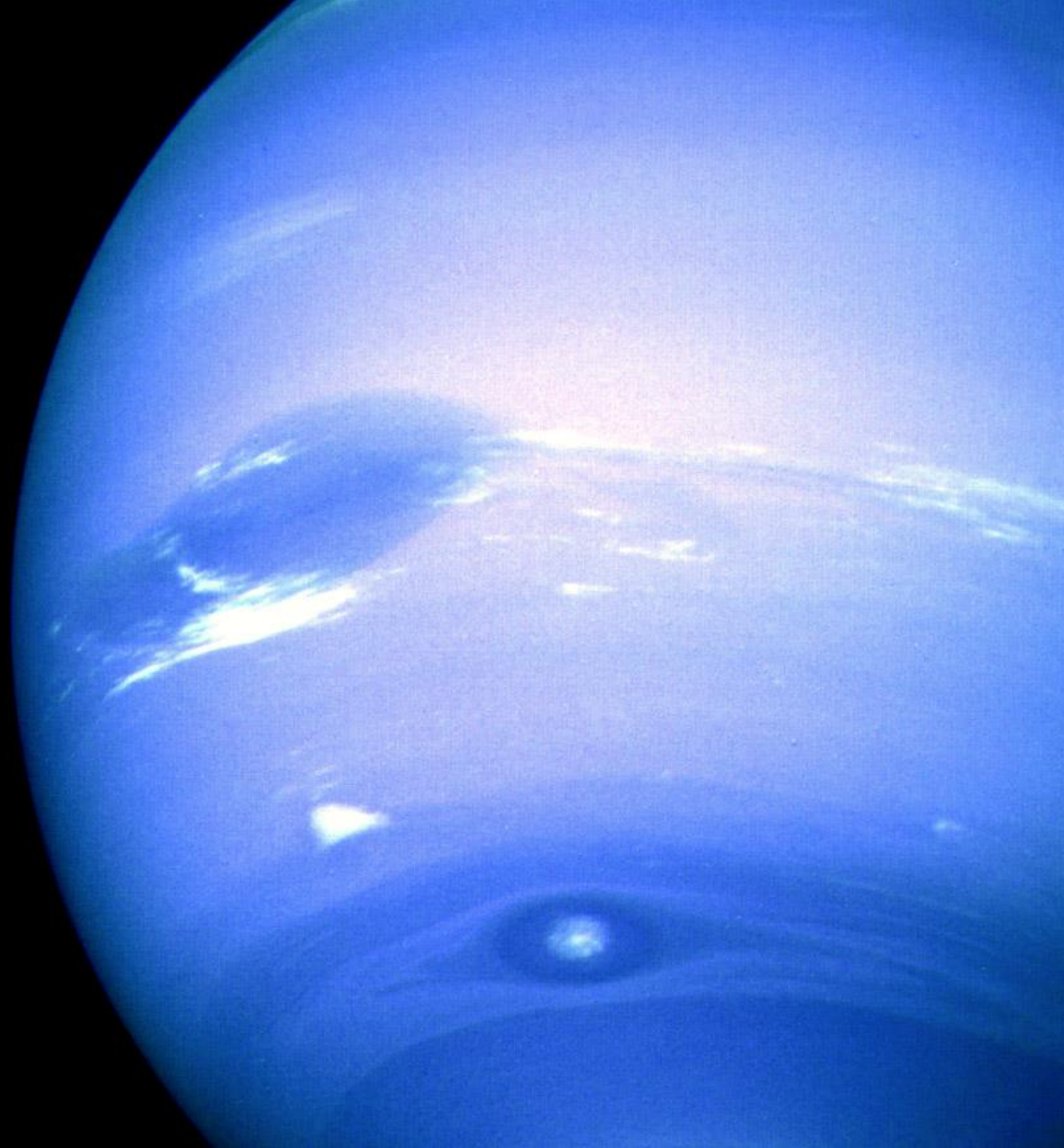


Neptune

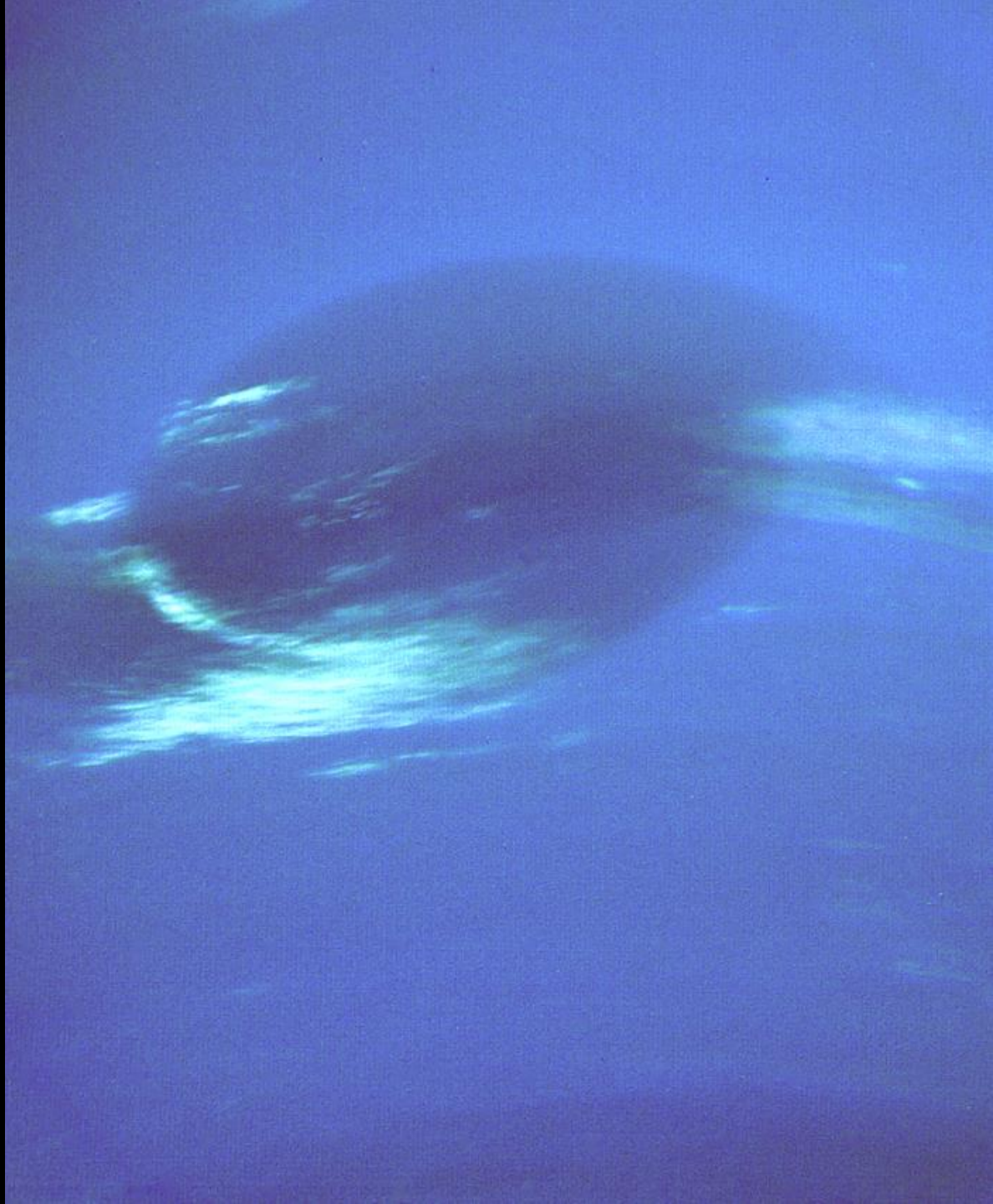


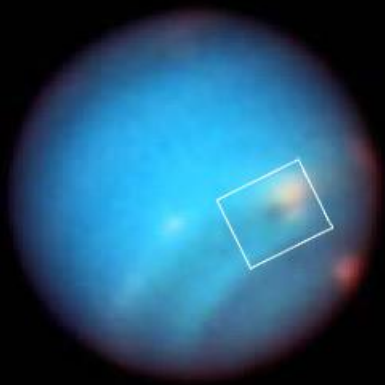




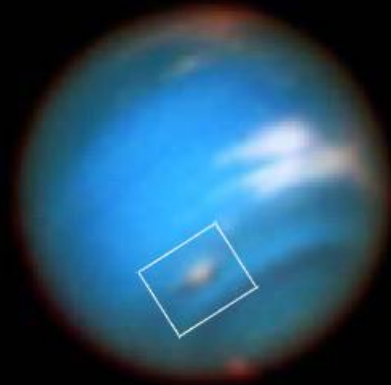




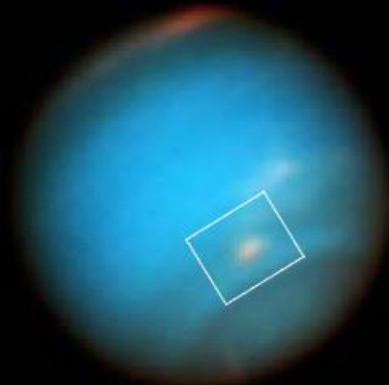




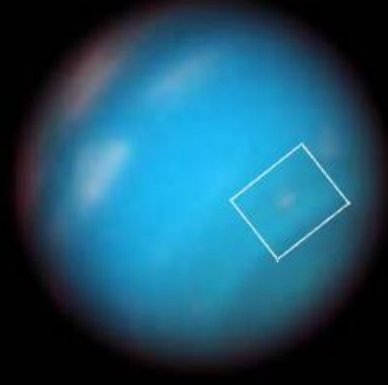
Sept. 18, 2015



May 16, 2016

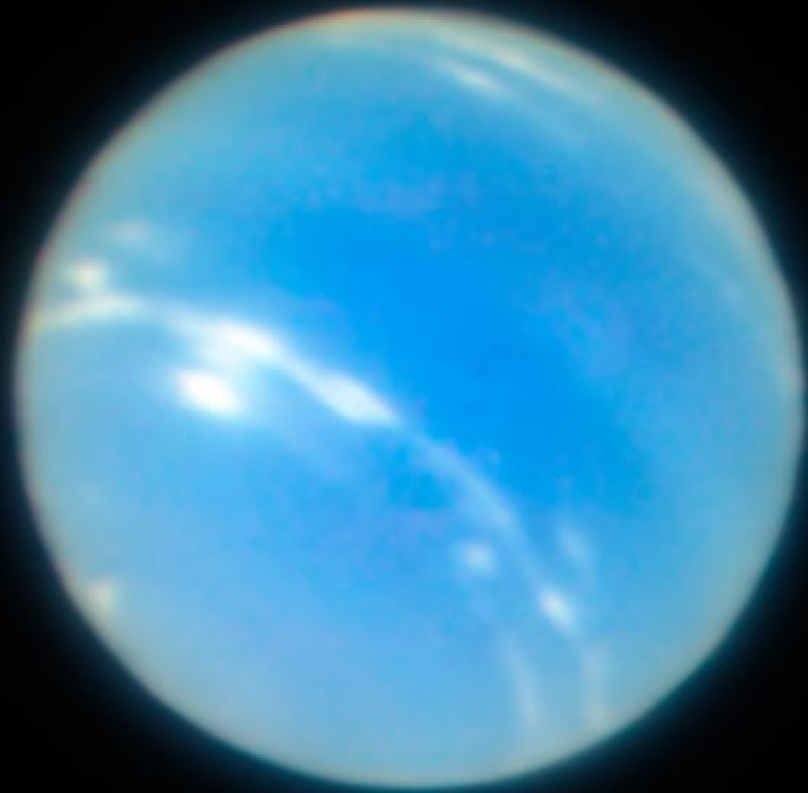


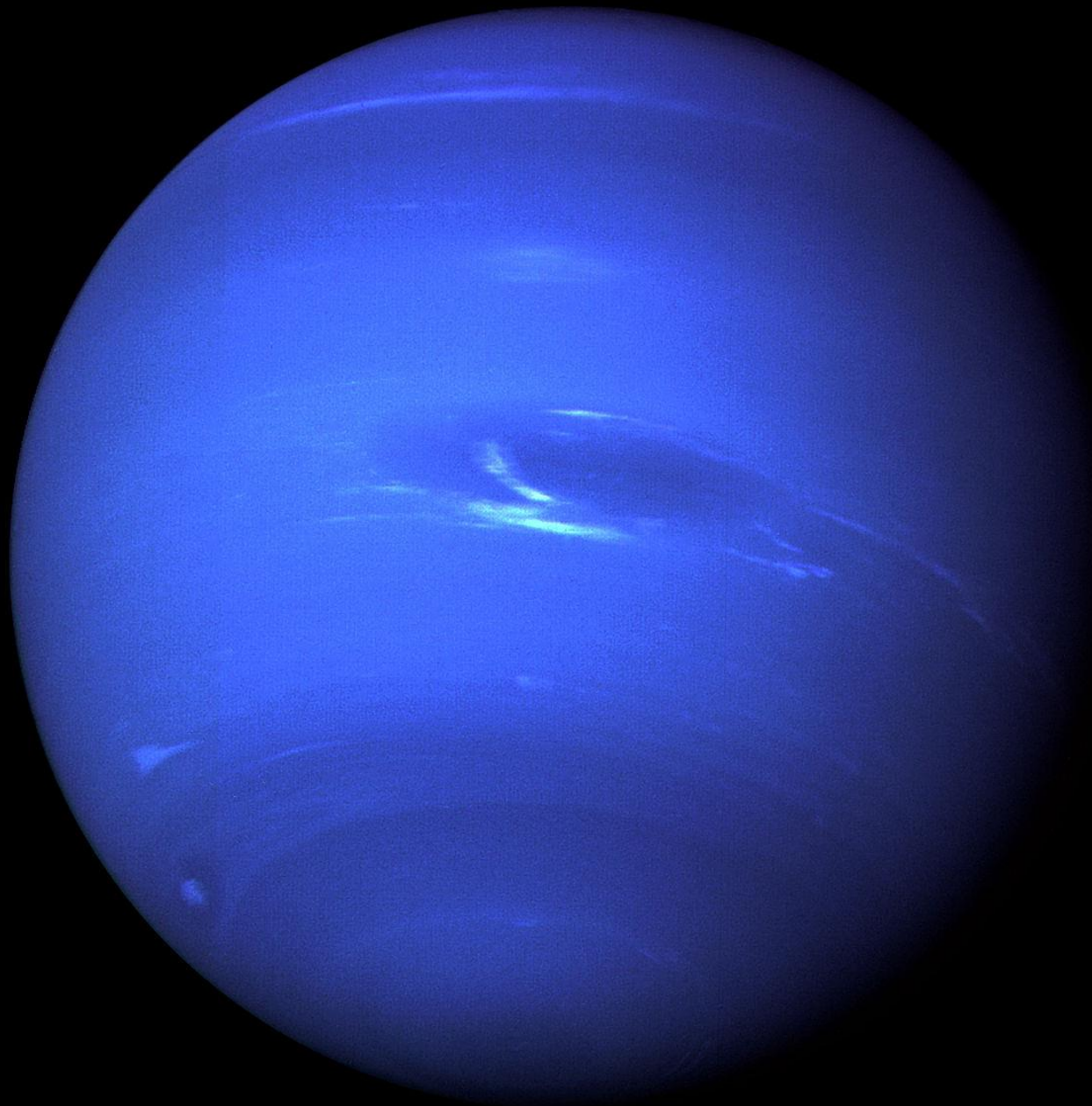
Oct. 3, 2016



Oct. 6, 2017

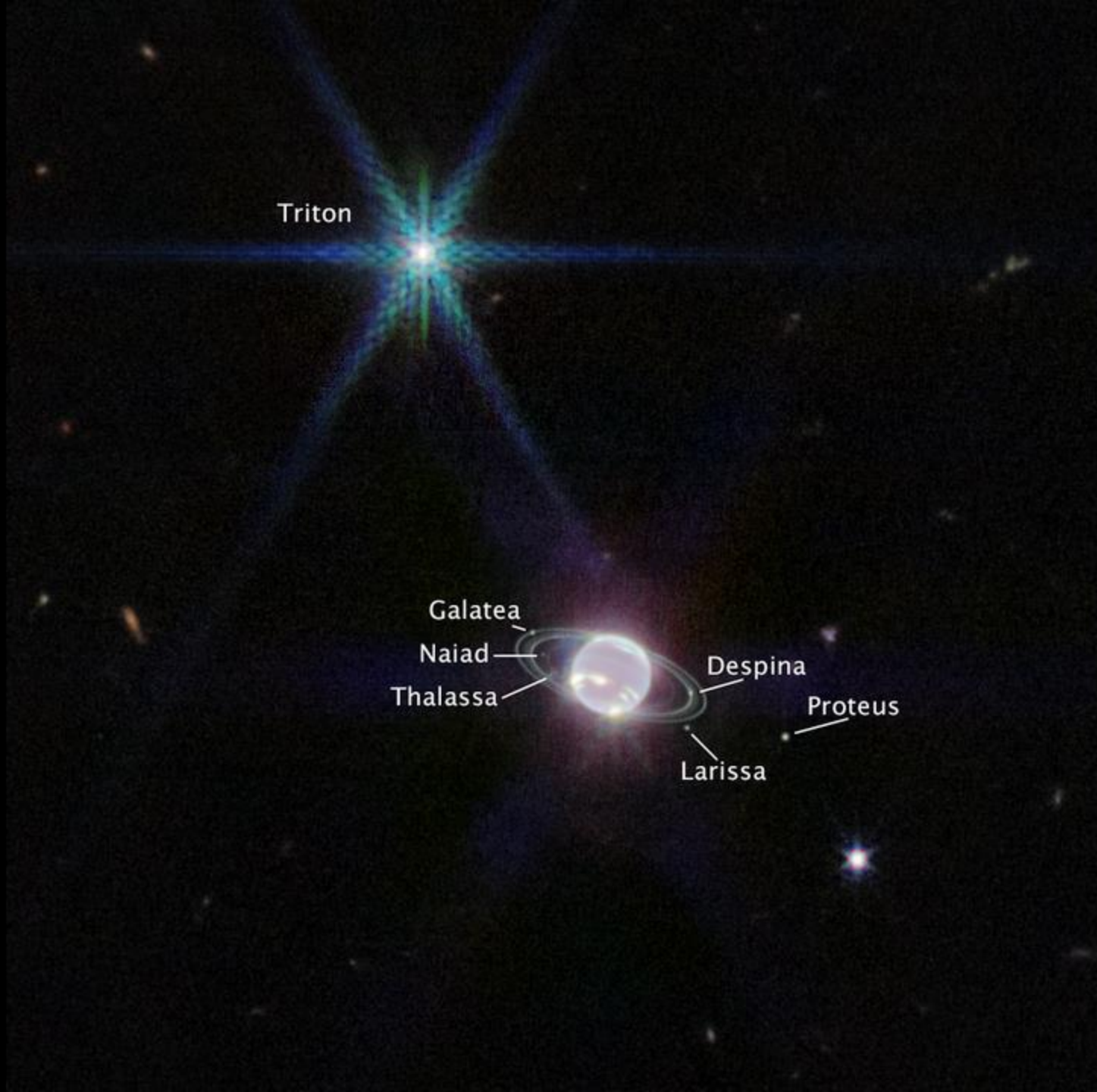




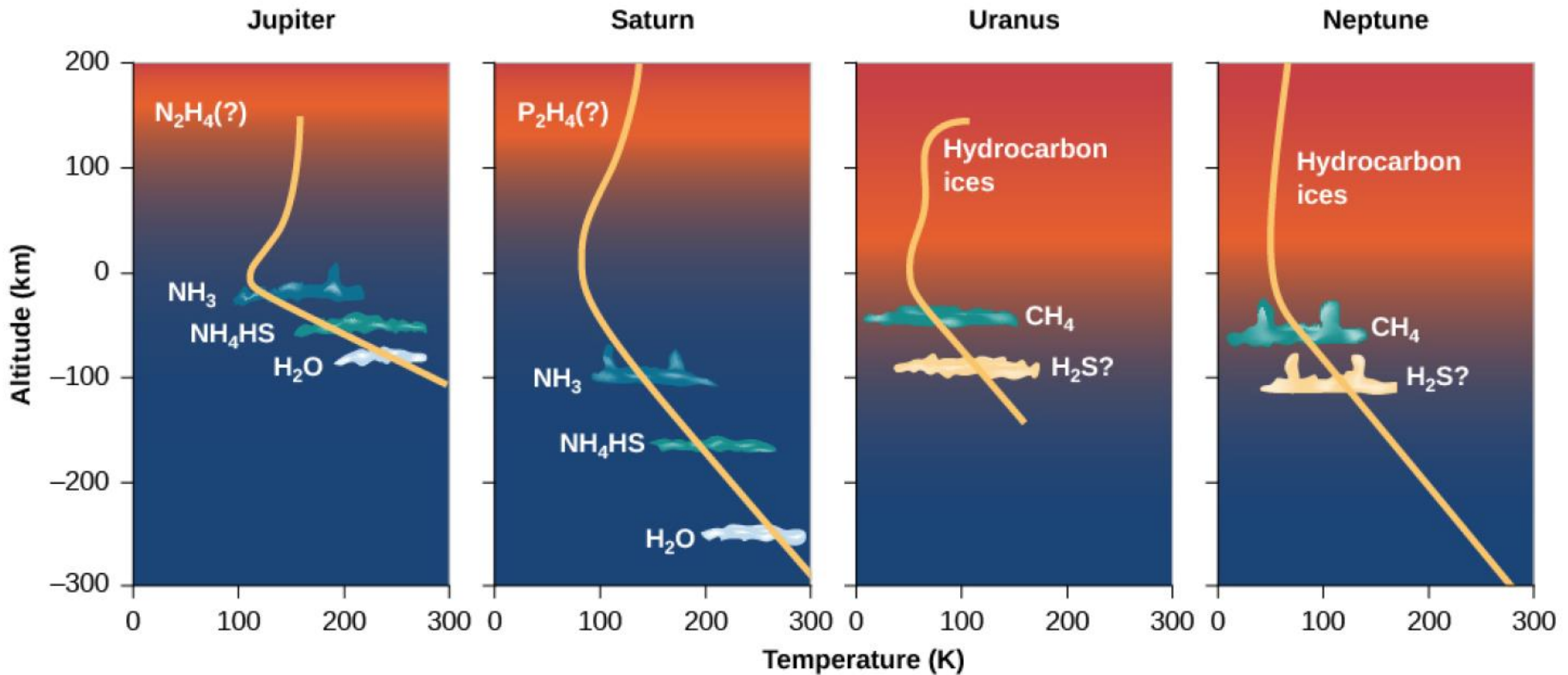
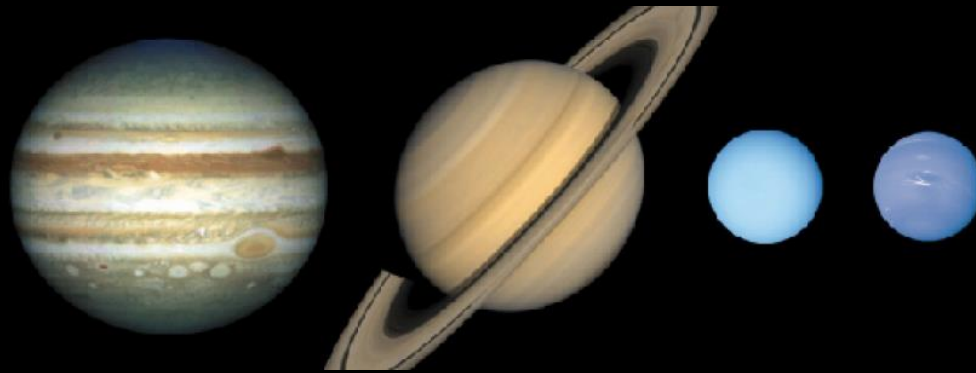


Triton

Galatea
Naiad
Thalassa
Despina
Larissa
Proteus



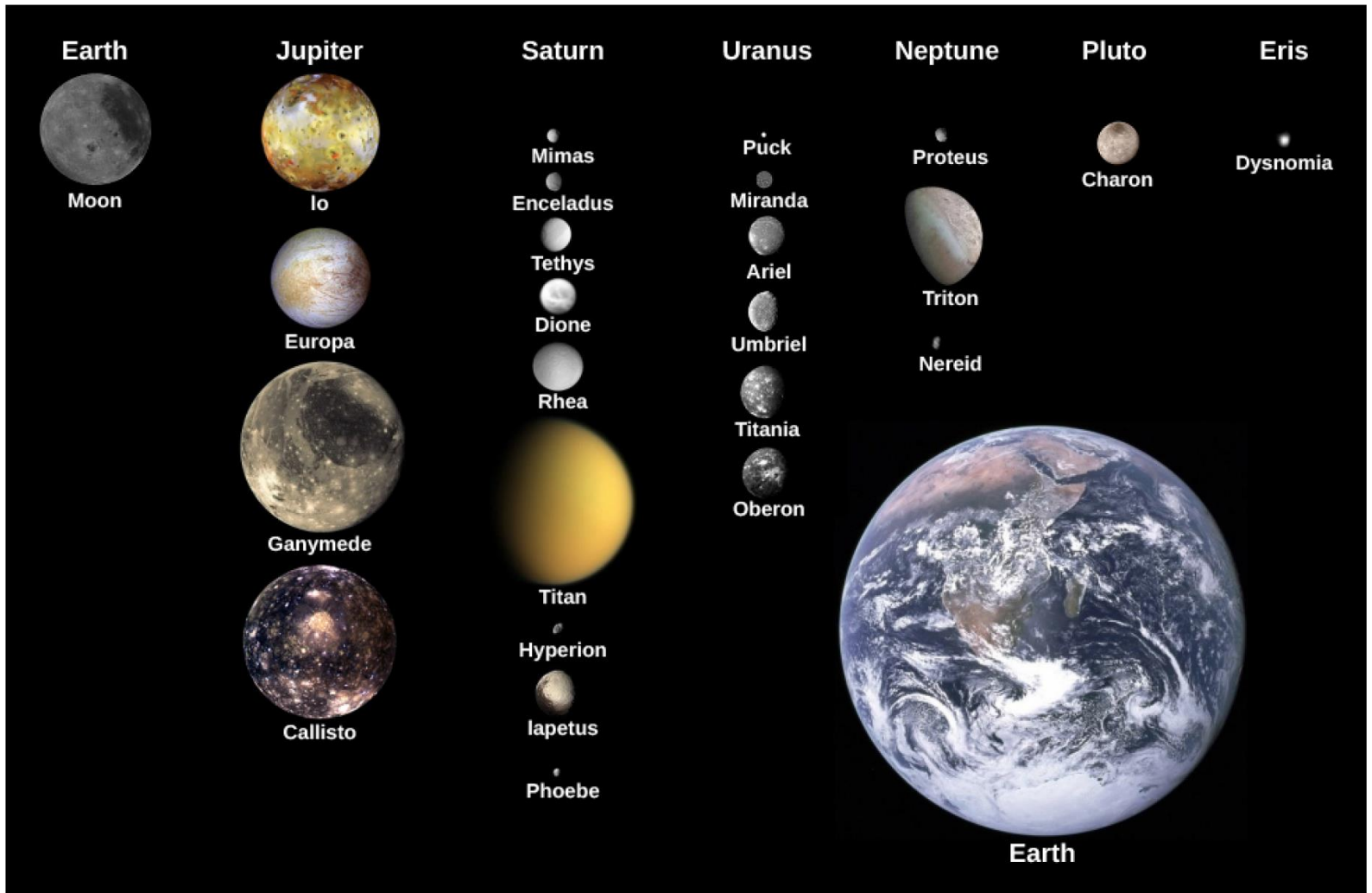
Clouds: scattering prevents detections of structure



Summary – number of moons

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

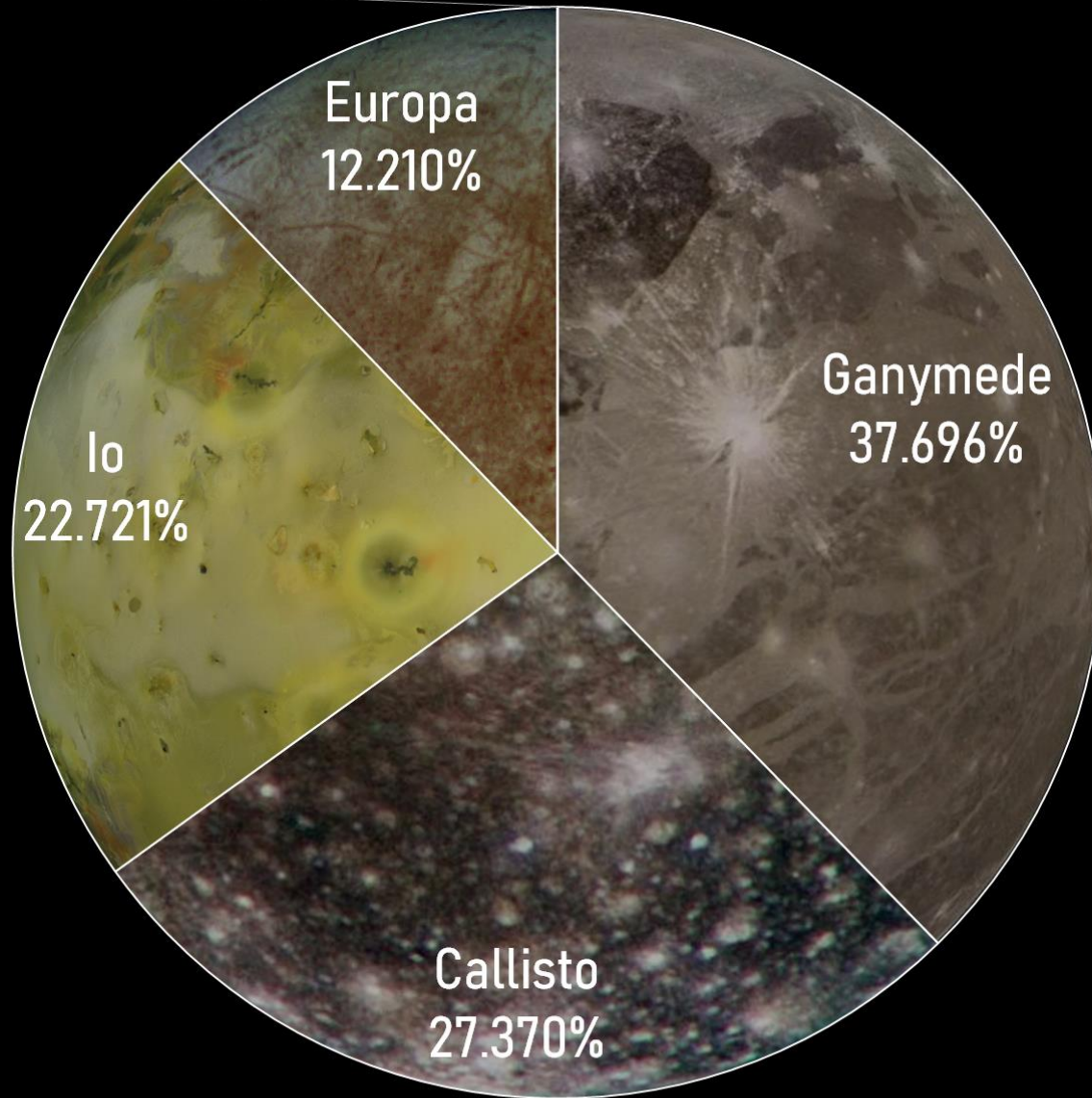
Dwarf planet	Ceres	Pluto	Haumea	Makemake	Eris
Number of moons	0	5	2	1	1



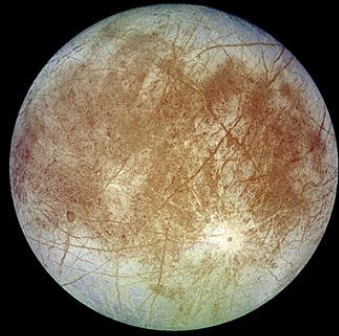
Order ^[note 3]	Label ^[note 4]	Name	Pronunciation	Image	Abs. magn.	Diameter (km) ^[note 5]	Mass ($\times 10^{16}$ kg)	Semi-major axis (km) ^[46]	Orbital period (d) ^[46] ^[note 6]	Inclination (°) ^[46]	Eccentr. ^[41]	Discovery year ^[23]	Discoverer ^[23]	Group ^[note 7]
1	XVI	Metis	/ˈmiːtɪs/		10.5	60×40×34	≈3.6	128 852	+7h 10m 16s	2.226	0.0077	1979	Synnott (Voyager 1)	Inner
2	XV	Adrastea	/əˈdræstiə/		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	/ˈθiːbi/		9.0	116×98×84	≈43	222 452	+16h 16m 02s	2.909	0.0180	1979	Synnott (Voyager 1)	Inner
5	I	Io ♄	/ˈaioʊ/		−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 ♃	/ˈjuːˈroʊpə/ ^[49]		−1.4	3 121.6	4 800 000	671 034	+3.5512	0.471 ^[48]	0.0094	1610	Galilei	Galilean
7	III	Ganymede ♃♄	/ˈɡænɪmiːd/ ^[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 ♃♄	/ˈkɑːlɪstoʊ/		−1.2	4 820.6	10 759 000	1 882 709	+16.689	0.205 ^[48]	0.0074	1610	Galilei	Galilean
9	XVIII	Themisto†	/θiːˈmɪstoʊ/		13.5	8	0.069	7 393 216	+129.87	45.762	0.2115	1975/2000	Kowal & Roemer/Sheppard et al.	<i>Themisto</i>
10	XIII	Leda†	/liːdə/		12.8	16	0.6	11 187 781	+240.82	27.562	0.1673	1974	Kowal	Himalia
11	VI	Himalia†	/hɑːˈmɪliə/		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

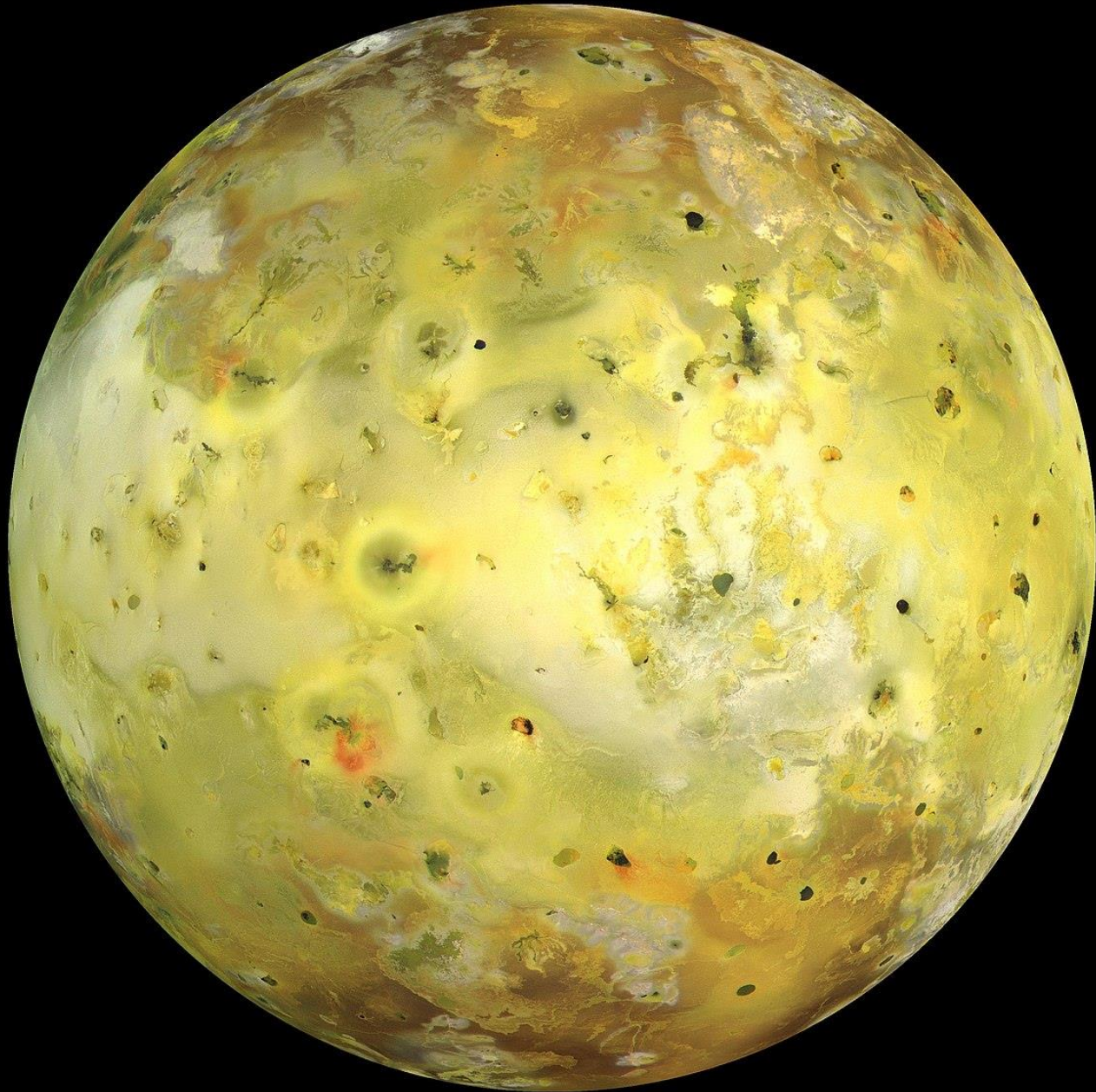
All Other
Moons
0.003%

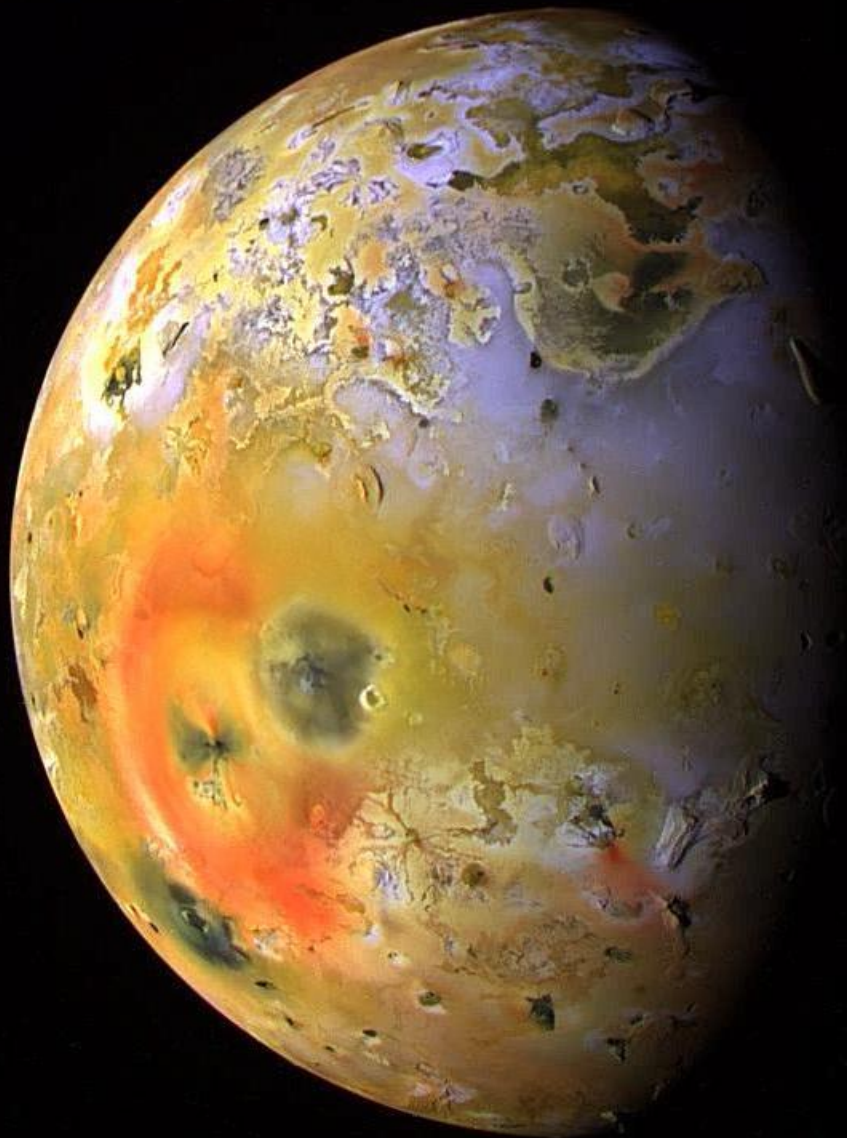


Galilean satellites of Jupiter



Io: a volcanic moon heated by tides





Io Surface Changes

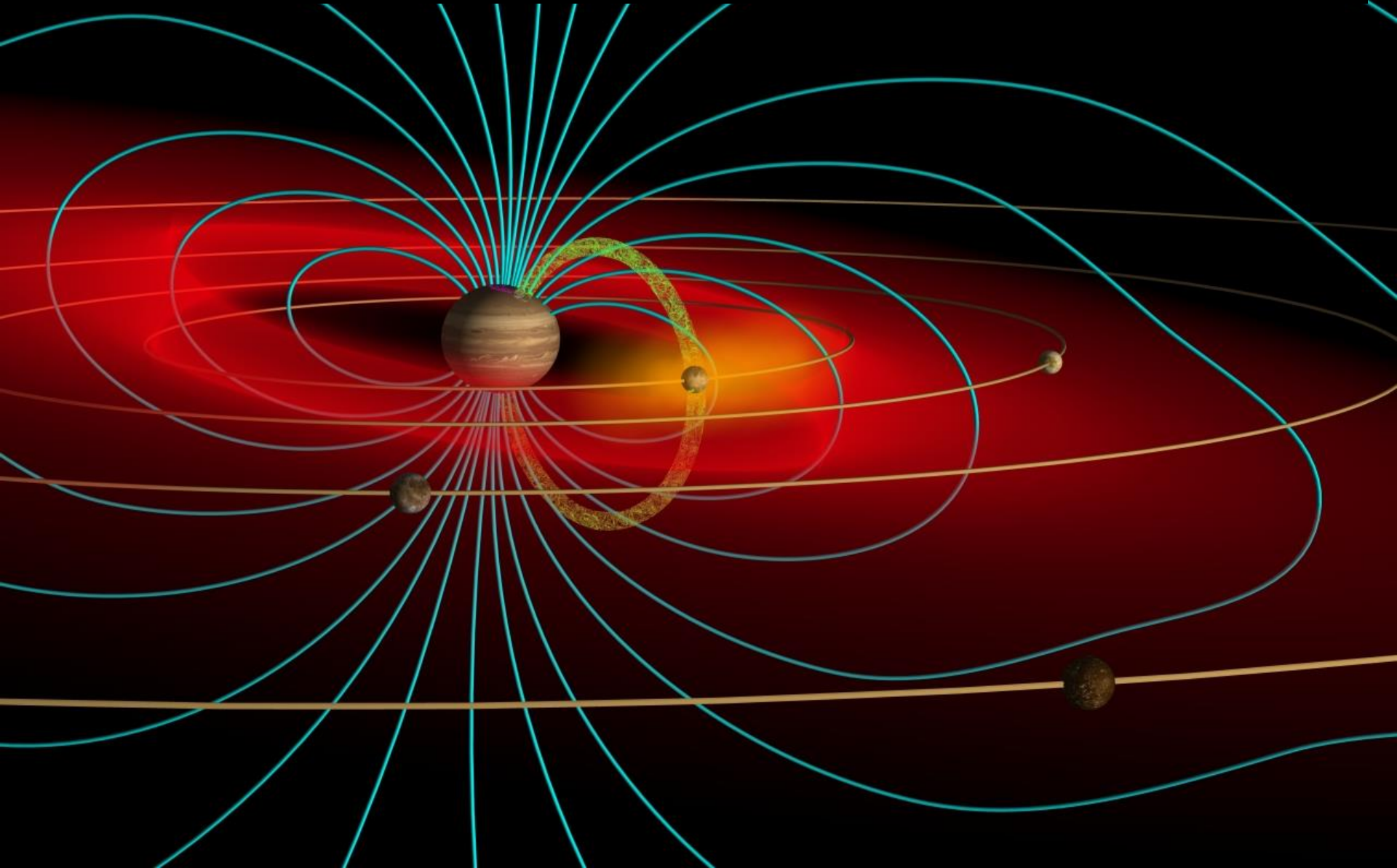
Galileo 1999



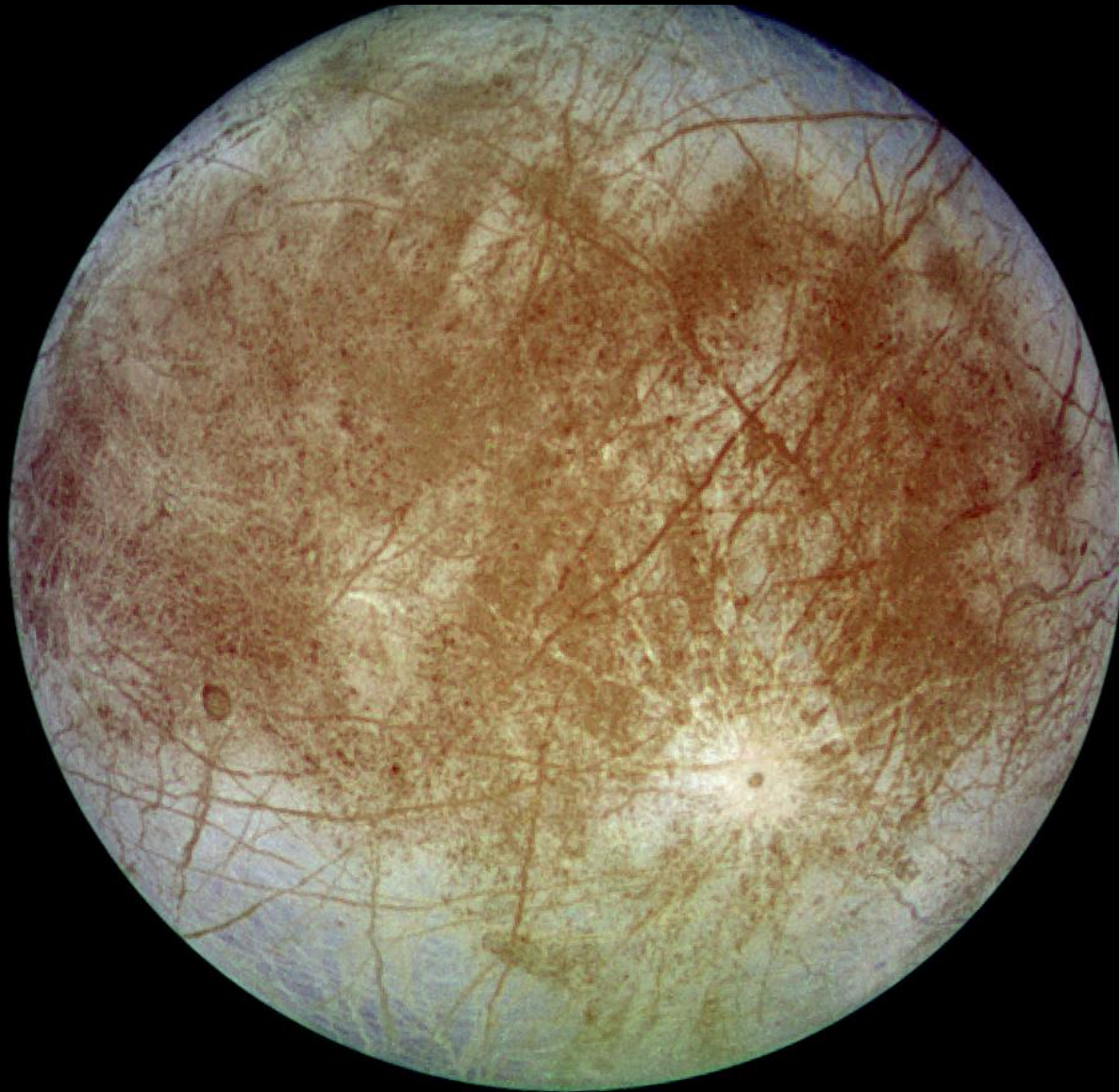
New Horizons 2007

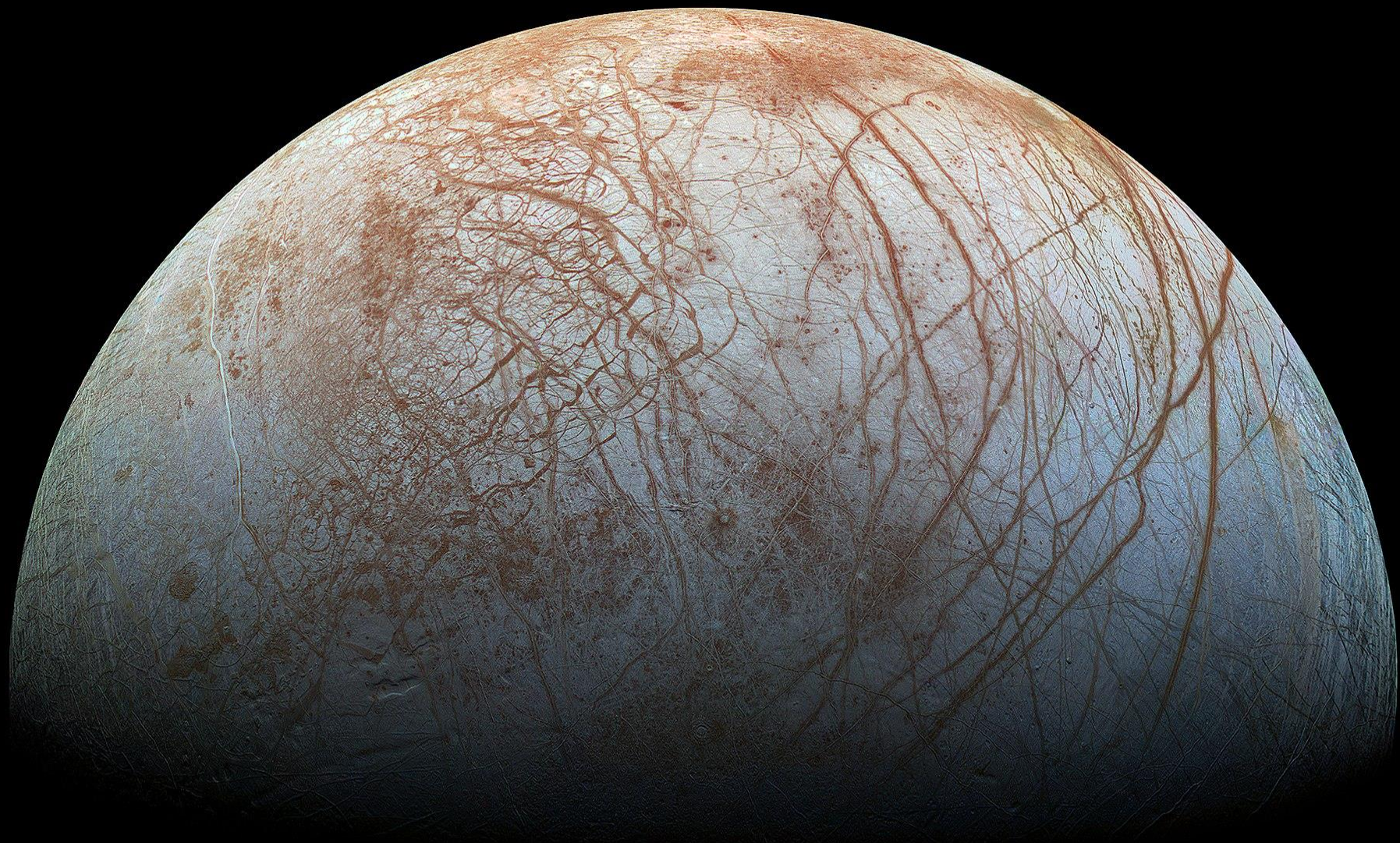


Io: cloud around Io because of
Jupiter's magnetic field

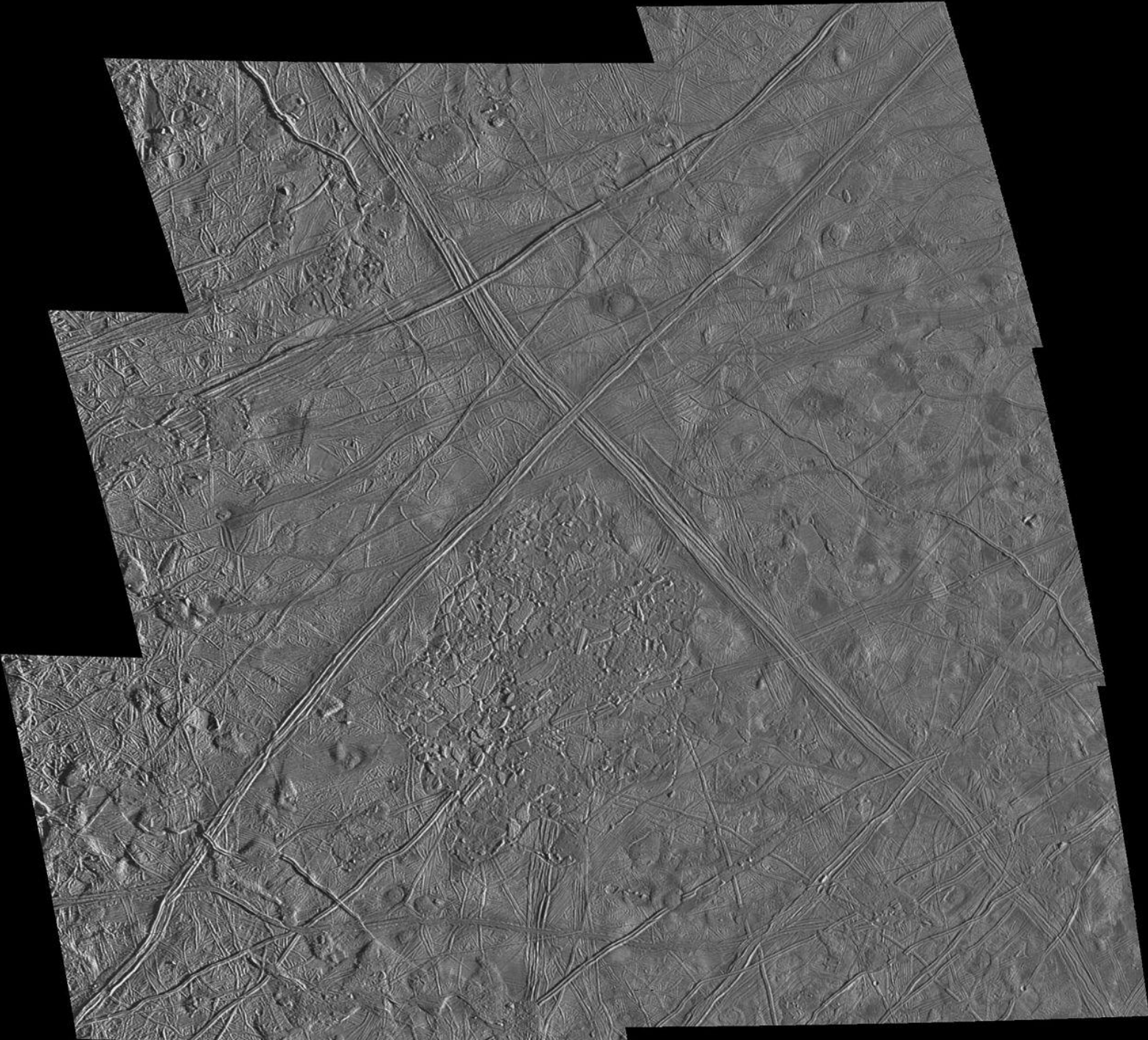


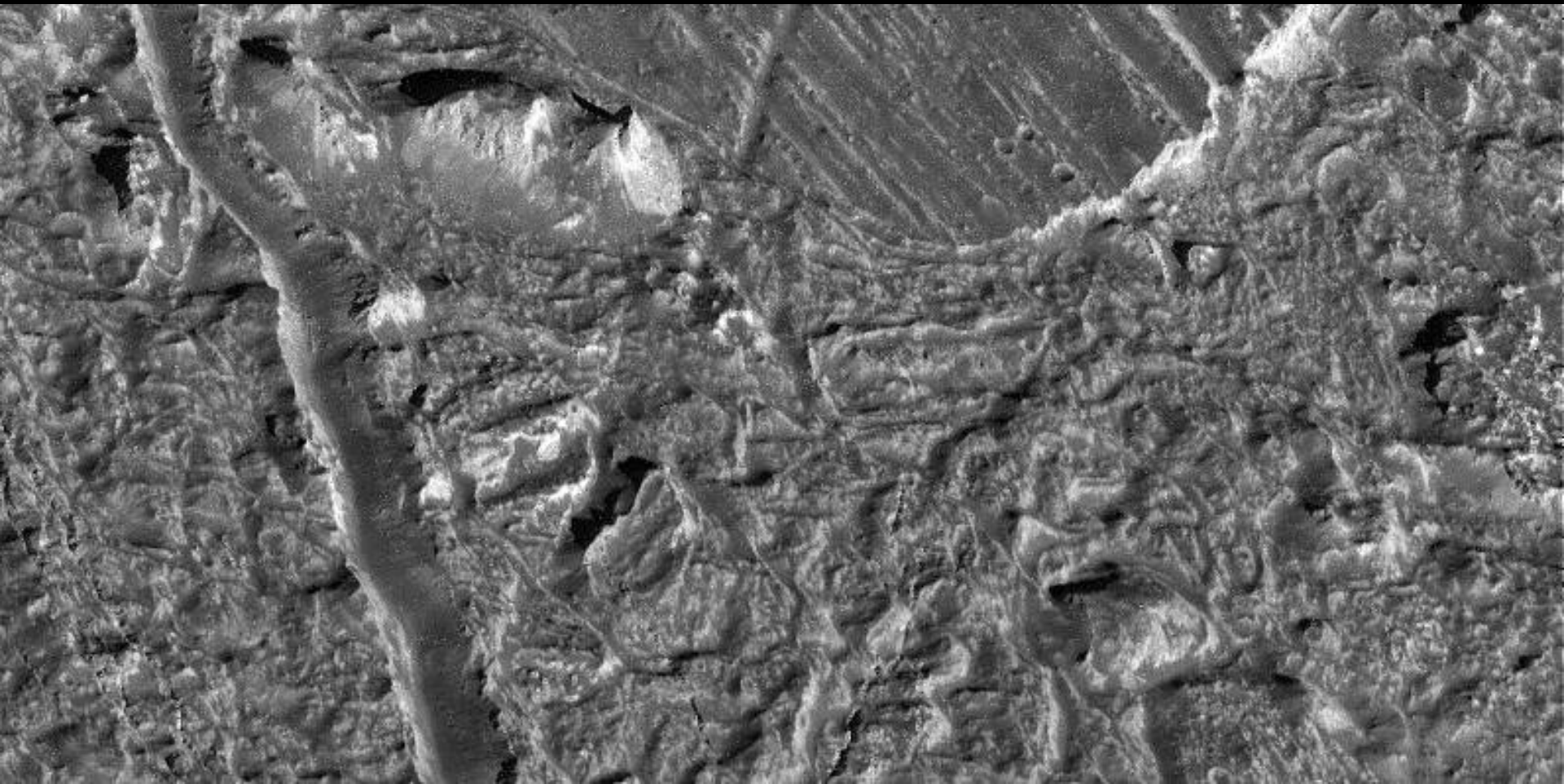
Europa: smallest of inner moons; ice world

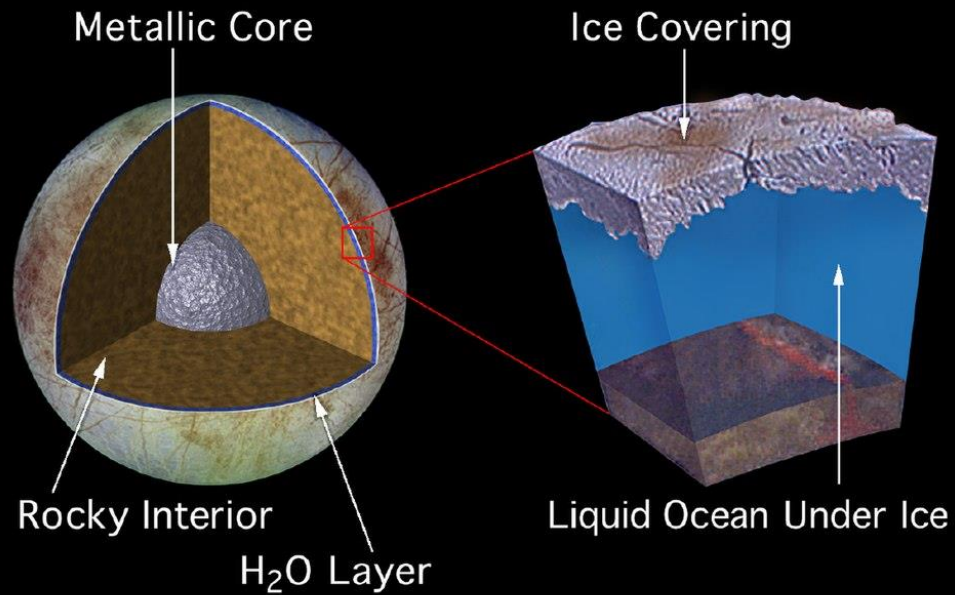
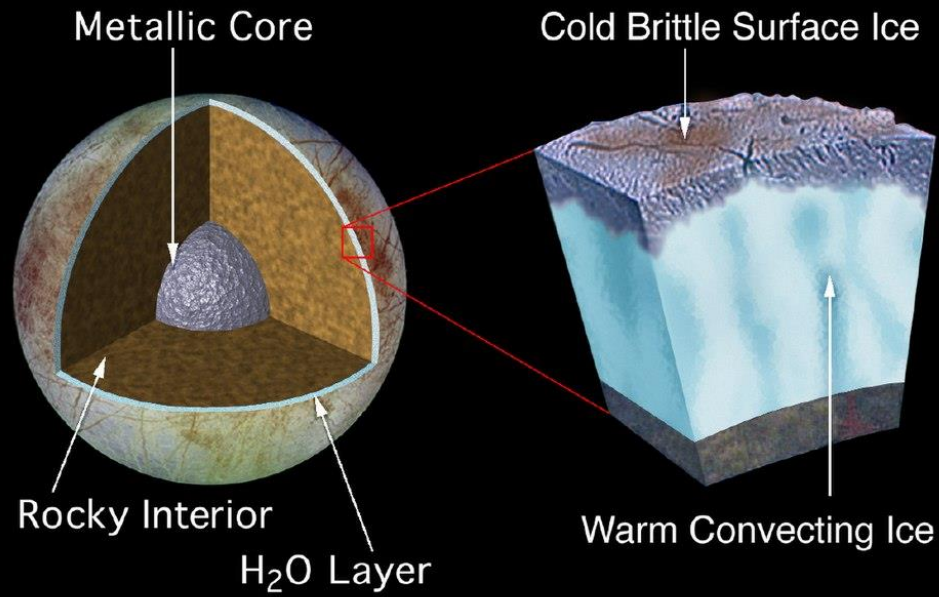


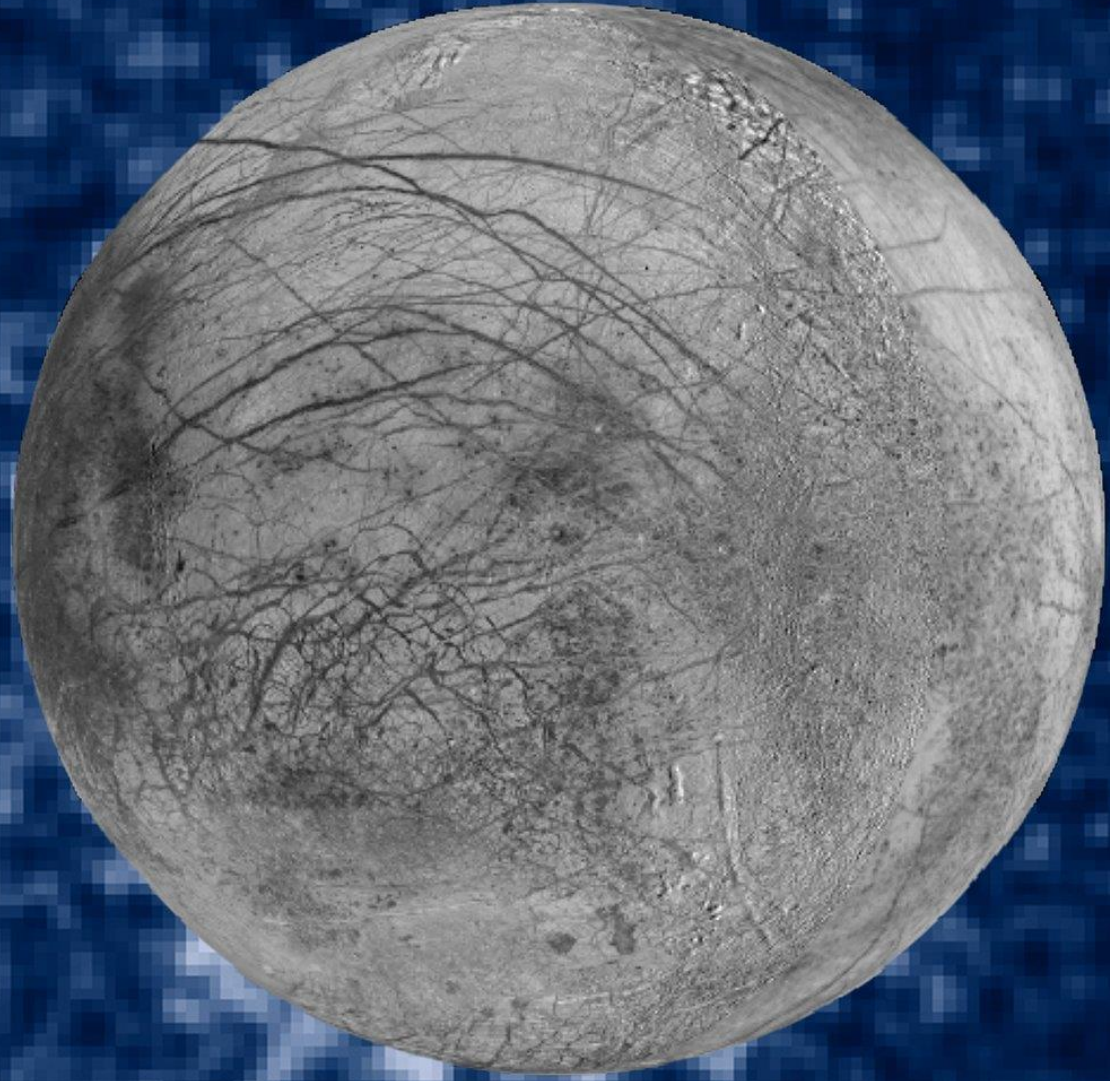


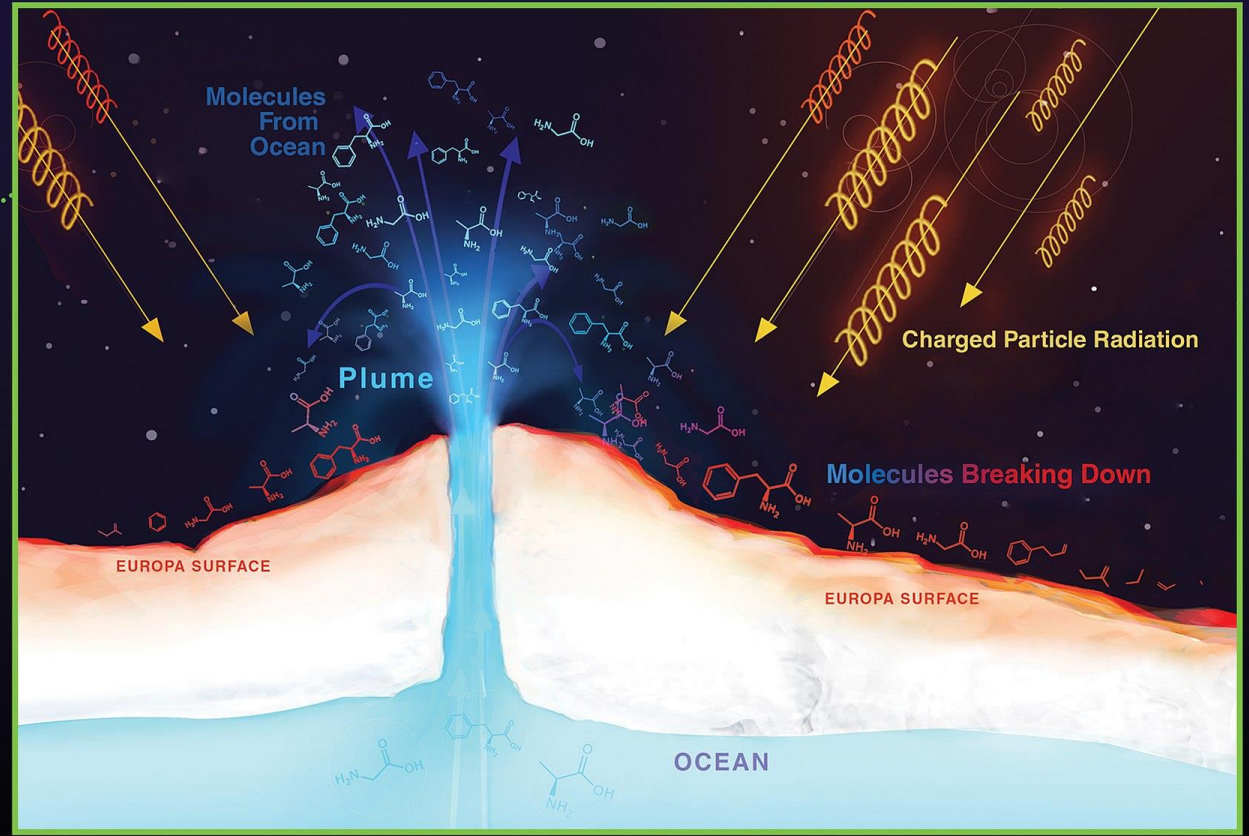
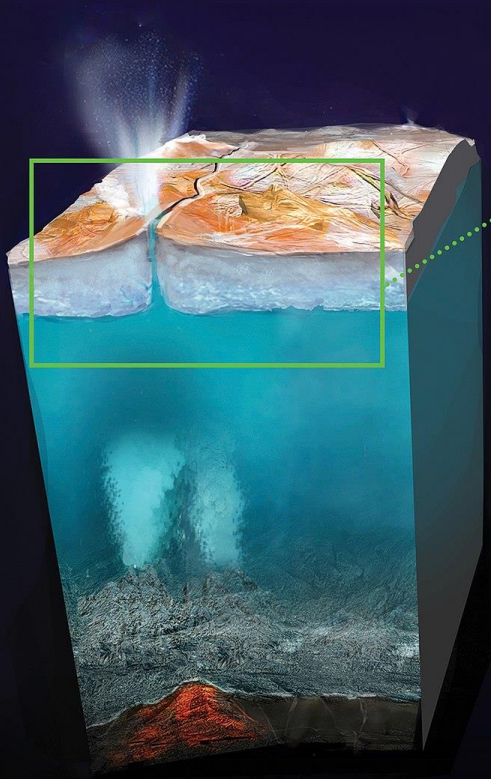






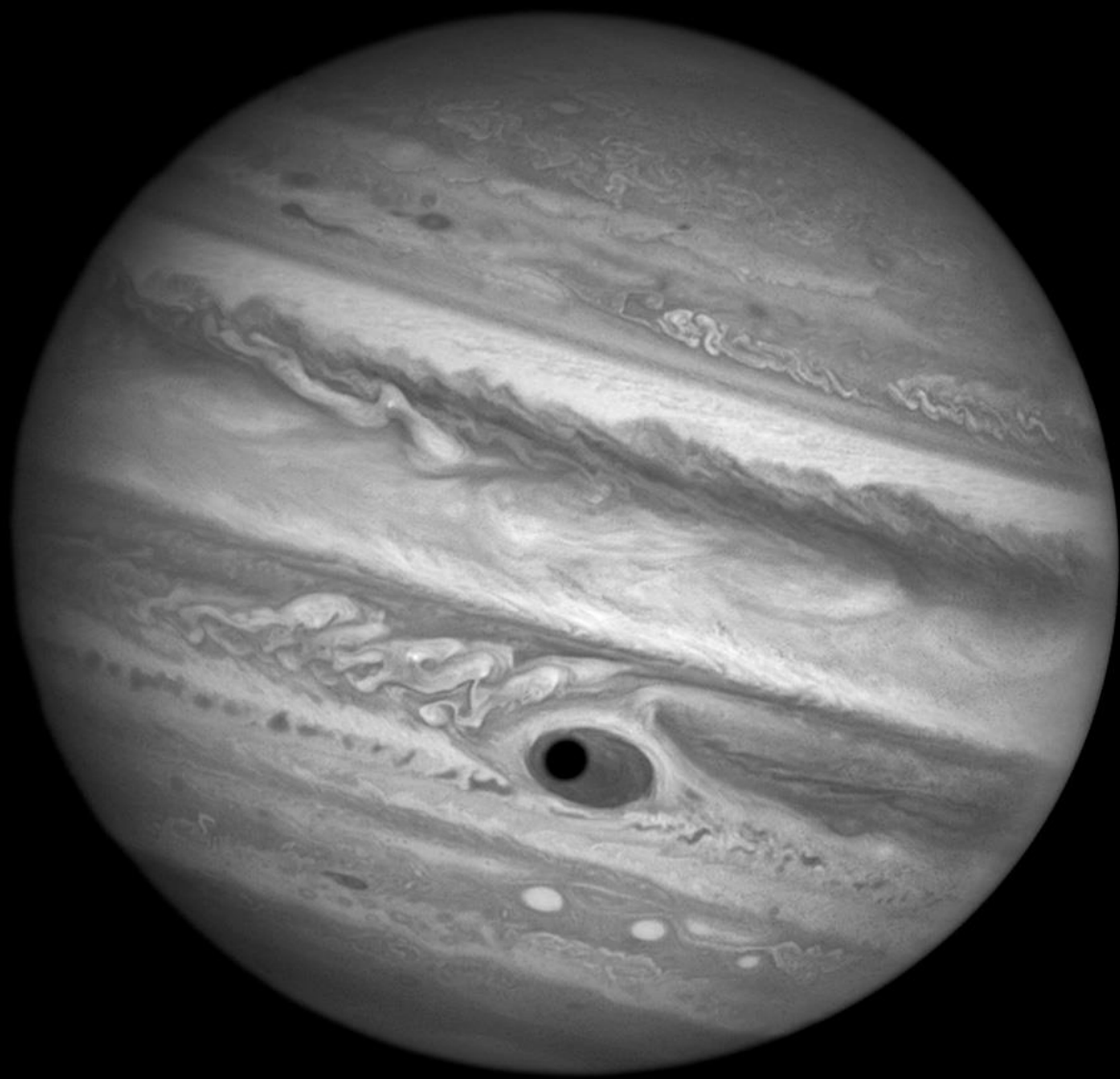


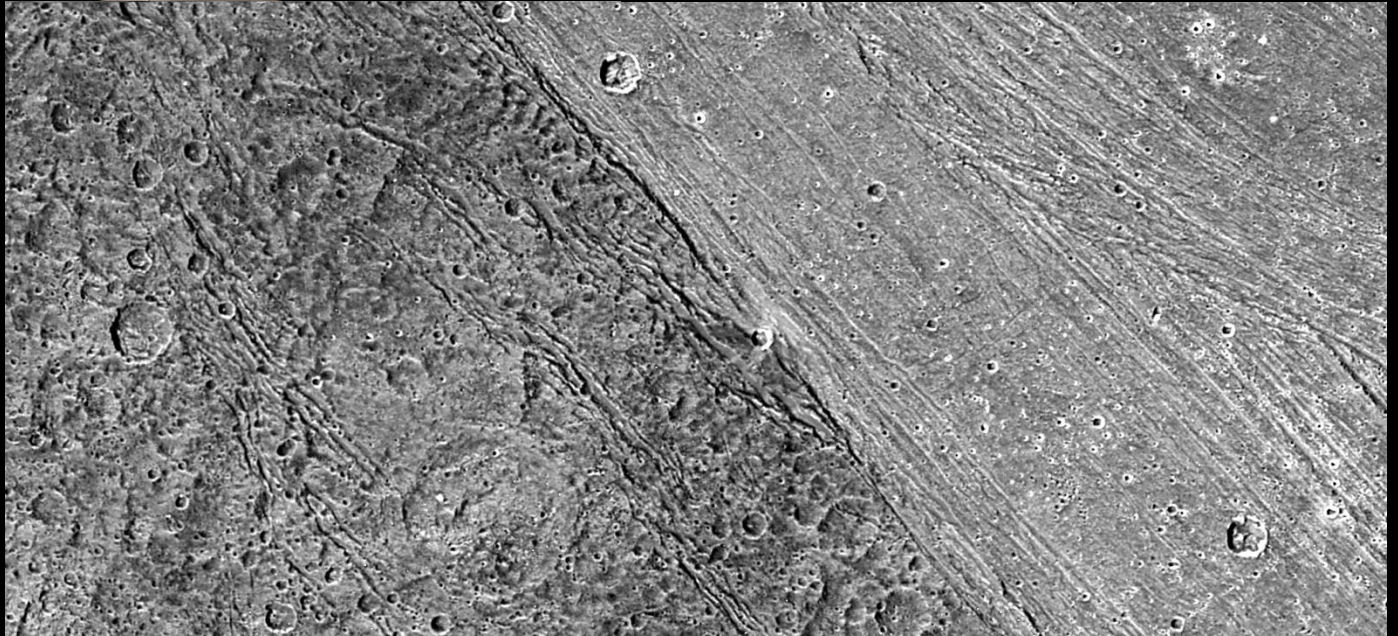




Ganymede and Callisto

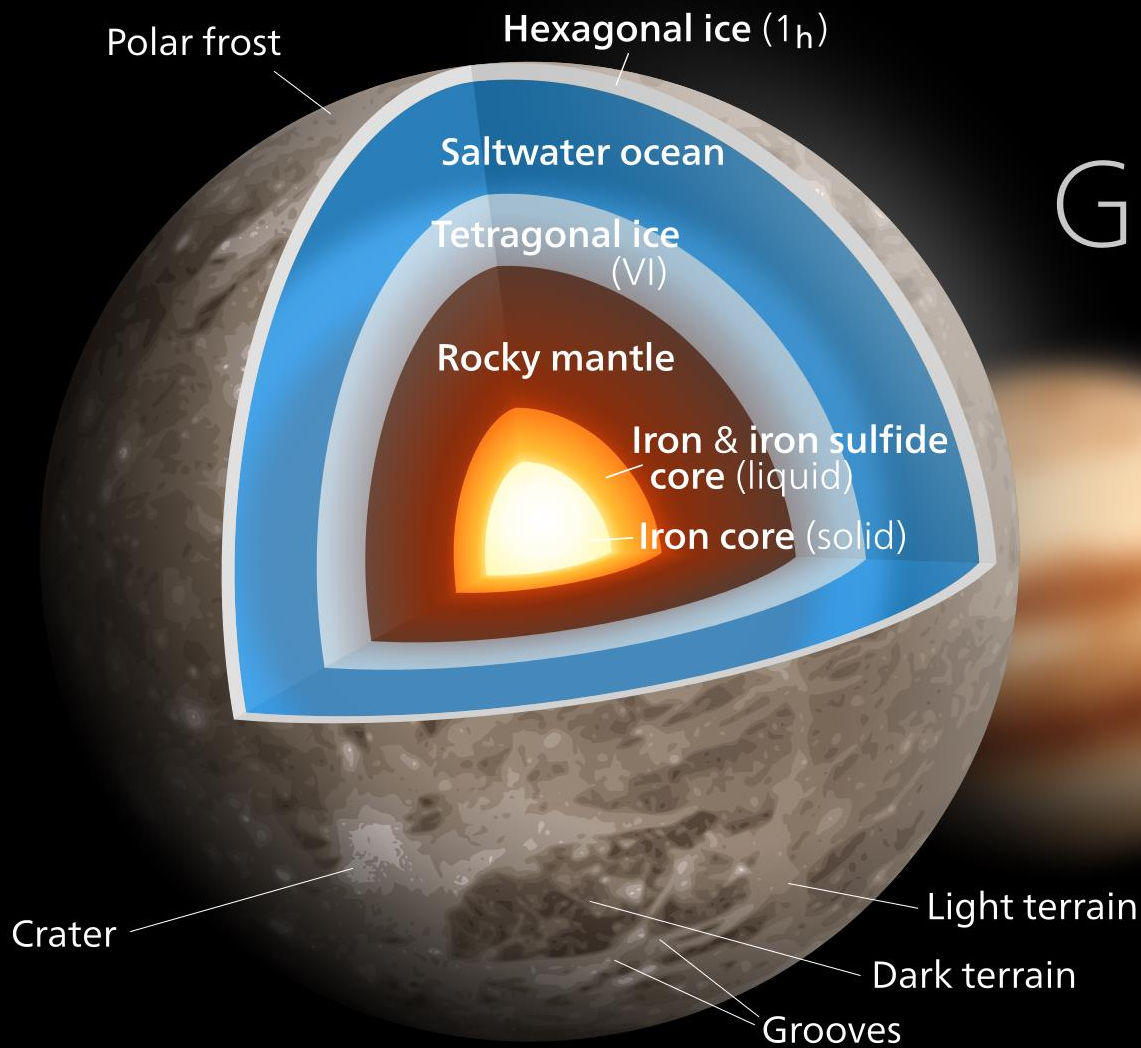


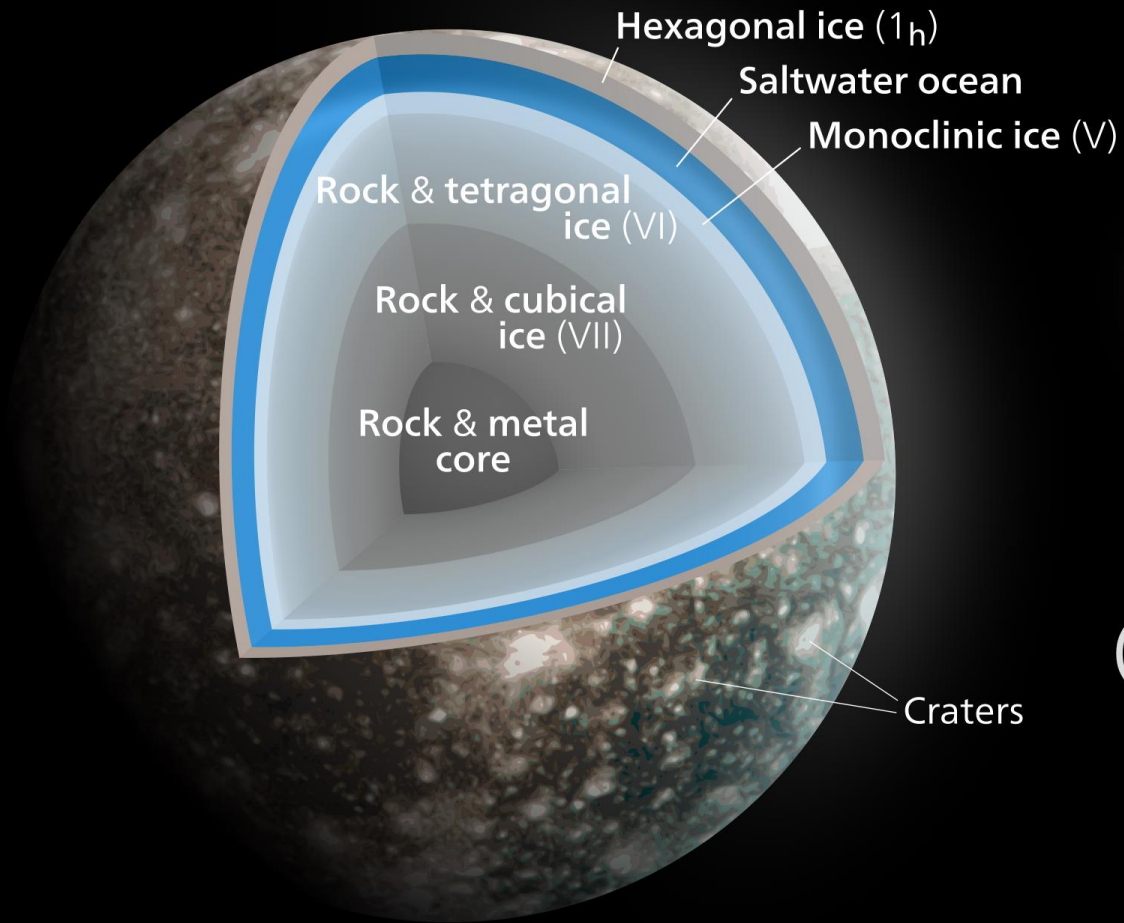




Ganymede

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:

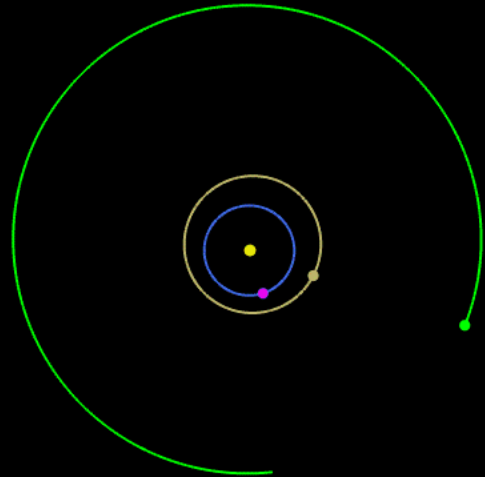
Confirm liquid water between ice and ice-ocean exchange

Composition and chemistry

Geology of surface features



2024-10-10 03:55 Europa Clipper



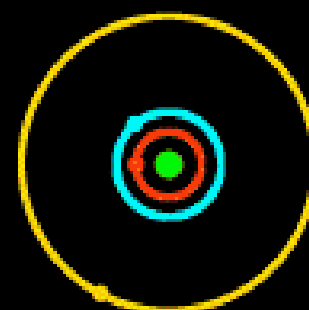
0.000km/s

678,895,098km

(85.2 0.0)

2030-03-11 00:00

Europa Clipper



0.000km/s

21,461,301km

(88.4 0.0)

JUICE: Jupiter Icy Moons Explorer

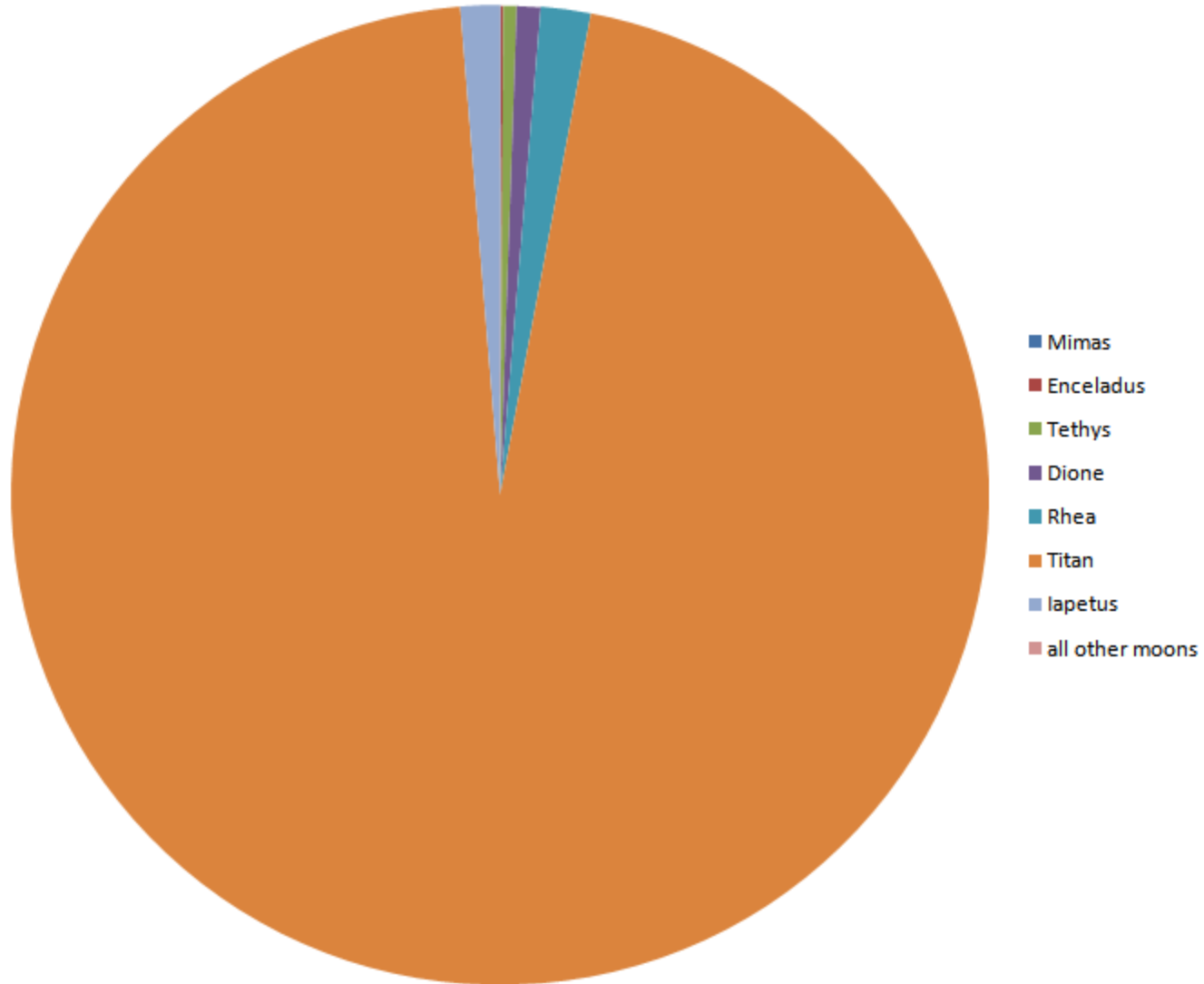
- Launched on 2023.04.14 by ESA (Europe)
- Arrive in 2031.07
- \$1.6B USD
- Will enter orbit around Ganymede
 - With flybys of Europa and Callisto

Similar science goals, but for Ganymede

Moons of Saturn

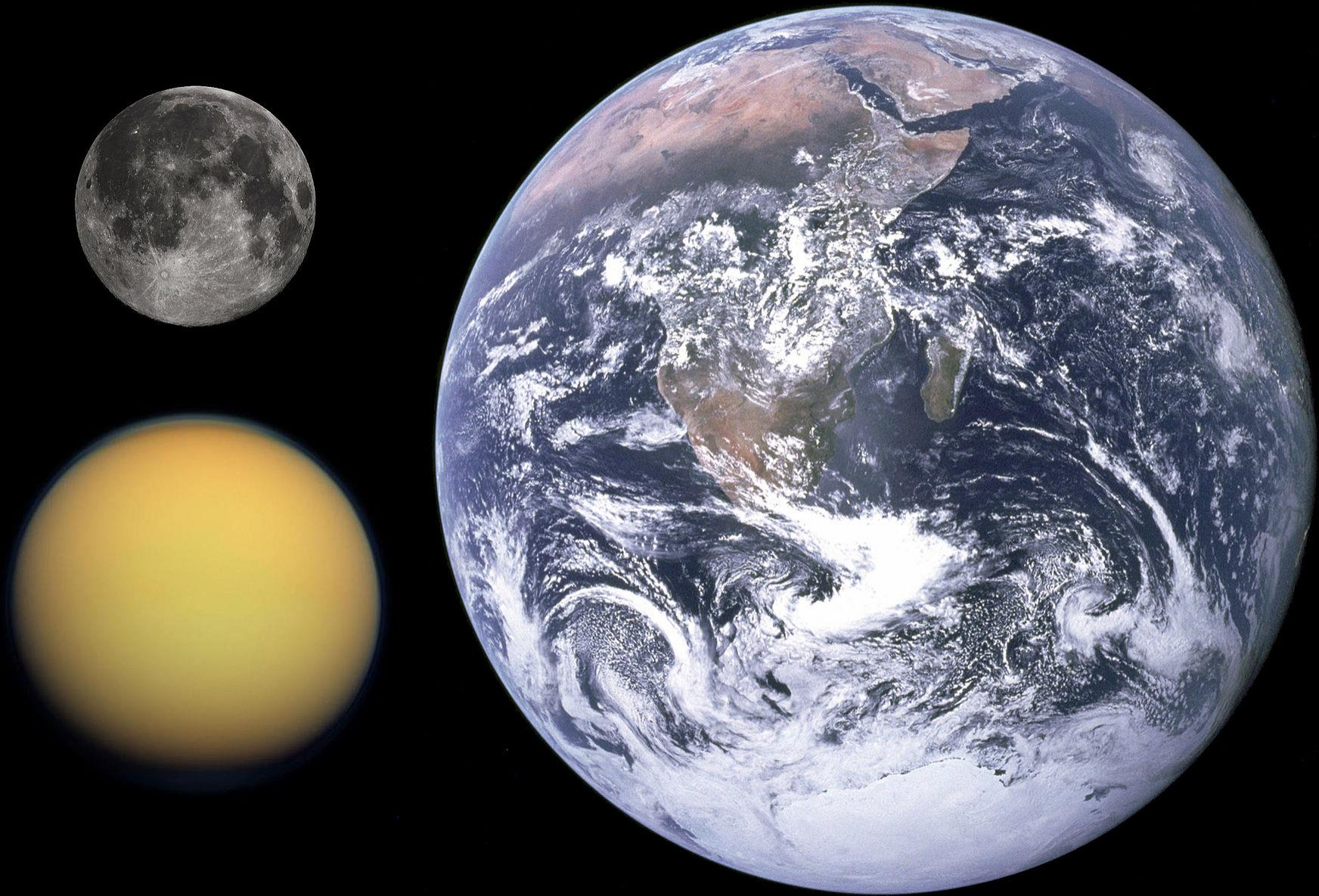


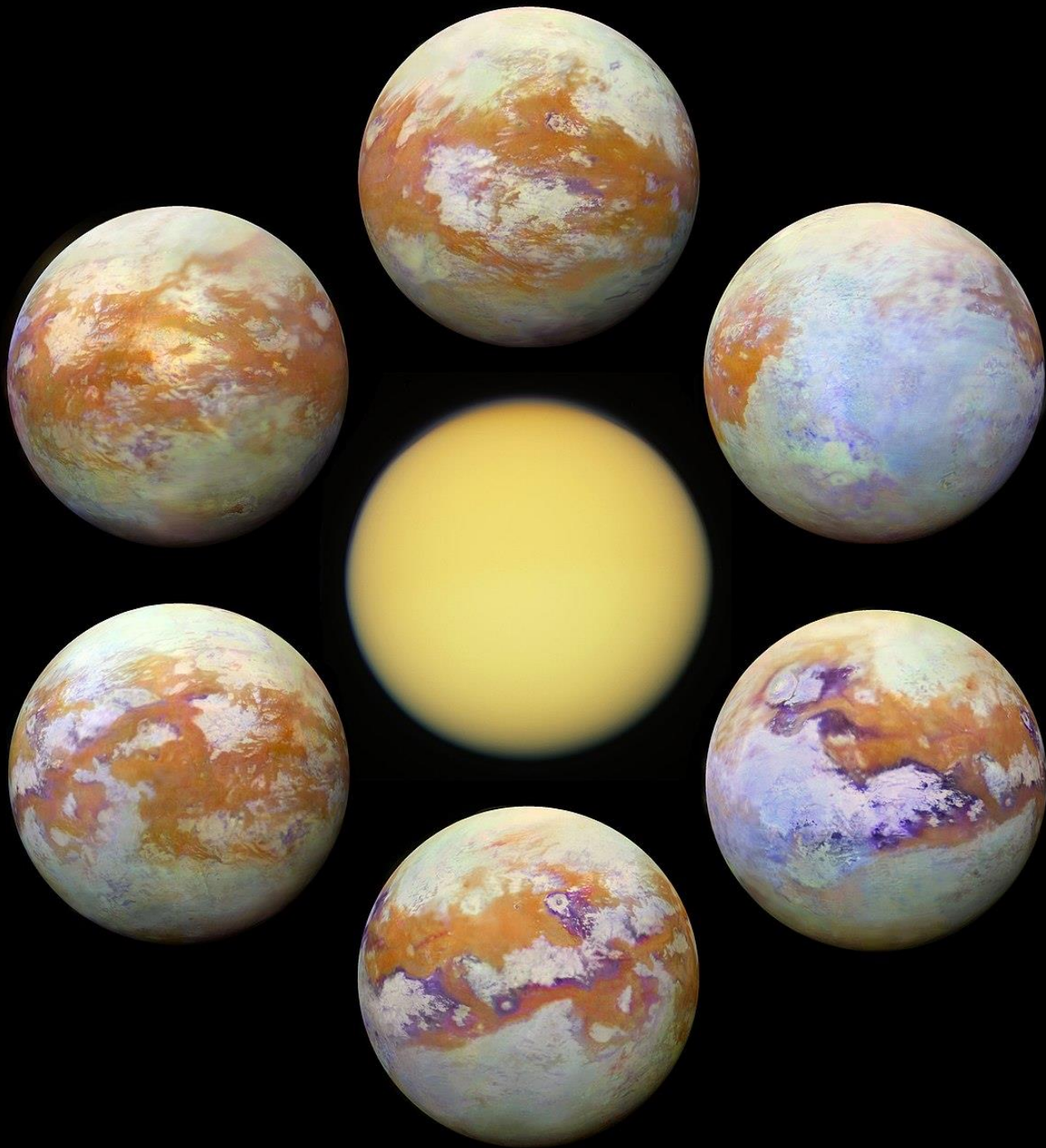
Moons of Saturn



Titan: the main moon of Saturn

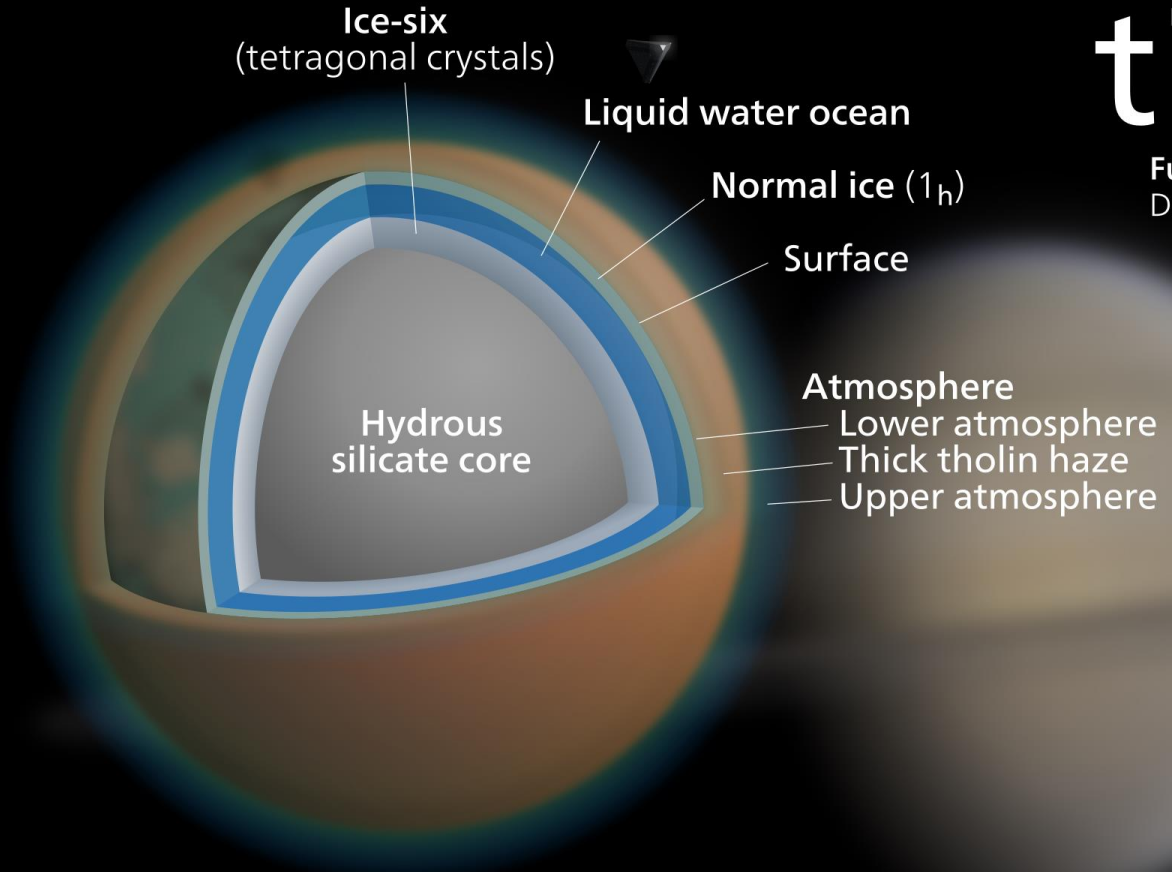


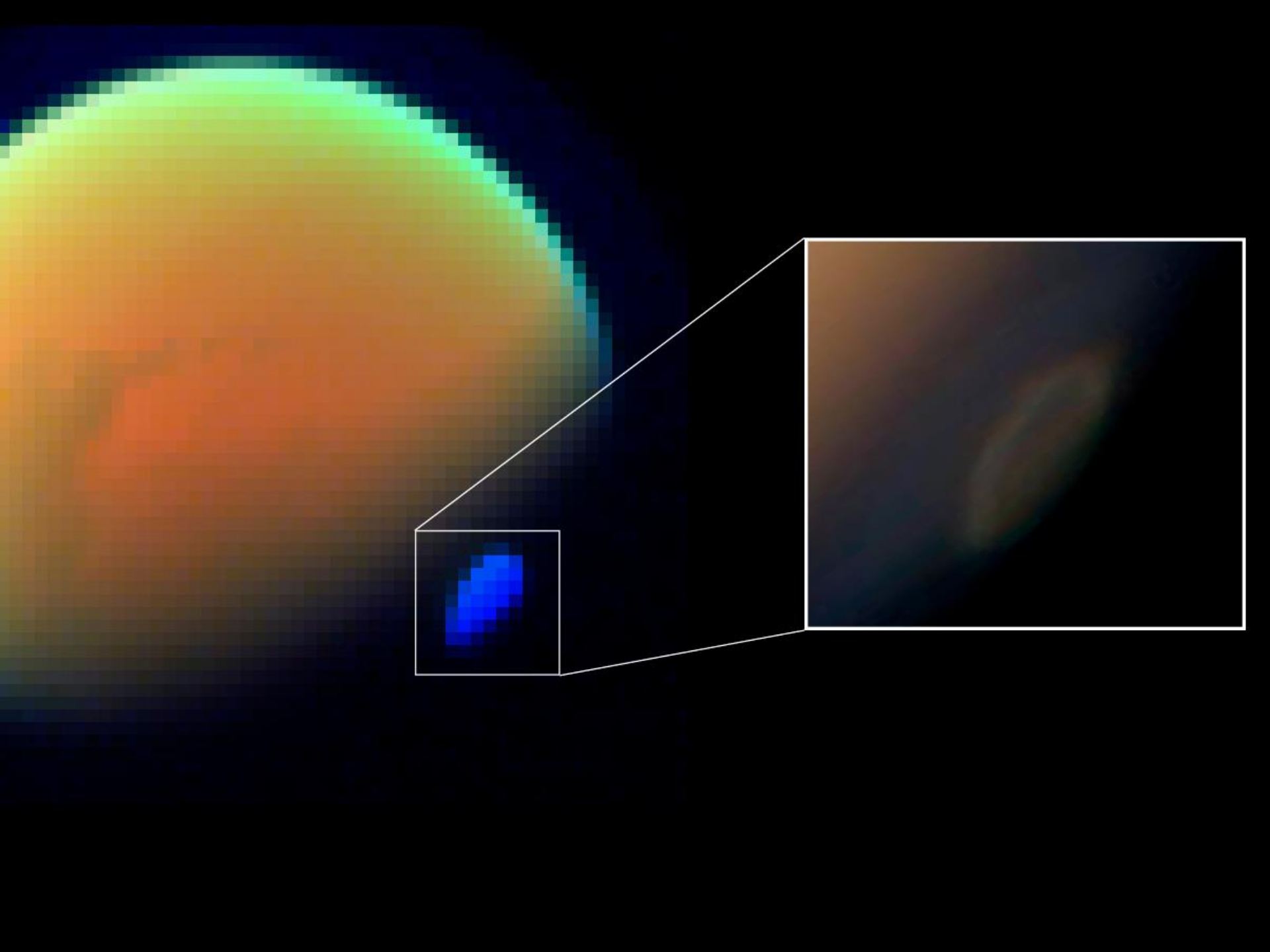


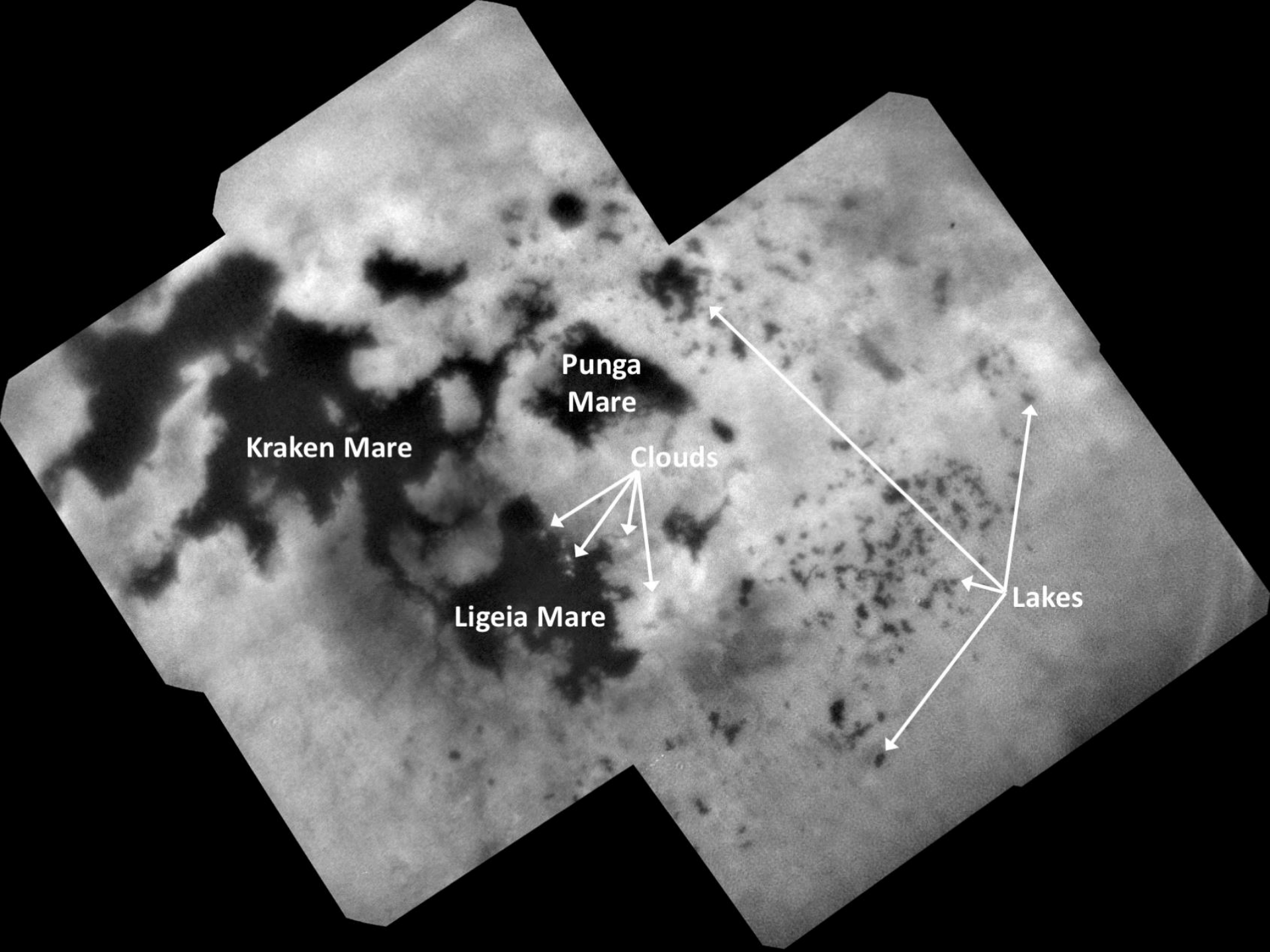


titan

Fully differentiated dense-ocean model
Drawn to scale







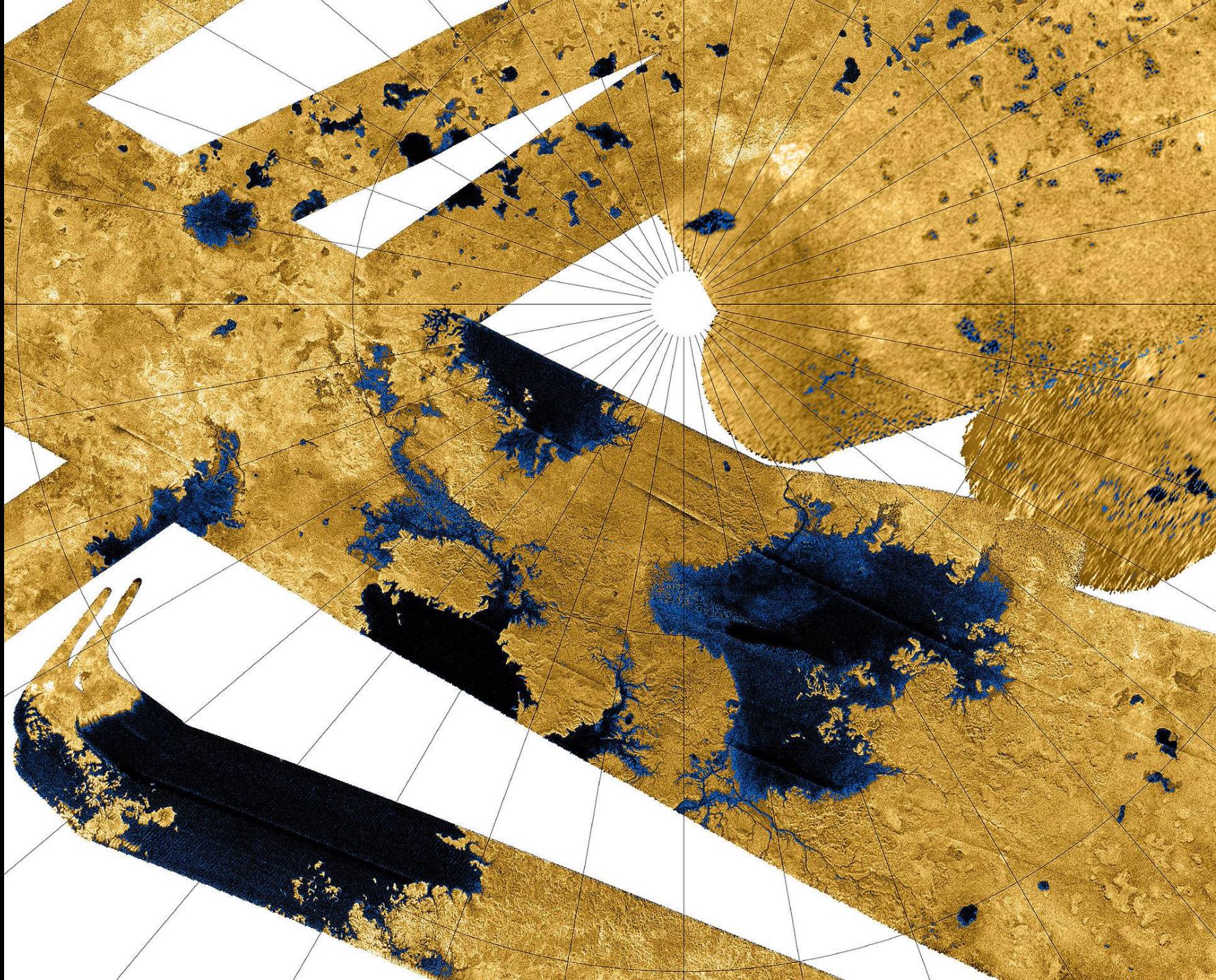
Kraken Mare

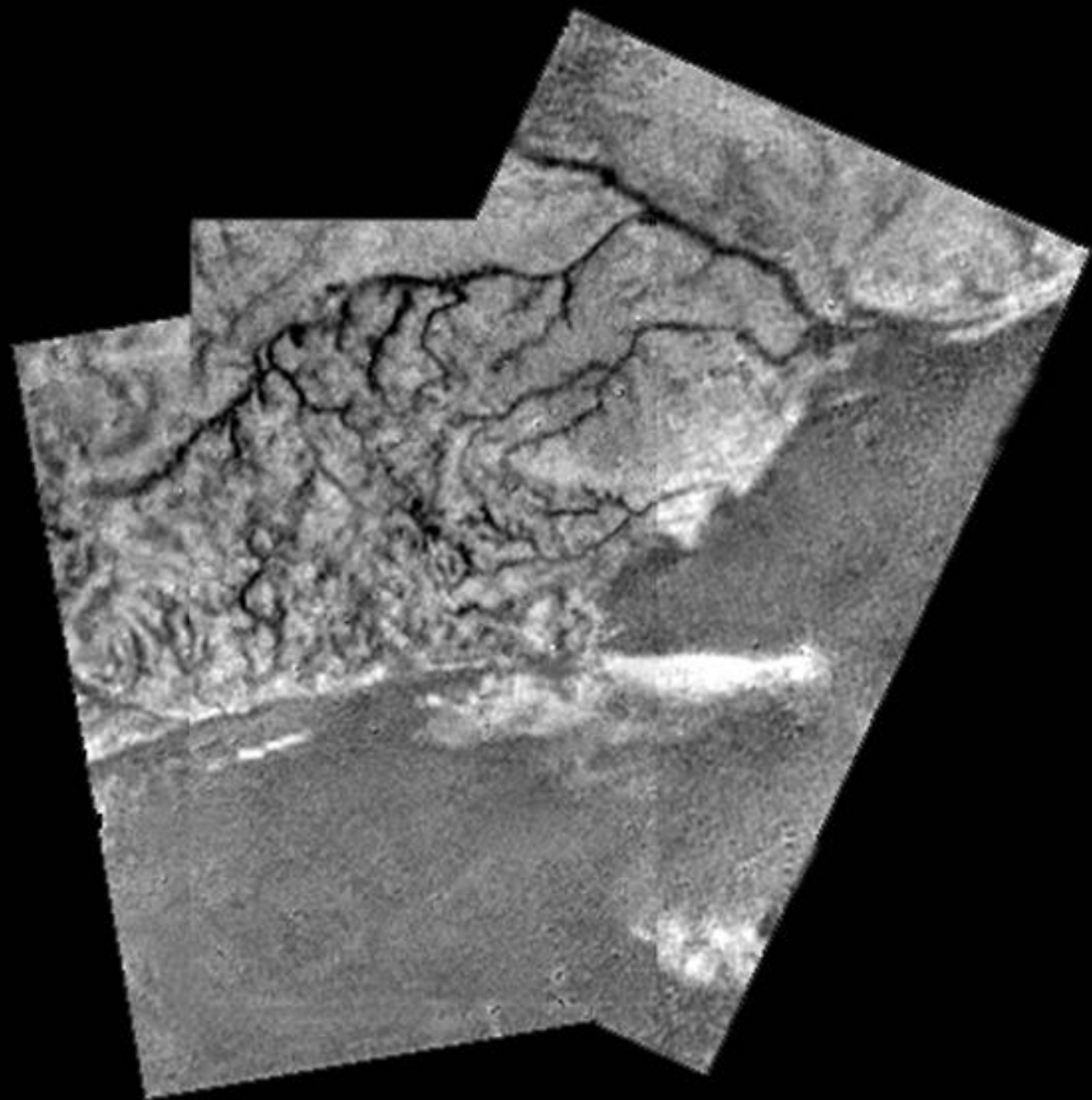
**Punga
Mare**

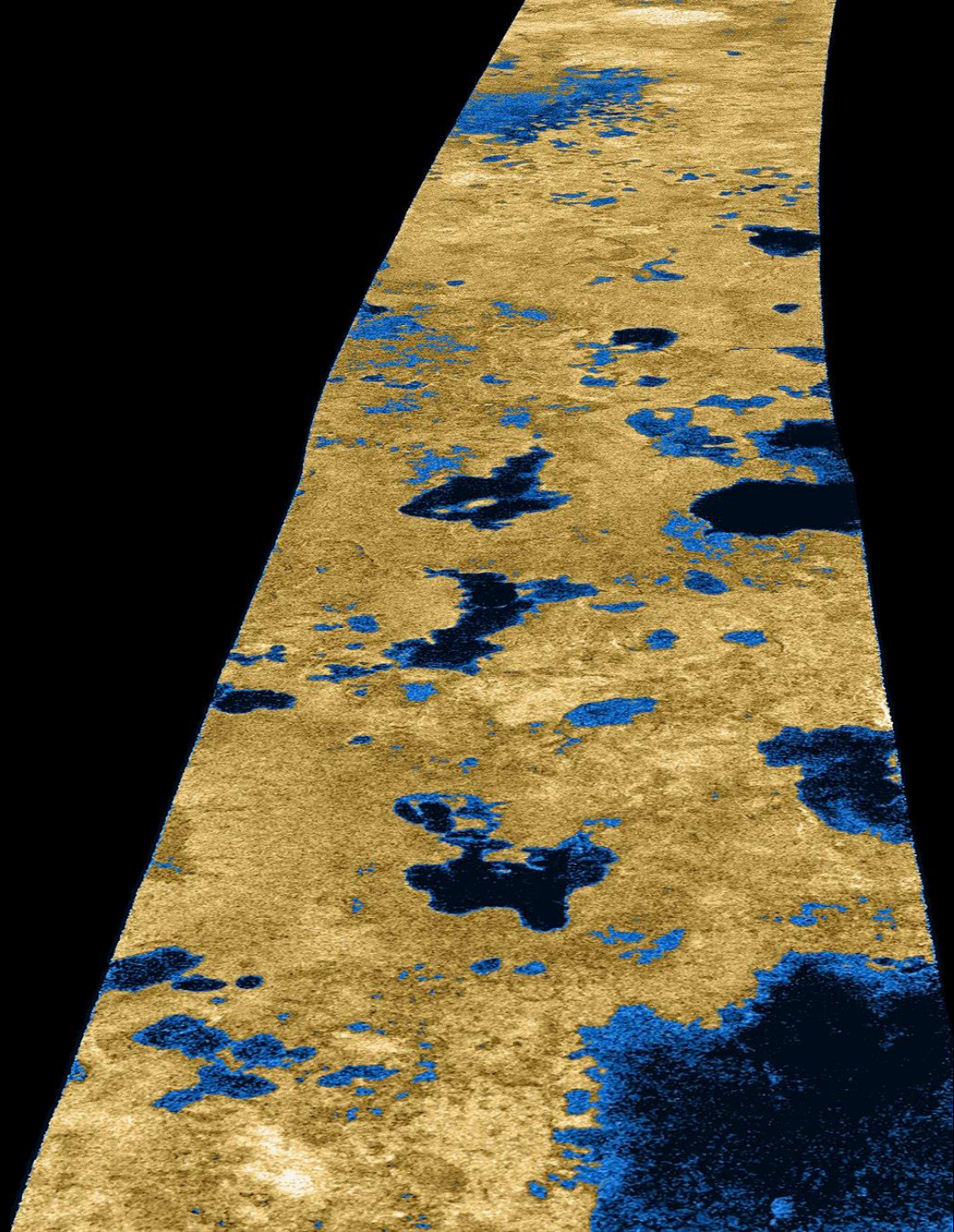
Clouds

Ligeia Mare

Lakes







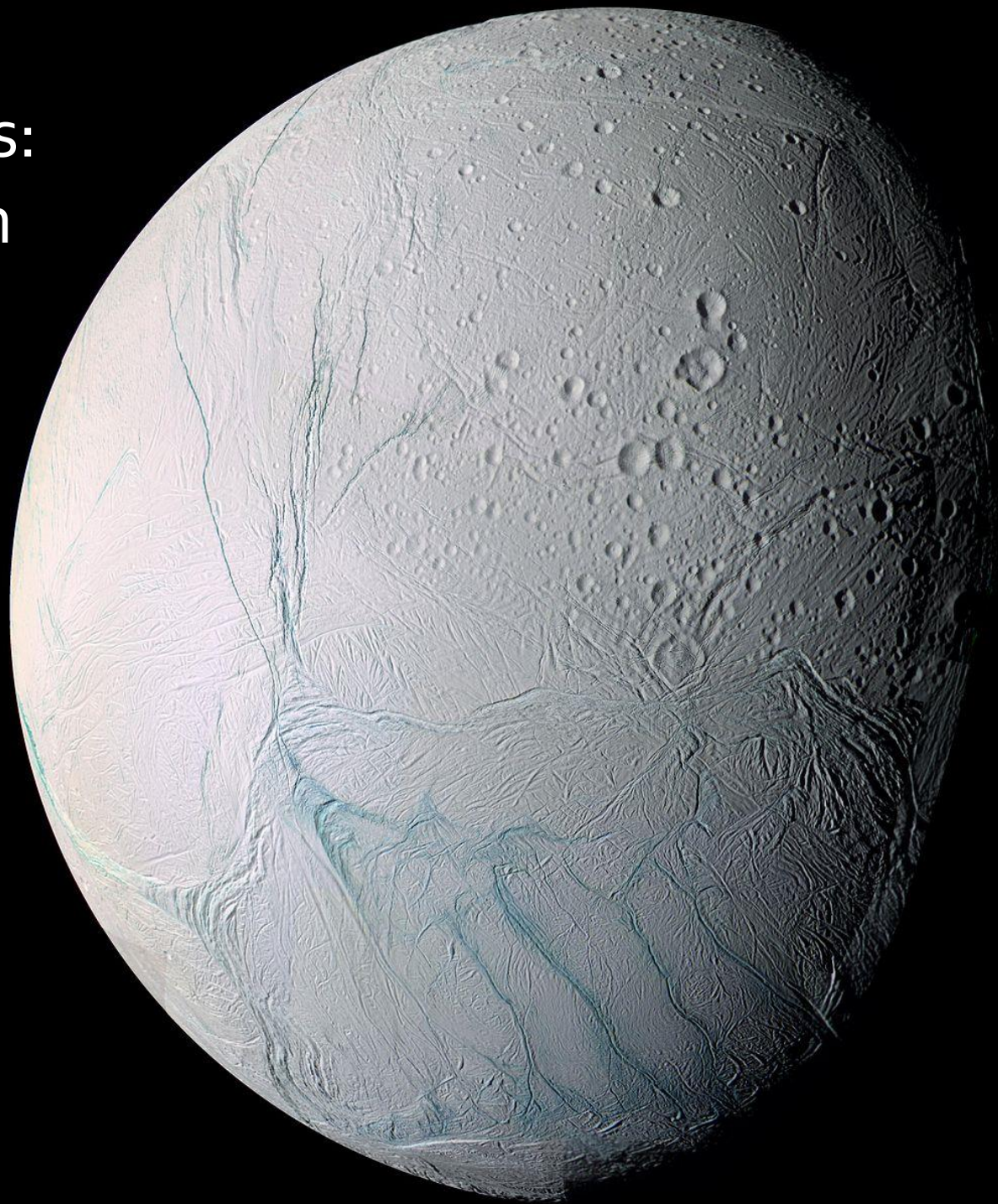


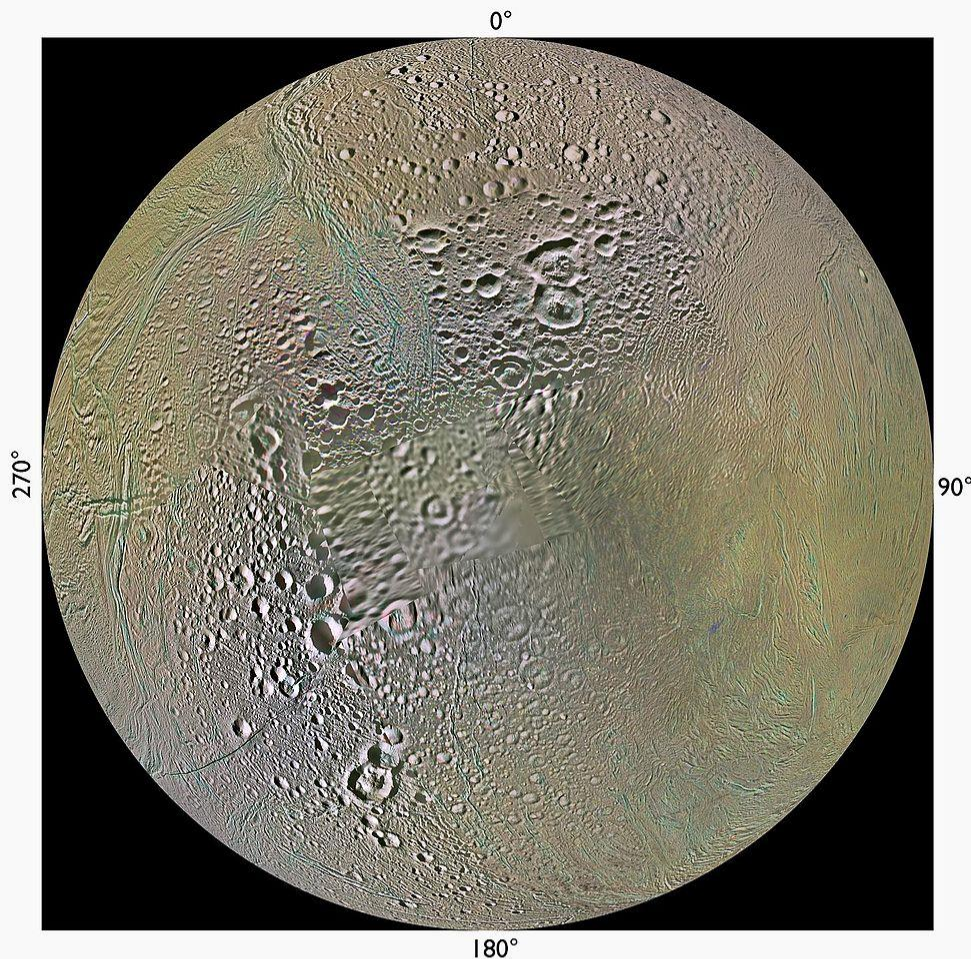




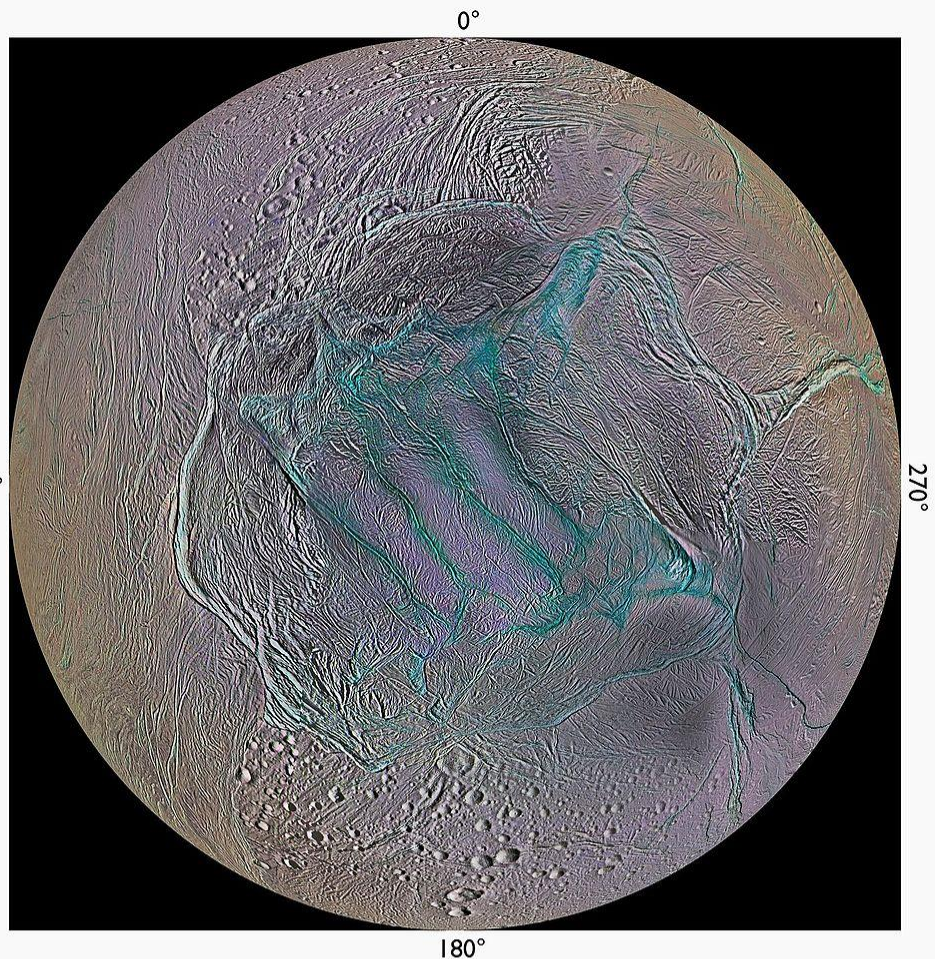
**NASA/Dragonfly Mission:
drone to Titan!**

Enceladus:
ice moon





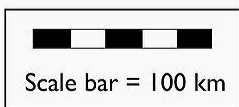
Northern Hemisphere
Orthographic map projection at 100 meters/pixel



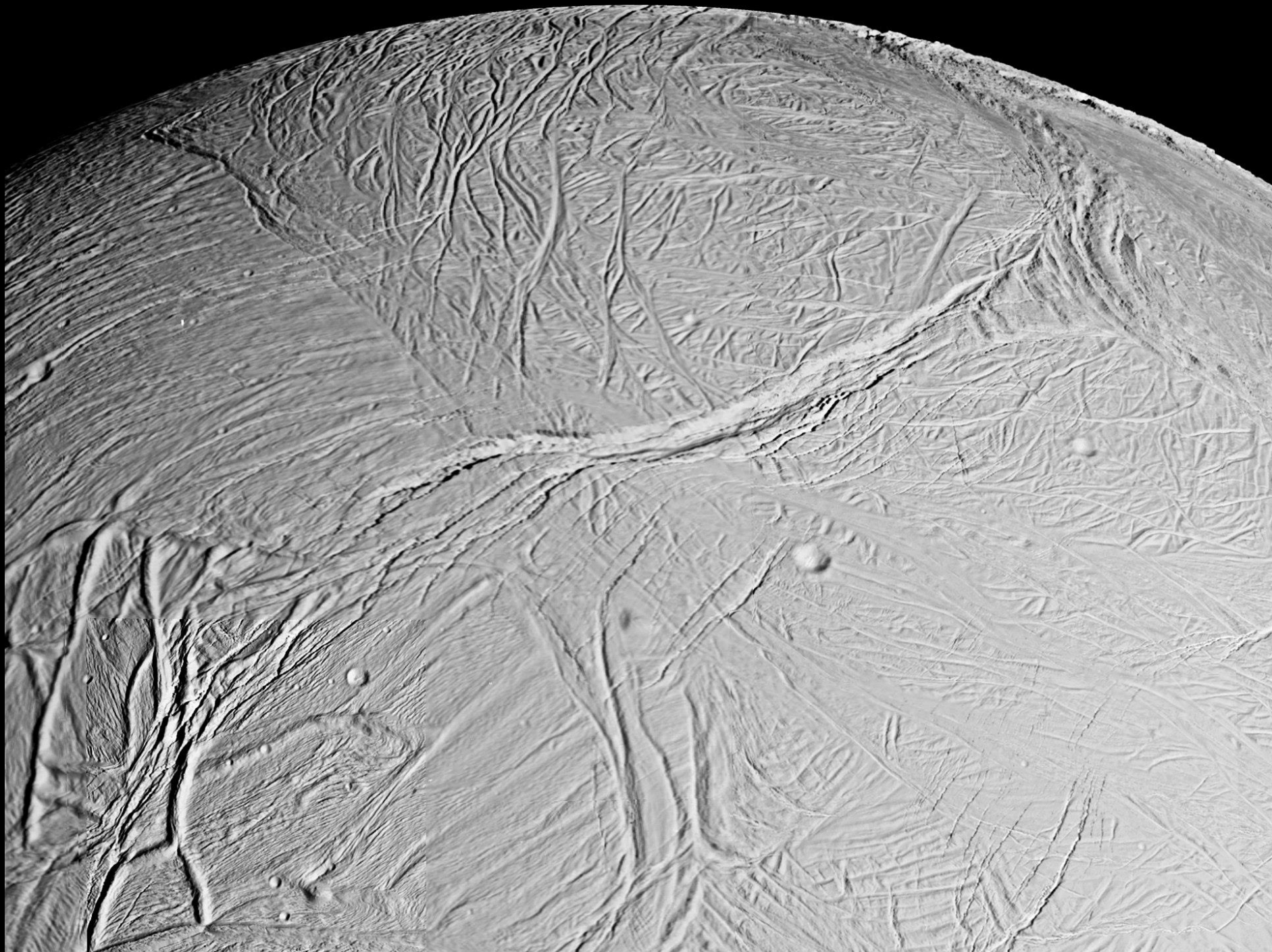
Southern Hemisphere
Orthographic map projection at 100 meters/pixel

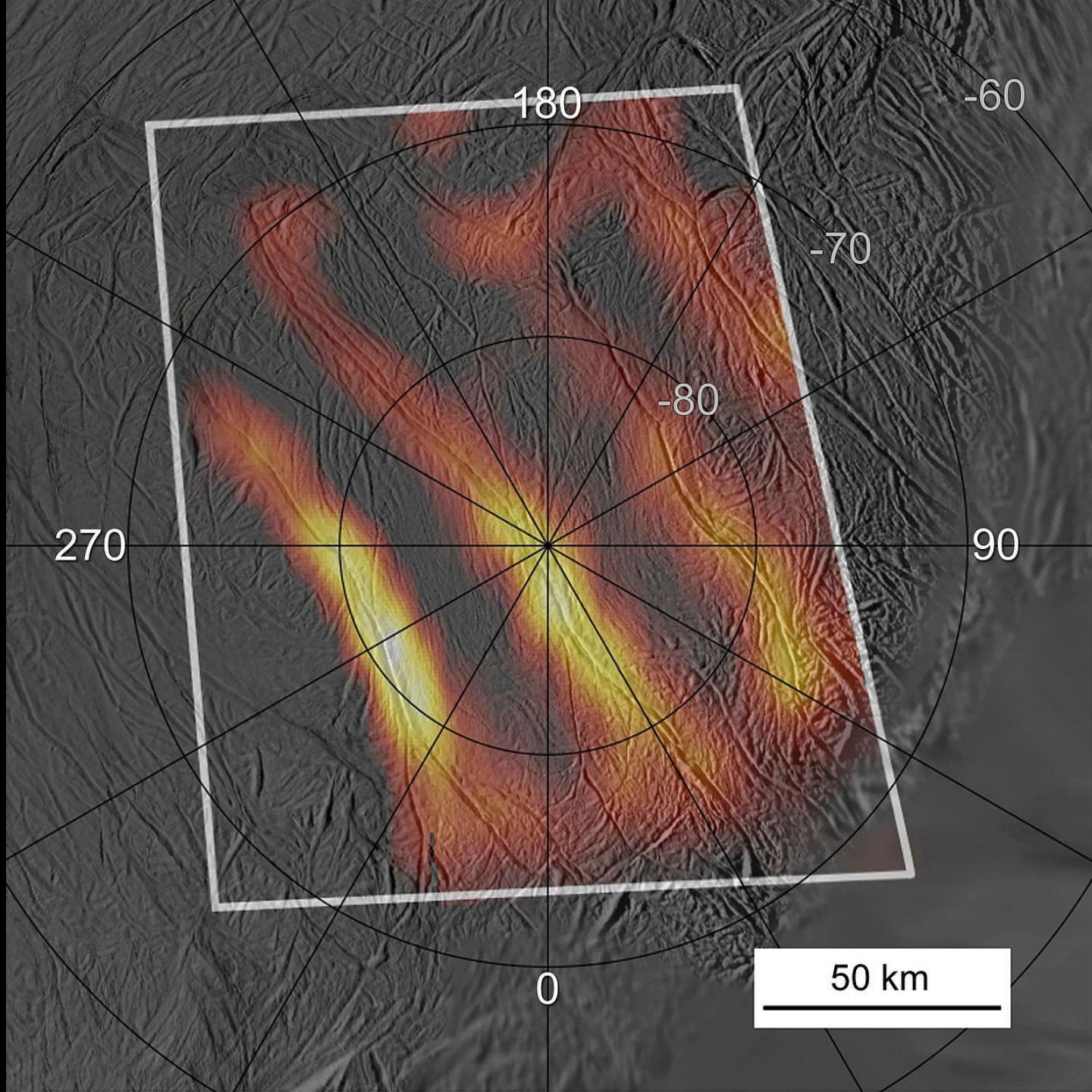
Global 3-Color Map of Enceladus (IR3-GRN-UV3)

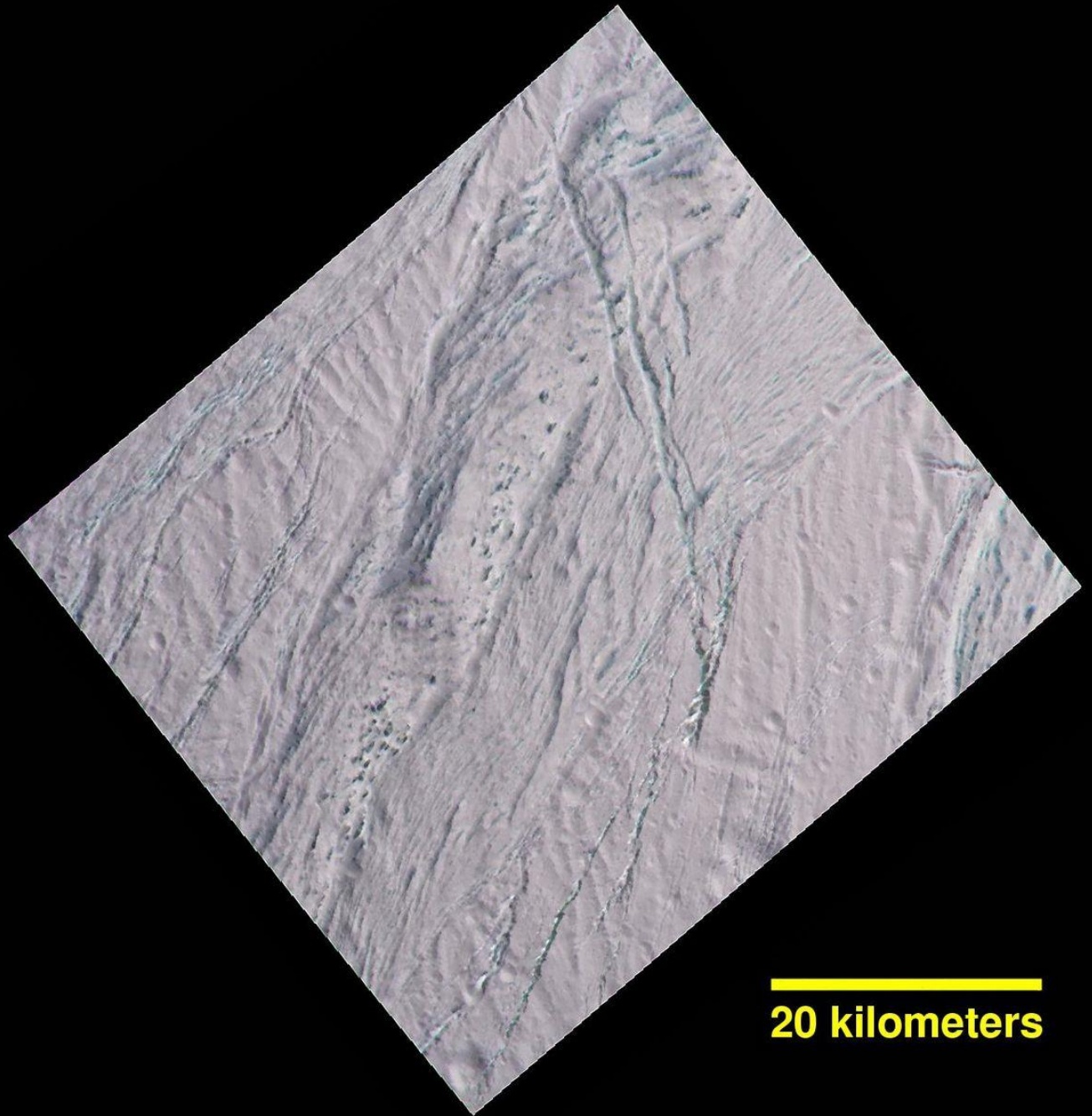
April 2014



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





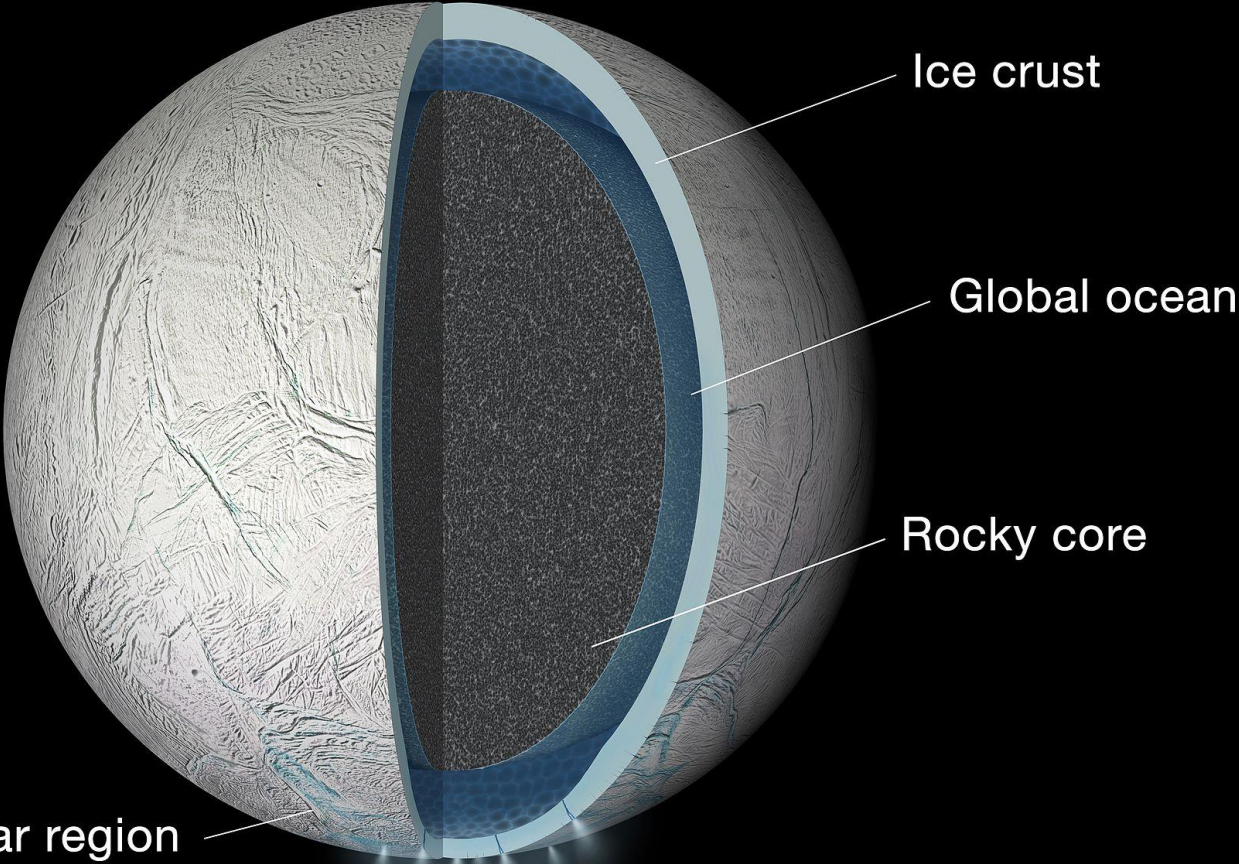


20 kilometers



**1 kilometer
(0.6 mile)**

Global Ocean on
Saturn's Moon
ENCELADUS



Ice crust

Global ocean

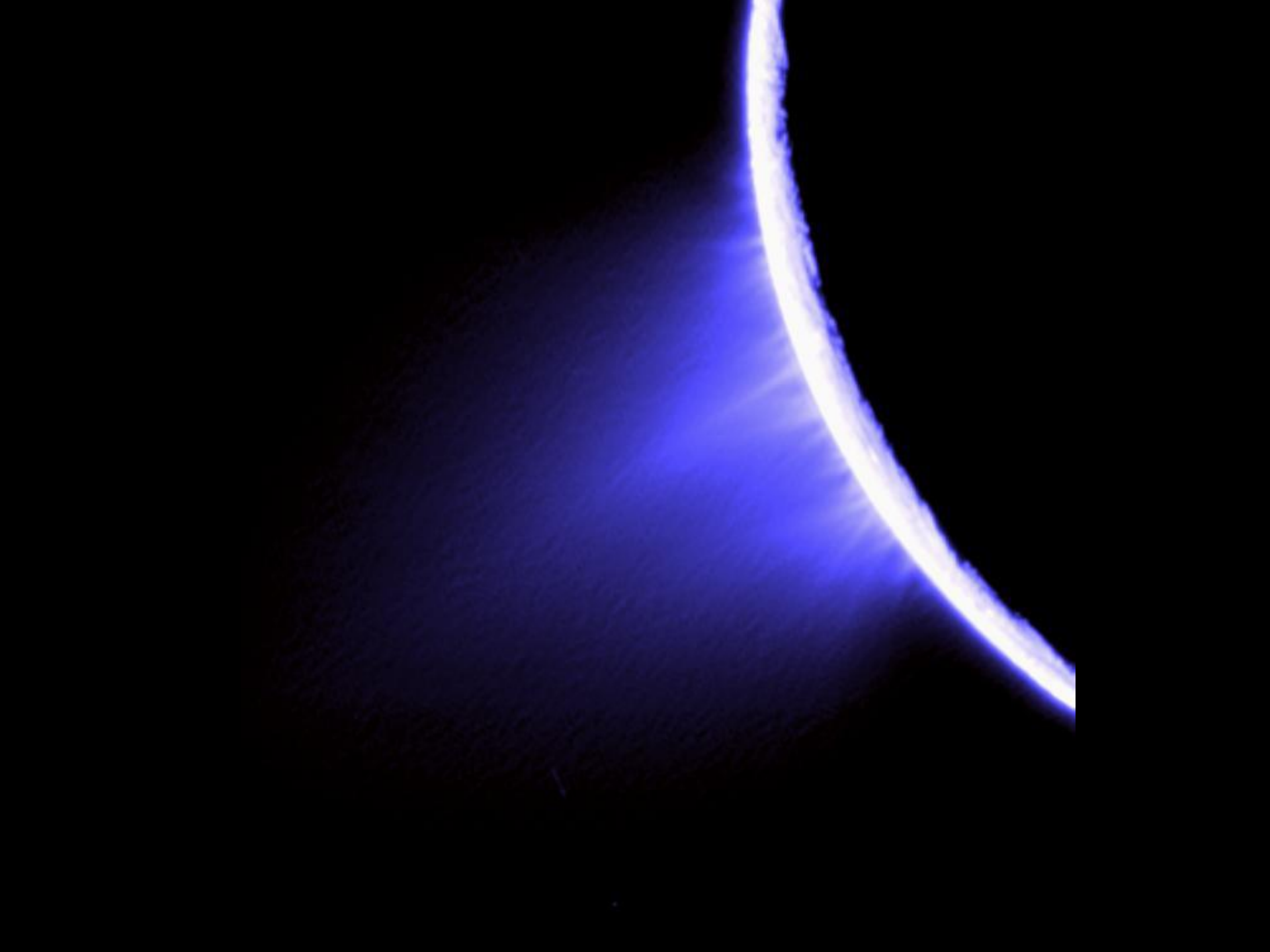
Rocky core

South polar region
with active jets

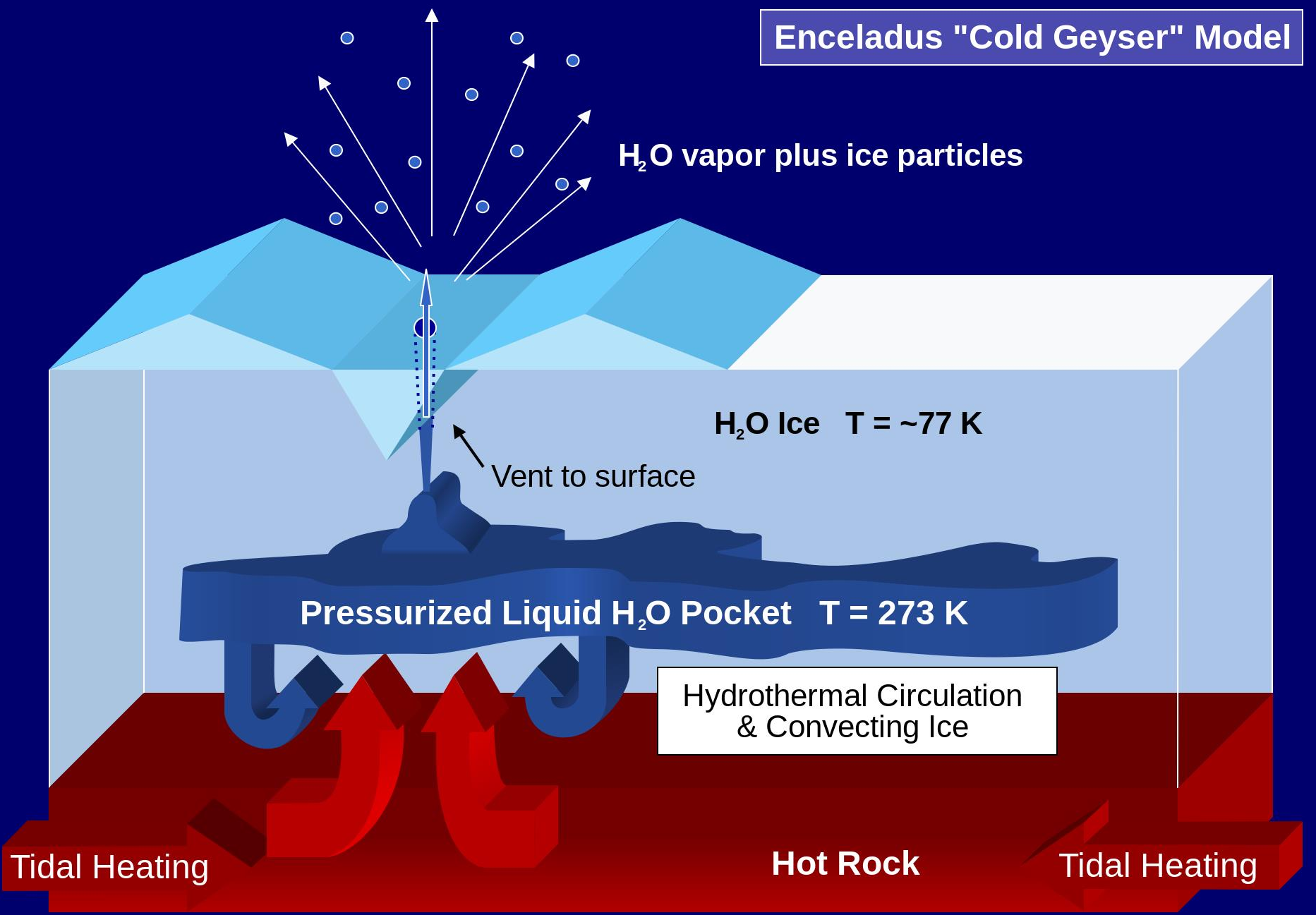
* Thickness of layers is not to scale

Enceladus:
geysers!

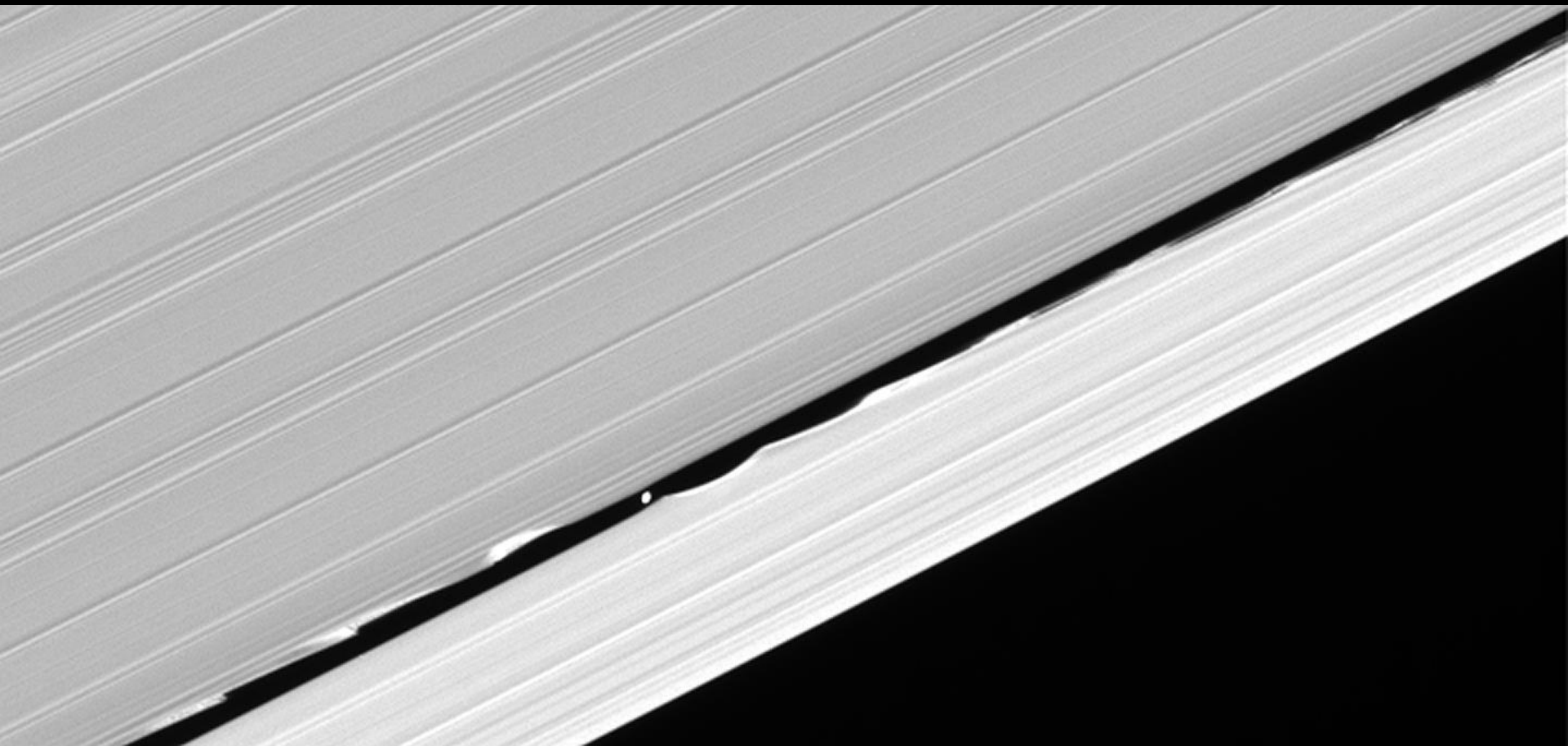




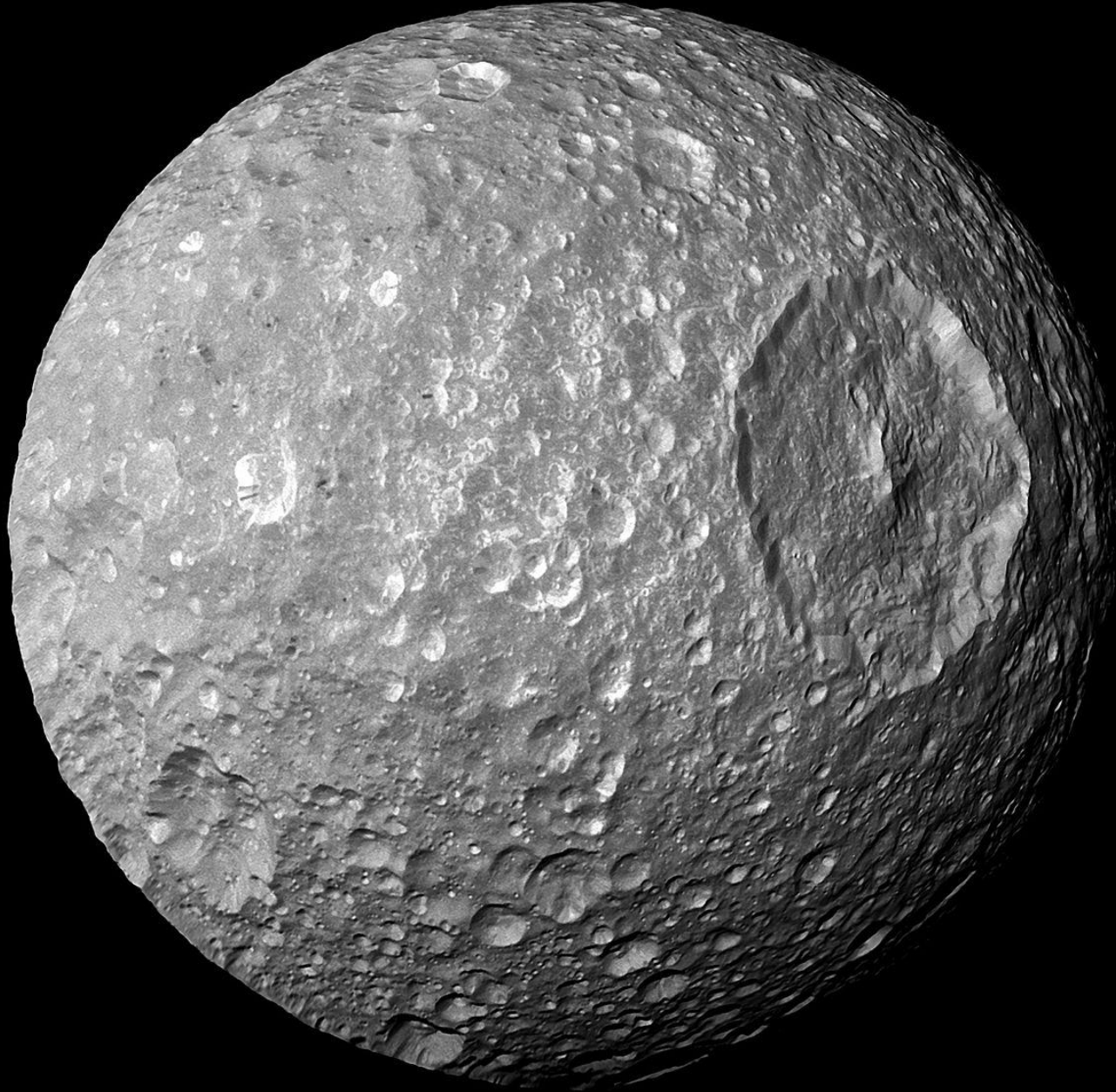
Enceladus "Cold Geyser" Model



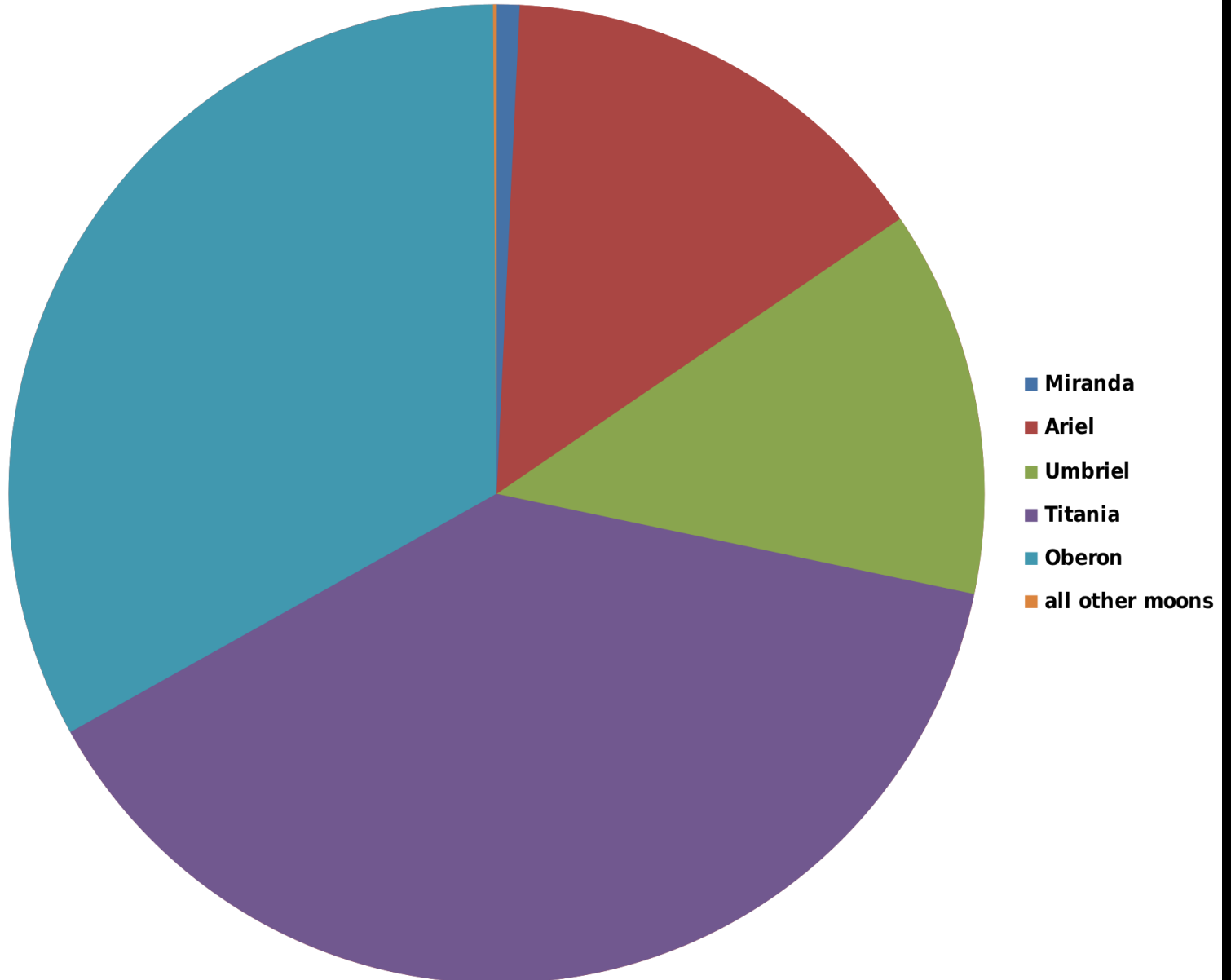
Daphnis: A shepherd moon

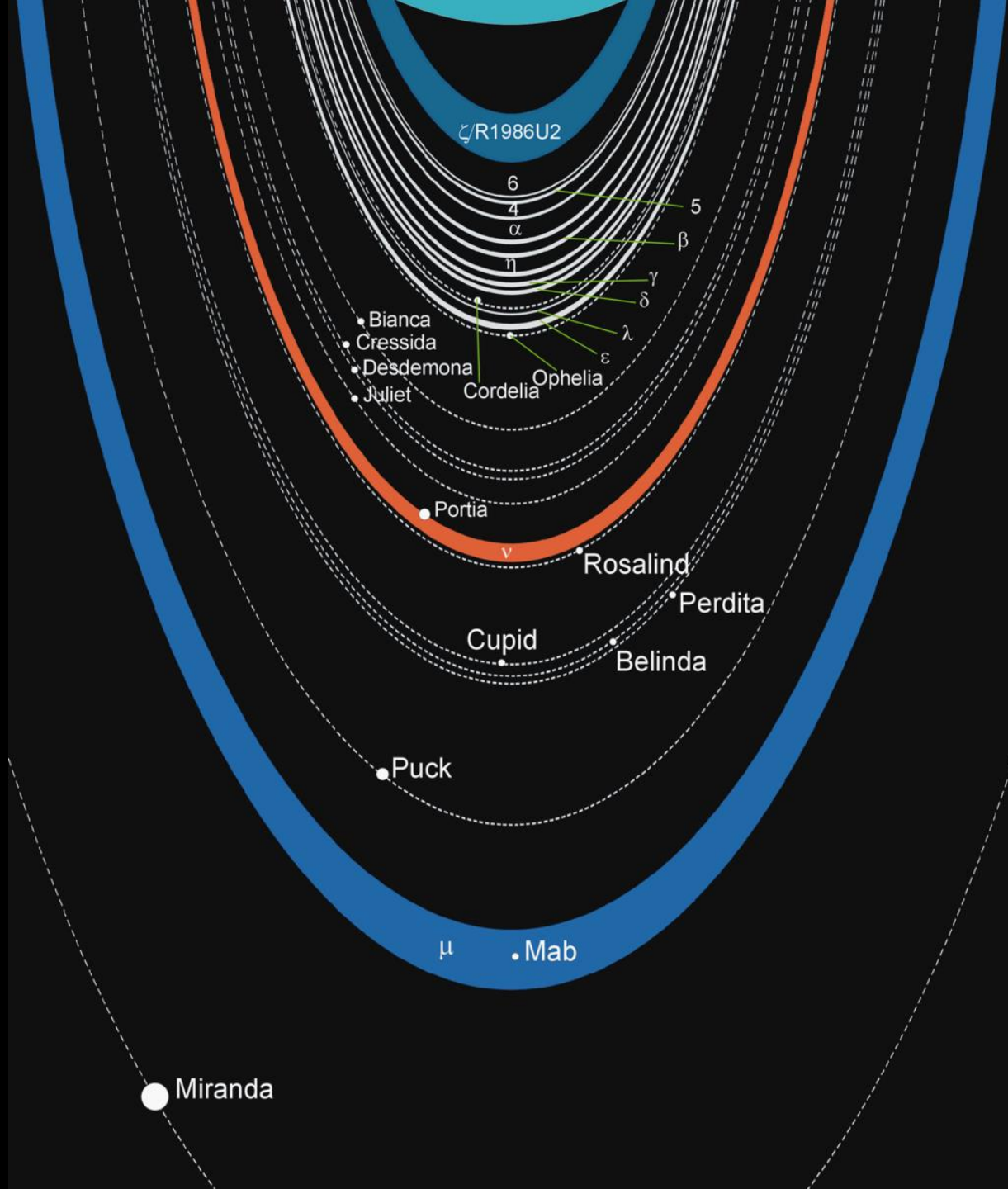


Mimas: the death star moon



Moons of Uranus





ζ R1986U2

6

4

α

η

5

β

γ

δ

λ

ϵ

Bianca
Cressida
Desdemona
Juliet

Cordelia
Ophelia

Portia

Rosalind

Perdita

Cupid

Belinda

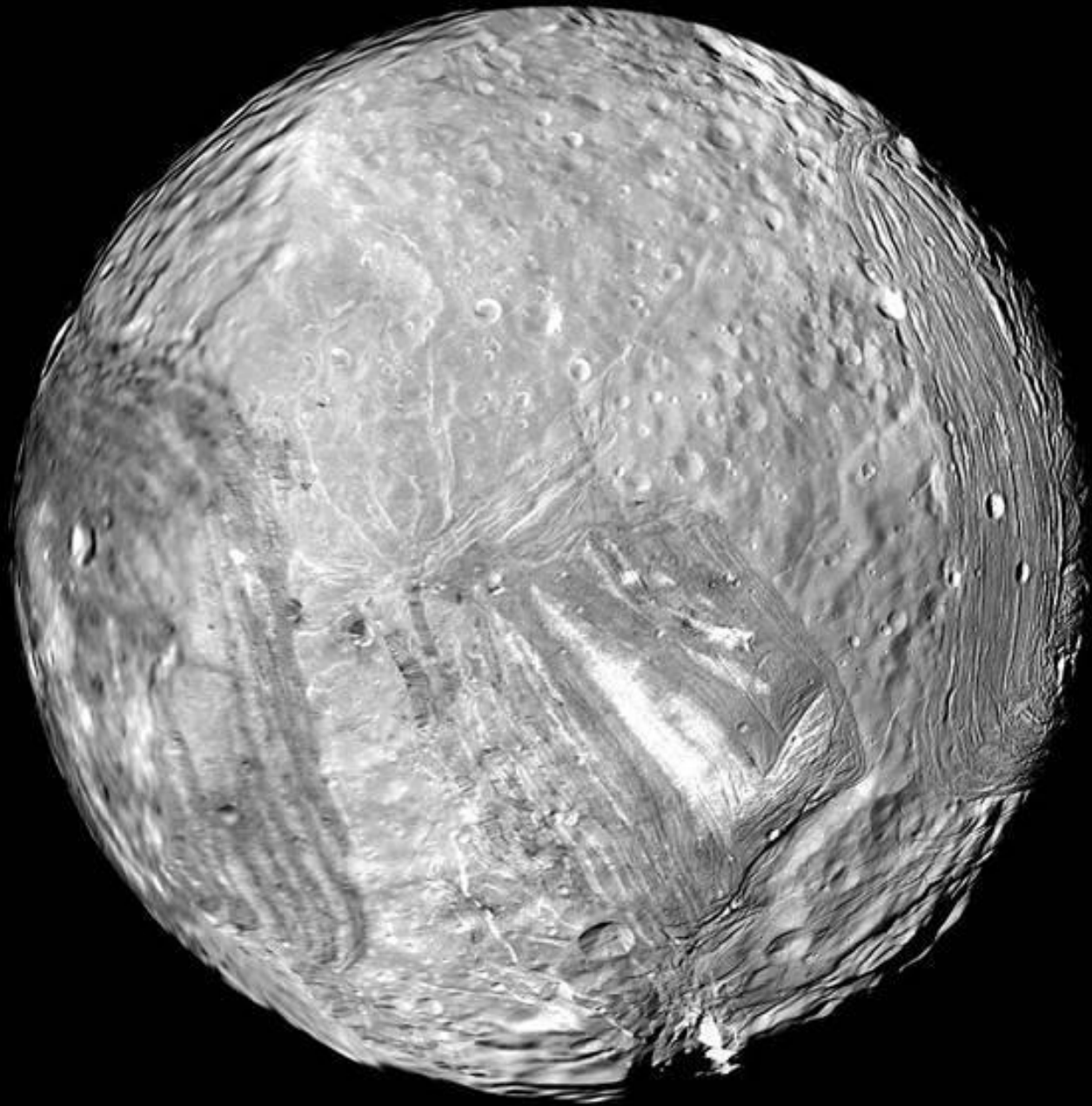
Puck

μ

Mab

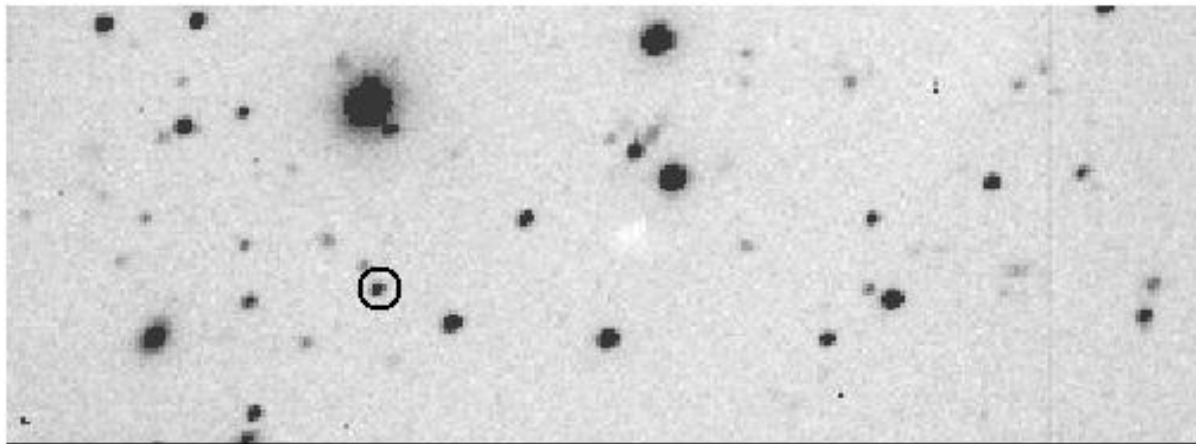
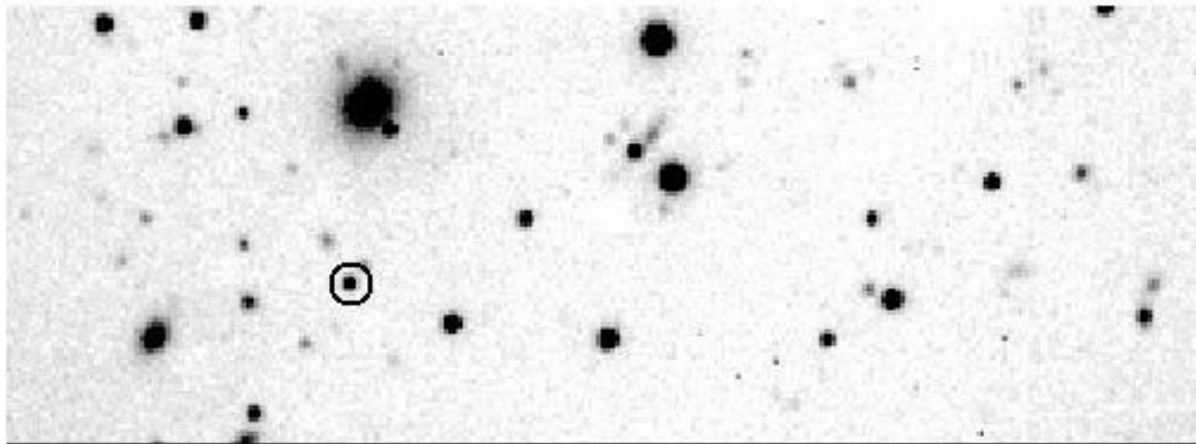
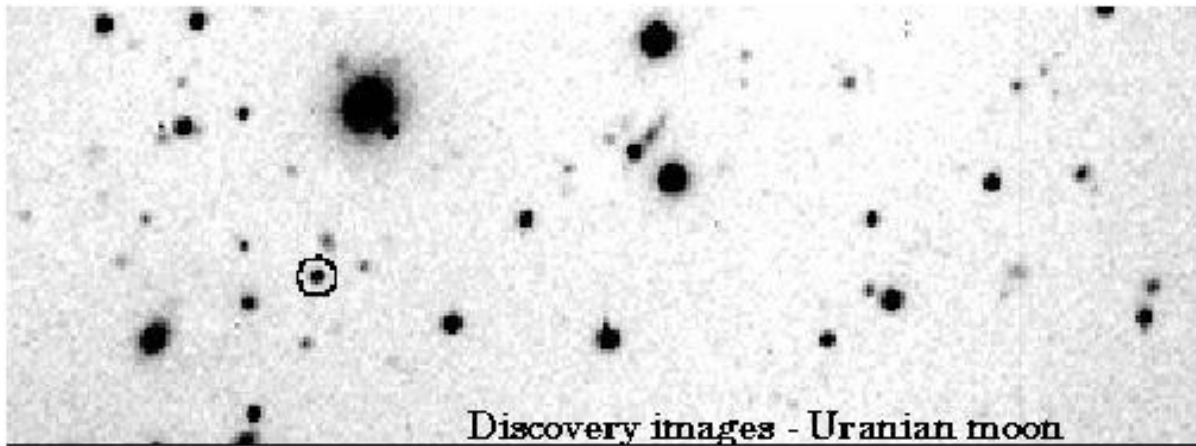
Miranda

Miranda: an ice world?



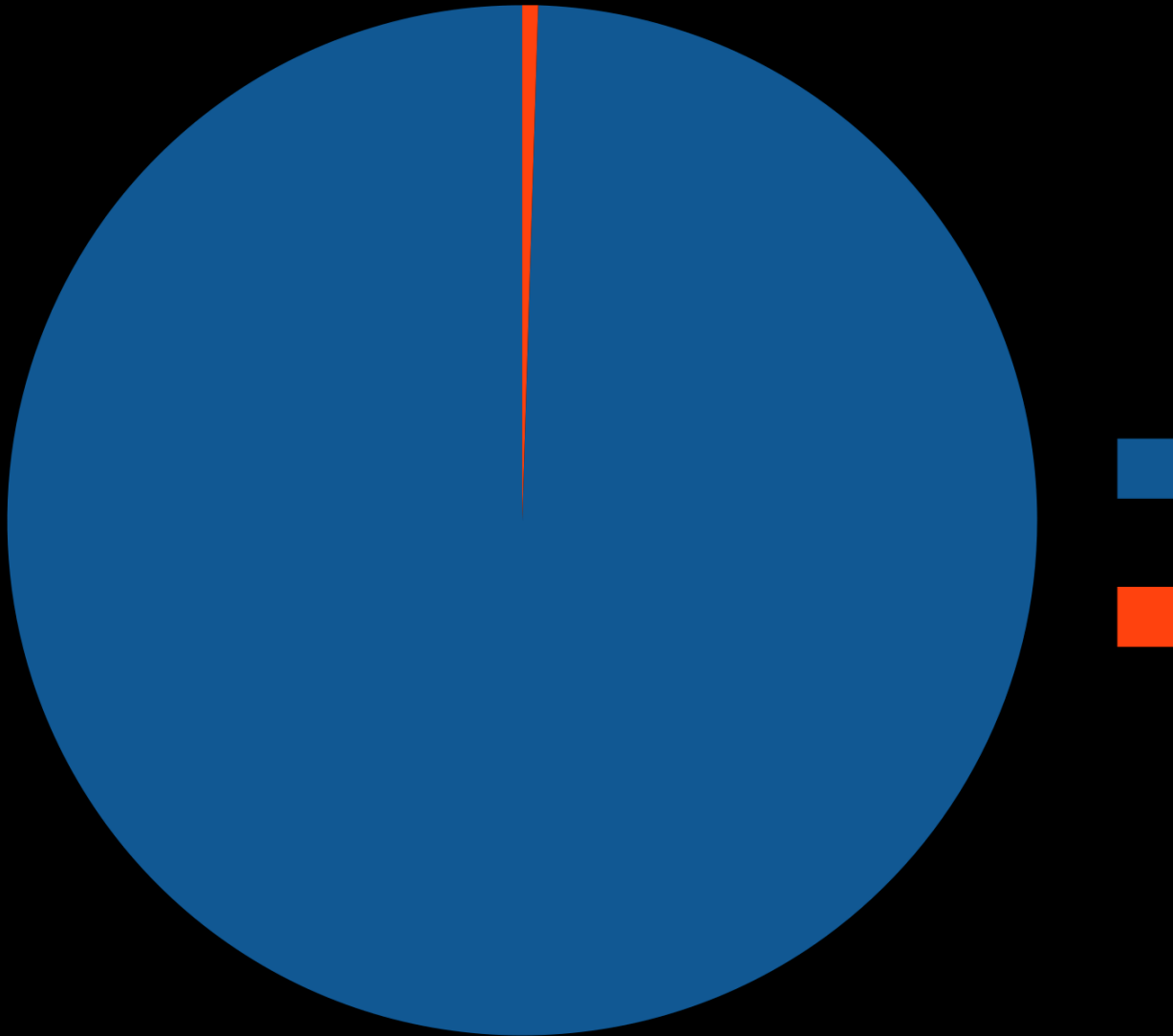
Umbriel: weird ring at the top



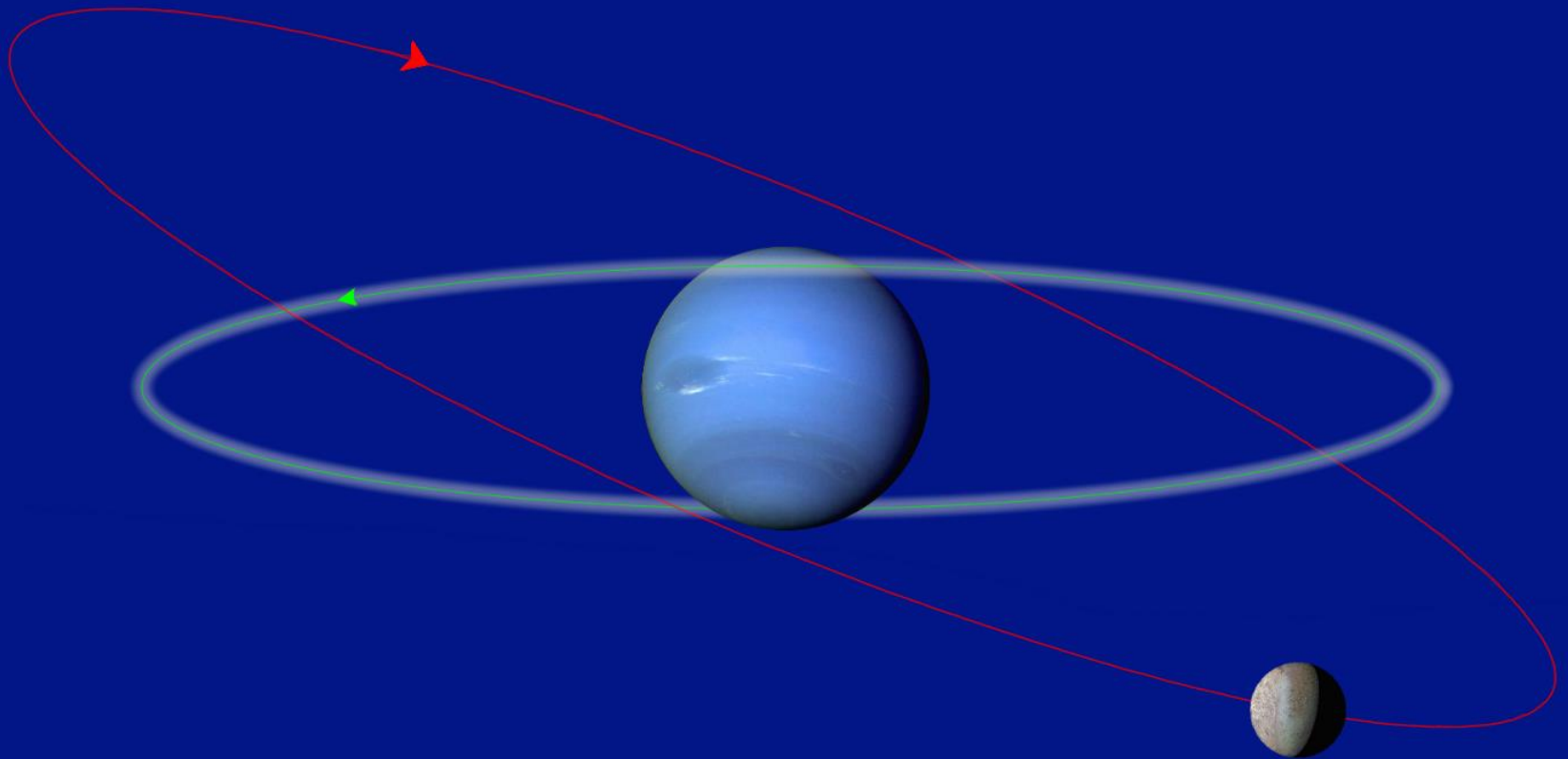


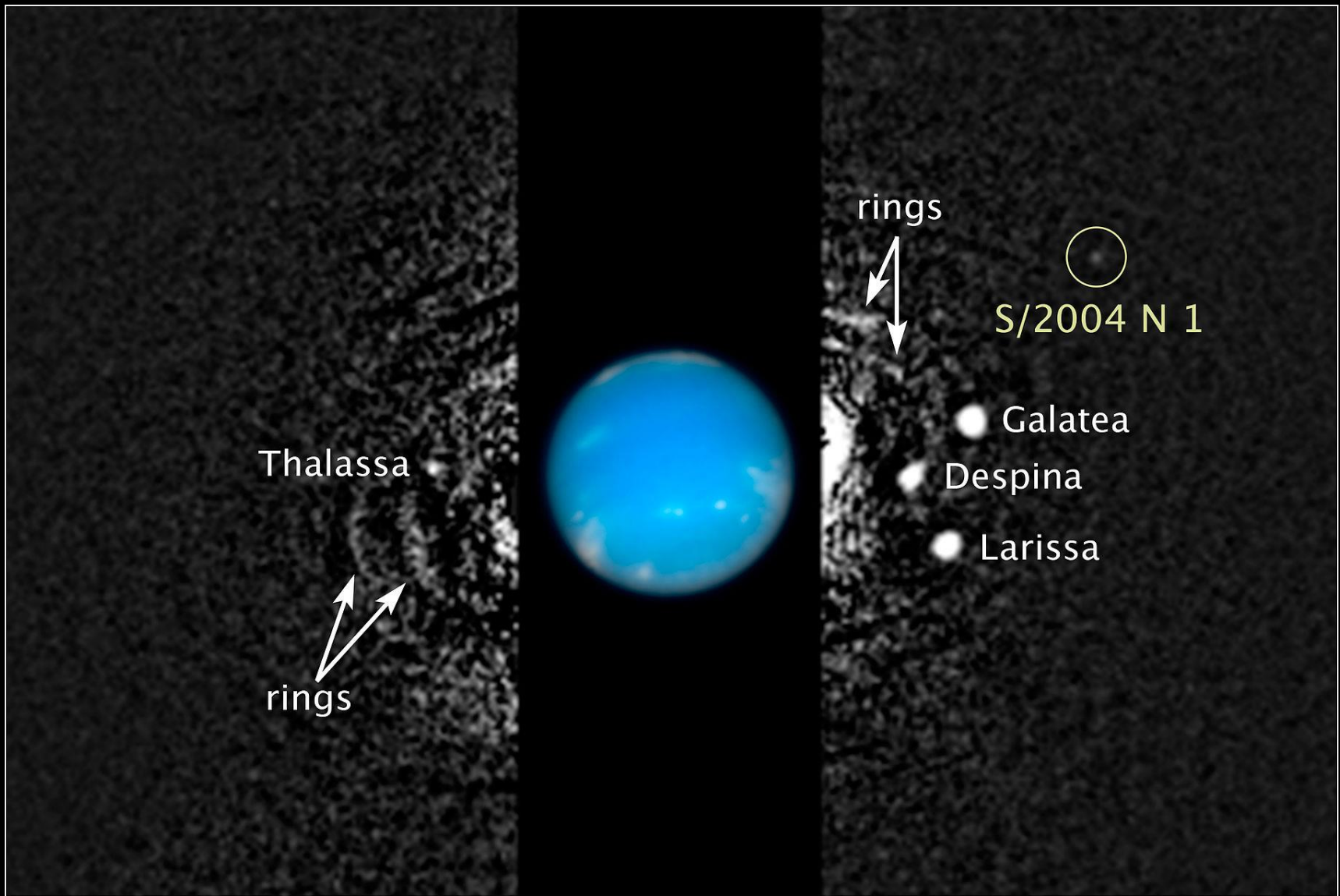
Sycorax:
example of how
the moons are
found

Moons of Neptune



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





Thalassa

rings

rings

S/2004 N 1

Galatea

Despina

Larissa

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

