

Announcements

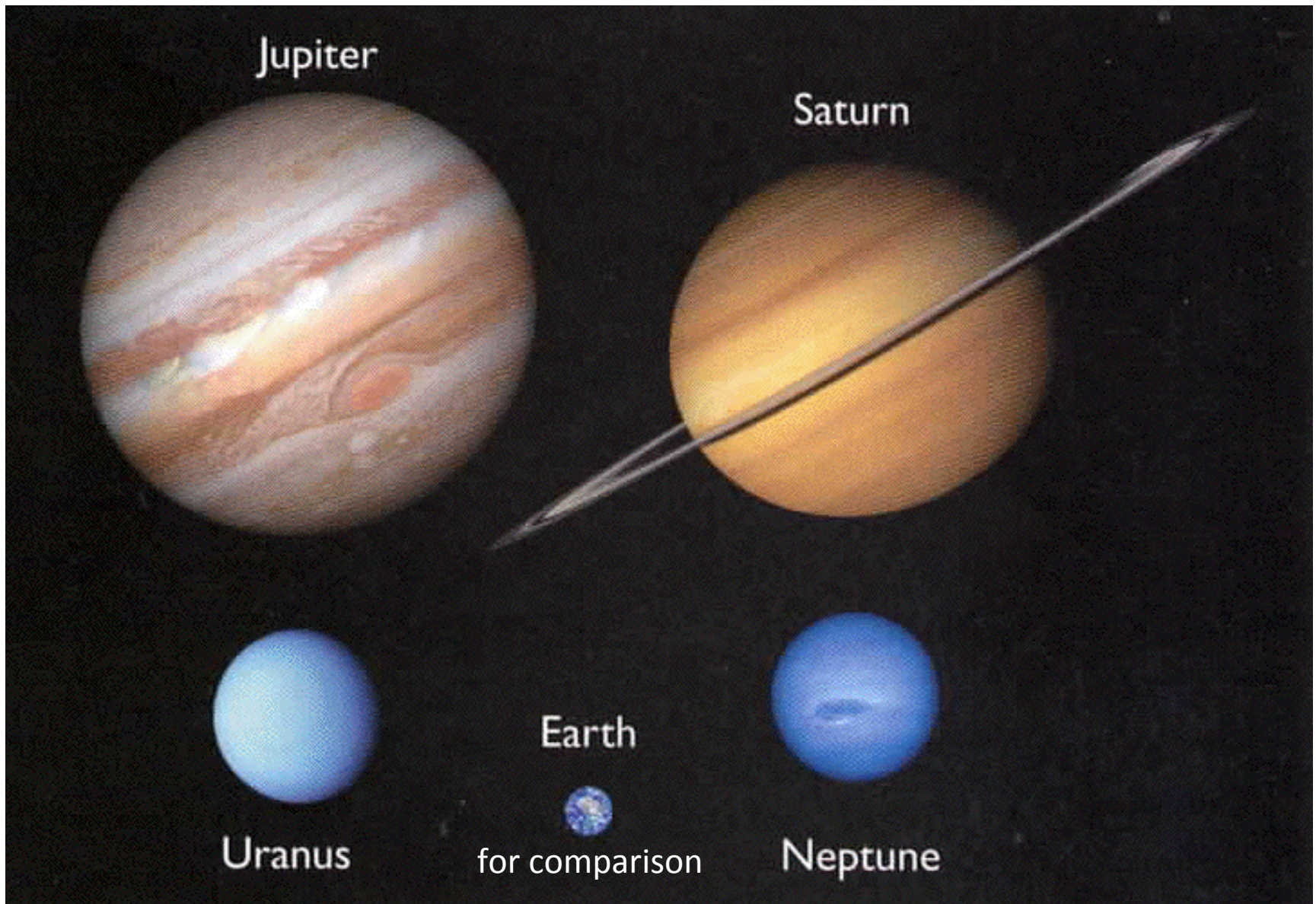
- Scantrons from midterm 2 here if you want them, grades and answers on D2L
- **Quiz 9** on the solar system due Monday
 - **Problem Set 9** for practice
 - Reminder: best 9 problem sets are 10% of final grade, deadline is May 12
 - Unlimited attempts, no cutoff date so you can use them for practice at any time, but don't leave them all to the end!
- Today: Jovian planets (Chapter 7, some Chapter 8)
- Monday: Extra-solar planets (Chapter 4.4)
- Wednesday April 10: Start Chapter 14, the Milky Way galaxy

Astronomy 103

The Jovian planets

Please read chapter 7

- The Jovian planets are Jupiter, Saturn, Uranus and Neptune
- We will begin by looking at the largest, Jupiter



Jupiter

Radius ~ 10 x Earth's

Mass ~ 300 x Earth's

Density $\sim 1300 \text{ kg/m}^3$ –
about same as water

Compose of mainly
hydrogen and helium

No surface

Strong magnetic field

Rapid rotation ~ 10 hrs

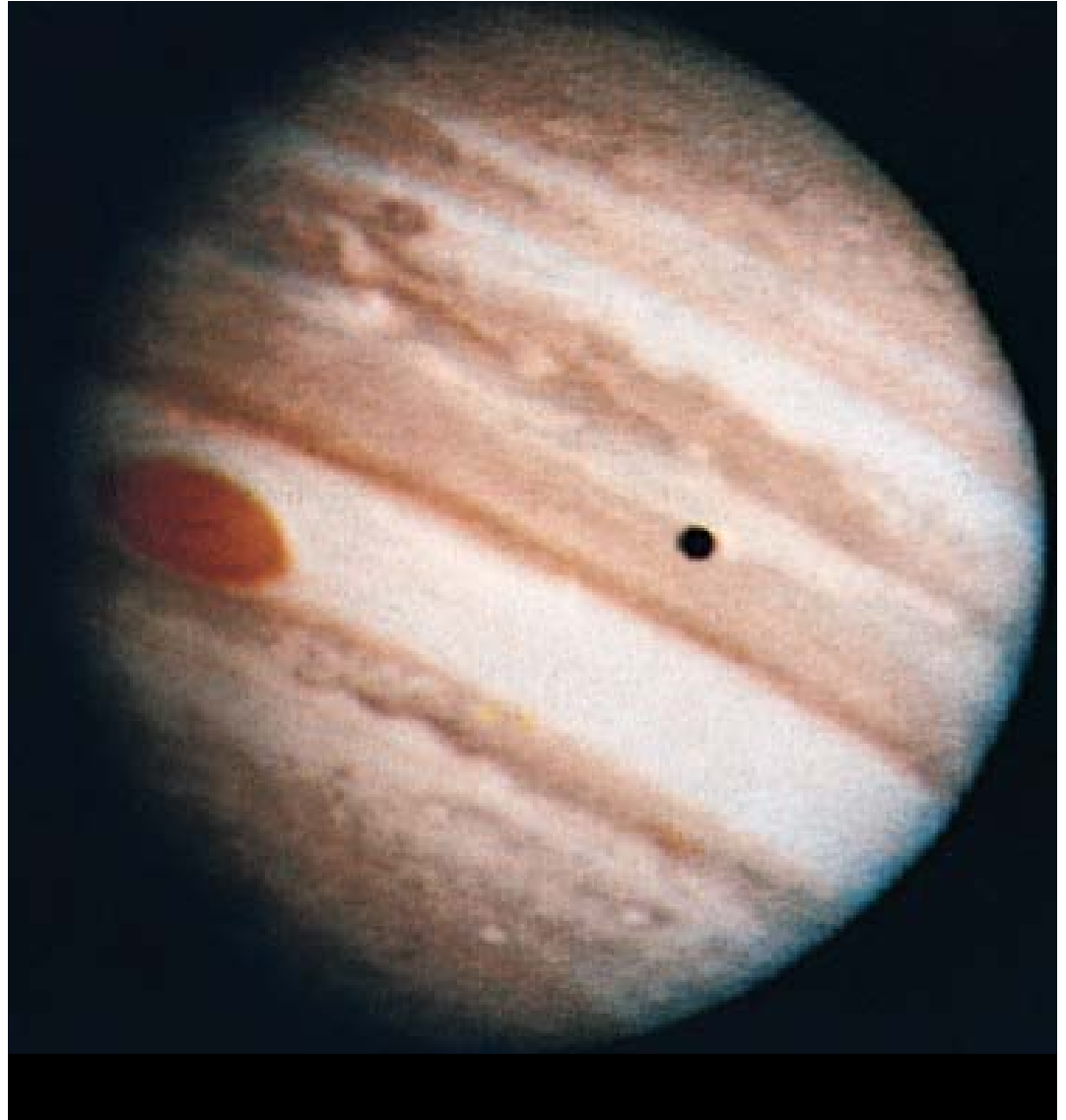


Weather of Jupiter

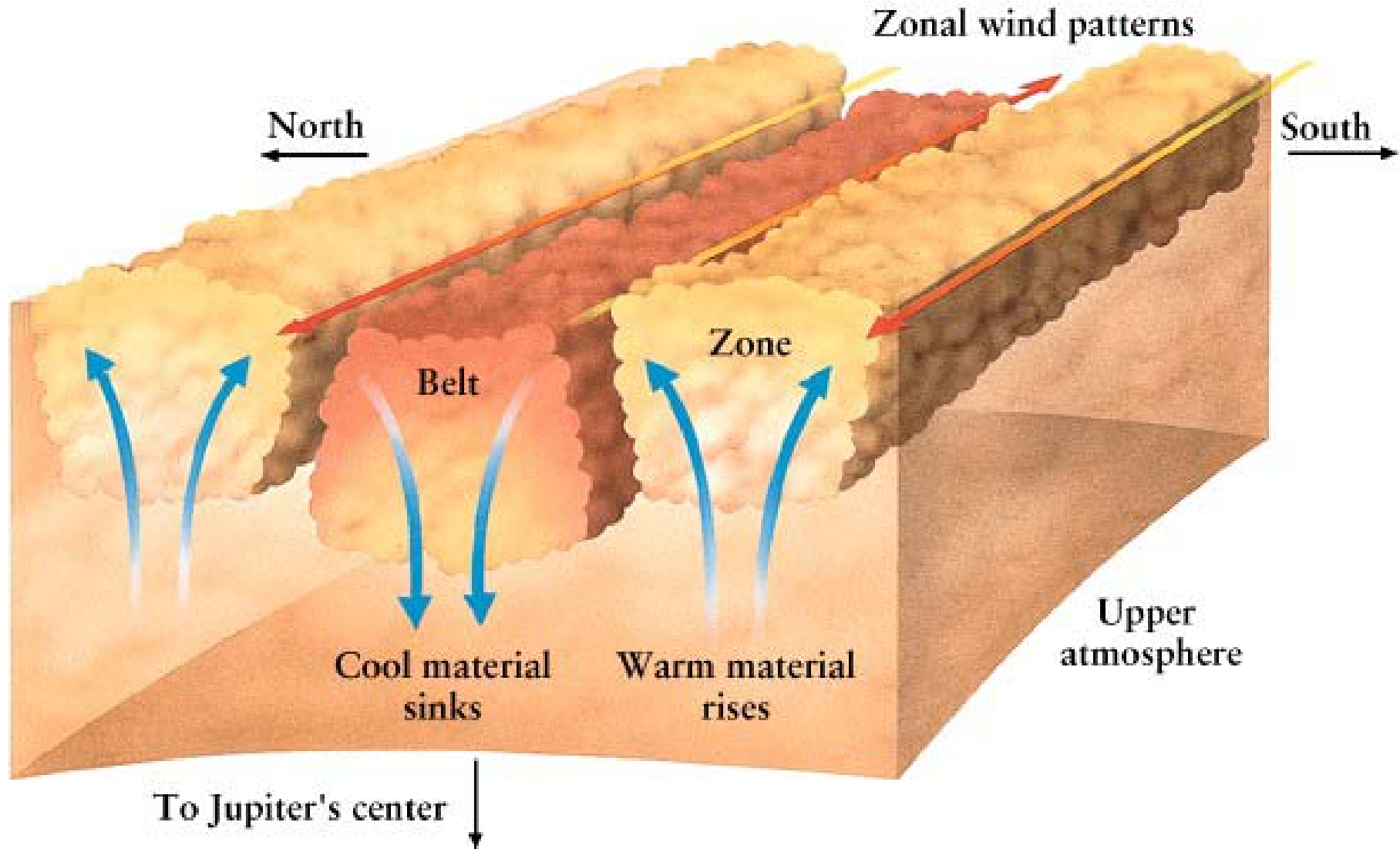
Multicolored bands in atmosphere

Bands are caused by convective cells that are stretched by rotation

Most prominent feature is the Great Red Spot – a hurricane that has persisted for at least 300 years



A convective cell in Jupiter's outer atmosphere



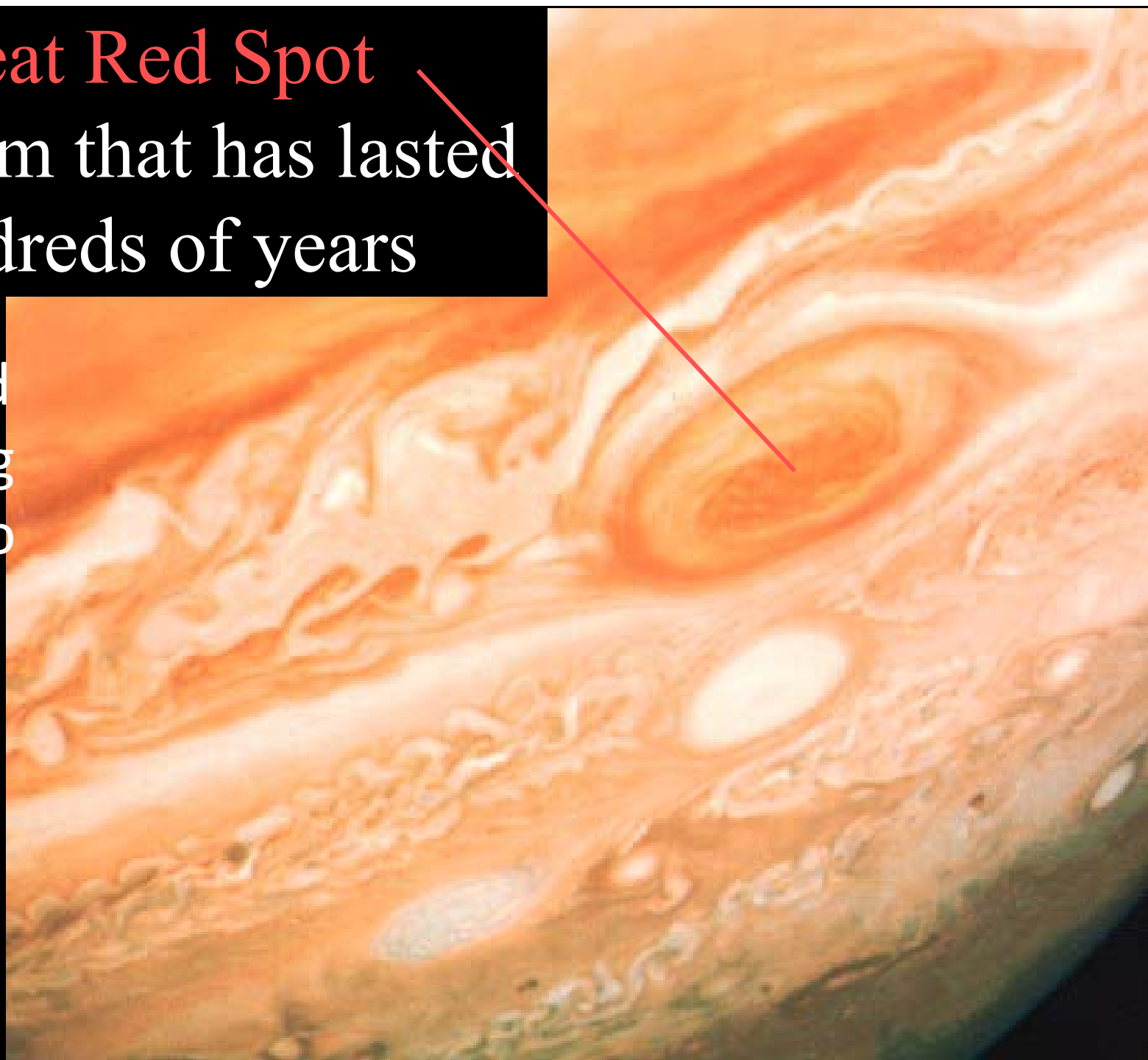
Jupiter's outer atmosphere

- These belts are high and low pressure regions, as we also have on Earth
- However, because of the Jupiter's rapid rotation and thick atmosphere, these belts stretch around the planet rather than being localized

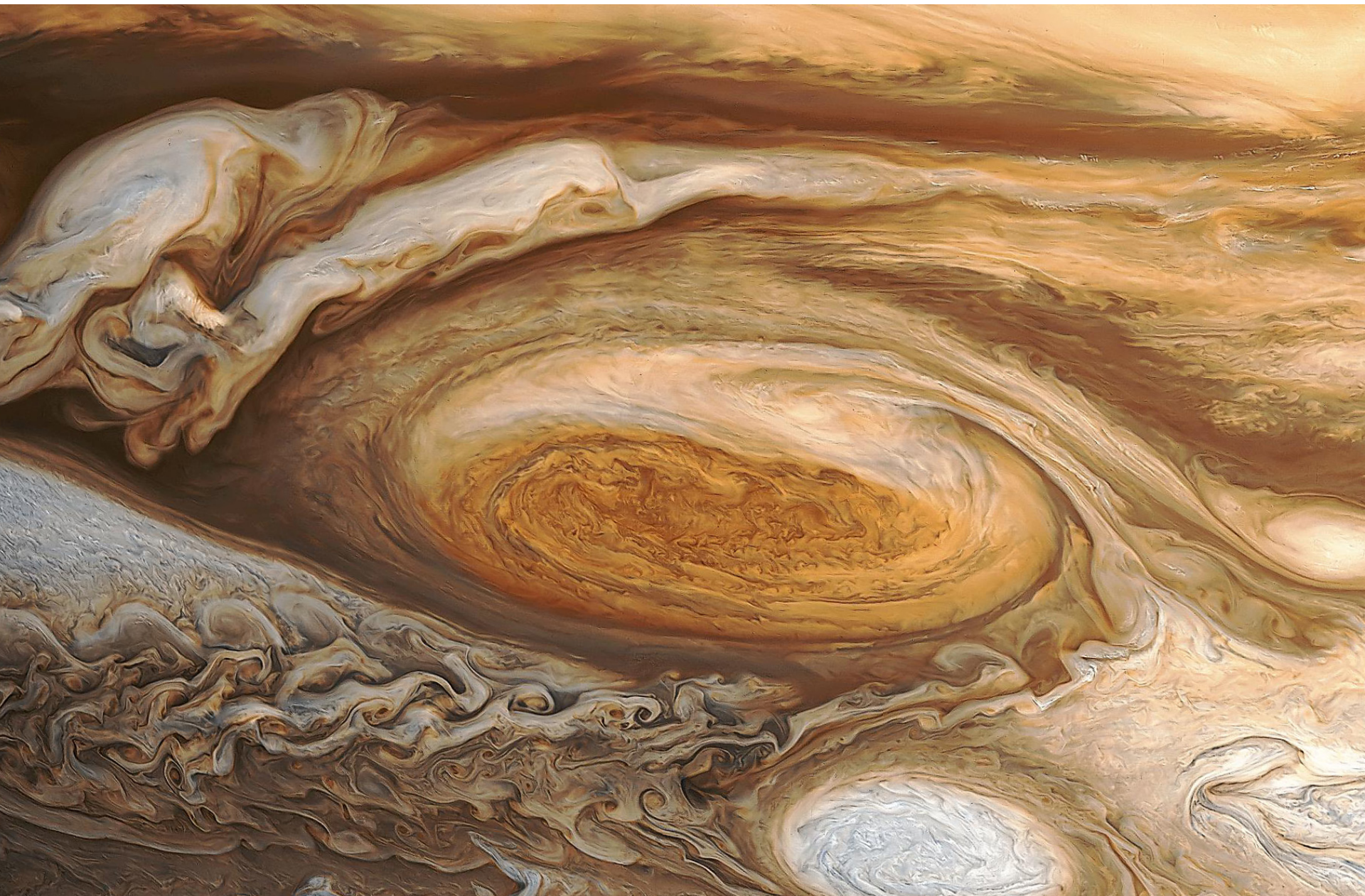


The **Great Red Spot**
is a storm that has lasted
for hundreds of years

Great Red
Spot is big
enough to
fit three
Earths
across its
length



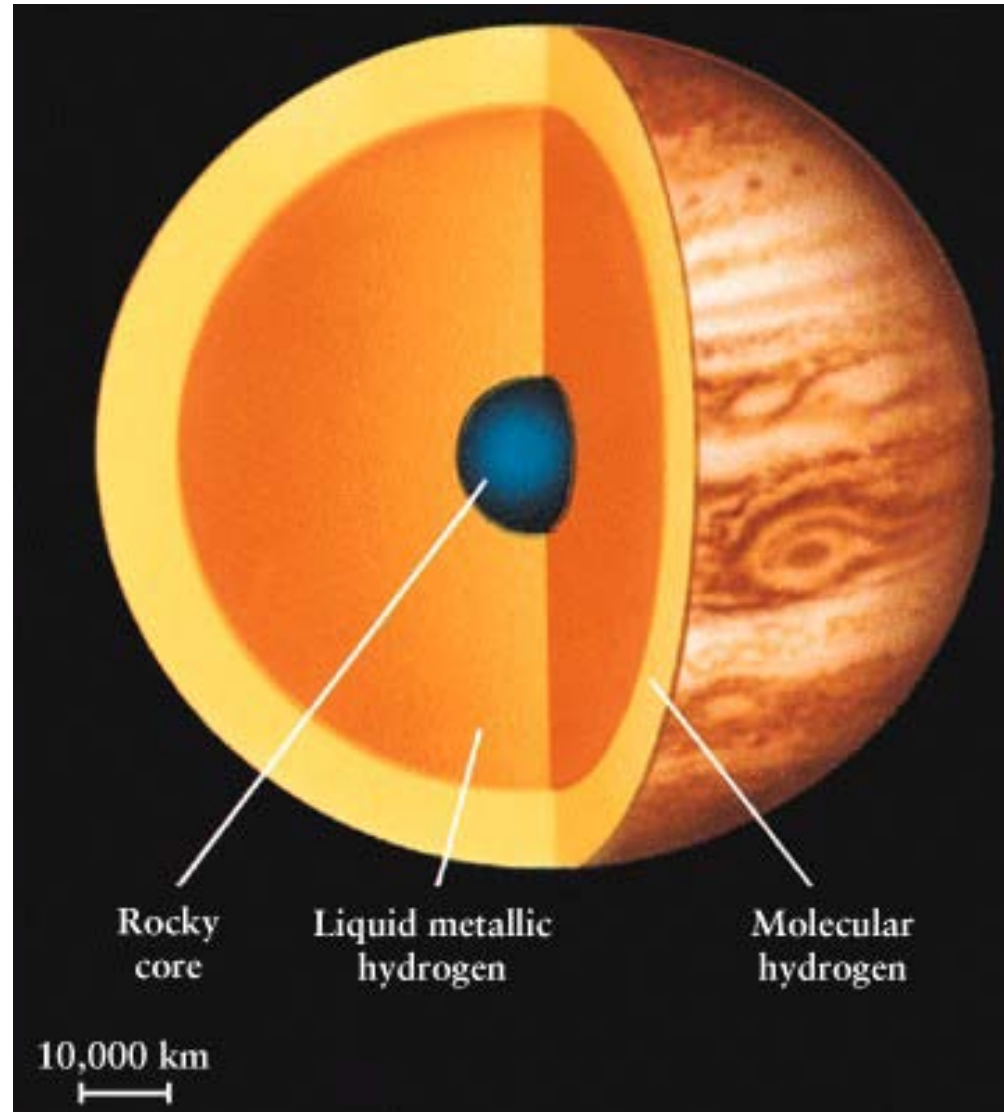
Jupiter's Great Red Spot



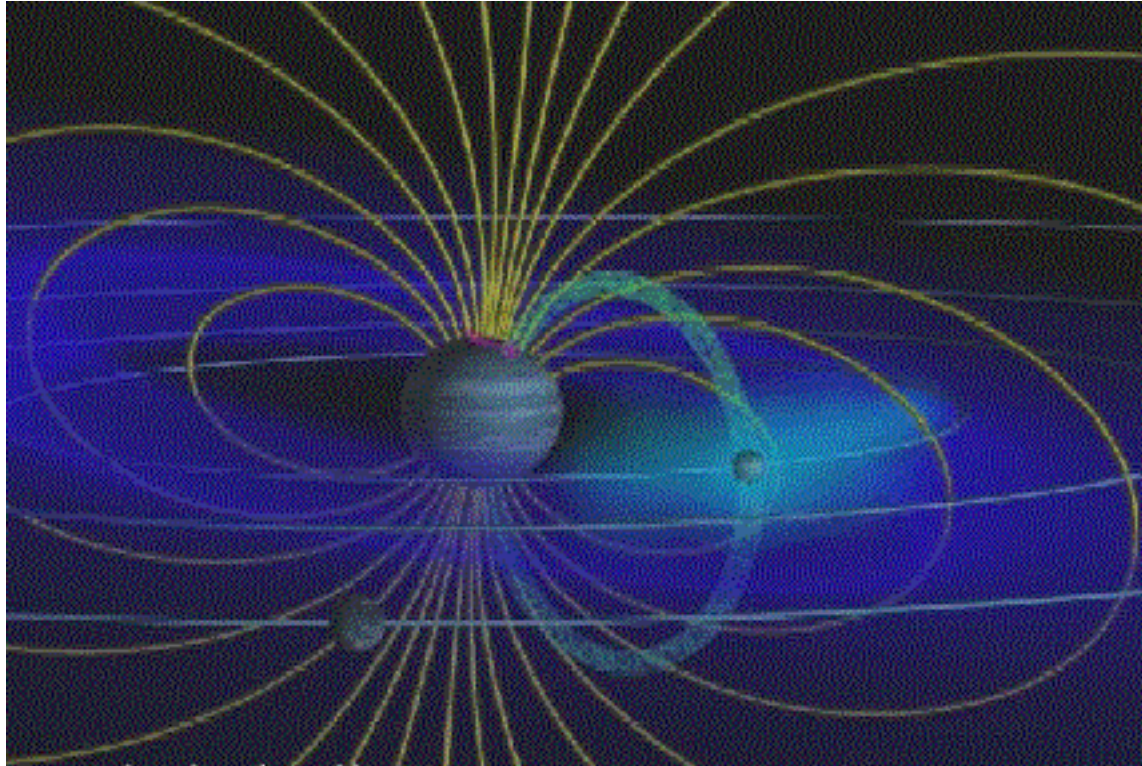


Structure of Jupiter

- Inner core rocky, like Earth
- Mantle is **liquid metallic hydrogen**: under very high pressures, hydrogen becomes liquid and acts like a metal – able to conduct electricity
- Outer mantle is molecular hydrogen
- Atmosphere very convective with large, persistent weather features

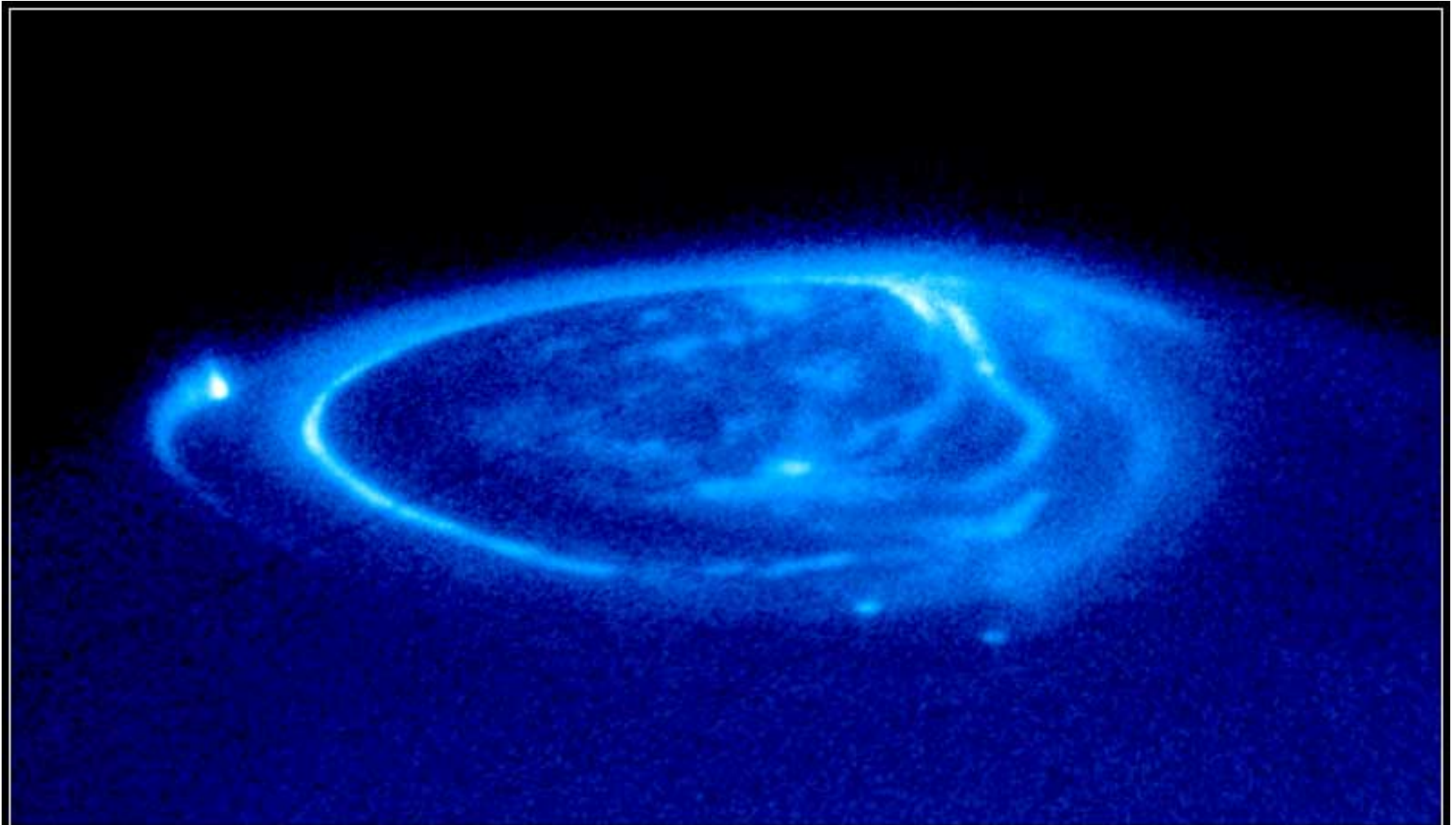


Magnetic field of Jupiter



The rapid rotation, strong convection and conducting metallic hydrogen in Jupiter give it a very strong magnetic field, 20,000 times stronger than that of Earth

Magnetic field of Jupiter



Jupiter Aurora

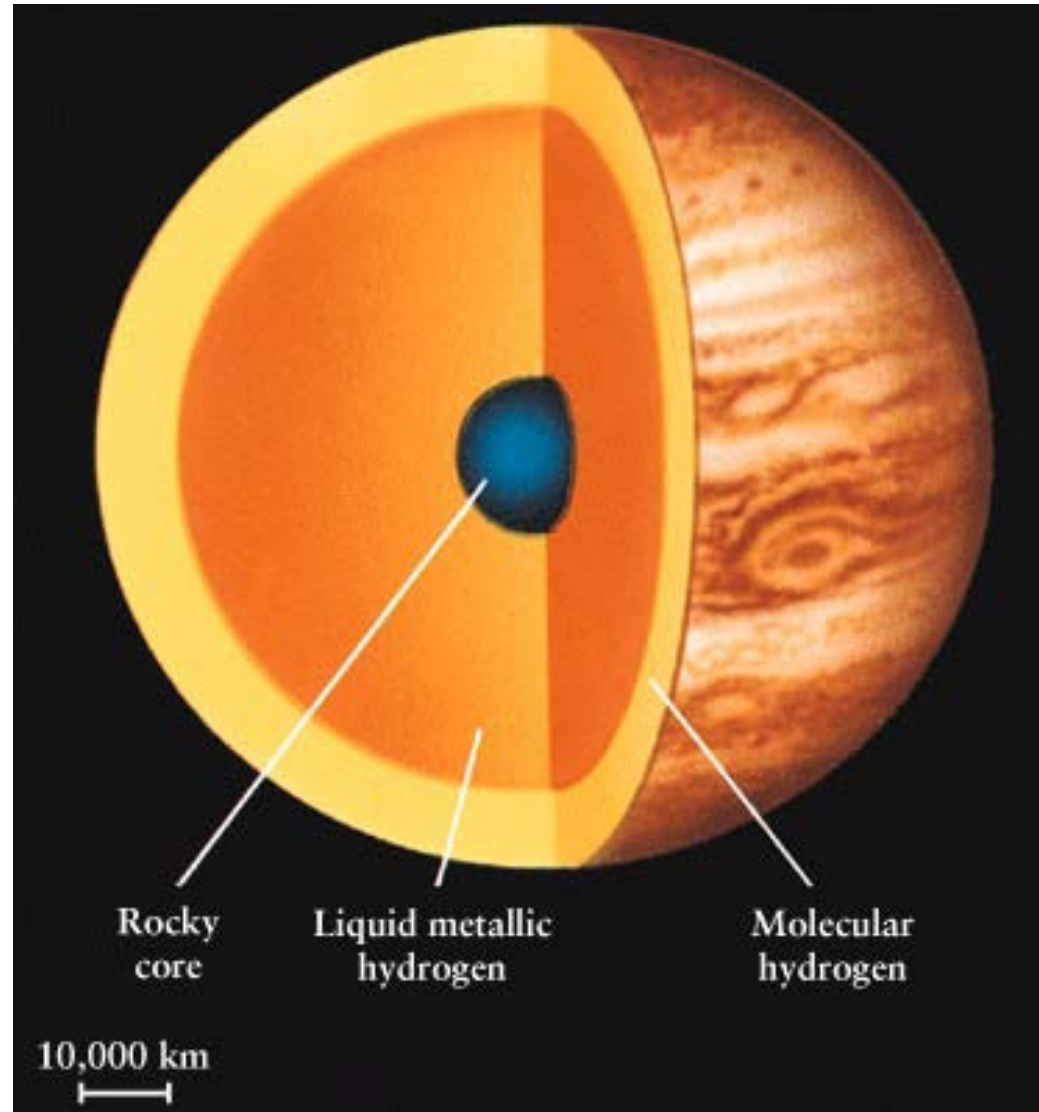
HST • STIS

NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

The interaction with the solar wind produces aurora on Jupiter like the aurora on Earth

Internal Heating

- Jupiter gives off twice as much heat as it receives from the Sun
- This heat is from its formation 4.5 billion years ago – it is still cooling!
- Transport of this heat drives convection in the metallic hydrogen mantle – produces strong magnetic field



Moons of Jupiter

Jupiter has at least 67 moons!

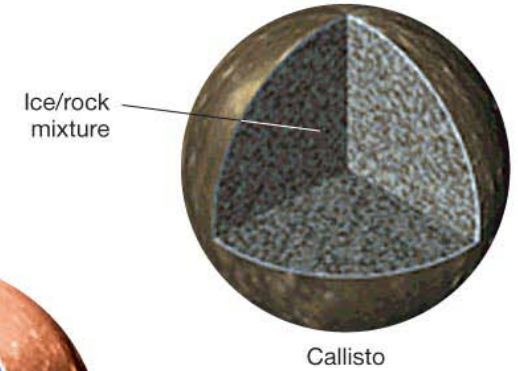
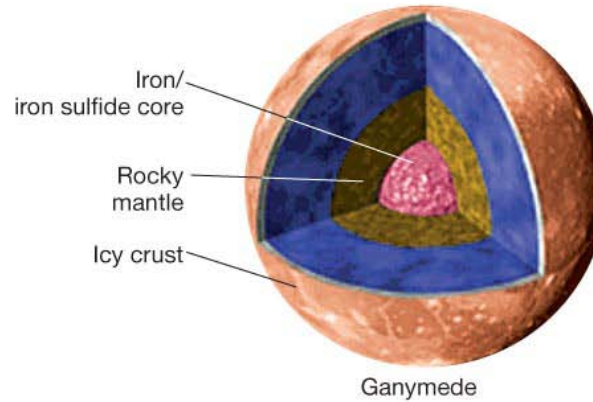
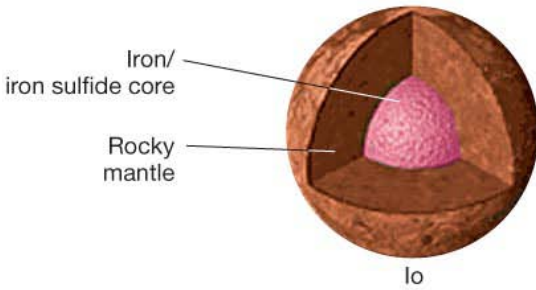
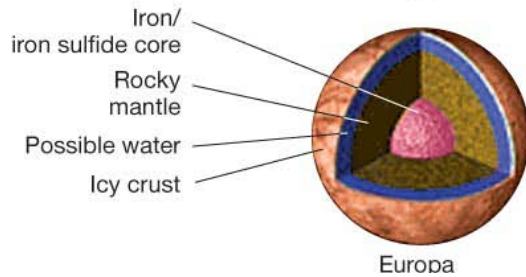
The 4 largest are the ones first observed by Galileo – they are called the Galilean satellites.

They are from closest to farthest from Jupiter:
Io, Europa, Ganymede, and Callisto

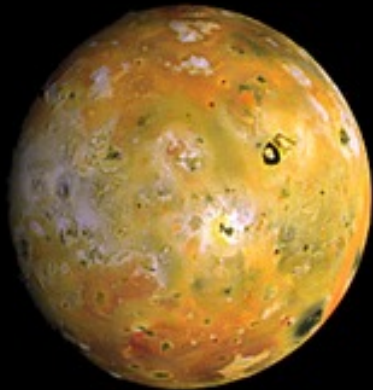


Moons of Jupiter

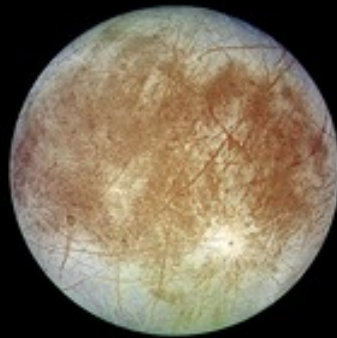
Density decreases with increasing distance from Jupiter



Io



Europa



Ganymede

Callisto

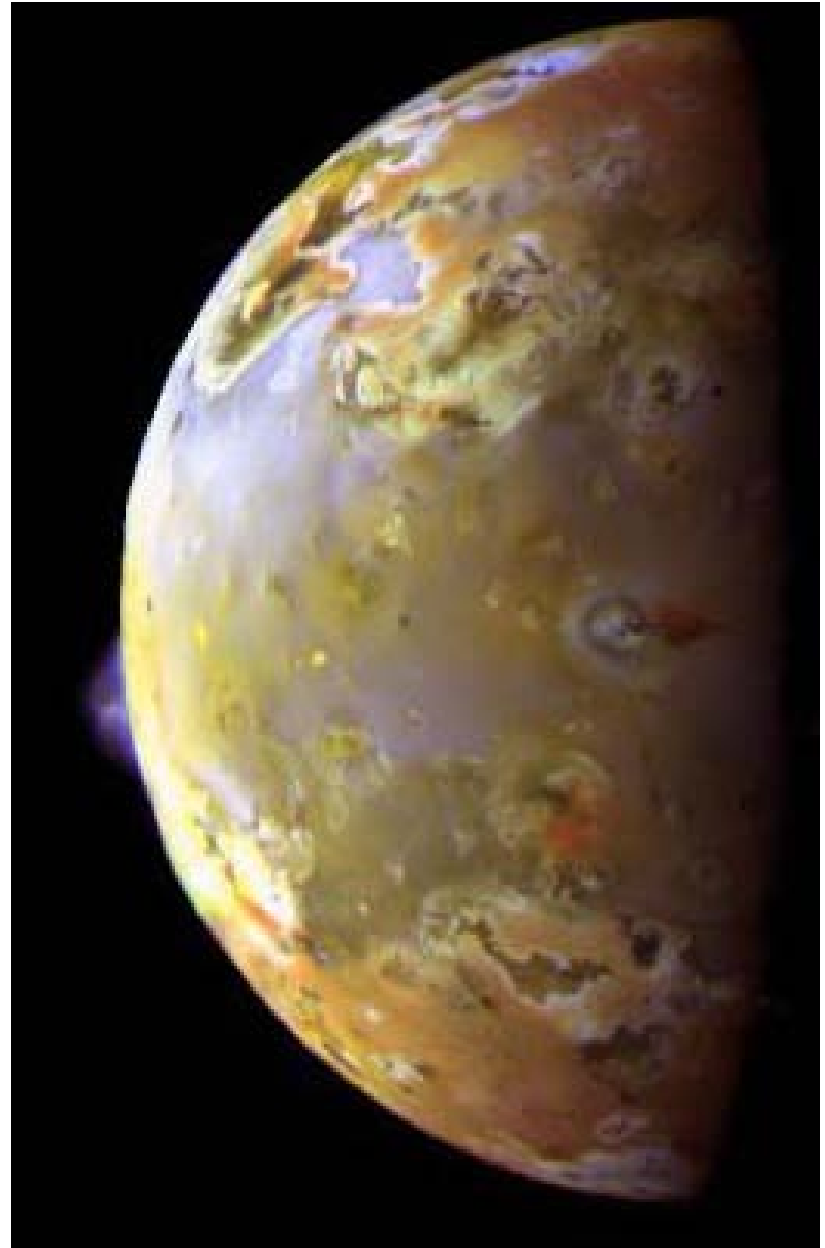


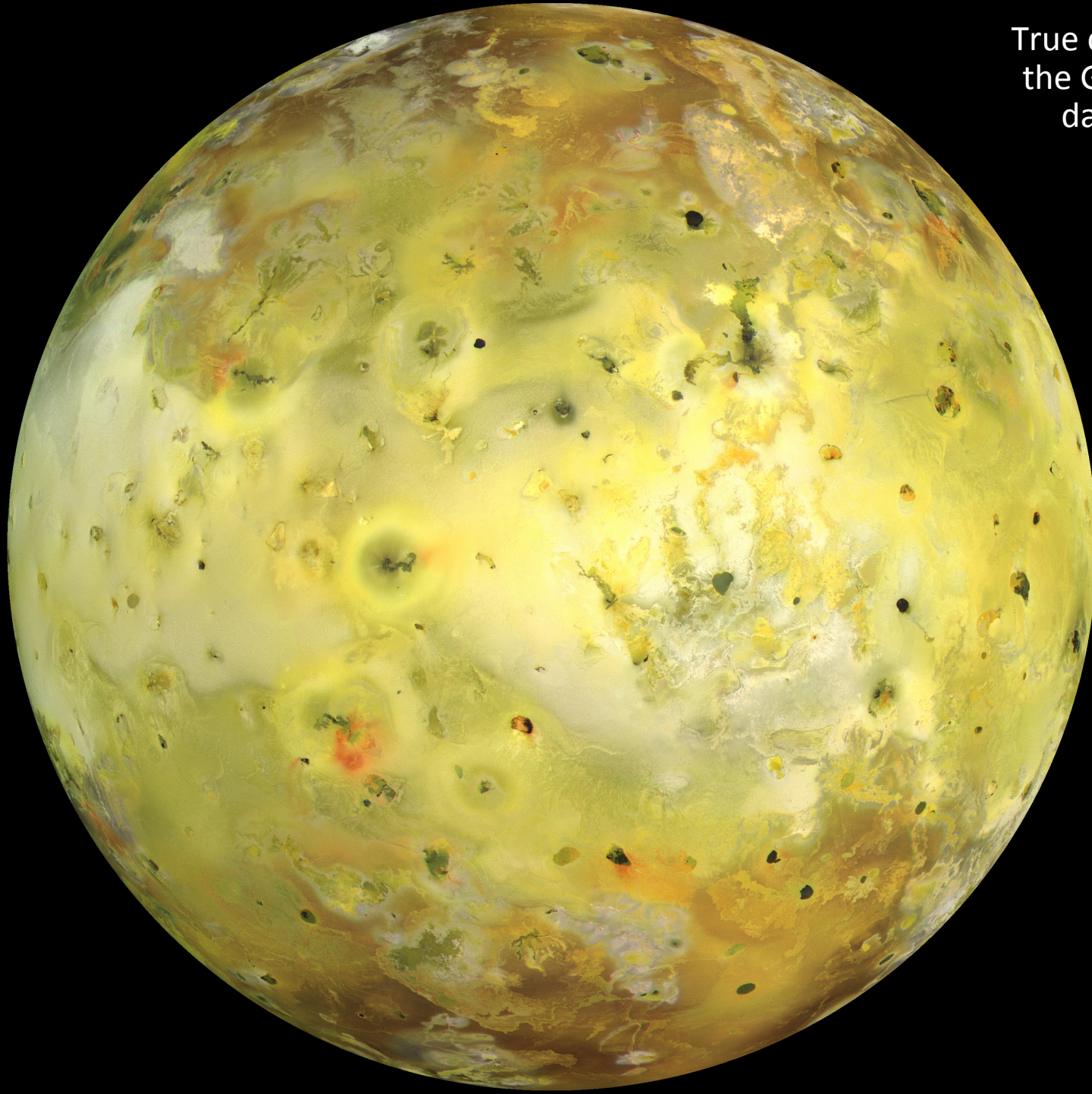
Io

Io is the closest of Jupiter's large moons and is the most volcanically active body in the solar system.

The volcanoes are powered by **tides** between Europa and Jupiter that trap Io in a tug-of-war. The heating melts the interior and drives the vulcanism.

Io's surface is very new – no craters!

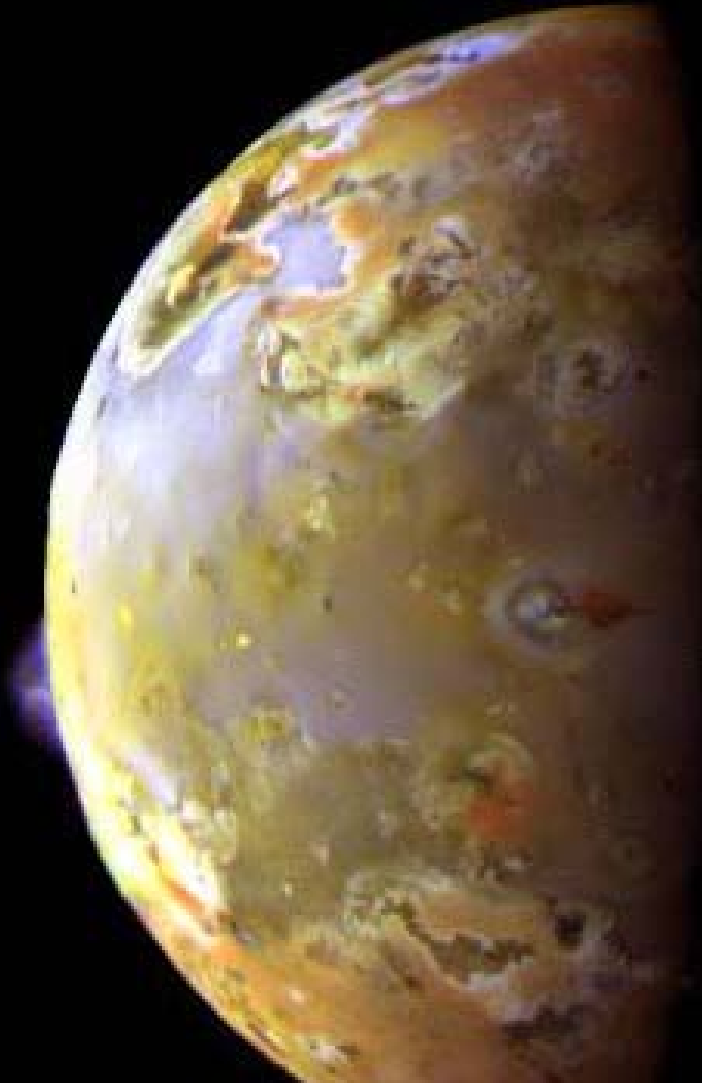




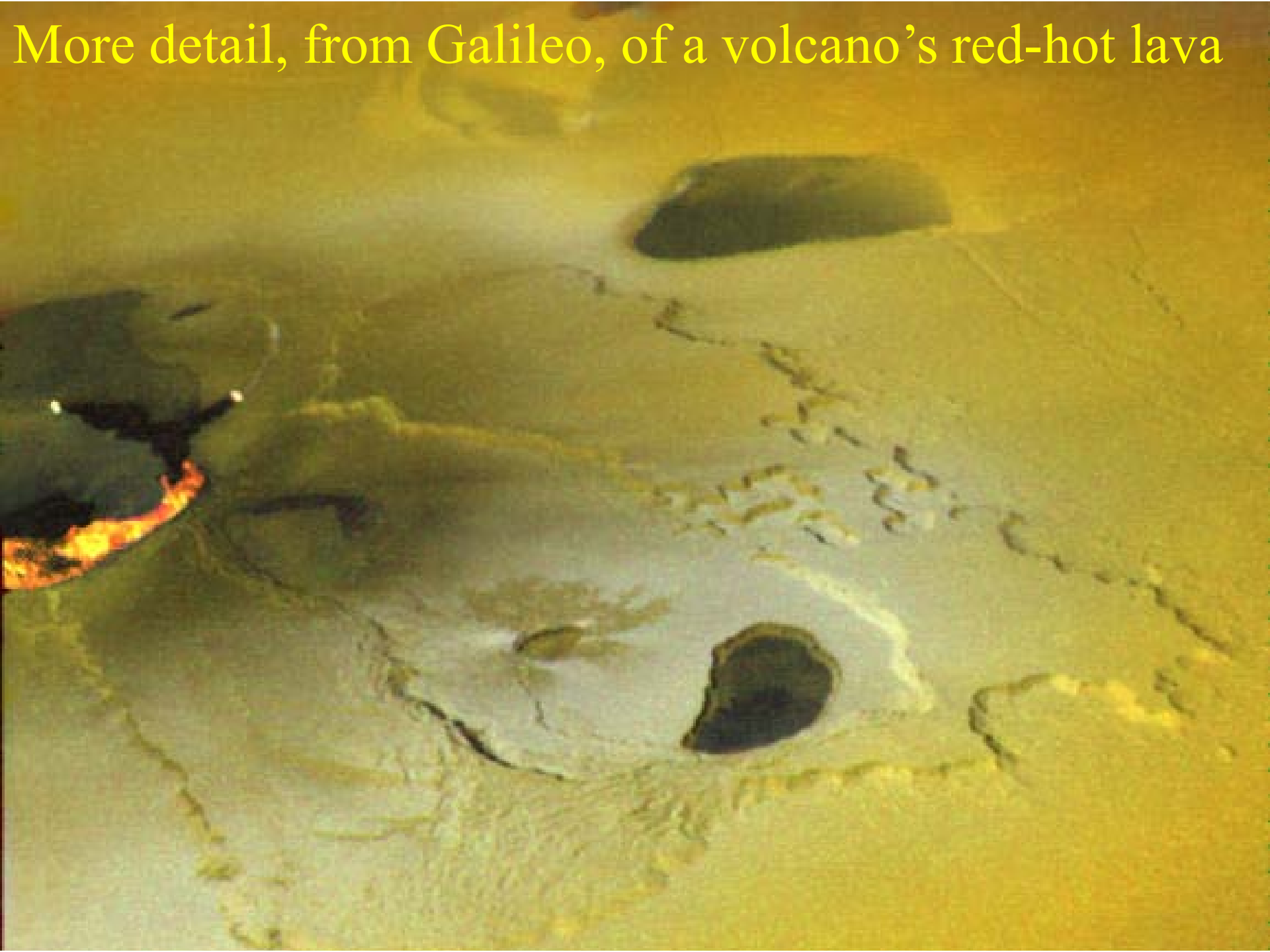
True color image of Io from the Galileo spacecraft. The dark spot just left of the center is the erupting volcano Prometheus.

The whitish plains on either side of it are coated with volcanically deposited sulfur dioxide frost, whereas the yellower regions contain a higher proportion of sulfur.

Closeups of two volcanos spewing plumes of sulfur and oozing molten rock.



More detail, from Galileo, of a volcano's red-hot lava



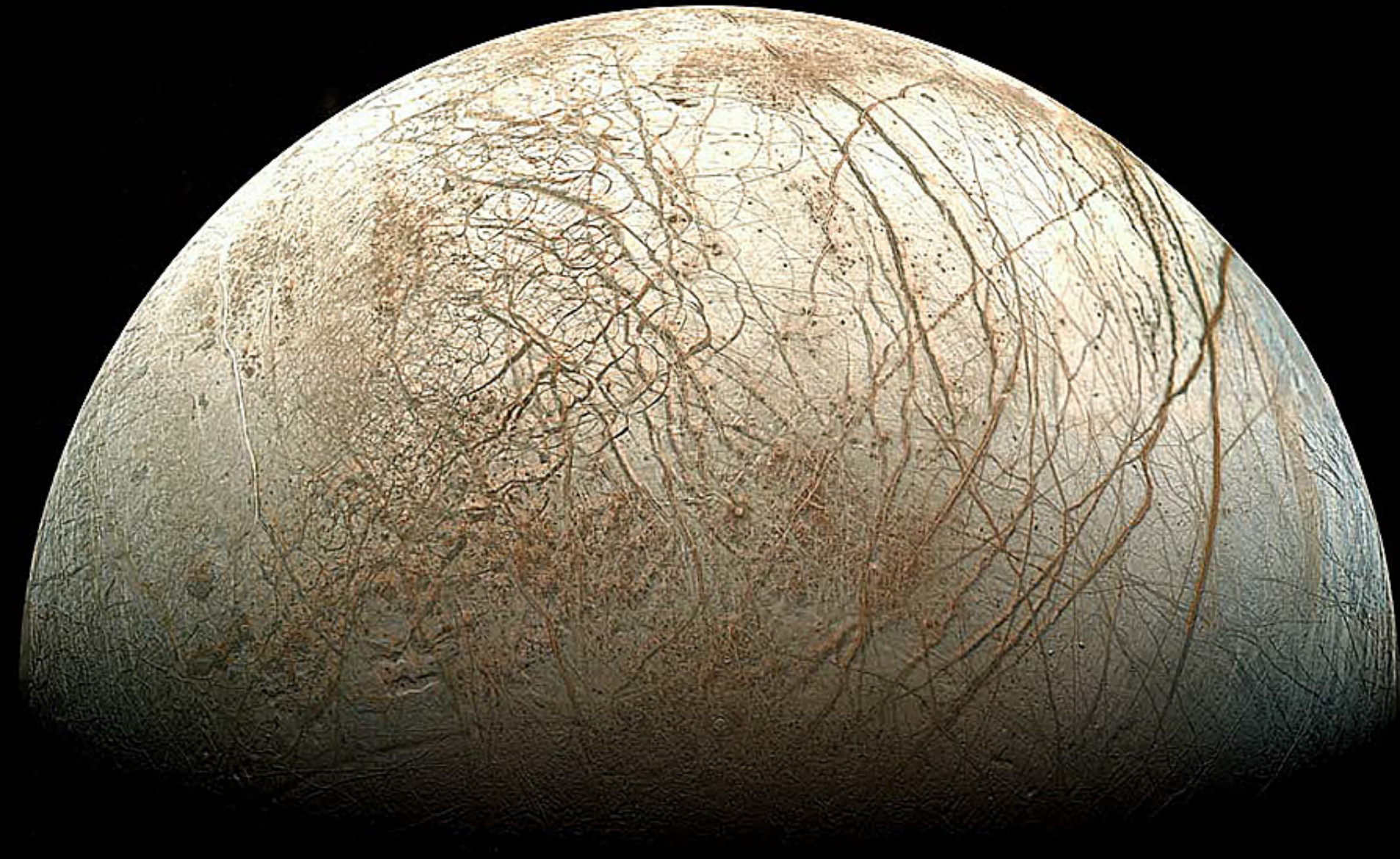
Europa

Europa is the next closest moon.

It has an icy surface with large cracks and no craters! This means that craters are filled in somehow.

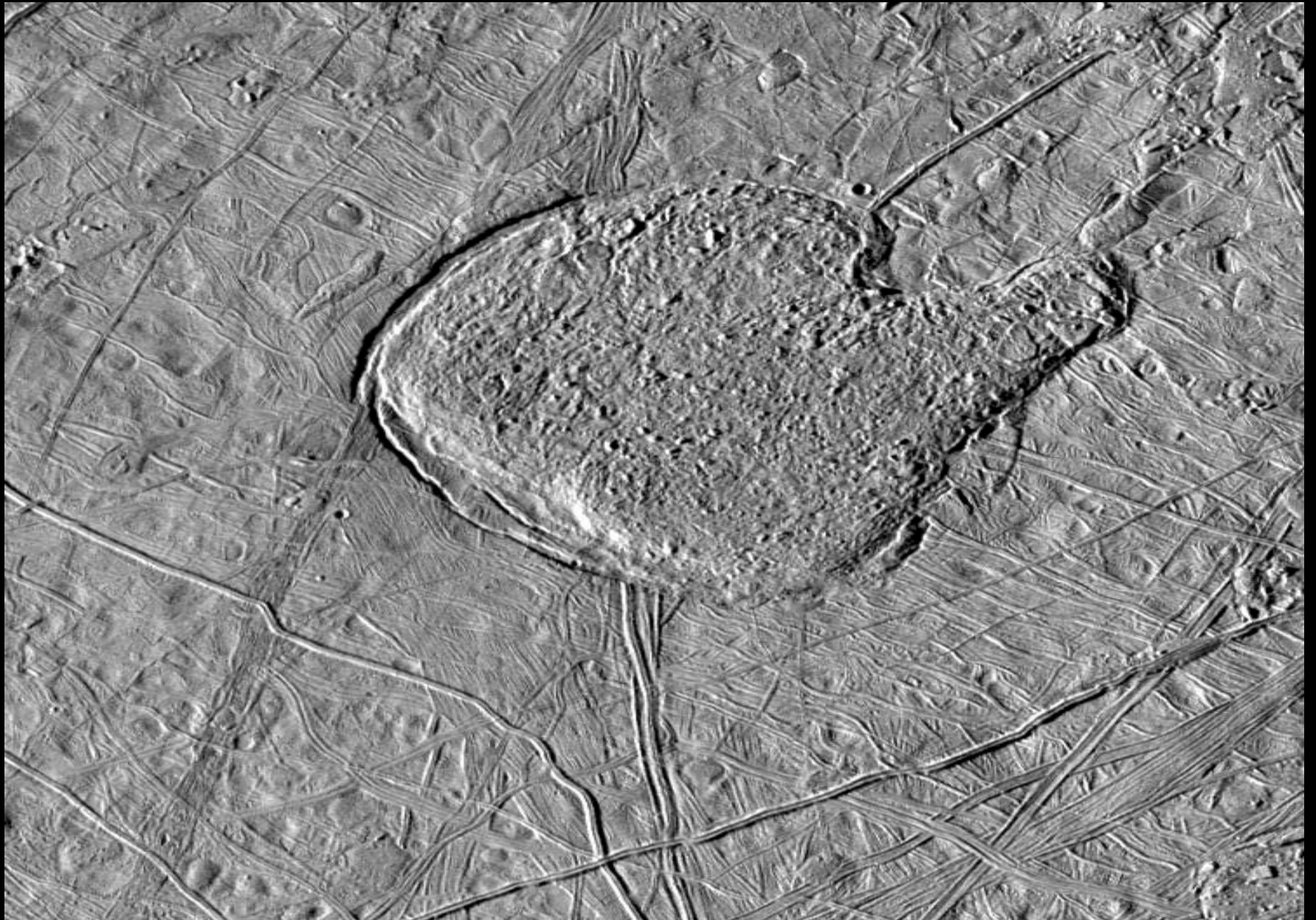
This suggests liquid (probably water) under the icy surface.

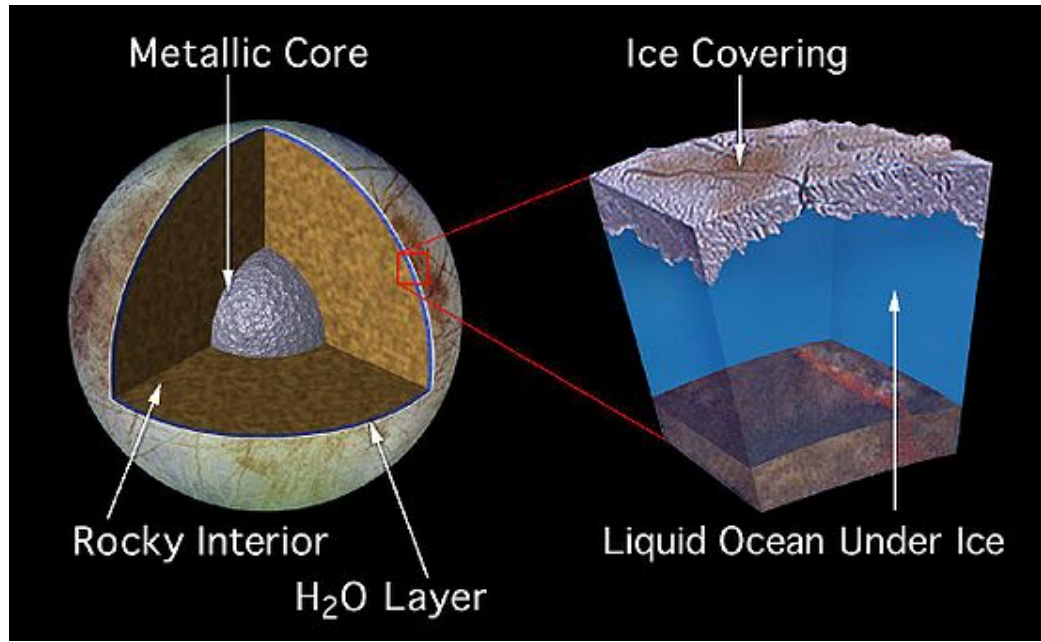




Europa in the gibbous phase, from the Galileo spacecraft. Europa has plains of bright ice, cracks that run to the horizon, and dark patches that likely contain both ice and dirt. Its surface is smooth, with few impact craters.

Closeups of Europa's Surface

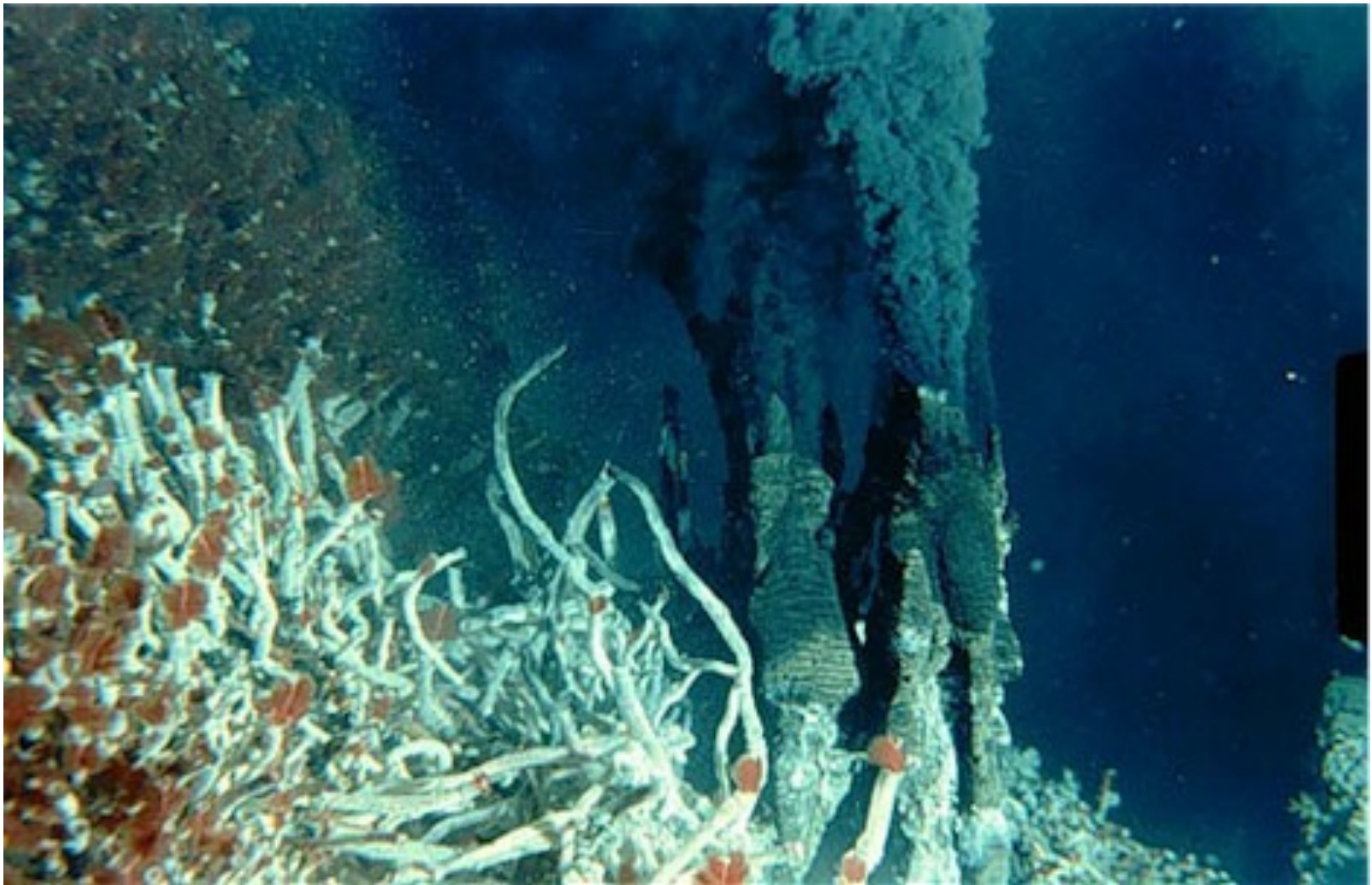




A model for the interior structure of Europa.

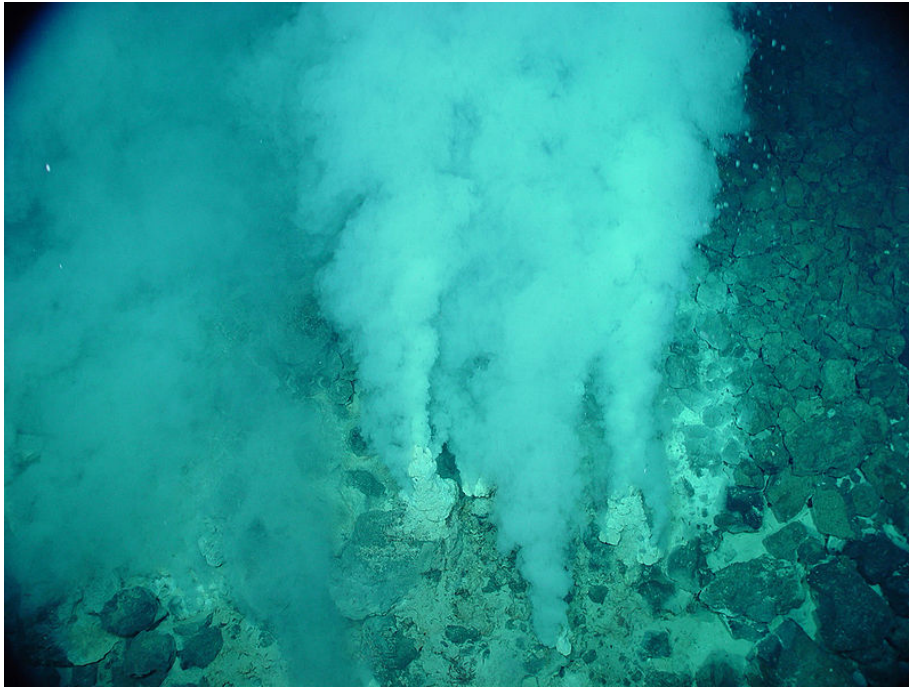
For there to be an ocean under the surface, there must be some heat source – probably tides from Jupiter.

Could Europa harbor life like that on the ocean's floor on Earth?

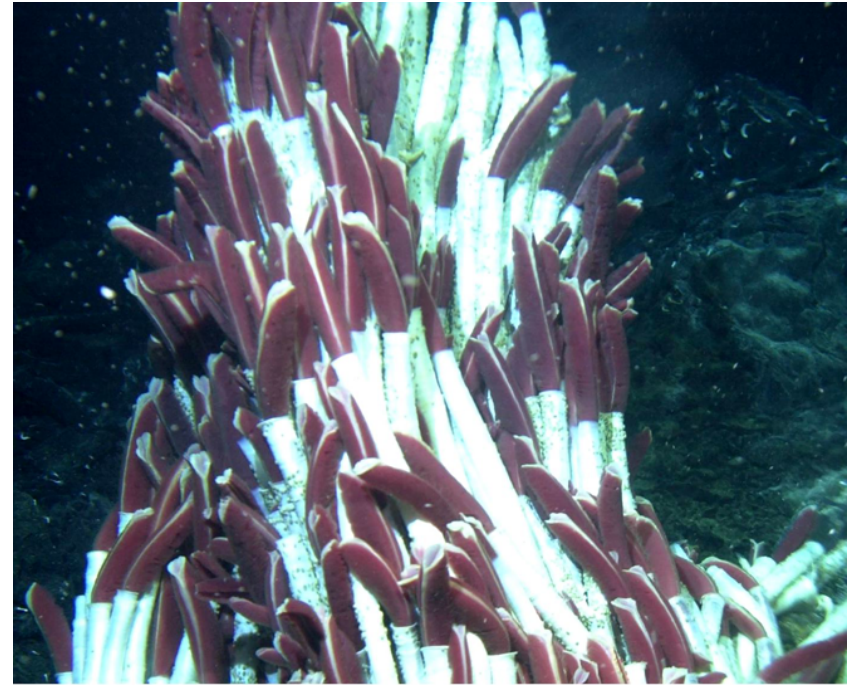


Because Europa's under-ice ocean must be heated, there is a possibility that life may exist on Europa like it exists in the undersea hydrothermal vents on Earth.

Hydrothermal vents and chemosynthesis



Hydrothermal vent



Giant tube worms live by chemosynthesis

- Hydrothermal vents on the ocean floor emit hot water and minerals, with temperatures from 60 – 460 °C
- Chemosynthetic organisms live in hydrothermal vents, living only on inorganic matter: chemosynthesis
- Does this also happen in the oceans of Europa?

Saturn

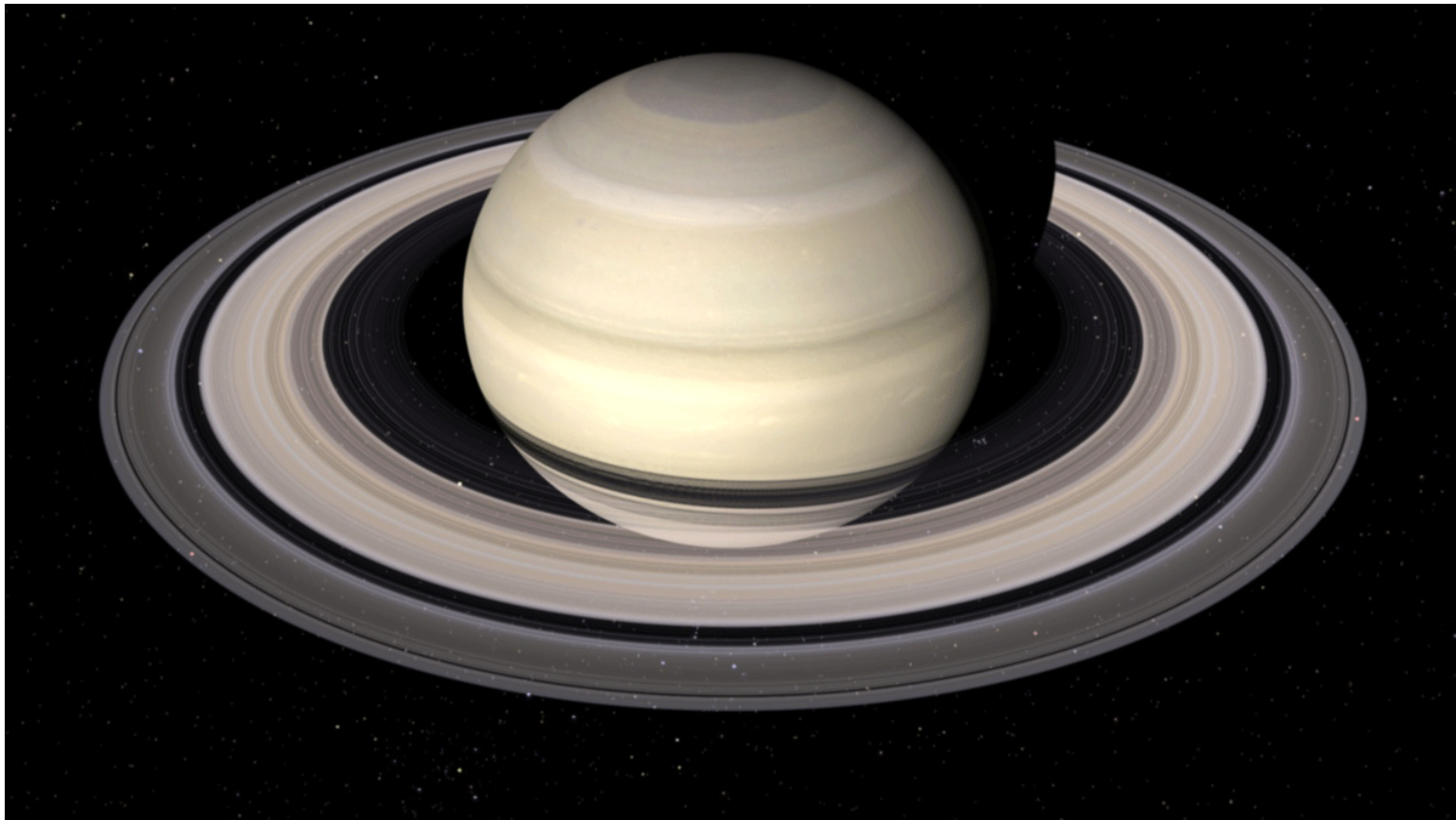
Radius \sim 10 times Earth, mass \sim 100 times Earth

Density \sim 700 kg/m³ – less than water, Saturn would float!

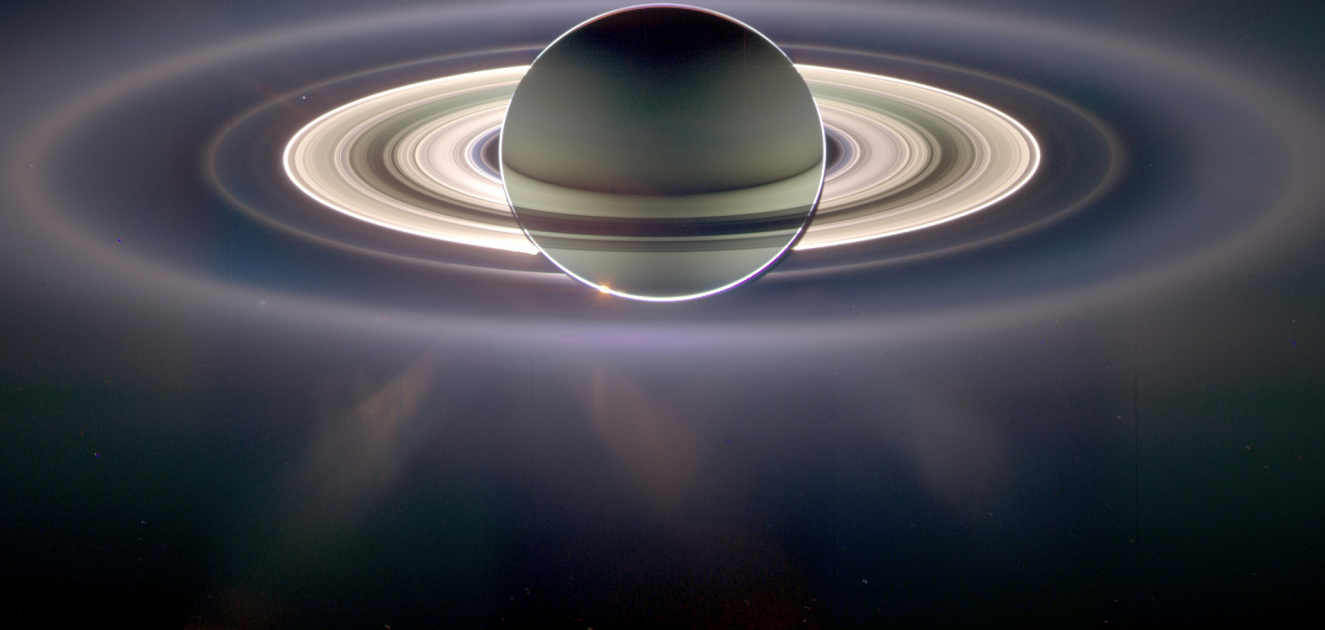
Composed of mainly hydrogen and helium

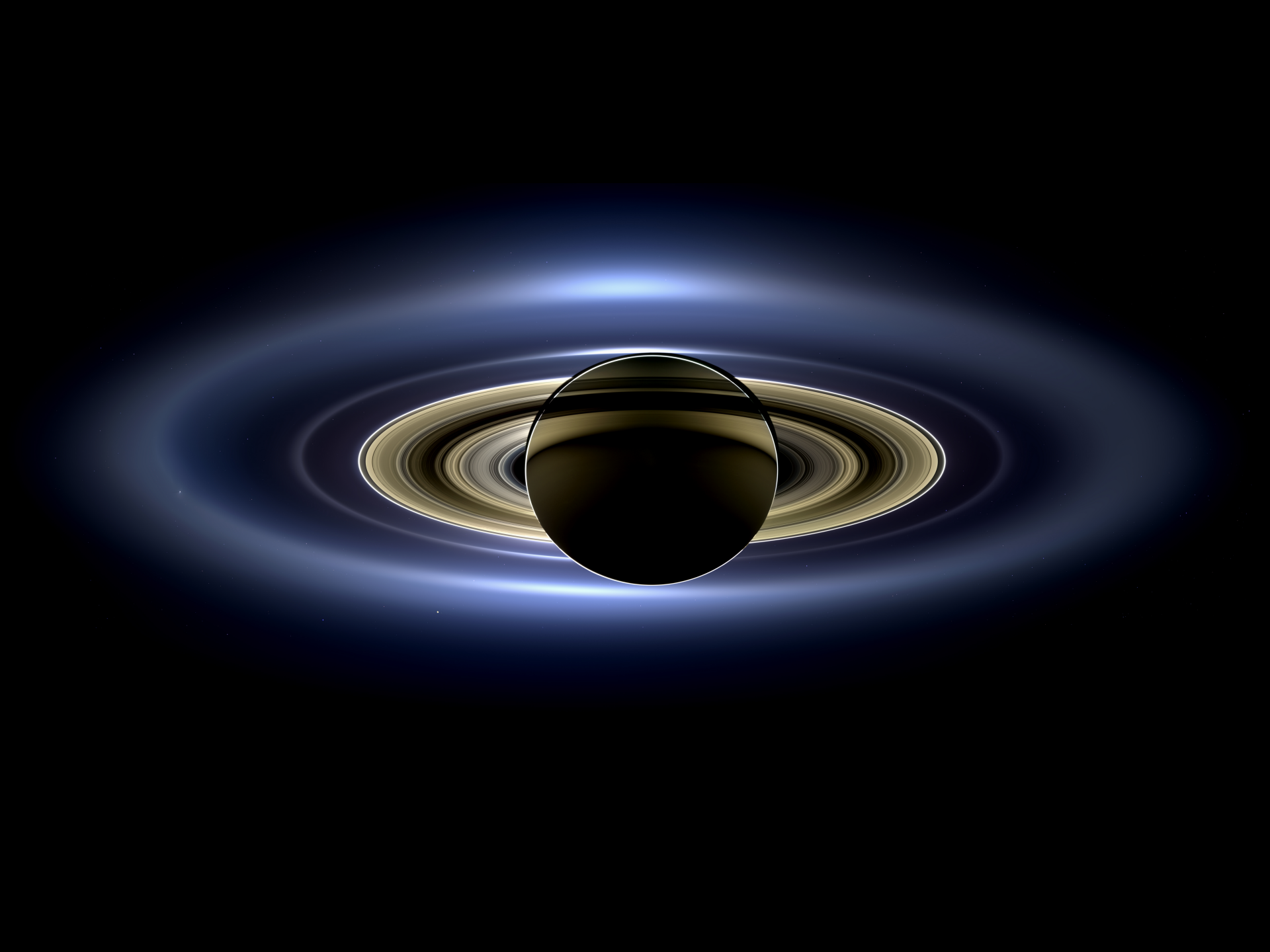
No surface

Strong magnetic field

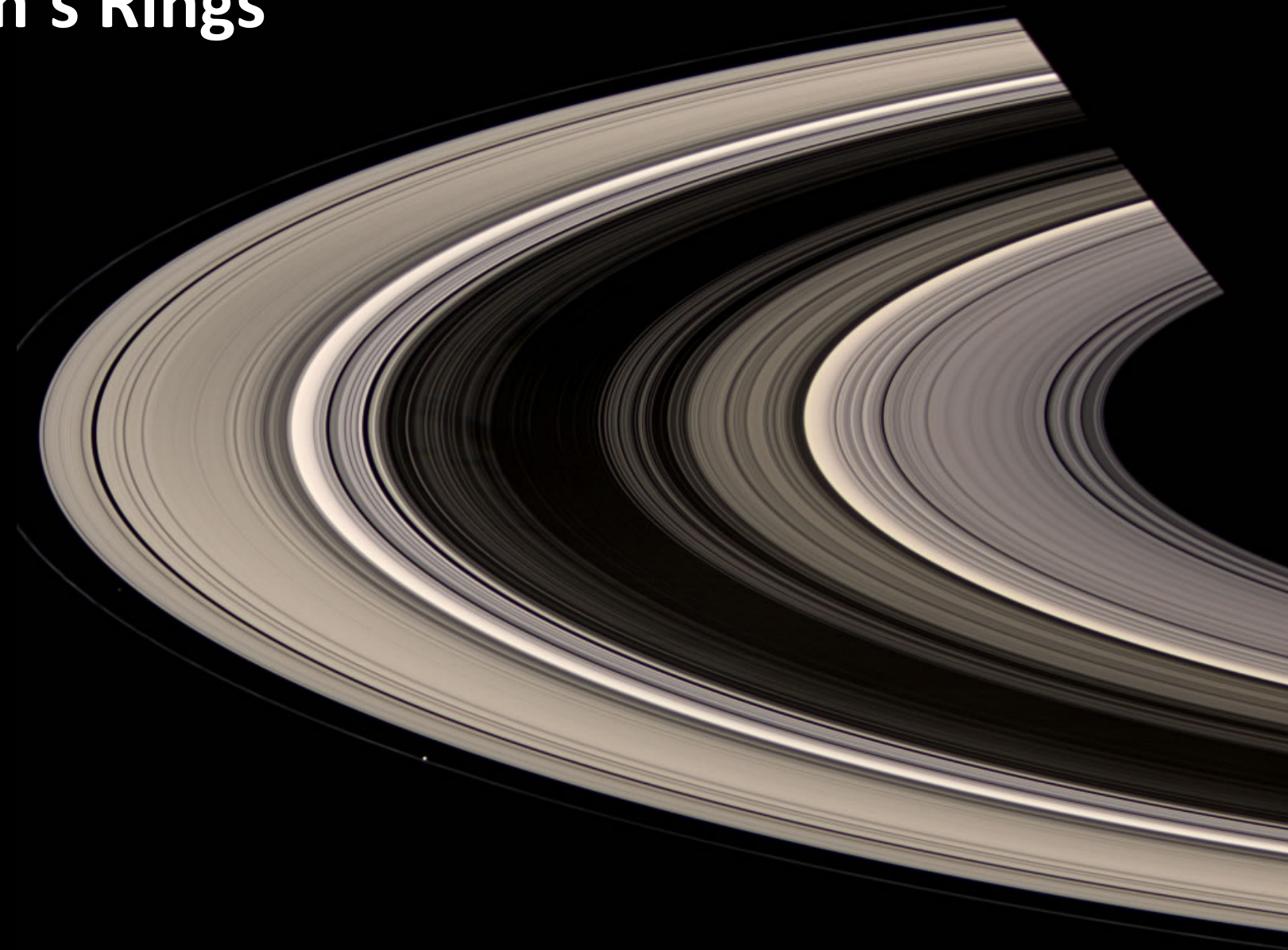


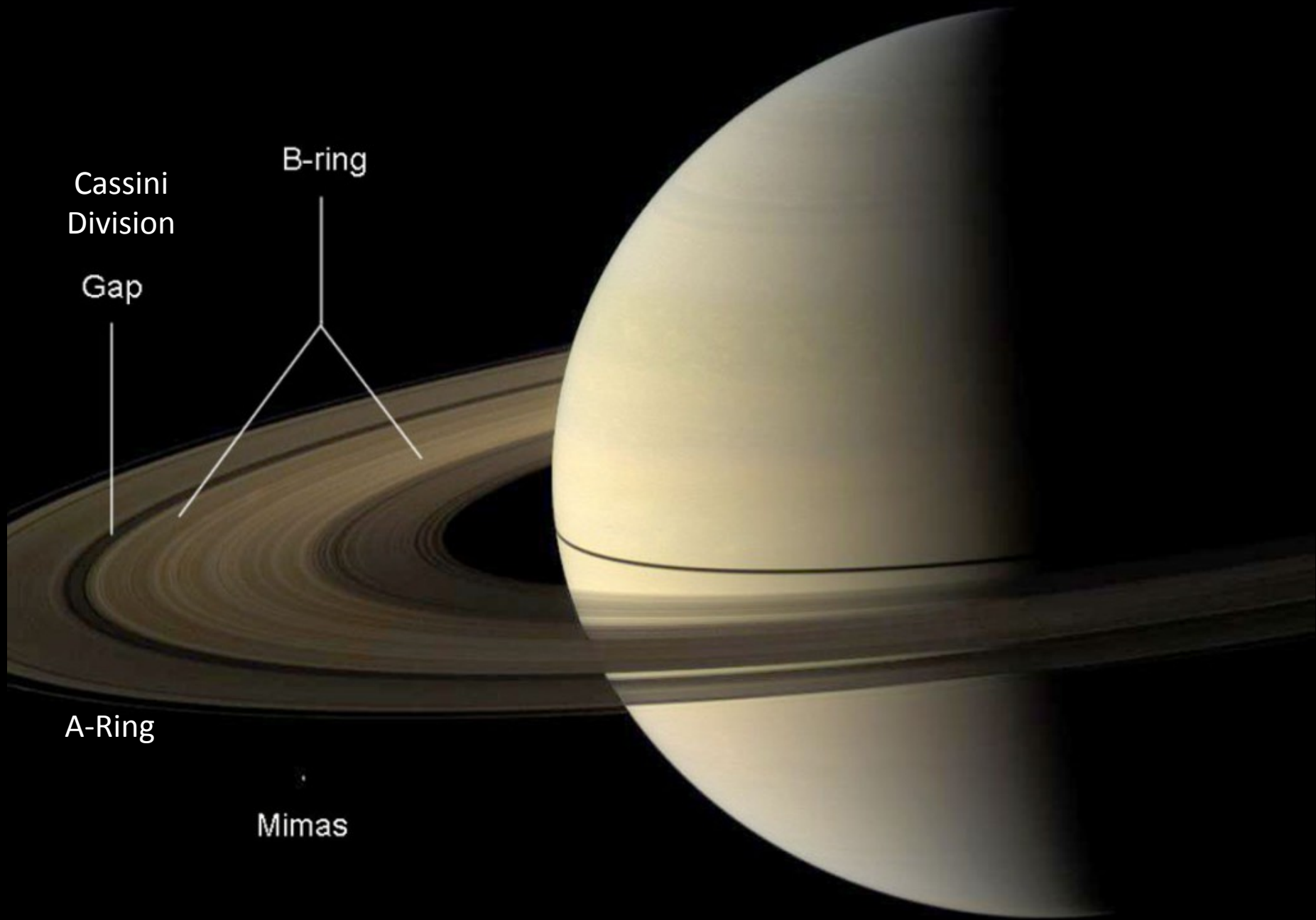
Saturn eclipses the Sun, from the Cassini spacecraft





Saturn's Rings





Cassini
Division

B-ring

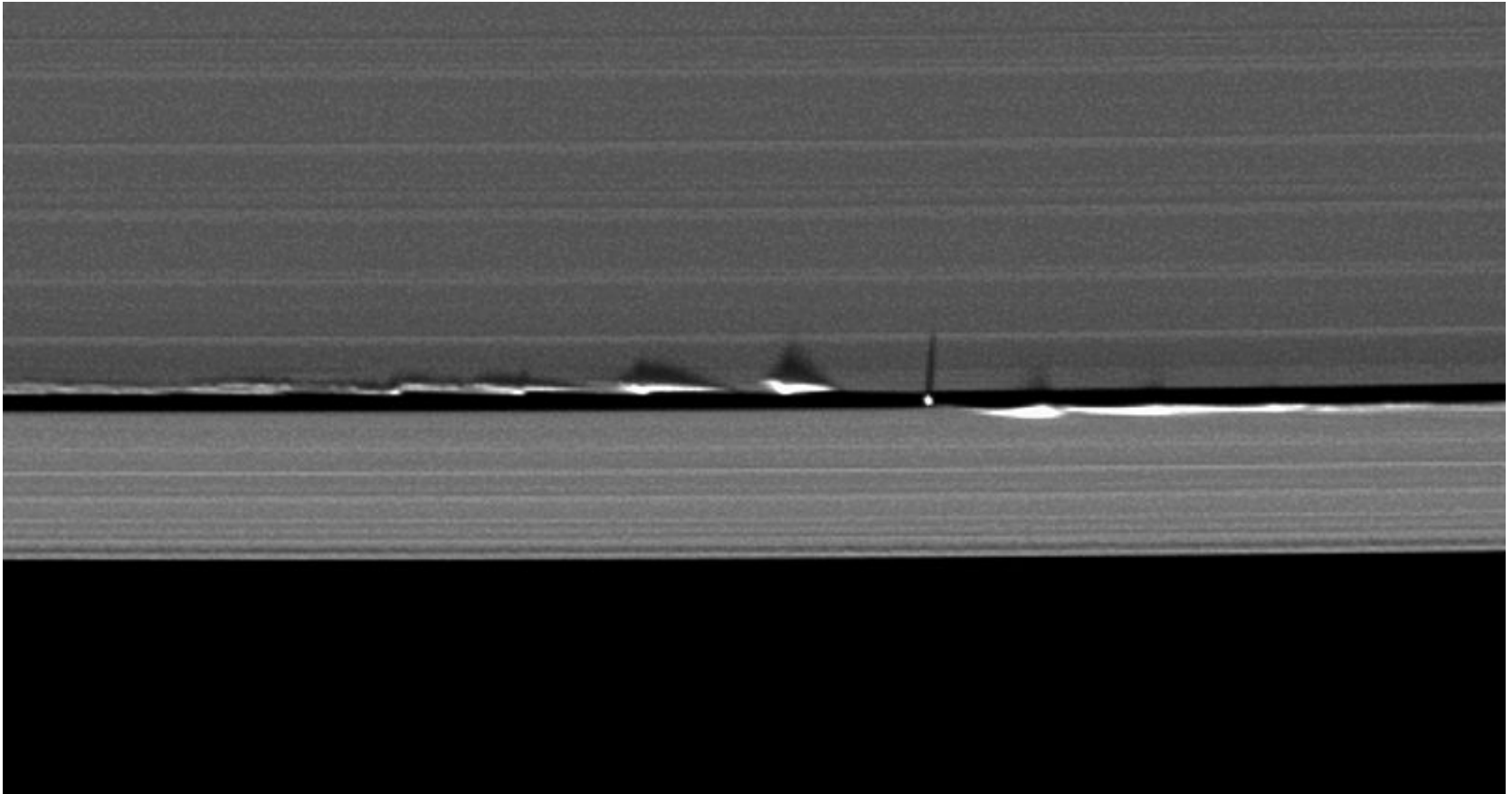
Gap

A-Ring

Mimas

Saturn's Rings

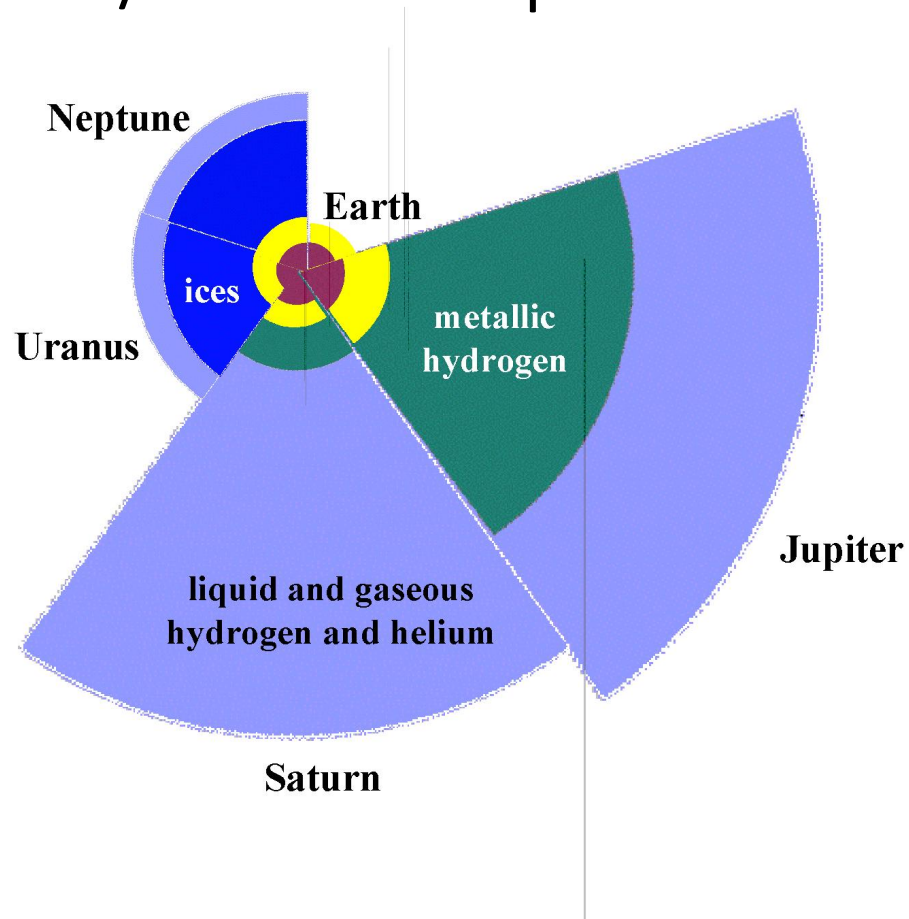
- Made of icy particles from 1 cm to a few meters in size
- The many divisions in the rings are due to tiny moons between the divisions known as **shepherd moons**



Structure of Saturn

The internal structure of Saturn is similar to Jupiter, but the amount of metallic hydrogen is much smaller.

Because there is less conducting material, Saturn has a weaker magnetic field – 1/20 that of Jupiter.



Cross-sections of the Jovian planets, with Earth for comparison

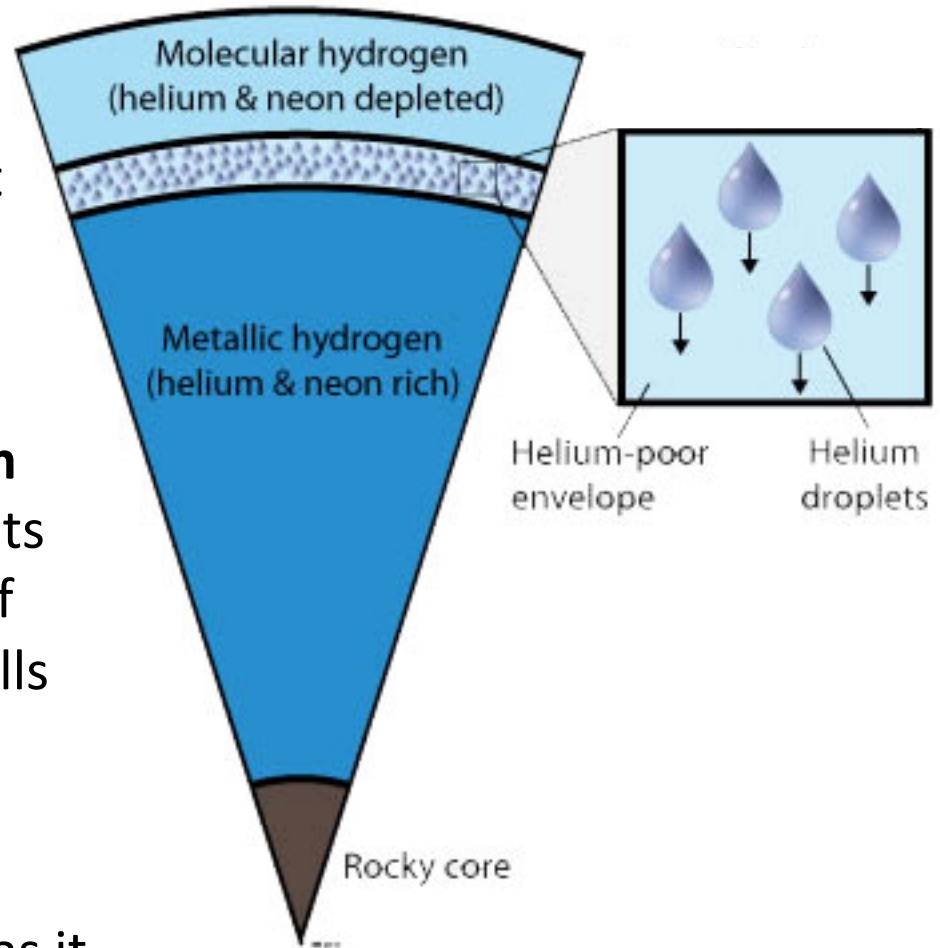
Internal Heating

Saturn gives off 3 times more heat than it receives from the Sun – more than Jupiter

Can't be explained by leftover heat from formation – Saturn is smaller than Jupiter and cooled quickly

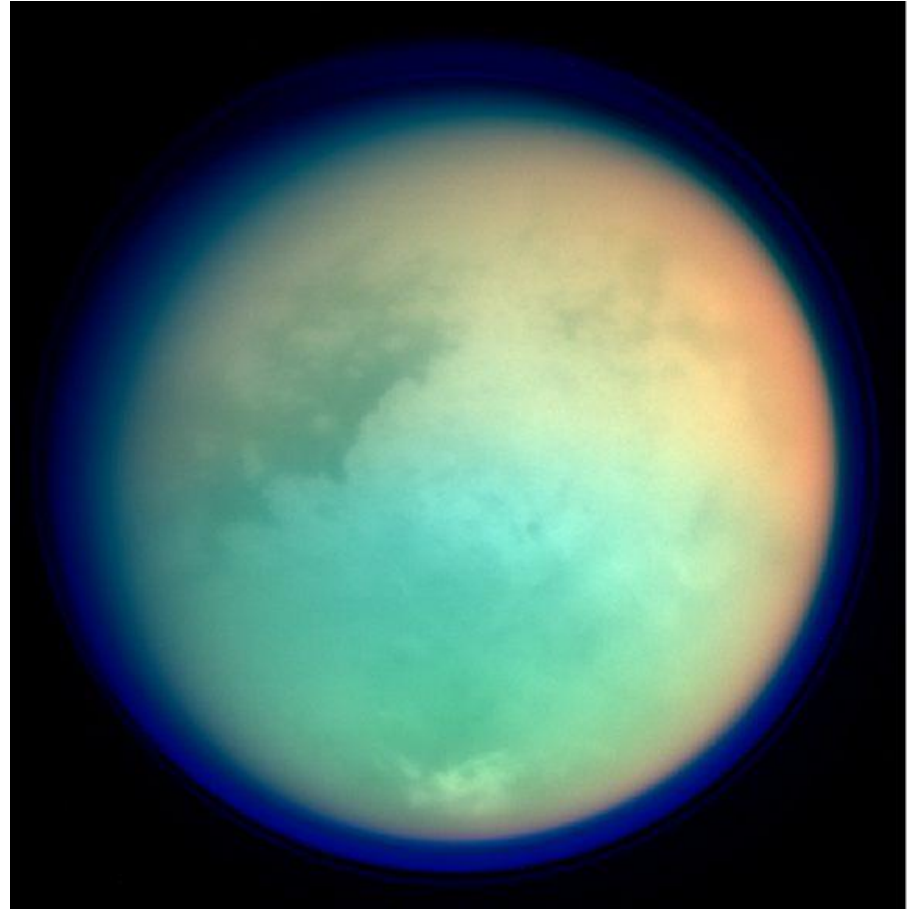
It is thought that Saturn has **helium rain**: helium condenses into droplets at the temperature and pressure of Saturn's upper atmosphere, and falls as rain – upper atmosphere is depleted in helium

Helium is compressed and heated as it falls, providing Saturn's internal heat source



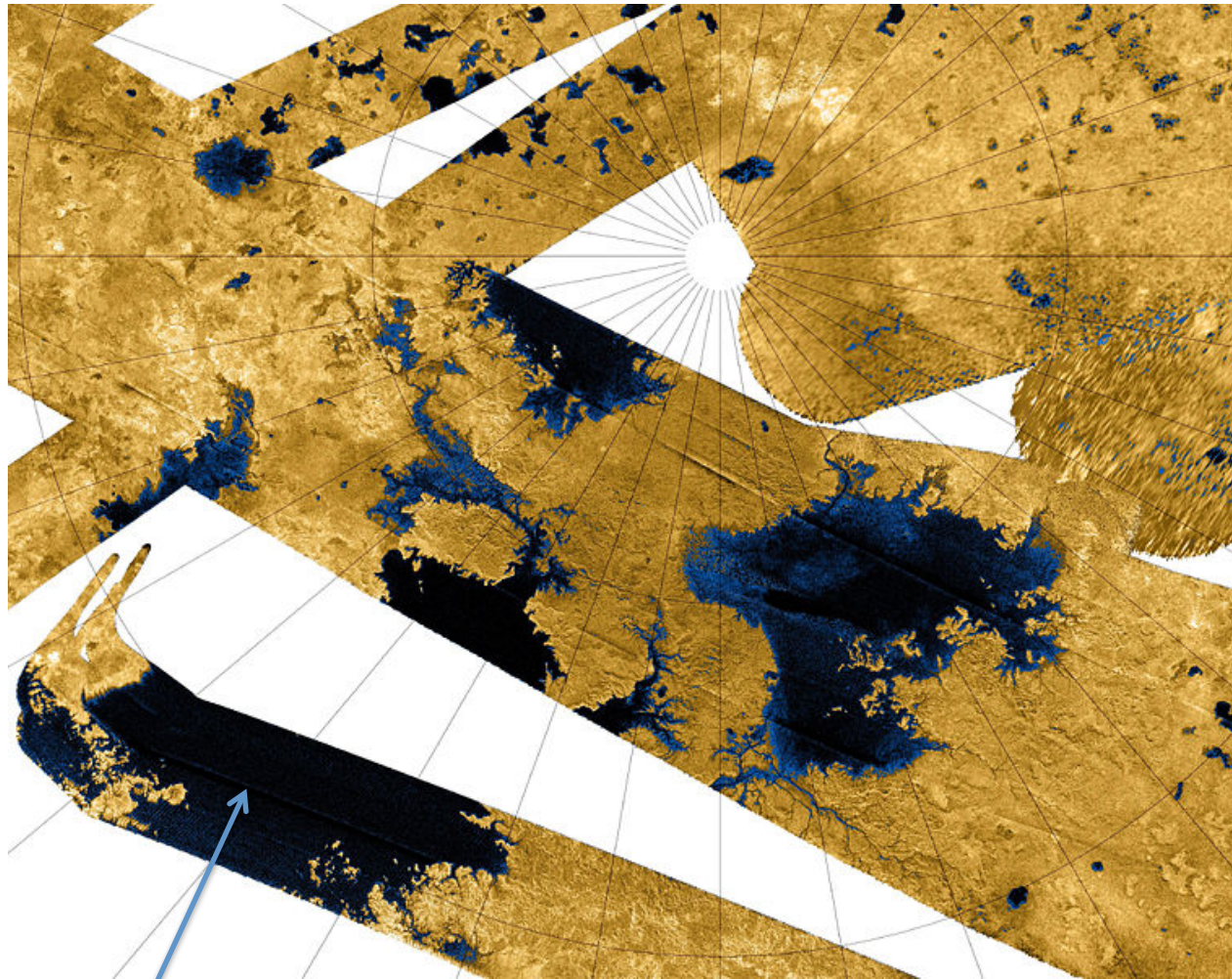
Moons of Saturn: Titan

- Saturn's largest moon – 2nd largest in solar system (Jupiter's Ganymede is largest)
- Only other body in solar system with **stable surface liquid**: seas and lakes of methane
- Nitrogen-rich (98%) atmosphere, thicker and denser than Earth's
- Evidence for methane rain



False color image of Titan

The Lakes of Titan



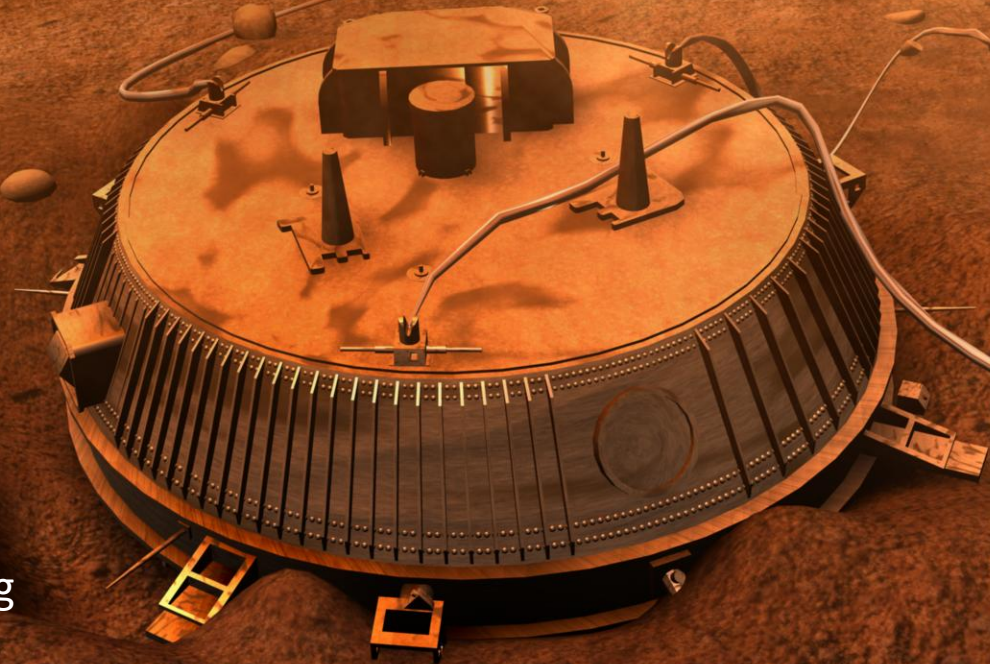
Titan is cold –
methane
becomes liquid

Kraken Mare

Radar mosaic of Titan's north polar region.
Blue coloring shows areas of low reflectivity
caused by lakes of liquid ethane and methane.

The Huygens Probe

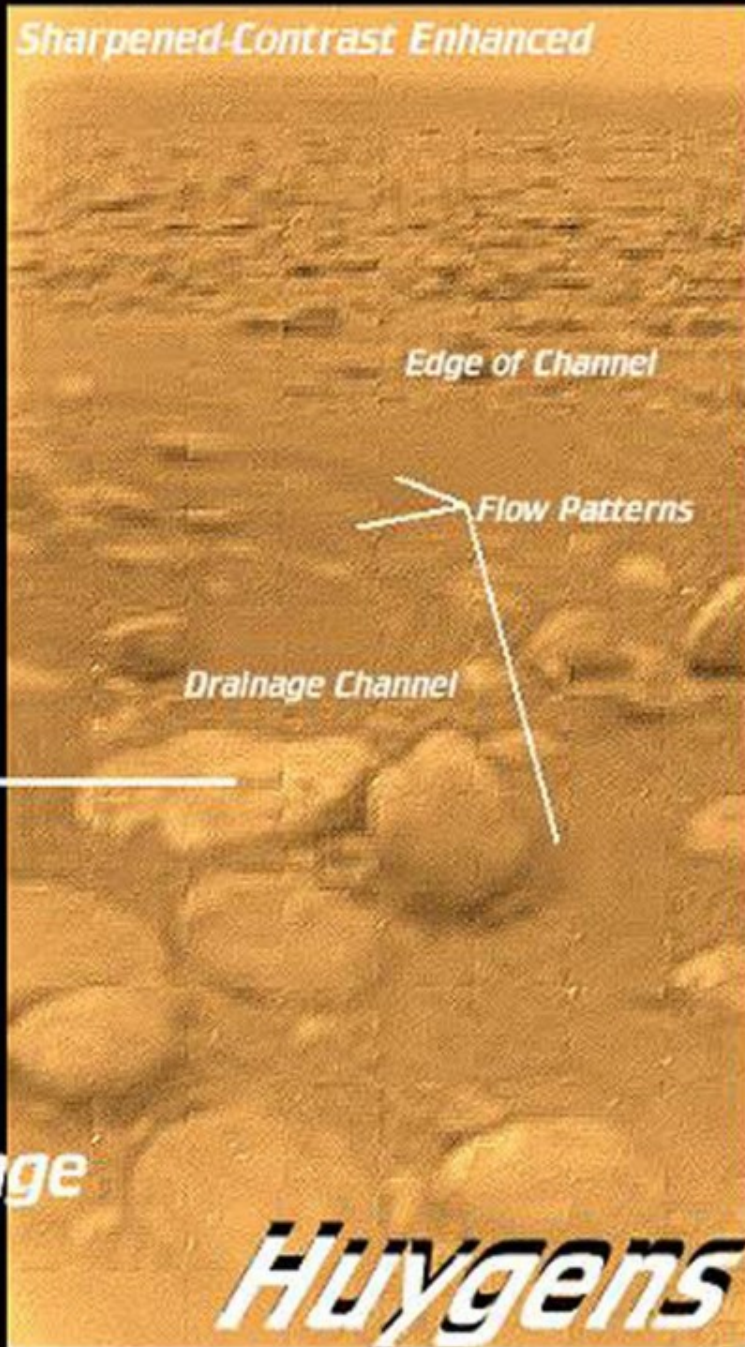
As part of the Cassini mission, the Huygens probe was dropped to the surface of Titan in 2005 – the first landing in the outer solar system, and still the most distant. This is an artist's impression reconstructed from Huygens data.



Drainage Patterns



Sharpened-Contrast Enhanced



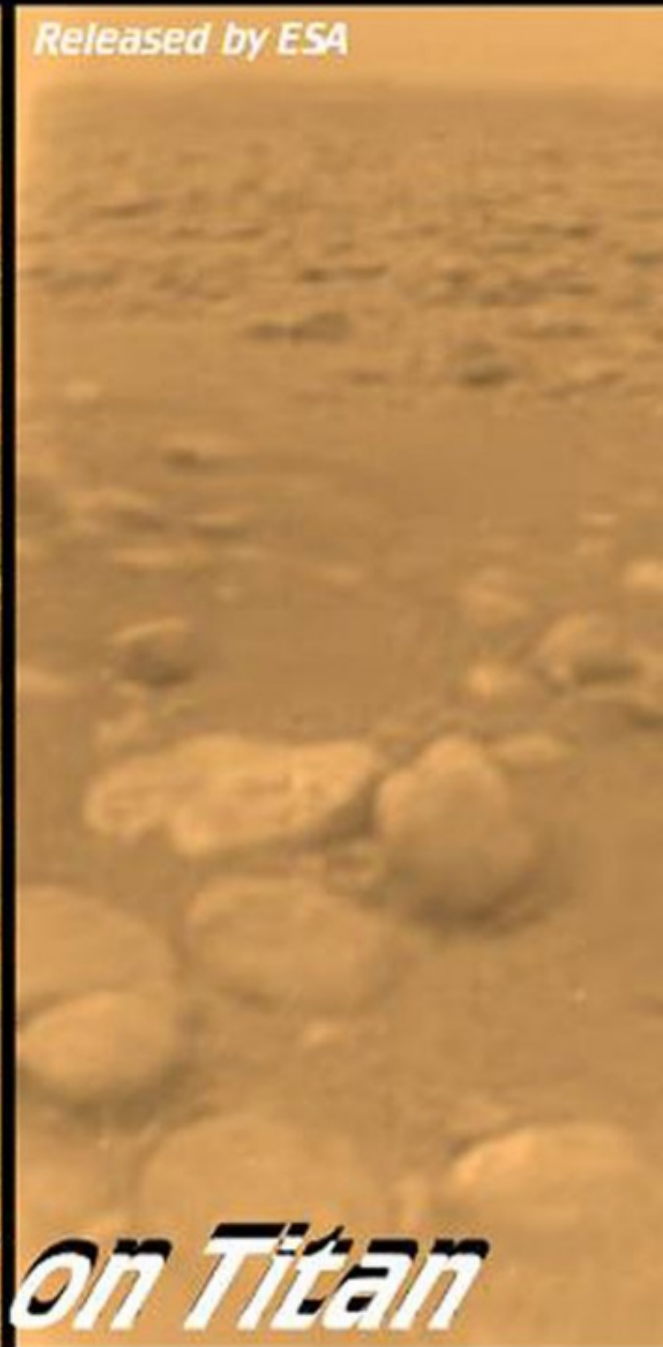
Edge of Channel

Flow Patterns

Drainage Channel

15 cm (6 inches)

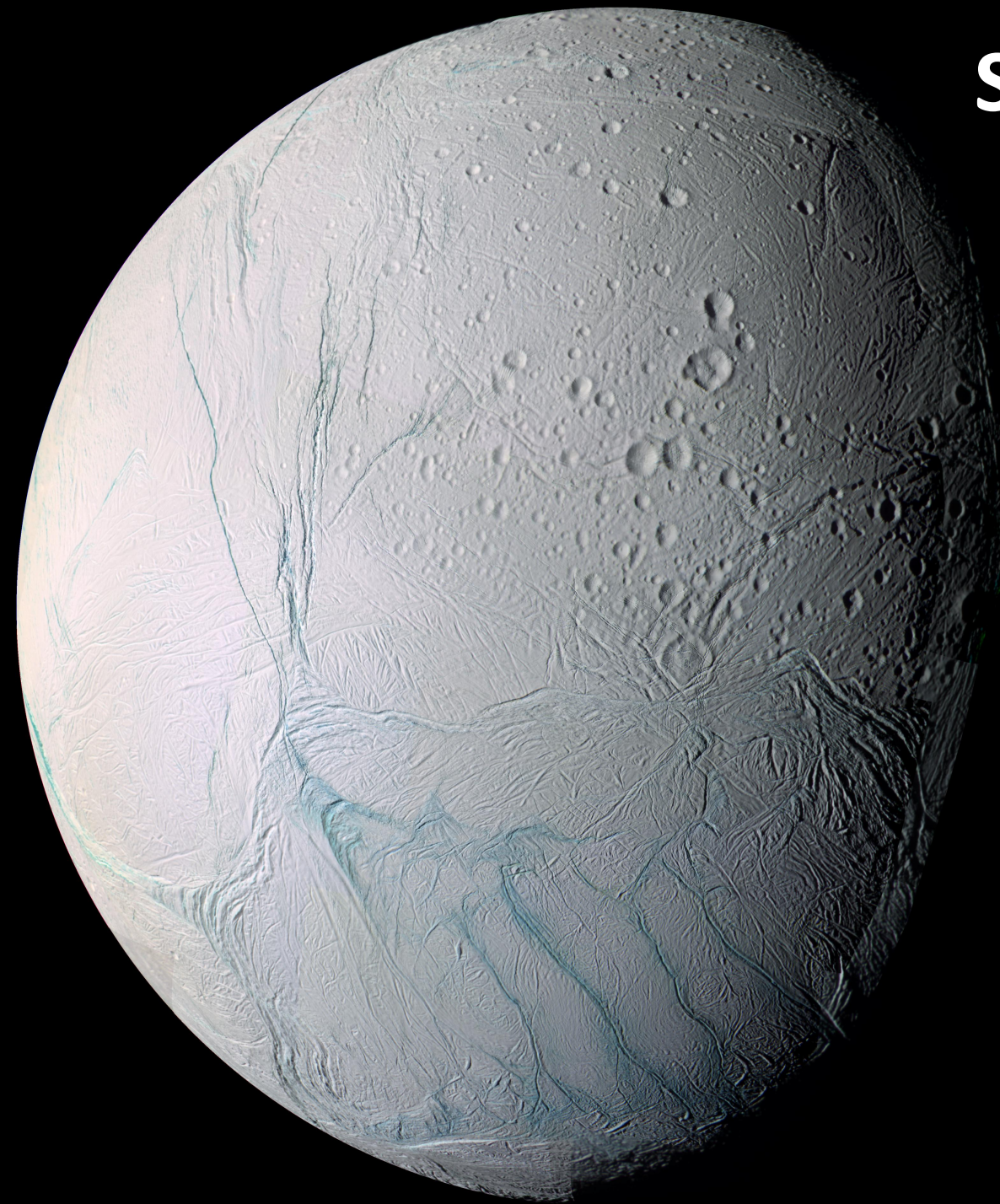
Released by ESA



First Color Image

Huygens on Titan

Saturn's Moons: Enceladus



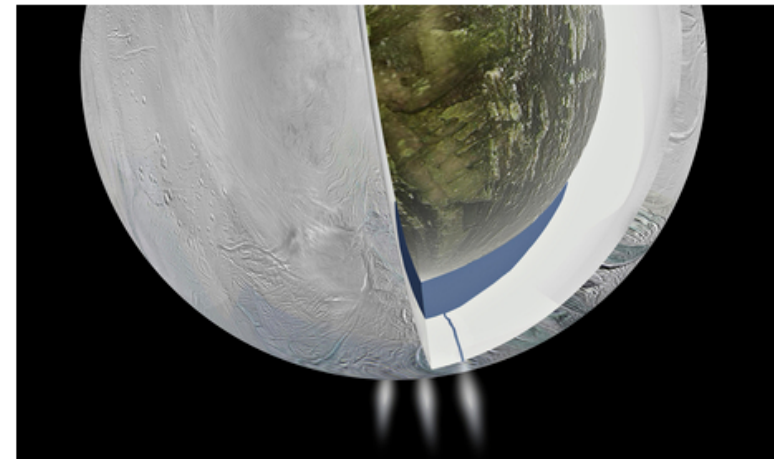
Ocean discovered on Enceladus may be best place to look for alien life

Evidence from Cassini spacecraft suggests a large body of liquid water beneath the surface of Saturn's moon Enceladus

• [Interactive: the discovery explained](#)

Ian Sample, science correspondent
The Guardian, Thursday 3 April 2014 14.25 EDT

[Jump to comments \(171\)](#)



An artist's impression of the interior of Saturn's moon Enceladus, based on data from the Cassini space probe suggesting the moon contains a water ocean beneath its south pole. Illustration: Nasa/JPL-Caltech

Researchers have discovered a deep saltwater ocean on one of the many small moons that orbit [Saturn](#), leading scientists to conclude it is the most likely place in the solar system for extraterrestrial life to be found.

Gravitational field measurements taken by Nasa's Cassini [space](#) probe revealed that a 10km-deep ocean of water, larger than Lake Superior, lurks beneath the icy surface of Enceladus at the moon's south pole.

New!

- April 3, 2014: scientists report evidence of liquid ocean at southern pole of Enceladus, probably heated by tidal forces from Saturn
- Enceladus also has plumes of water vapor containing organic molecules at the south pole
- Ocean would be in contact with rocky core, so elements useful for life (phosphorus, sulfur, potassium) may leach into the water
- A good place for life?

Uranus

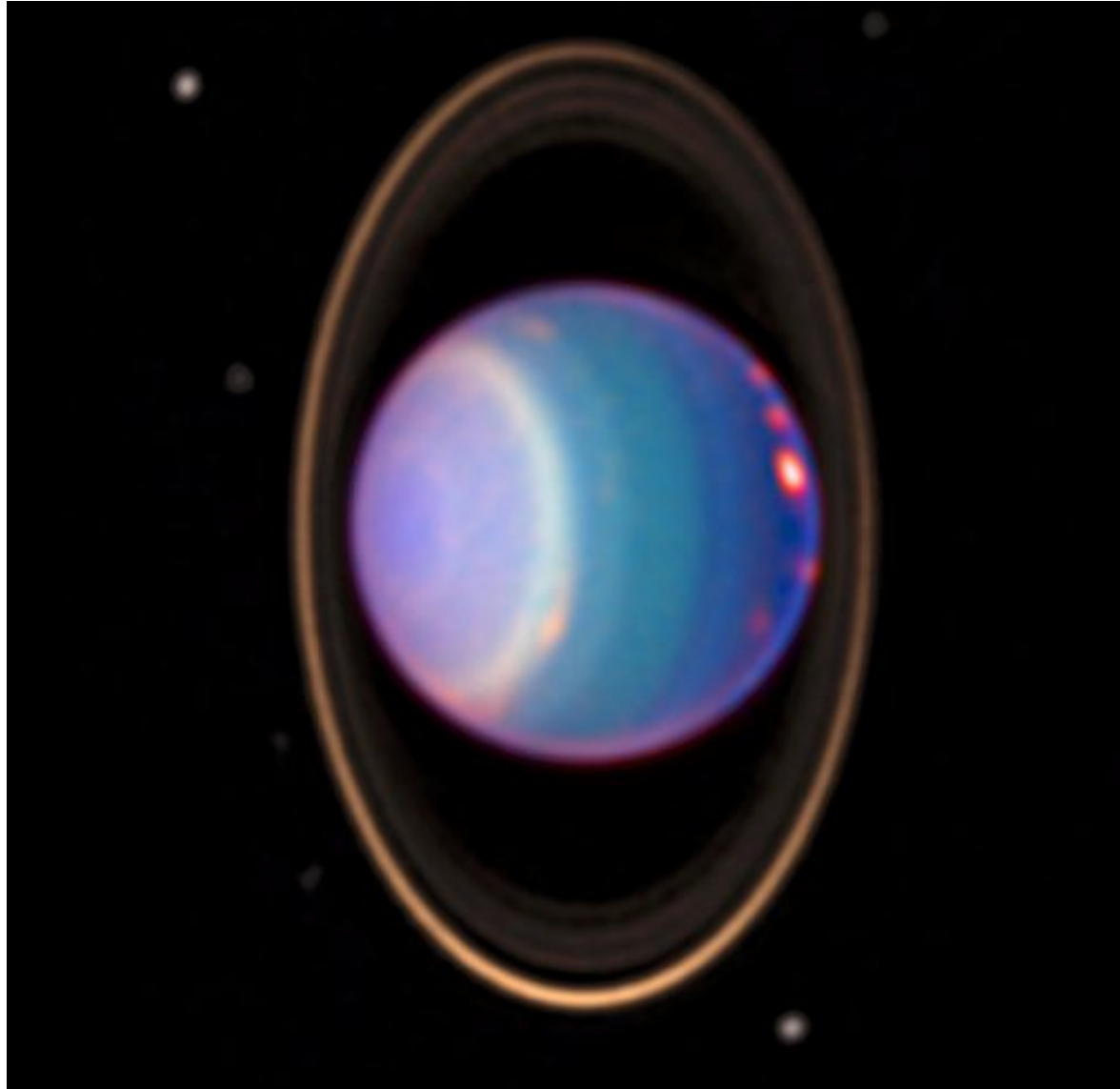
Radius \sim 4 times Earth

Mass \sim 15 times Earth

Nearly featureless –
image at right is a false
color image.

Rotation axis is tilted 98
degrees!

The tilt may be result of
a giant impact (?)



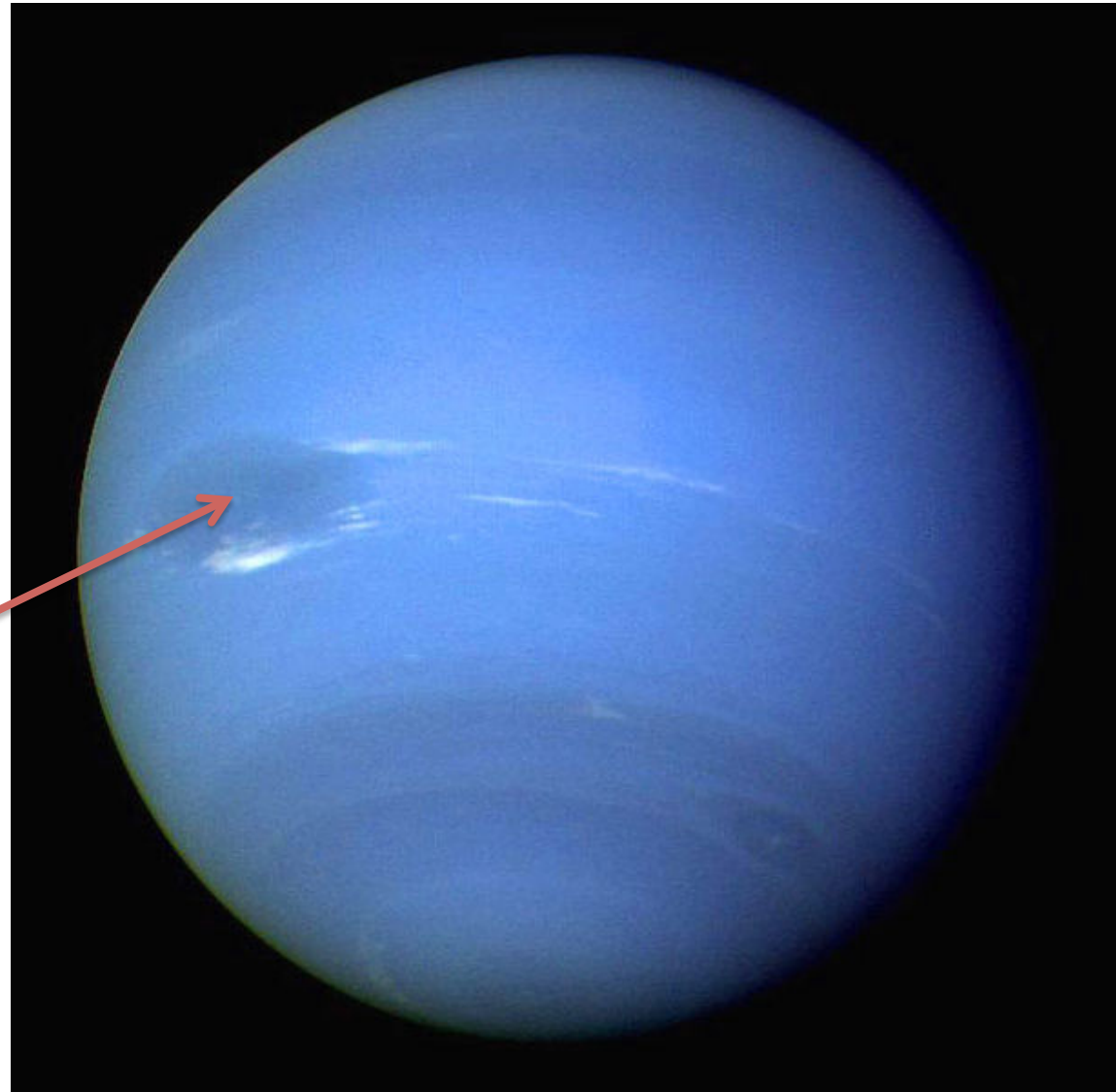
Neptune

Radius \sim 4x bigger than Earth.

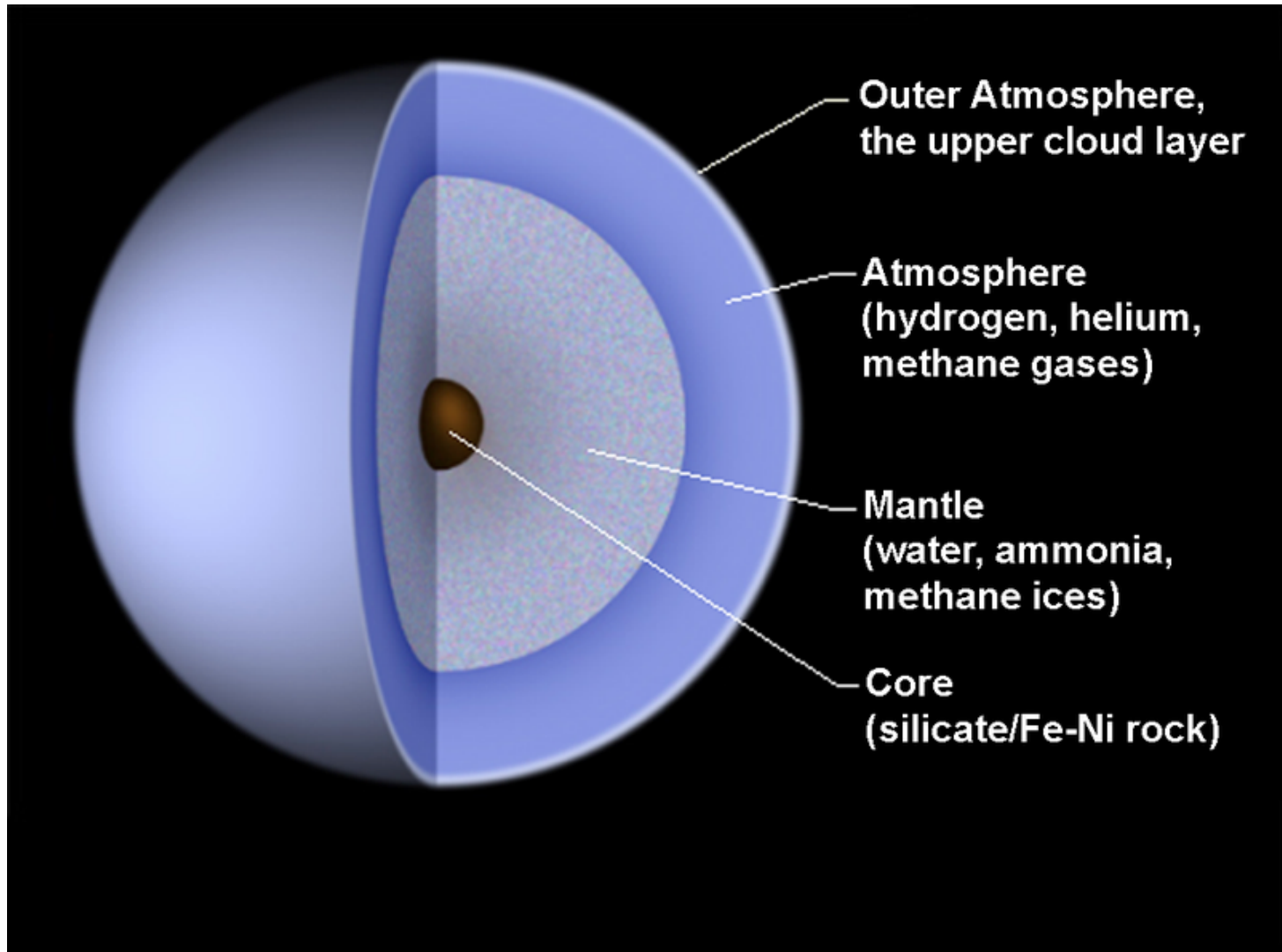
Mass \sim 17x Earth

Has bands of clouds unlike Uranus

Has a large storm on it called the Great Dark Spot.



Internal structure of Uranus and Neptune



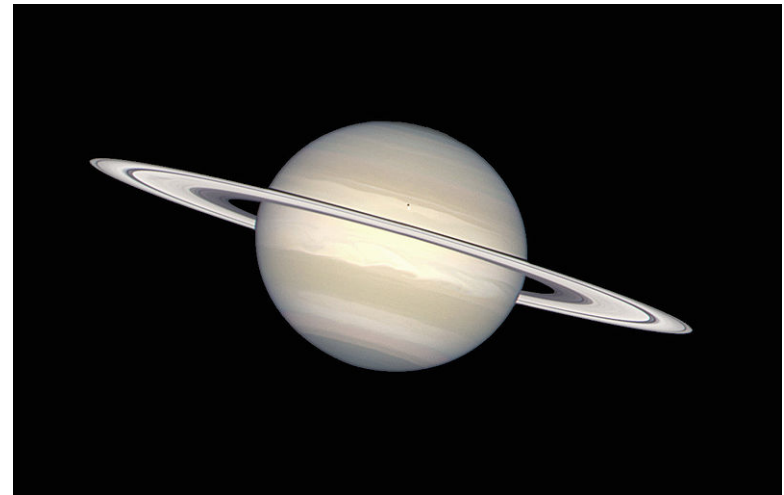
Uranus and Neptune appear to have a gaseous atmosphere on top of an icy mantle and a rocky/metallic core

Planetary rings

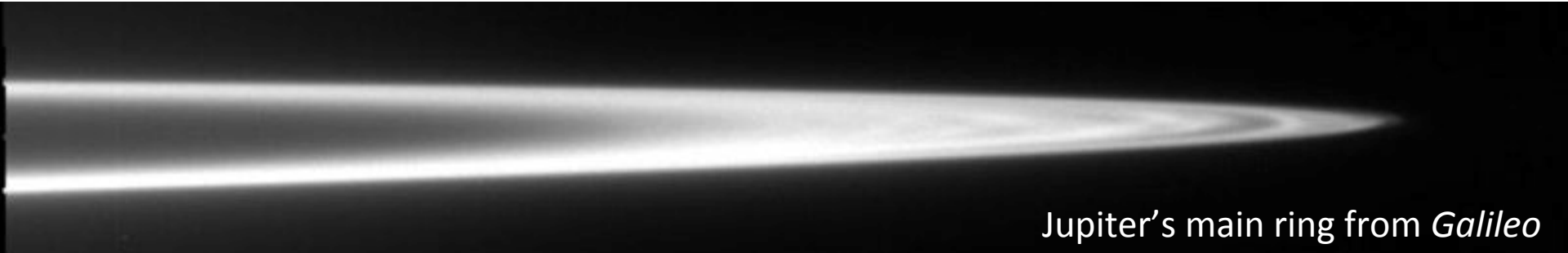
Saturn's rings from *Cassini*



- Saturn's are the most famous, but all four Jovian planets have rings
- Probably material from protoplanetary disk that was too close to planet to condense into a moon (because of tidal forces), or from the debris of a moon destroyed by an impact or by tidal forces



Planetary rings



Jupiter's main ring from *Galileo*



Saturn's rings from *Cassini*

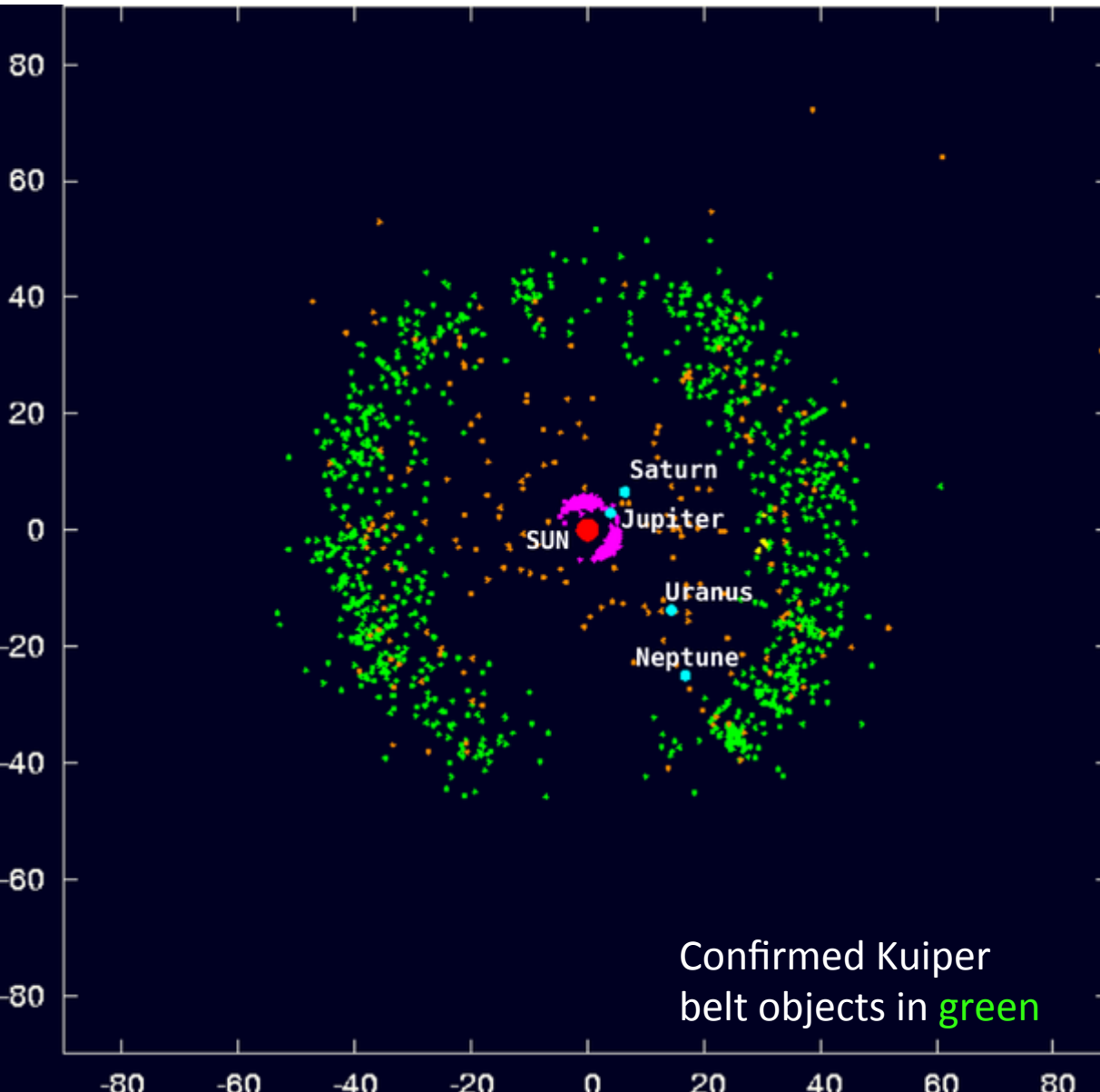


Uranus' rings from *Voyager2*



Neptune's rings from *Voyager2*

Pluto and the Kuiper Belt

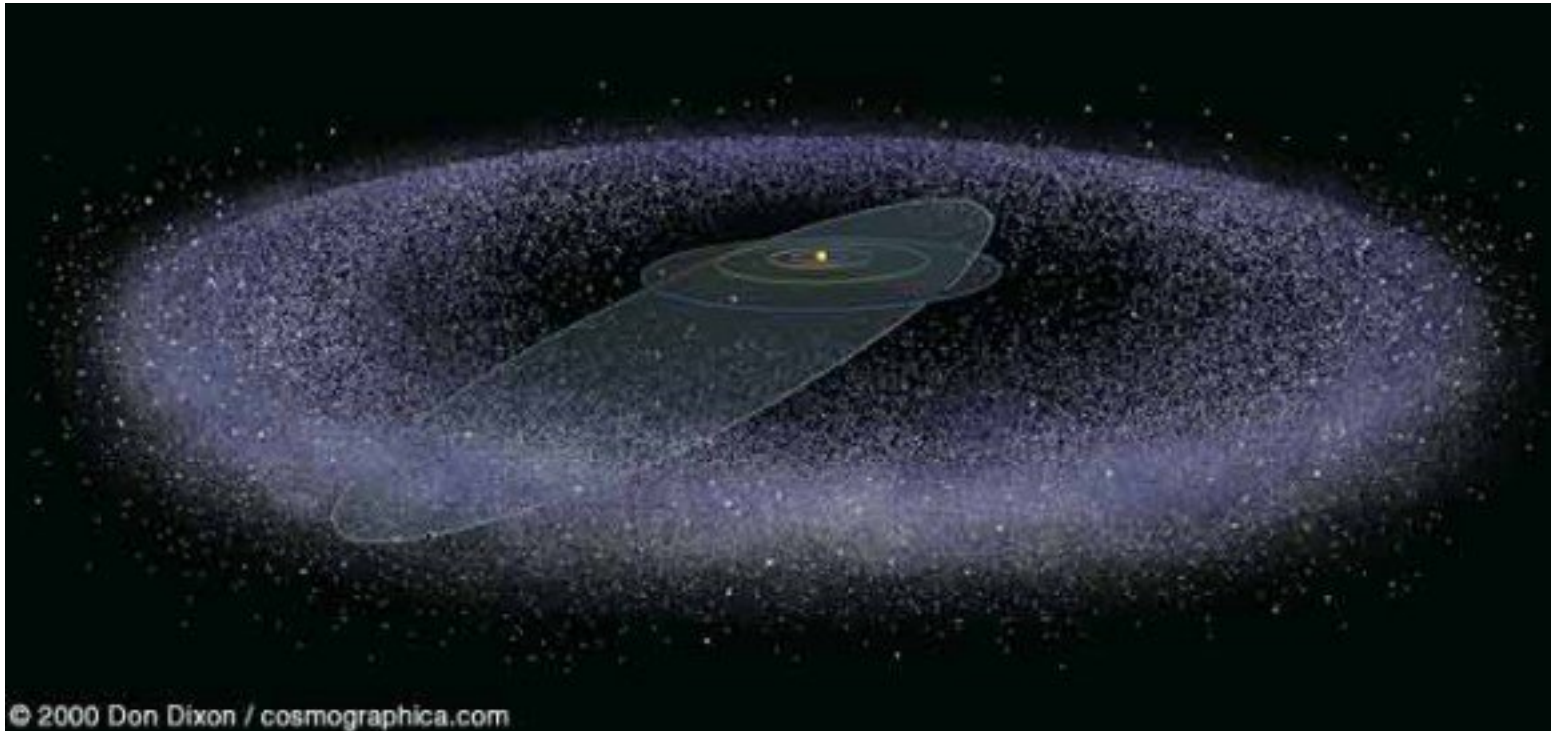


Recall: Kuiper belt extends from orbit of Neptune (20 AU) to 50 AU from Sun

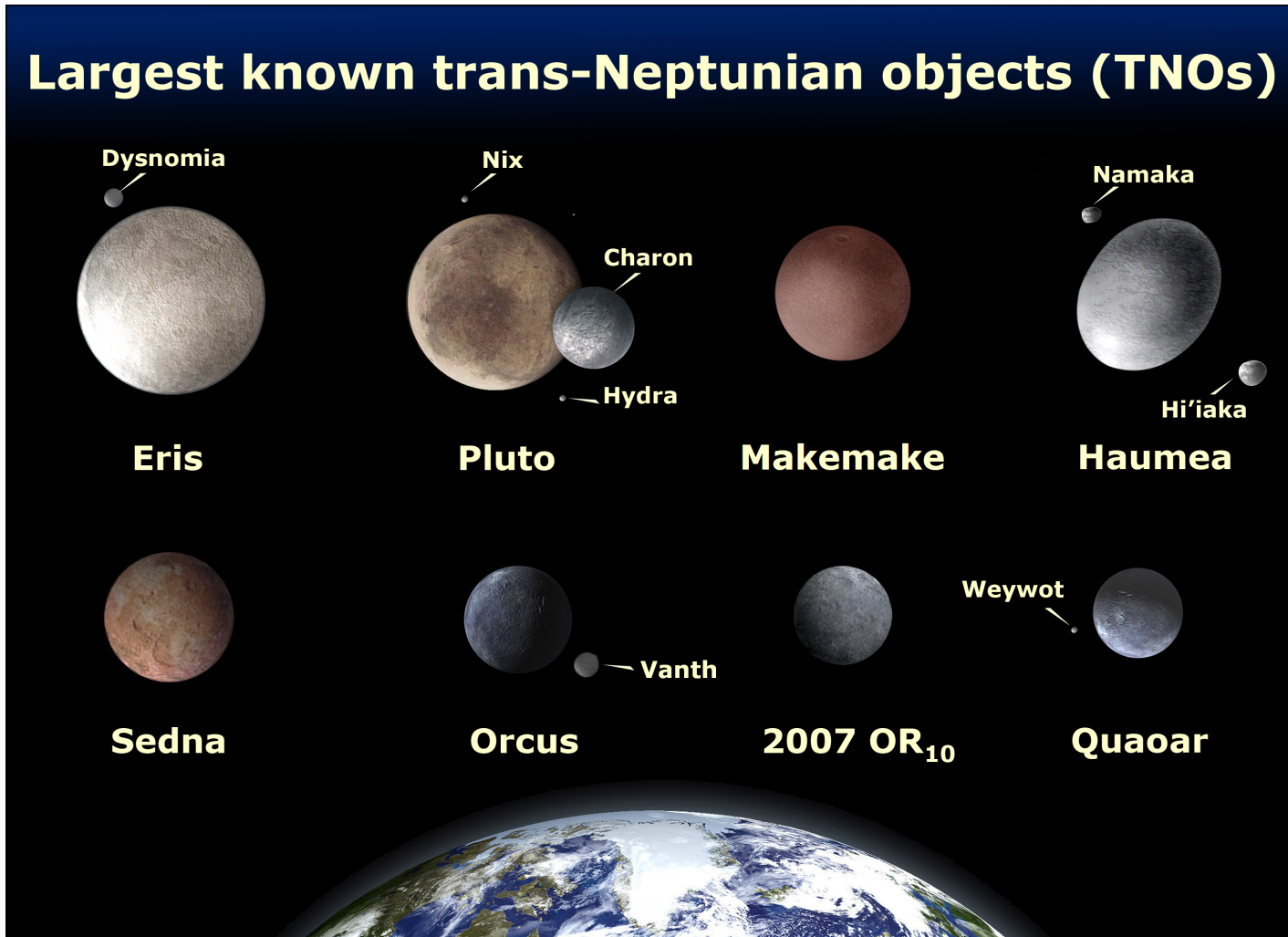
Contains many small, icy bodies

Pluto and the Kuiper Belt

- Pluto is just one member of the Kuiper Belt
- Consists of a large number of icy bodies that are not in a plane – more like a thick disk.
- Contrast this with the 8 planets which are in a plane to an accuracy of 1%



Pluto and the Kuiper Belt



Pluto is only the second largest of the Kuiper Belt objects – the largest is Eris. Also new discovery, 2012 VP113!

Pluto and the Kuiper Belt

Largest known trans-Neptunian objects (TNOs)



Discovery of Eris, other large Kuiper belt objects responsible for Pluto's demotion to dwarf planet – many Pluto-like objects out there

Pluto and the Kuiper Belt

Pluto has a large moon called Charon.

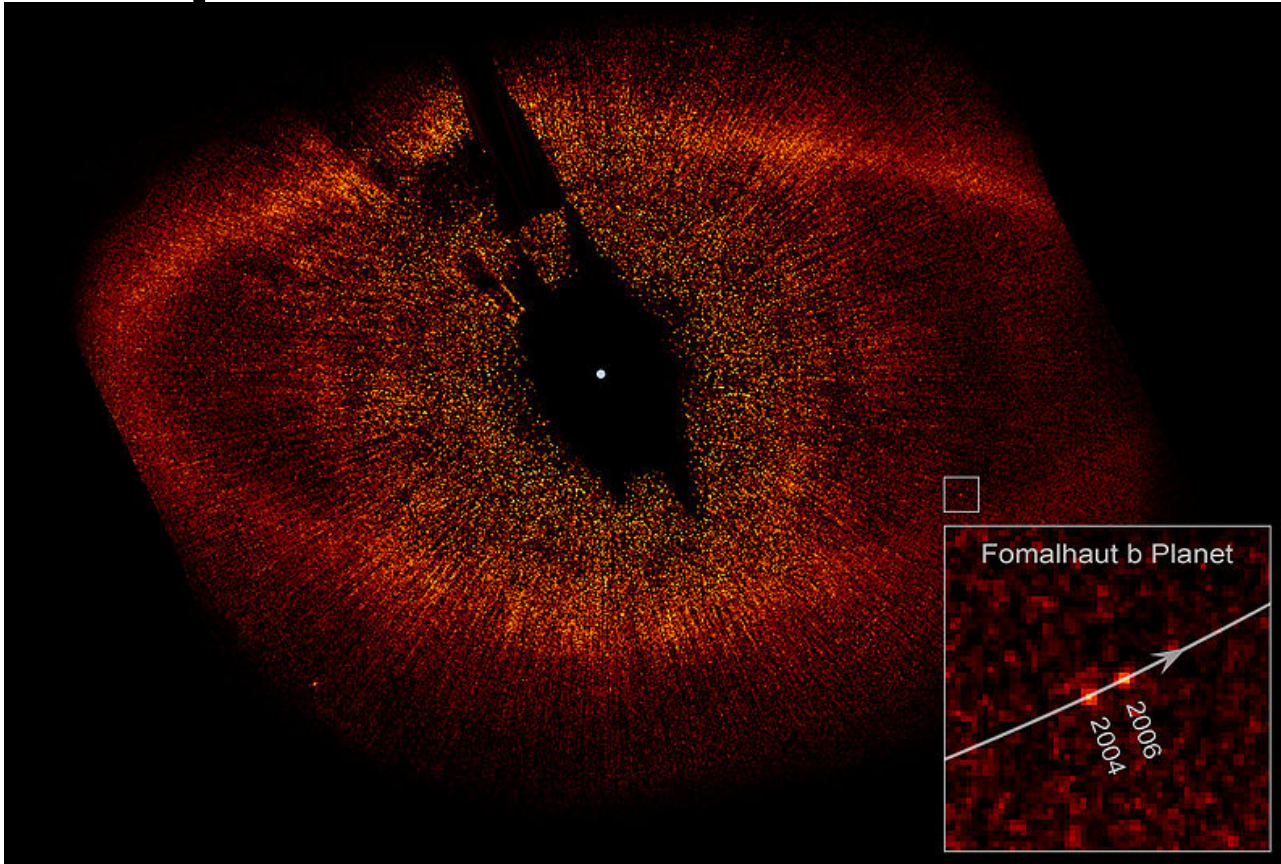
Pluto is about 1200 km in radius and Charon is just $\frac{1}{2}$ of that.

In addition, Pluto has two smaller moons Nix and Hydra

Two smaller moons have since been found:



Kuiper Belts around other Stars



- Kuiper belts or debris disks have also been found around other stars
- The picture above shows the debris disk around the star Fomalhaut
- Inner edge of the debris disk may be due to a planet