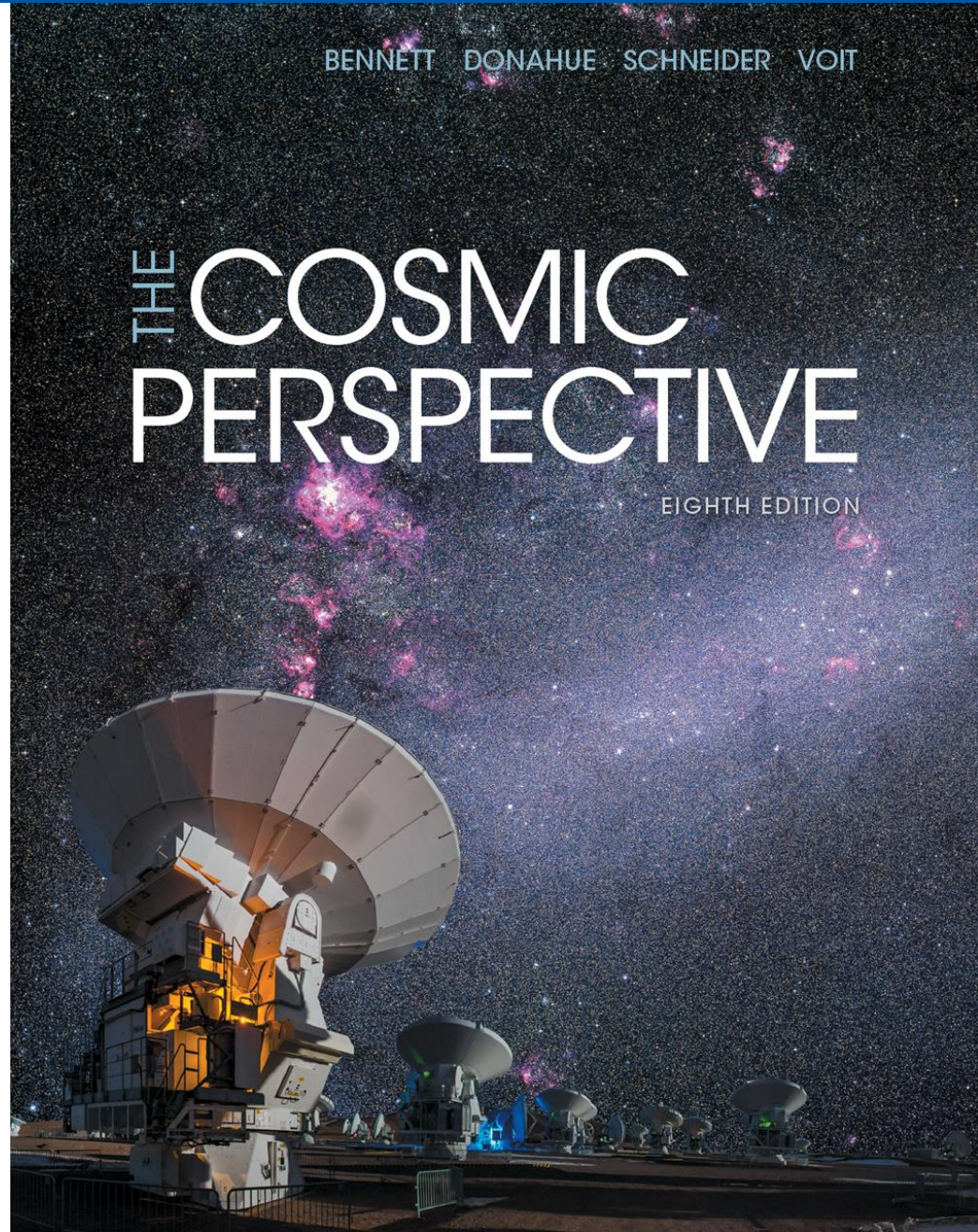
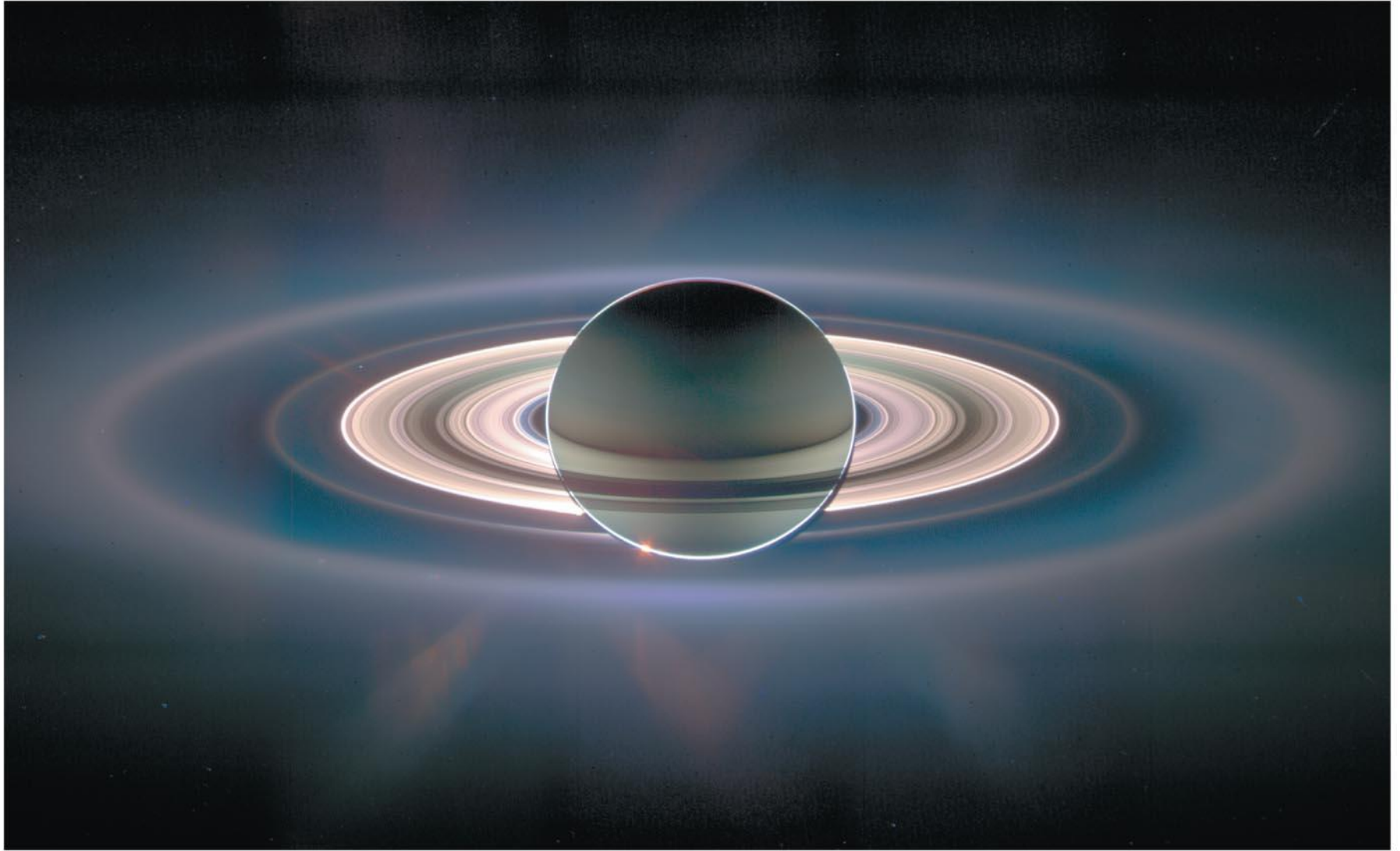


Chapter 11 Lecture

Chapter 11: Jovian Planet Systems



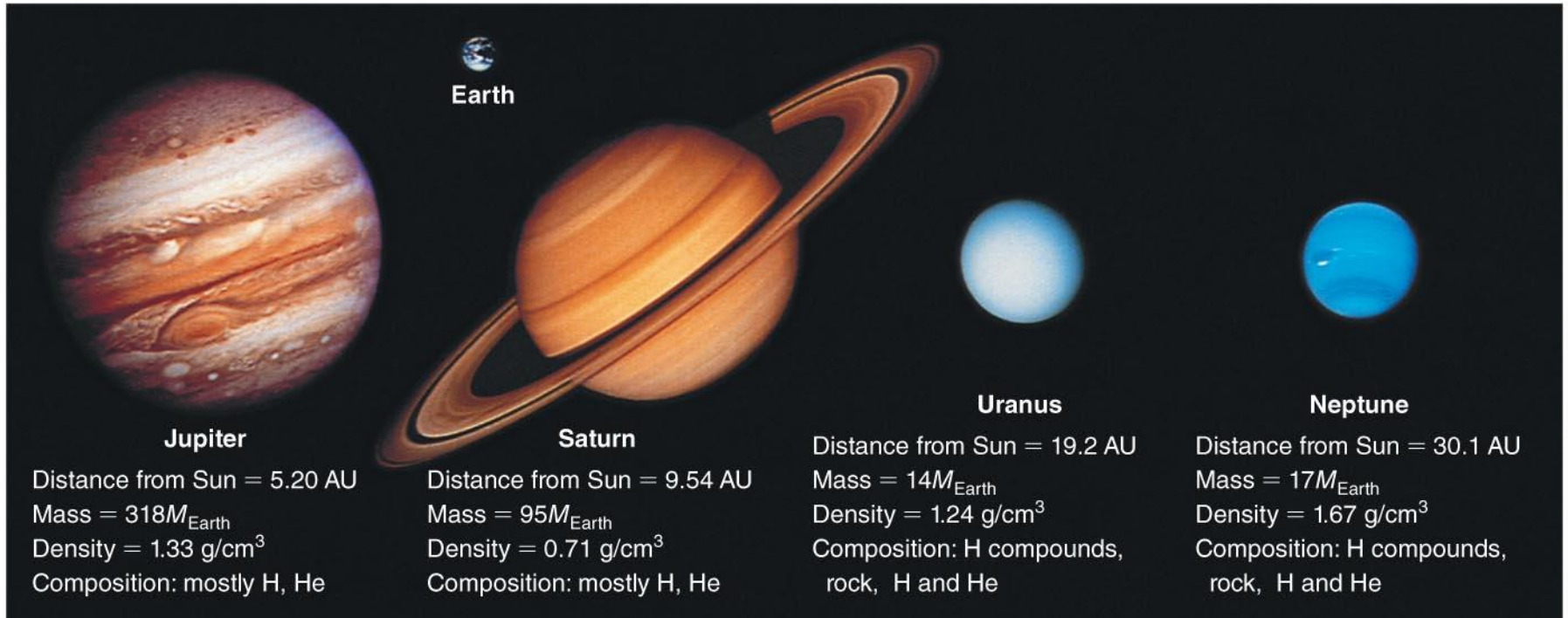
Jovian Planet Systems



11.1 A Different Kind of Planet

- Our goals for learning:
 - **Are jovian planets all alike?**
 - **What are jovian planets like on the inside?**
 - **What is the weather like on jovian planets?**
 - **Do jovian planets have magnetospheres like Earth's?**

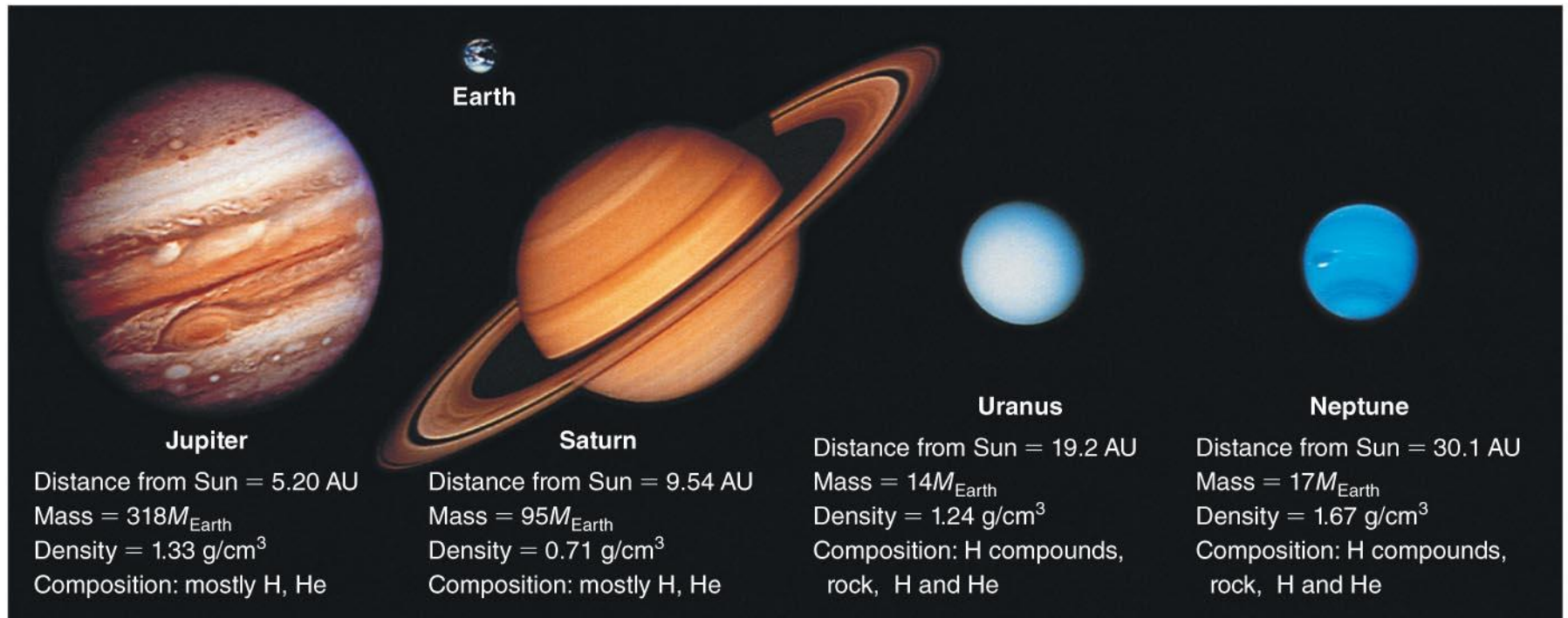
Are jovian planets all alike?



Jovian Planet Composition

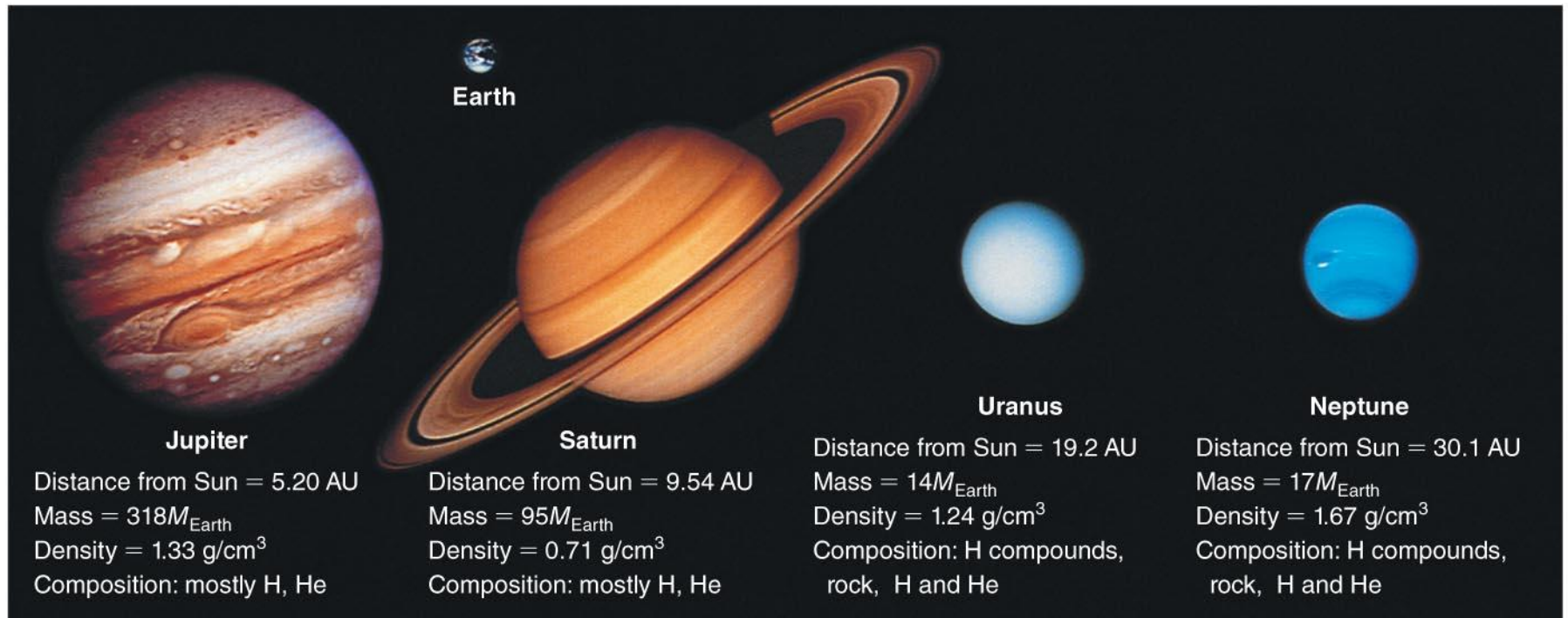
- Jupiter and Saturn
 - Mostly H and He
- Uranus and Neptune
 - Mostly hydrogen compounds: water (H_2O), methane (CH_4), ammonia (NH_3)
 - Some H, He, and rock

Density Differences



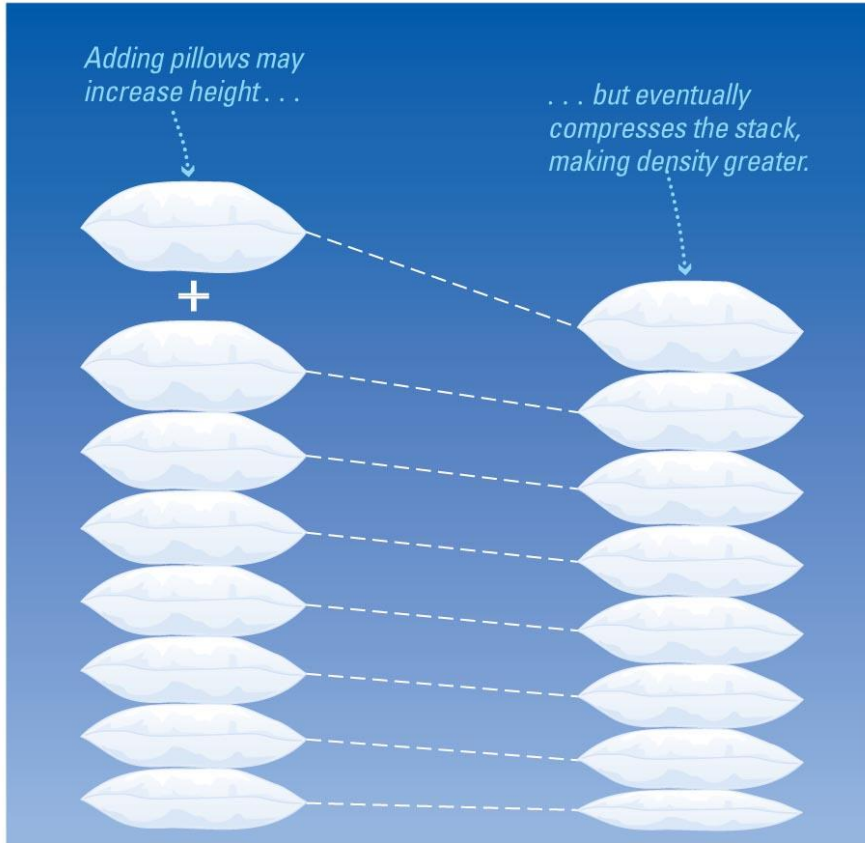
- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately.

Density Differences



- But that explanation doesn't work for Jupiter....

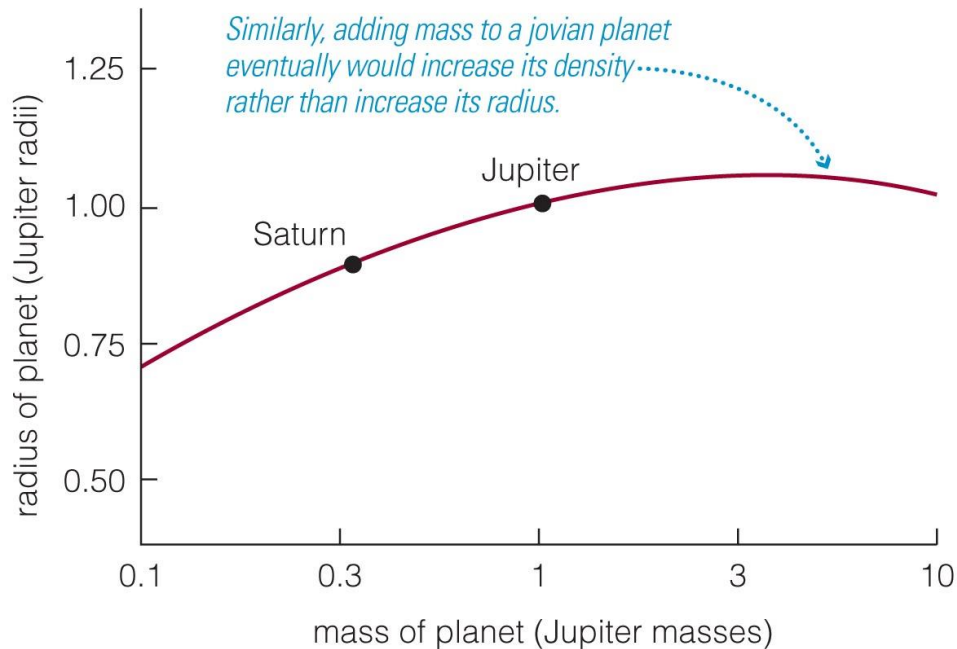
Sizes of Jovian Planets



- Adding mass to a jovian planet compresses the underlying gas layers.

a Adding pillows to a stack may increase its height at first but eventually just compresses the stack, making its density greater. Similarly, adding mass to a jovian planet eventually will increase its density rather than increasing its radius.

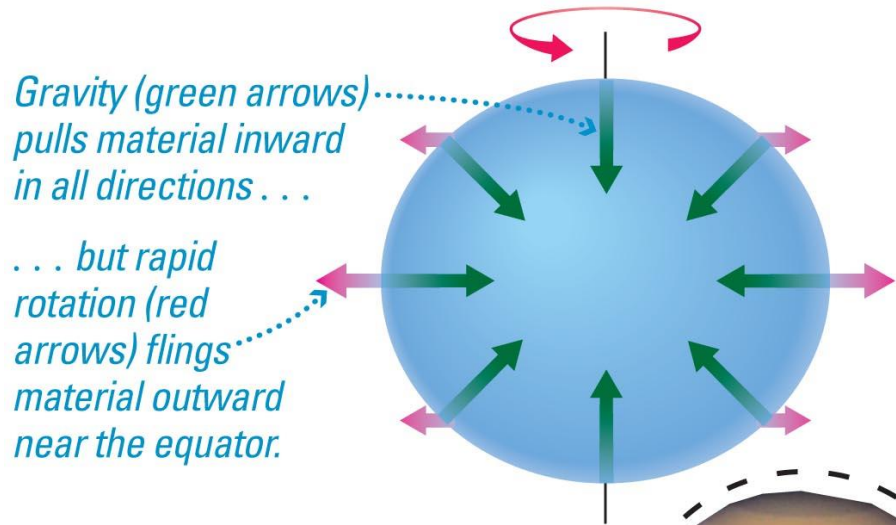
Sizes of Jovian Planets



b This graph shows how radius depends on mass for a hydrogen/helium planet. Notice that Jupiter is only slightly larger in radius than Saturn, despite being three times as massive. Gravitational compression of a planet much more massive than Jupiter would actually make it smaller in size.

- Greater compression is why Jupiter is not much larger than Saturn even though it is three times more massive.
- Jovian planets with even more mass can be smaller than Jupiter.

Rotation and Shape

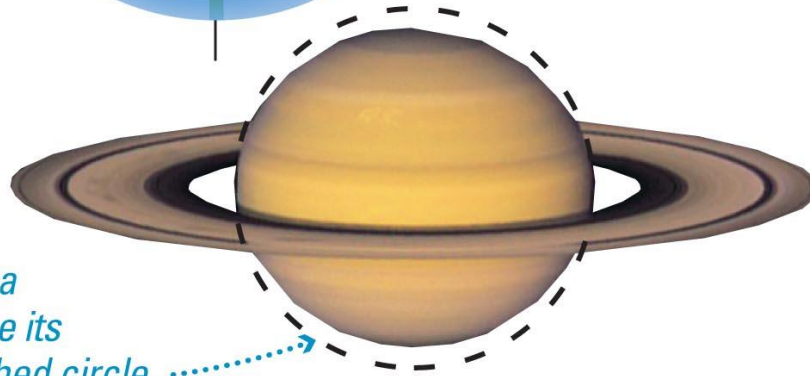


Gravity (green arrows) pulls material inward in all directions . . .

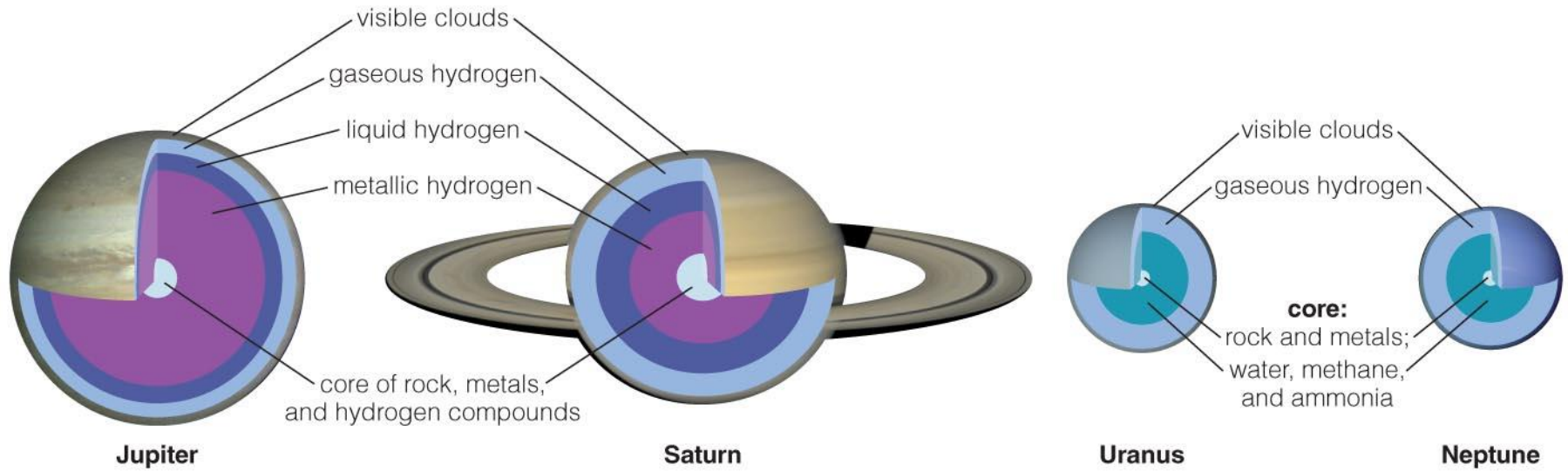
. . . but rapid rotation (red arrows) flings material outward near the equator.

- Jovian planets are not quite spherical because of their rapid rotation.

That is why Saturn isn't a perfect sphere. Compare its actual shape to the dashed circle.



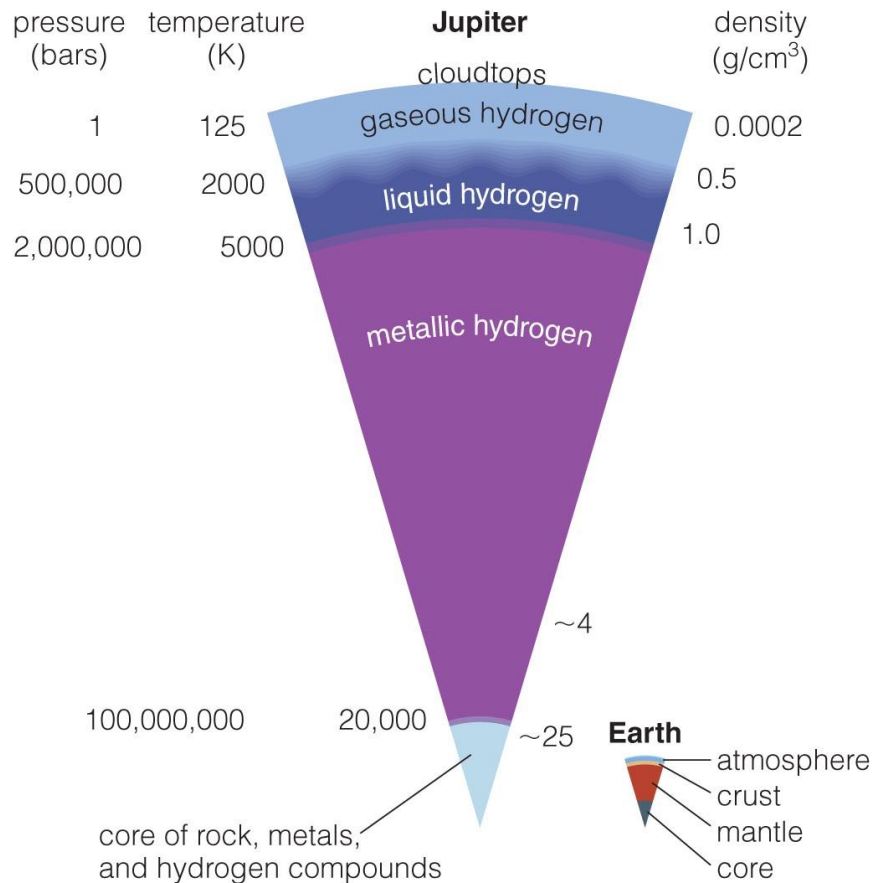
What are jovian planets like on the inside?



Interiors of Jovian Planets

- No solid surface
- Layers under high pressure and temperatures
- Cores (~10 Earth masses) made of hydrogen compounds, metals, and rock
- The layers are different for the different planets.
WHY?

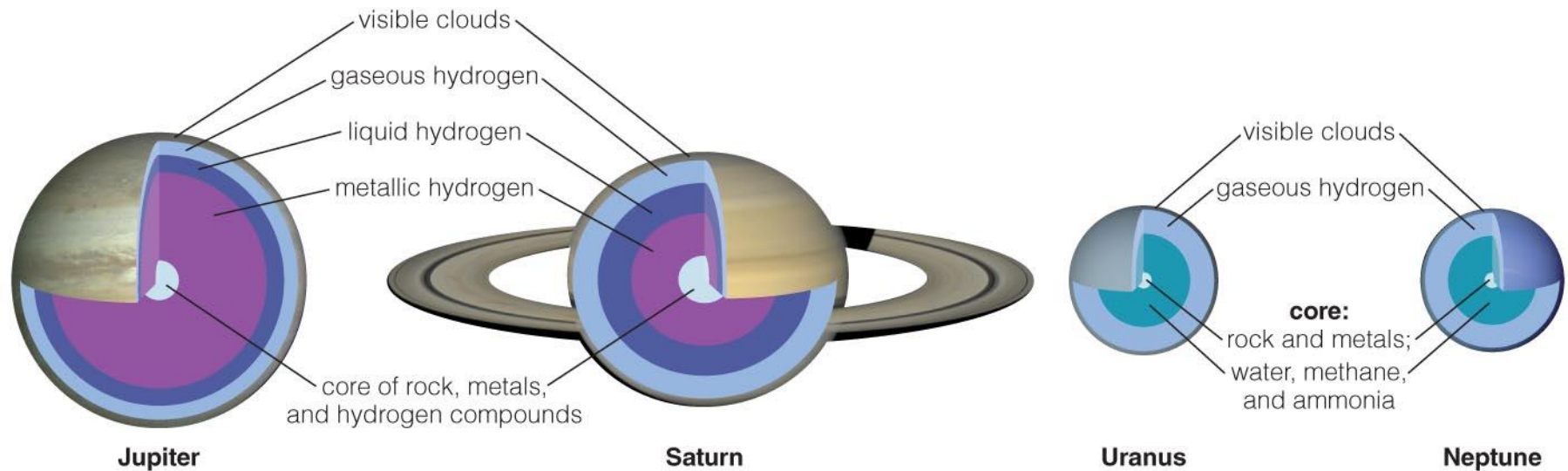
Inside Jupiter



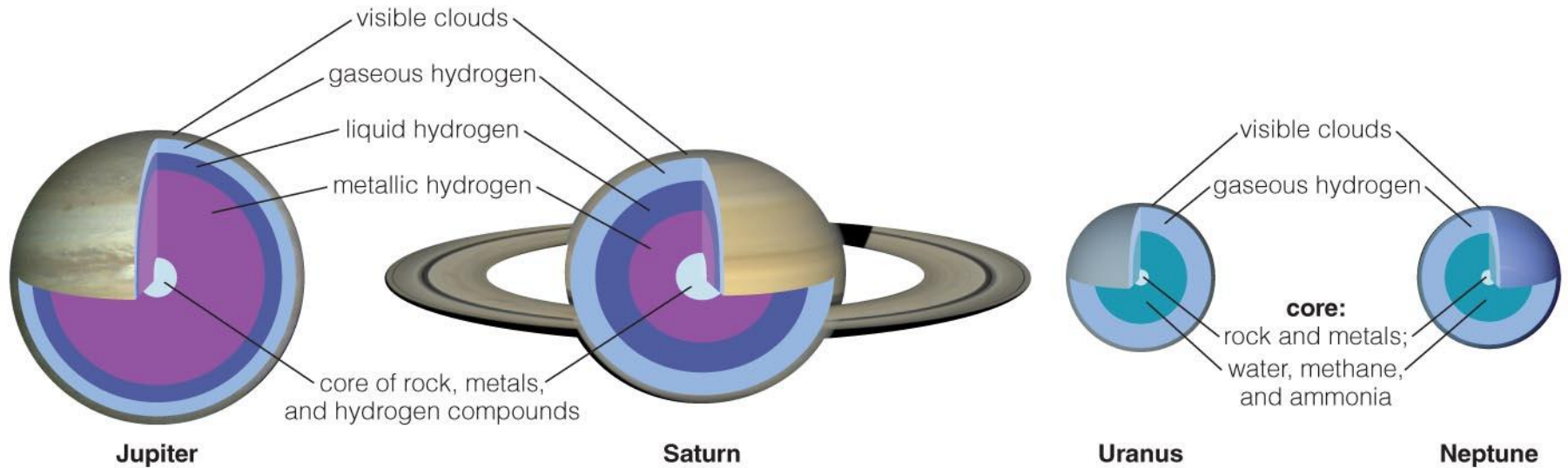
- High pressures inside Jupiter cause phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.

Inside Jupiter

- Core is thought to be made of rock, metals, and hydrogen compounds.
- Core is about same size as Earth but 10 times as massive.

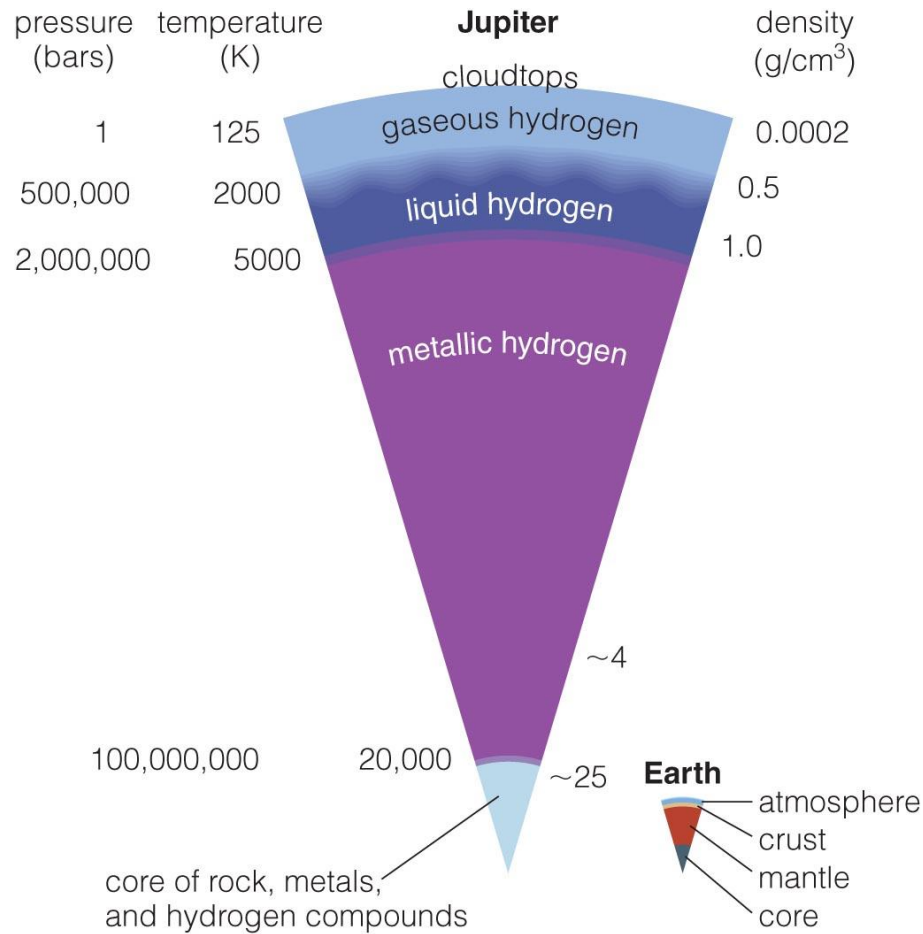


Comparing Jovian Interiors



- Models suggest cores of jovian planets have similar composition.
- Lower pressures inside Uranus and Neptune mean no metallic hydrogen.

Jupiter's Internal Heat

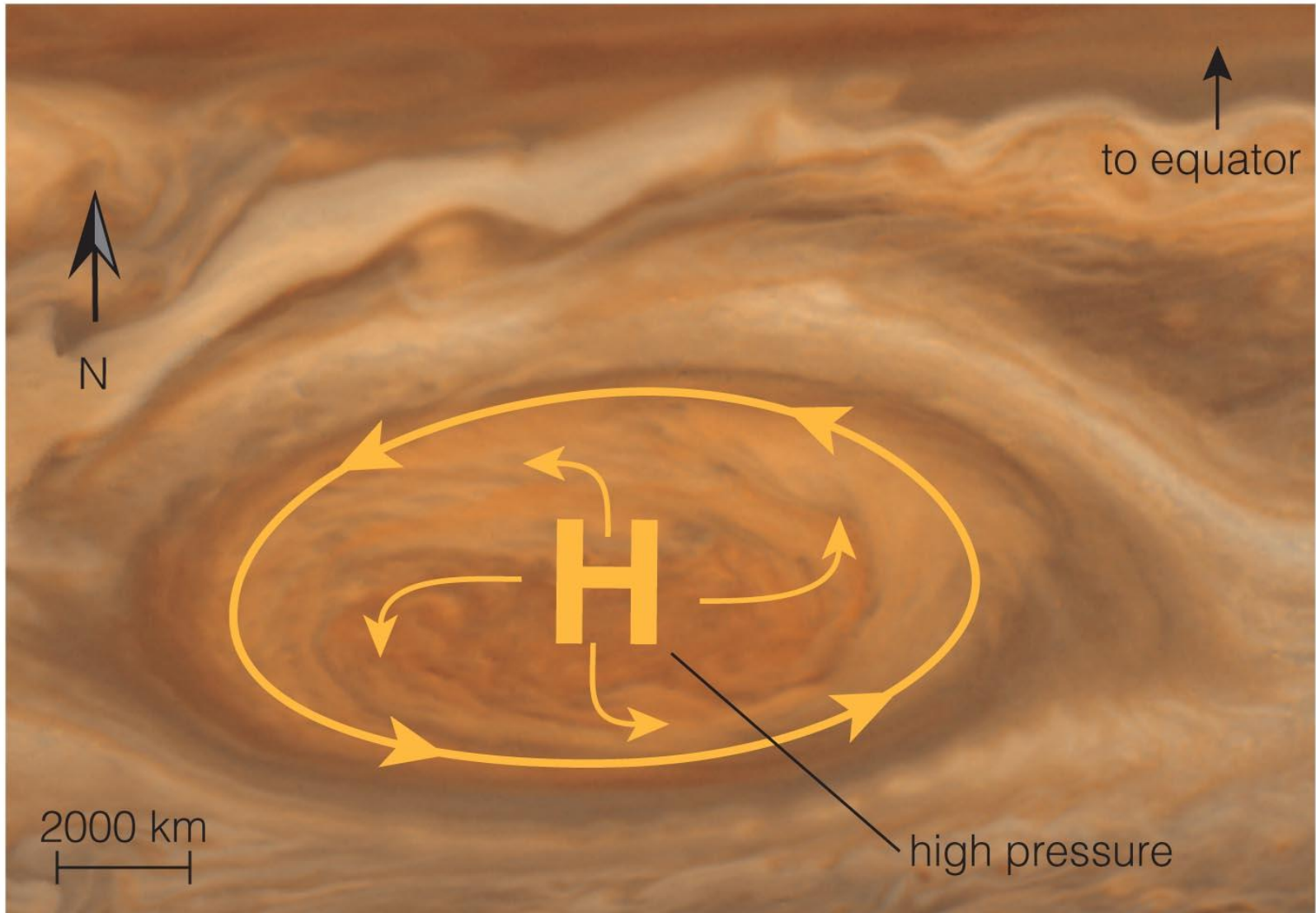


- Jupiter radiates twice as much energy as it receives from the Sun.
- Energy probably comes from slow contraction of interior (releasing potential energy).

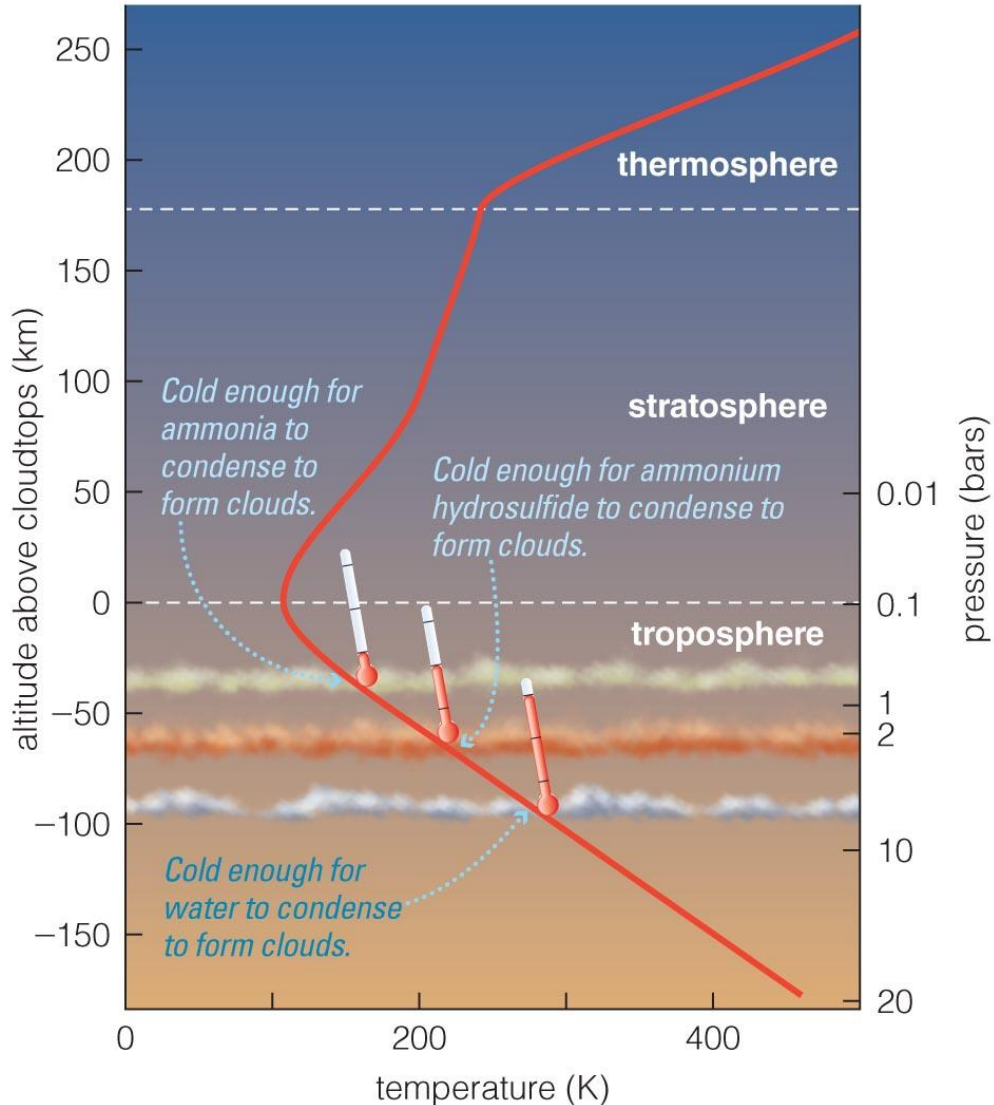
Internal Heat of Other Planets

- Saturn also radiates twice as much energy as it receives from the Sun.
- Energy probably comes from differentiation (helium rain).
- Neptune emits nearly twice as much energy as it receives, but the source of that energy remains mysterious.

What is the weather like on jovian planets?

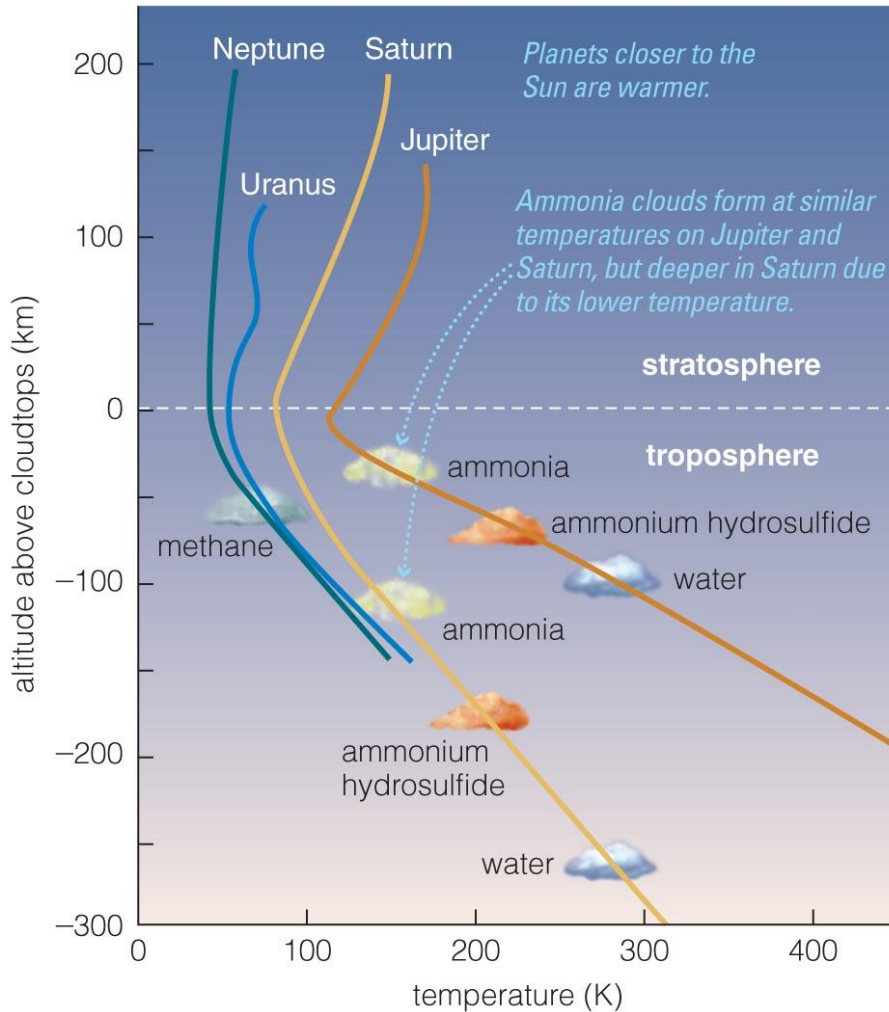


Jupiter's Atmosphere



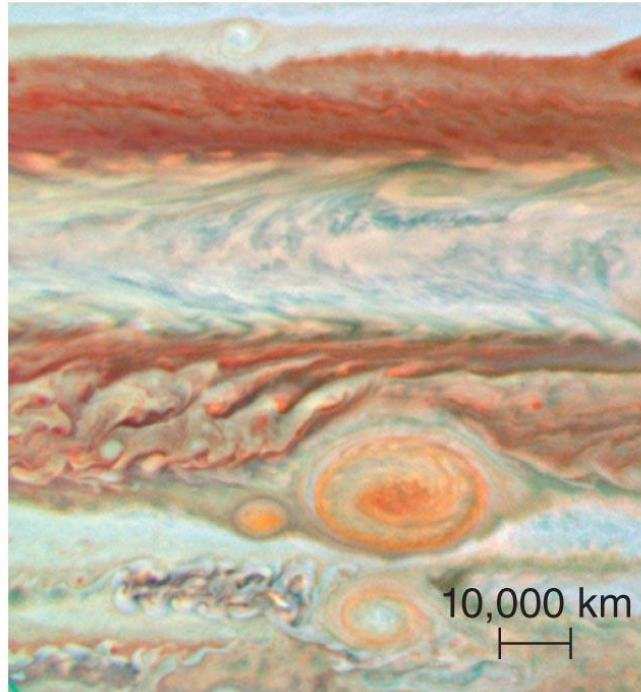
- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to freezing points of different hydrogen compounds.

Jovian Planet Atmospheres



- Other jovian planets have cloud layers similar to Jupiter's.
- Different compounds make clouds of different colors.

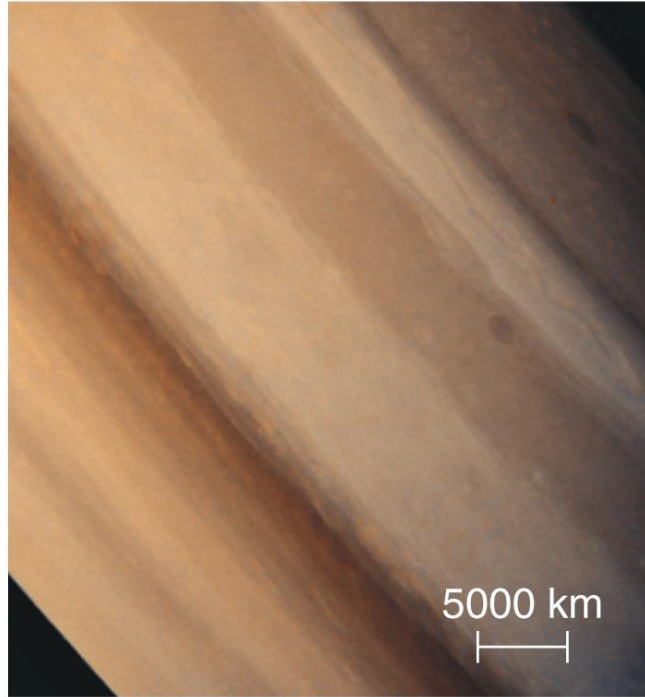
Jupiter's Colors



a This Hubble Space Telescope image shows Jupiter's southern hemisphere with the Great Red Spot, "Baby Red" (to its left), and "Red Jr." (below). Baby Red was torn apart by the Great Red Spot a few days later.

- Ammonium sulfide clouds (NH_4SH) reflect red/brown.
- Ammonia, the highest, coldest layer, reflects white.

Saturn's Colors

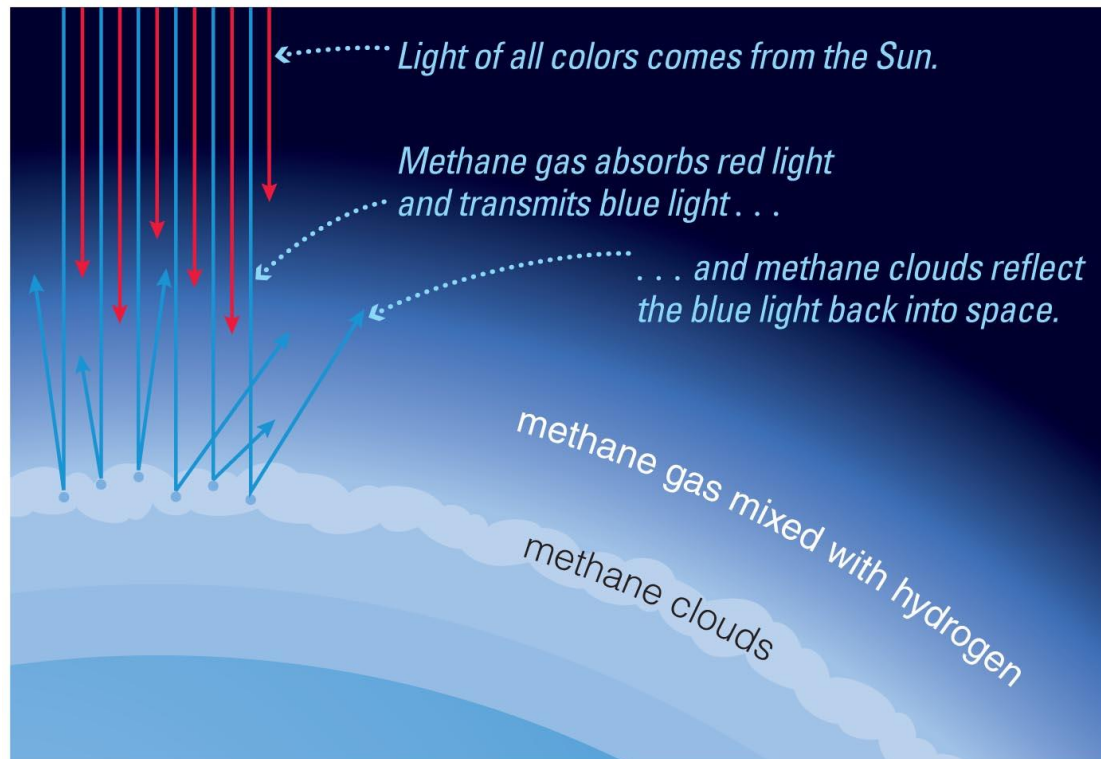


b Saturn's atmosphere, photographed by *Voyager 1*. Its banded appearance is very similar to that of Jupiter, but it has even faster winds.

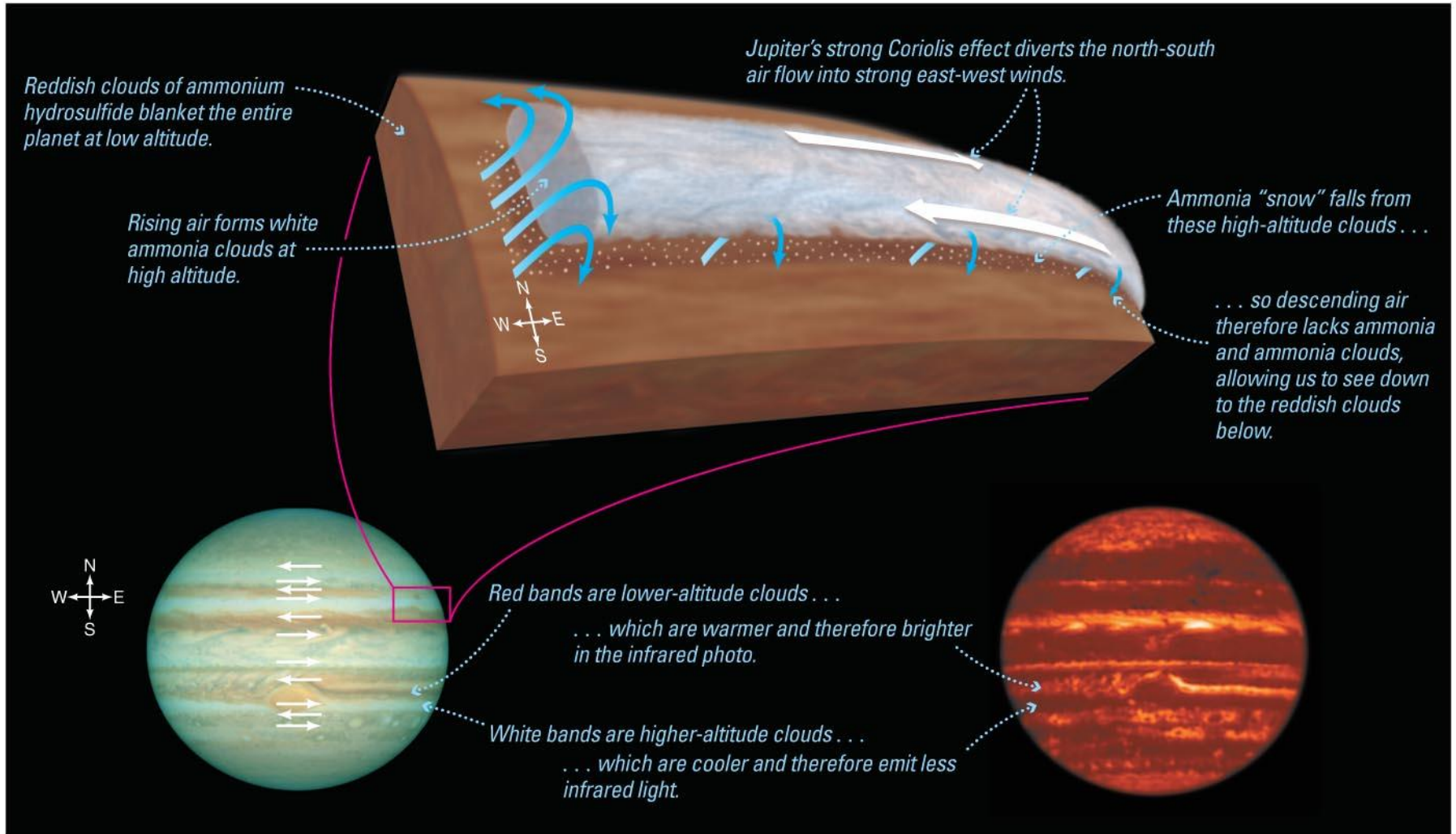
- Saturn's layers are similar, but deeper in and farther from the Sun (more subdued).

Methane on Uranus and Neptune

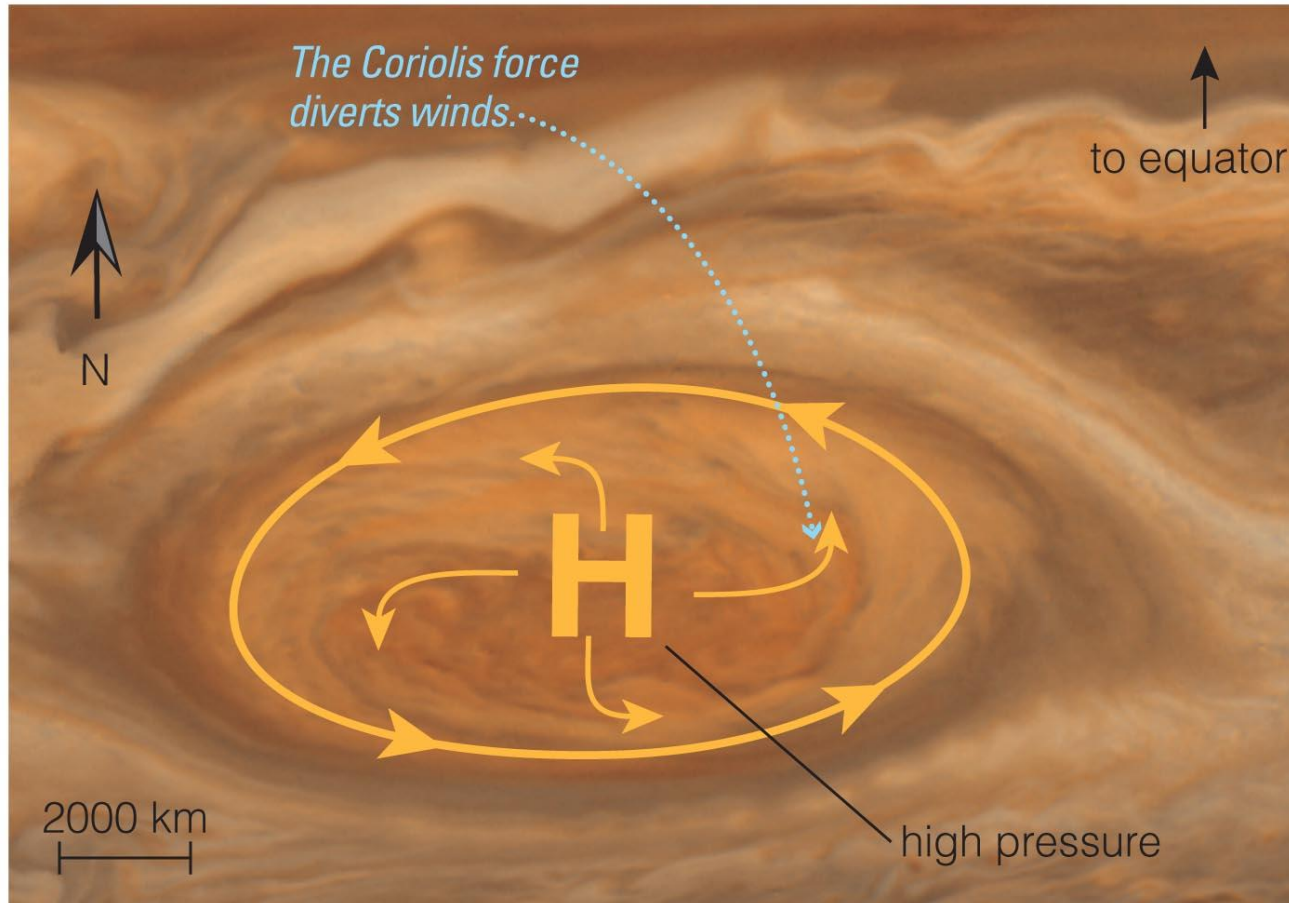
- Methane gas of Neptune and Uranus absorbs red light but transmits blue light.
- Blue light reflects off methane clouds, making those planes look blue.



Jupiter's Bands

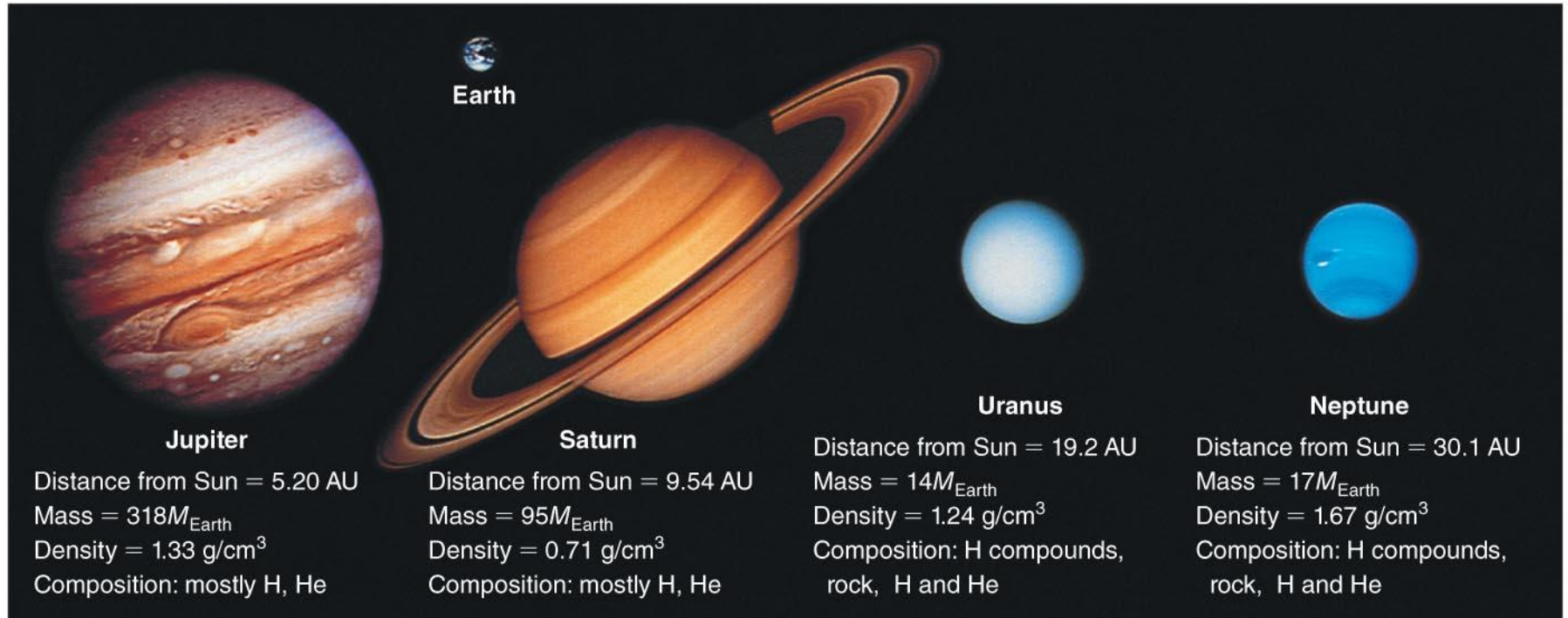


Jupiter's Great Red Spot



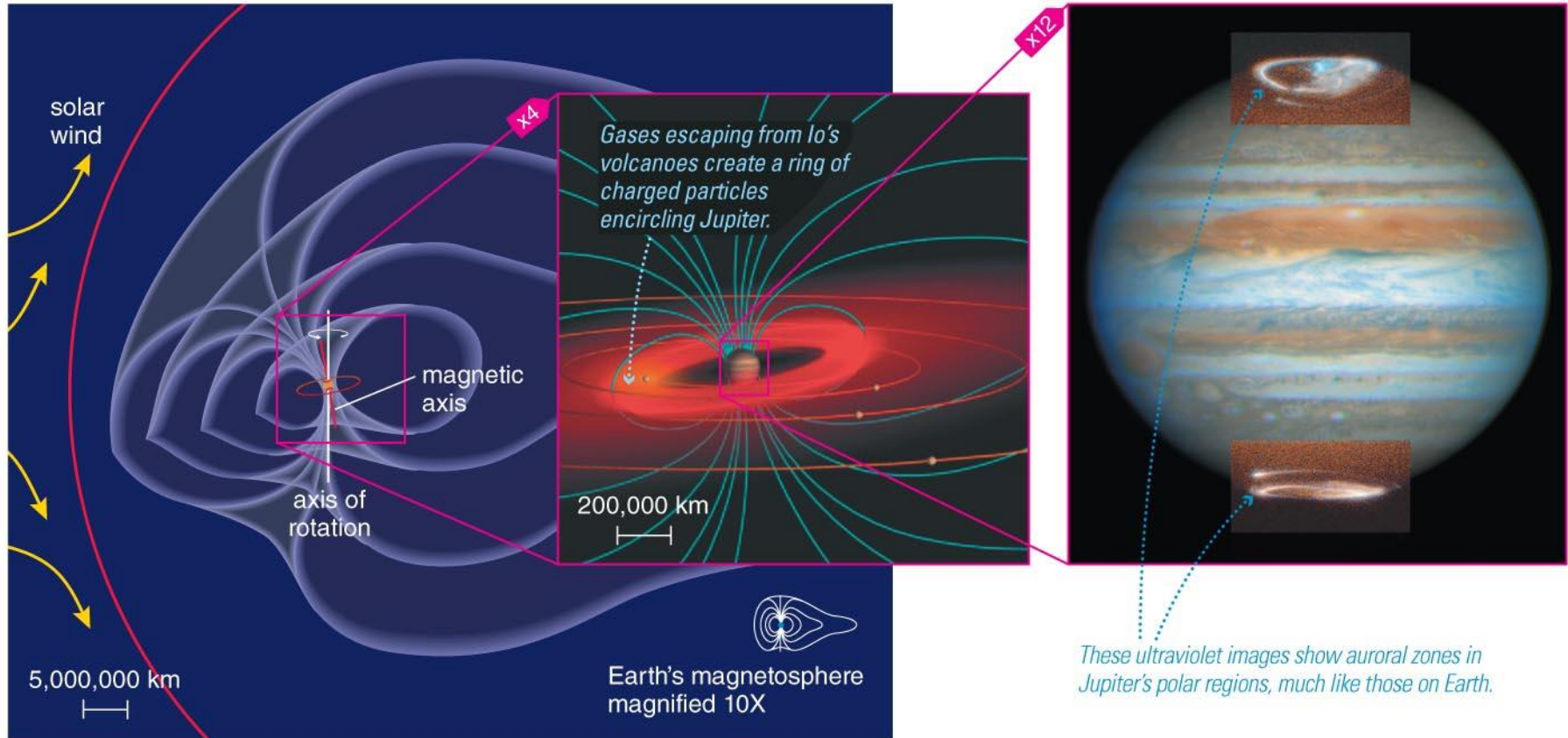
- Is a storm twice as wide as Earth
- Has existed for at least three centuries

Weather on Jovian Planets

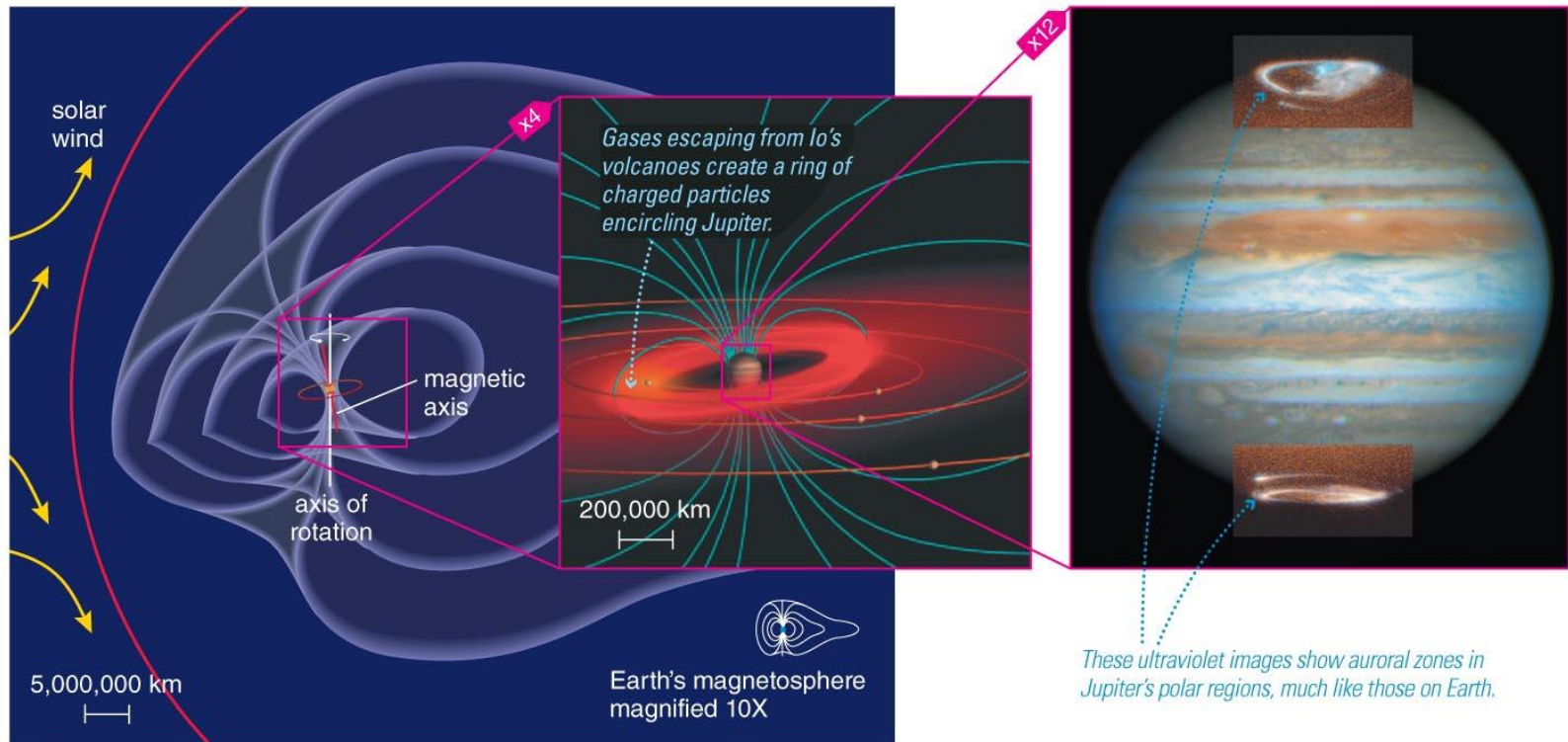


- All the jovian planets have strong winds and storms.

Do jovian planets have magnetospheres like Earth's?

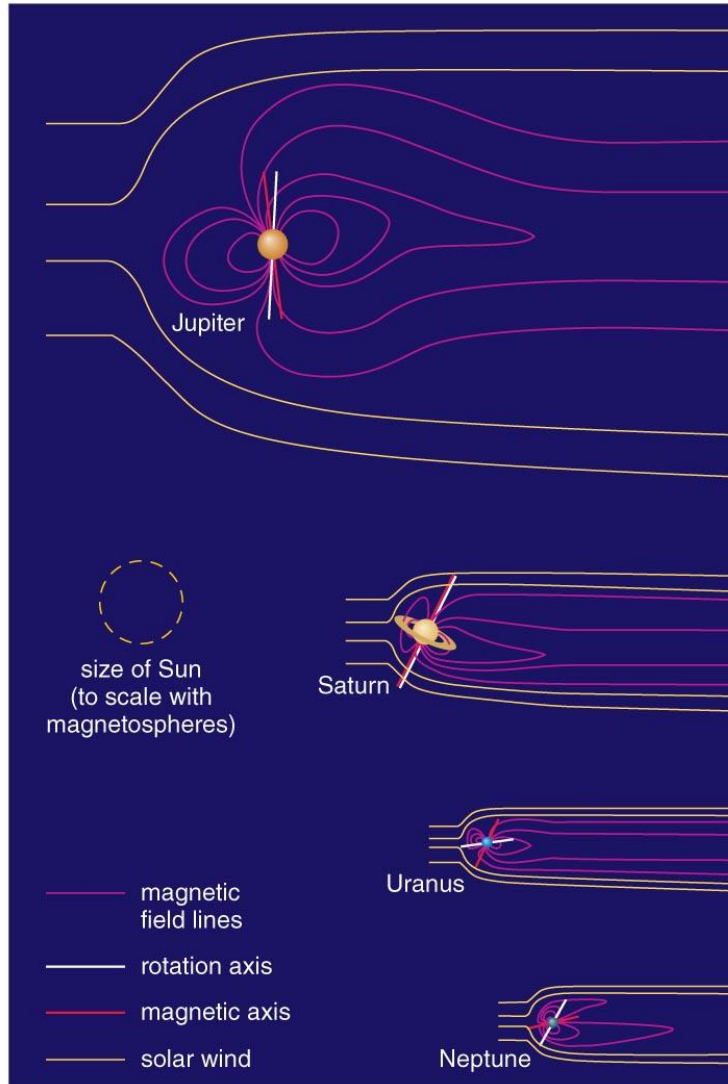


Jupiter's Magnetosphere



- Jupiter's strong magnetic field gives it an enormous magnetosphere.
- Gases escaping Io feed the donut-shaped Io torus.

Other Magnetospheres



- All jovian planets have substantial magnetospheres, but Jupiter's is the largest by far.

Thought Question

Jupiter does *not* have a large metal core like the Earth. How can it have a magnetic field?

- a) The magnetic field is left over from when Jupiter accreted.
- b) Its magnetic field comes from the Sun.
- c) It has metallic hydrogen inside, which circulates and makes a magnetic field.
- d) Its core creates a magnetic field, but it is very weak.

Thought Question

Jupiter does *not* have a large metal core like the Earth. How can it have a magnetic field?

- a) The magnetic field is left over from when Jupiter accreted.
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- c) It has metallic hydrogen inside, which circulates and makes a magnetic field.**
- d) Its core creates a magnetic field, but it is very weak.

What have we learned?

- **Are jovian planets all alike?**
 - Jupiter and Saturn are mostly H and He gas.
 - Uranus and Neptune are mostly H compounds.
- **What are jovian planets like on the inside?**
 - Layered interiors with very high pressure and cores made of rock, metals, and hydrogen compounds
 - Very high pressure in Jupiter and Saturn can produce metallic hydrogen.

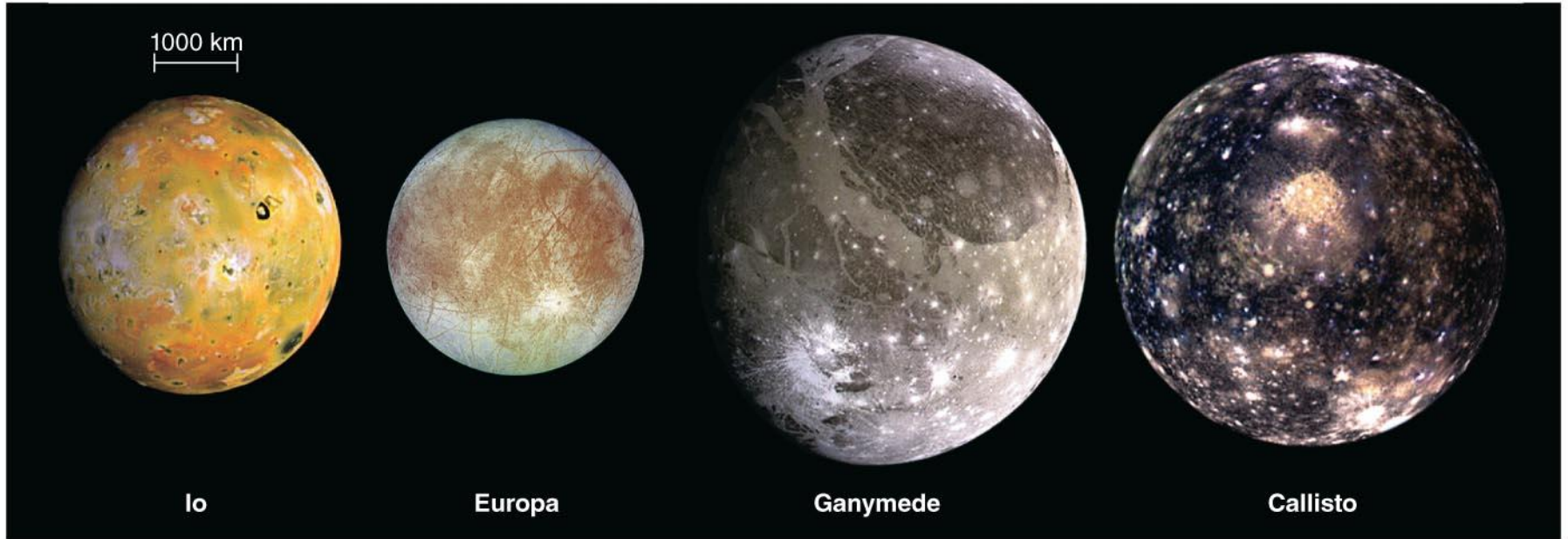
What have we learned?

- **What is the weather like on jovian planets?**
 - Multiple cloud layers determine colors of jovian planets.
 - All have strong storms and winds.
- **Do jovian planets have magnetospheres like Earth's?**
 - All have substantial magnetospheres.
 - Jupiter's is the largest by far.

11.2 A Wealth of Worlds: Satellites of Ice and Rock

- Our goals for learning:
 - **What kinds of moons orbit the jovian planets?**
 - **Why are Jupiter's Galilean moons so geologically active?**
 - **What geological activity do we see on Titan and other distant moons?**
 - **Why are small icy moons more geologically active than small rocky planets?**

What kinds of moons orbit the jovian planets?



Sizes of Moons

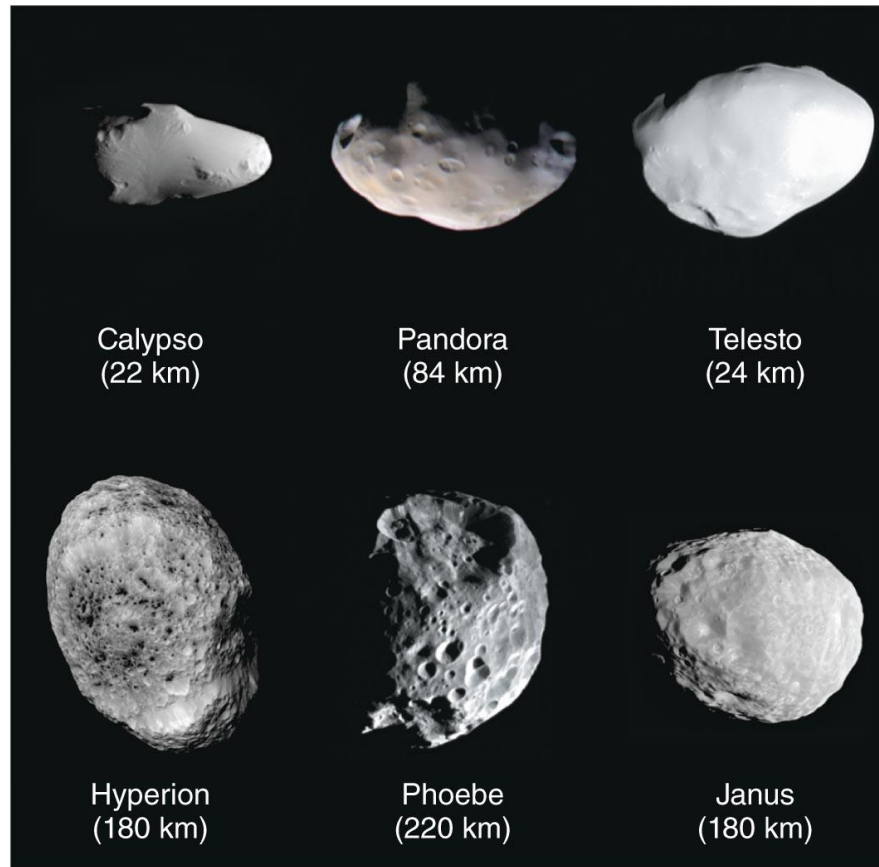
- Small moons (< 300 km)
 - No geological activity
- Medium-sized moons (300–1500 km)
 - Geological activity in past
- Large moons (> 1500 km)
 - Ongoing geological activity

Medium and Large Moons



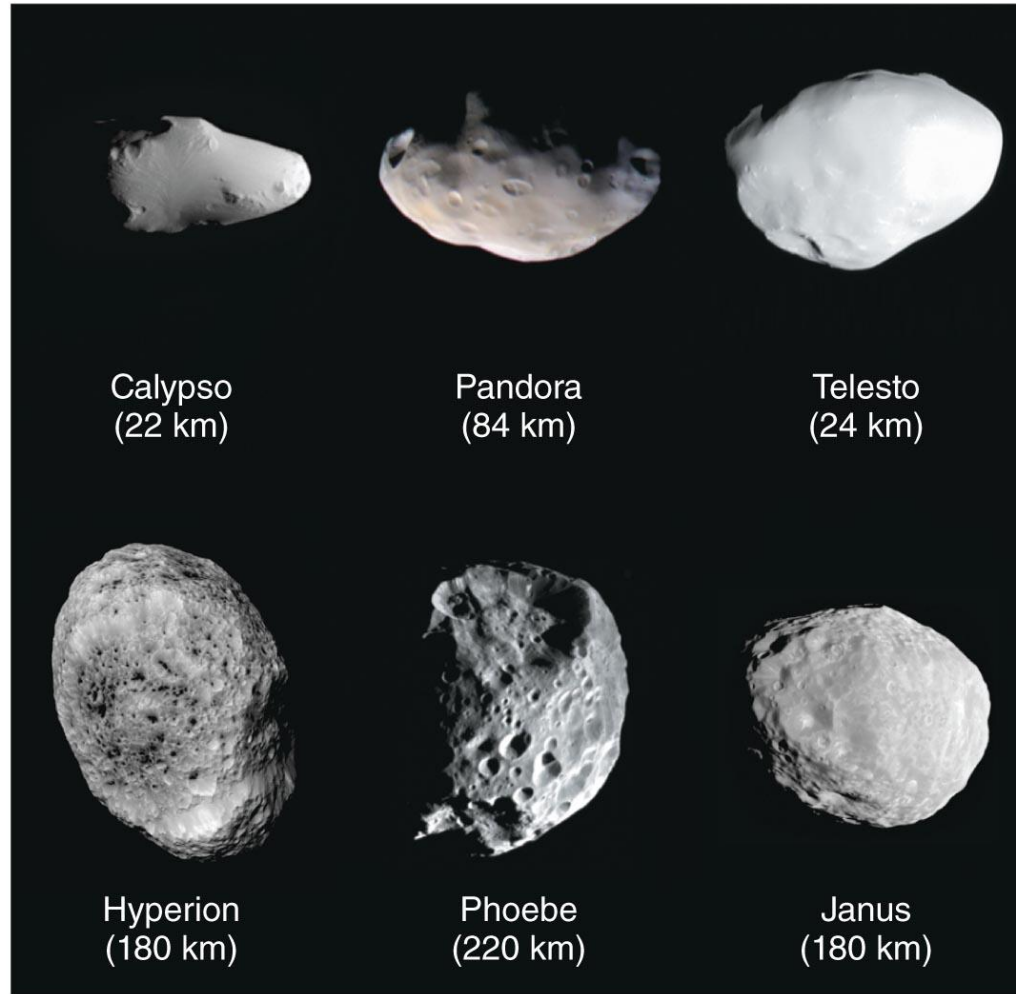
- Enough self-gravity to be spherical
- Have substantial amounts of ice
- Formed in orbit around jovian planets
- Circular orbits in same direction as planet rotation

Small Moons



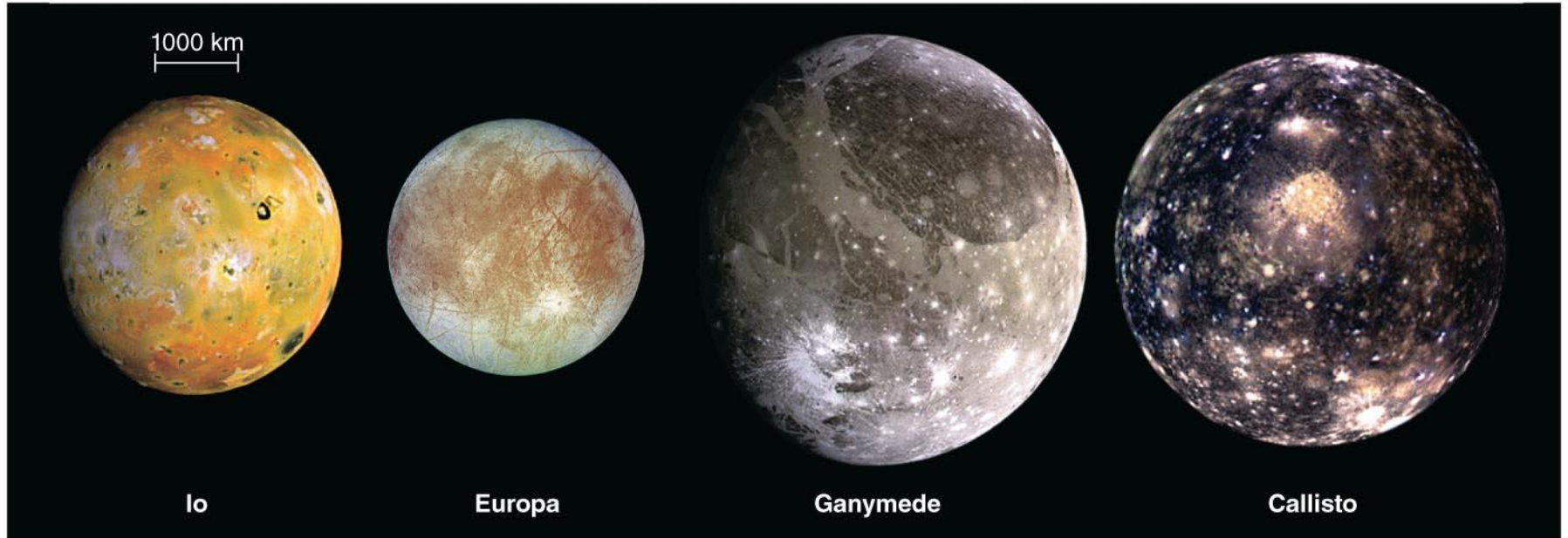
- These are far more numerous than the medium and large moons.
- They do not have enough gravity to be spherical: Most are "potato-shaped."

Small Moons

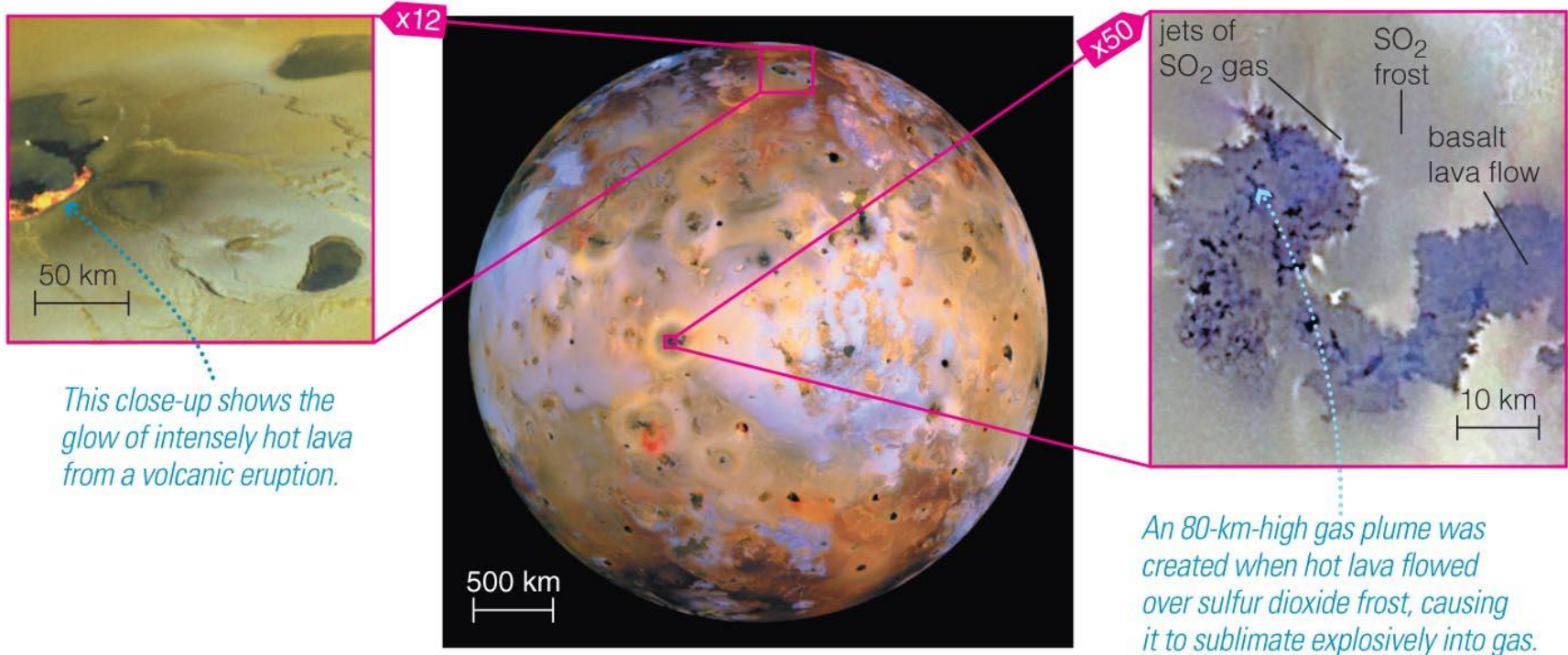


- They are captured asteroids or comets, so their orbits do not follow usual patterns.

Why are Jupiter's Galilean moons so geologically active?

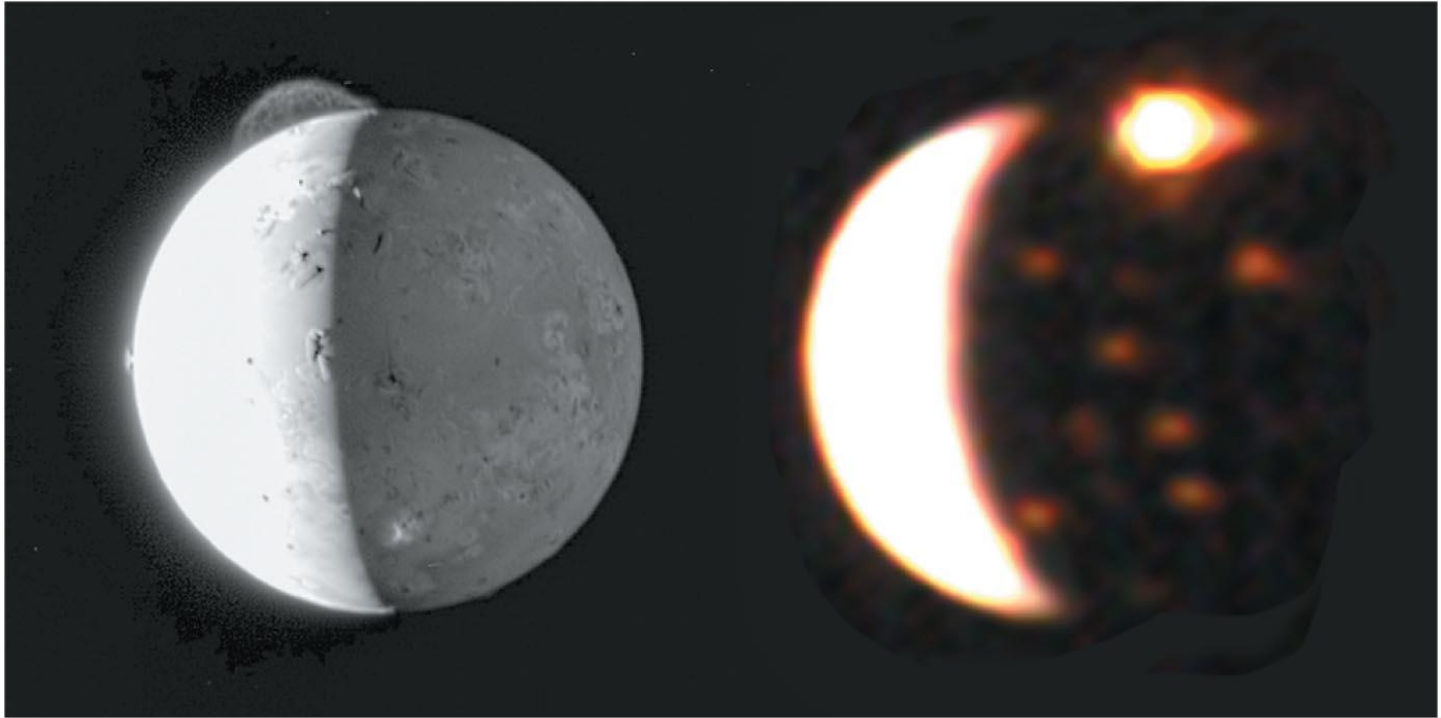


Io's Volcanic Activity



- Io is the most volcanically active body in the solar system, but why?

Io's Volcanoes

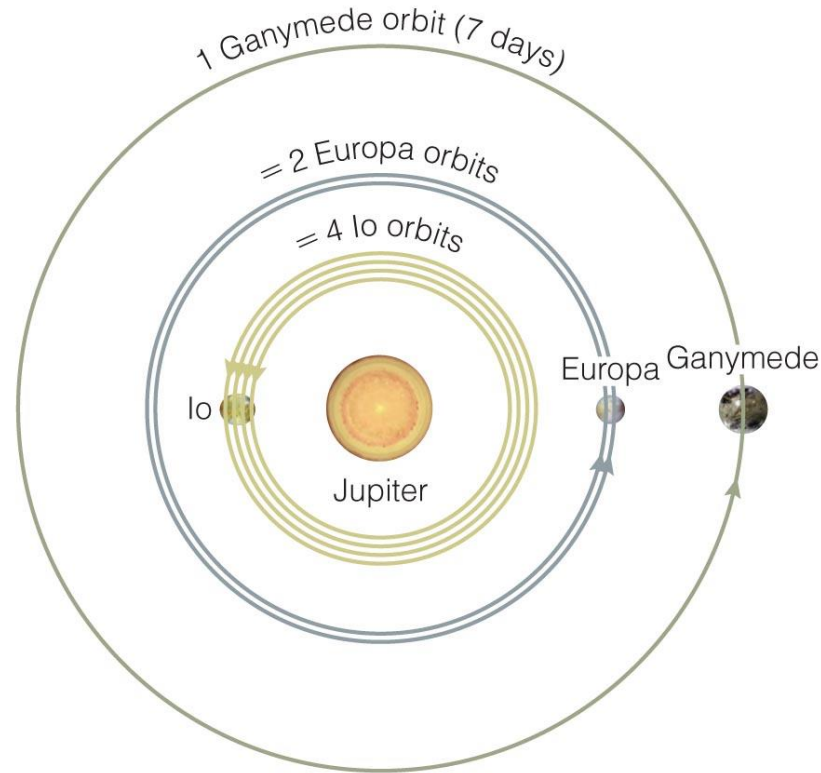


- Volcanic eruptions continue to change Io's surface.

Tidal Heating

- Io is squished and stretched as it orbits Jupiter.
- But why is its orbit so elliptical?

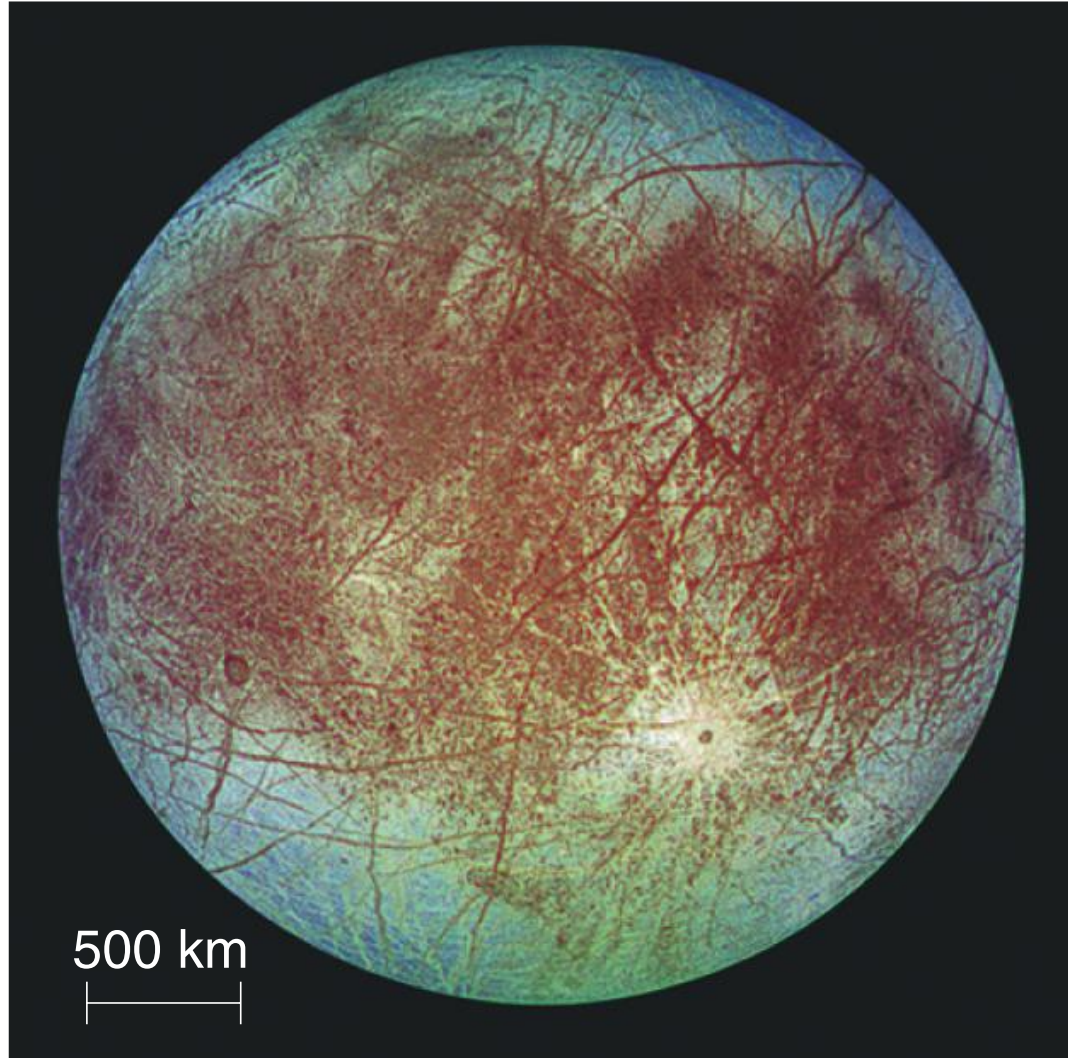
Orbital Resonances



b Io's orbit is elliptical because of the orbital resonance Io shares with Europa and Ganymede.

- Every 7 days, these three moons line up.
- The tugs add up over time, making all three orbits elliptical.

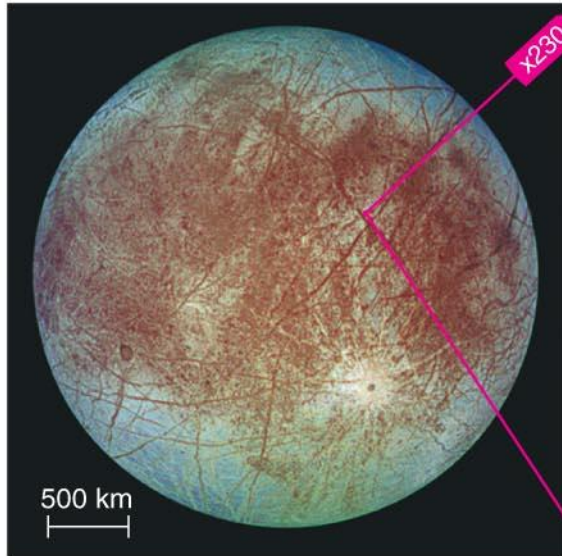
Europa: Waterworld?



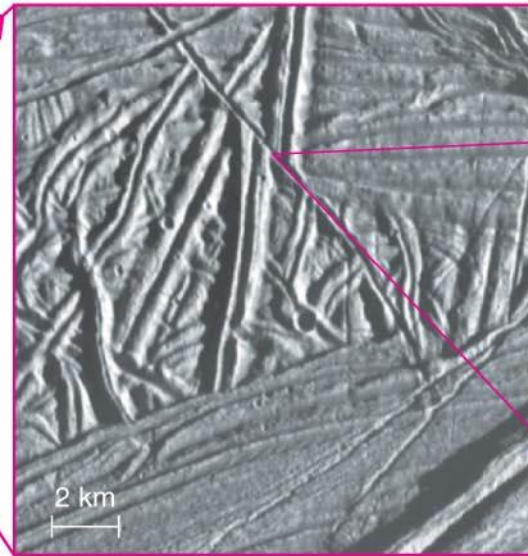
Europa's surface appears heavily cracked even from a distance.

NASA/JPL/DLR

Tidal stresses crack Europa's surface ice.

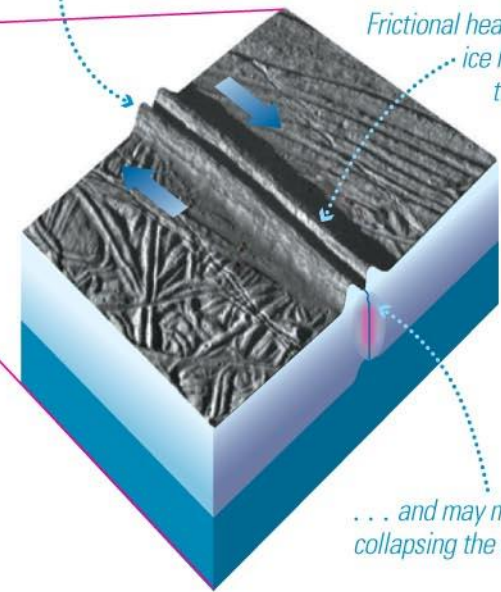


Europa's surface appears heavily cracked even from a distance.



Close-up photos show double-ridged cracks, best explained by an icy crust moving upon a soft or liquid layer below.

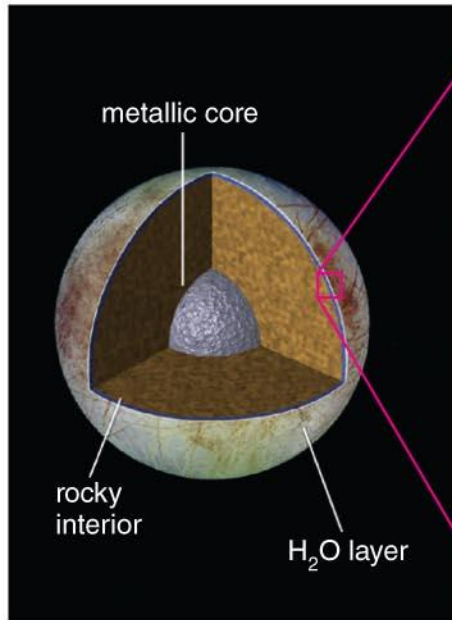
Tidal stresses cause parts of Europa's icy crust to slowly slide past each other.



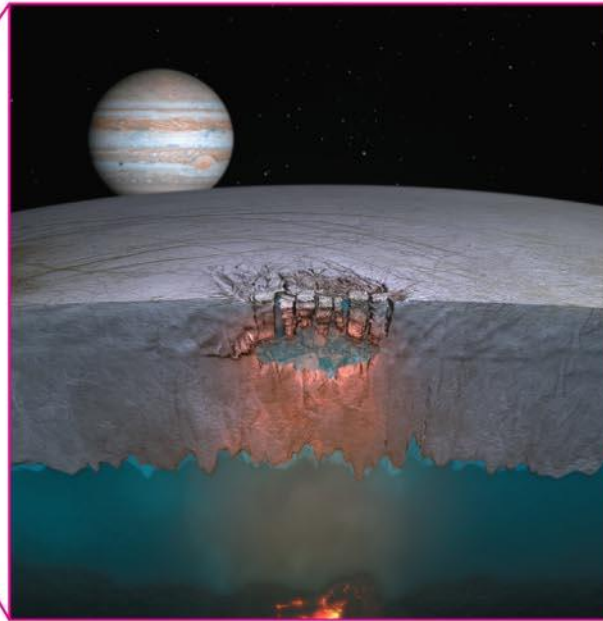
Frictional heating expands ice here, forming the ridge . . .

. . . and may melt ice here, collapsing the ridge center.

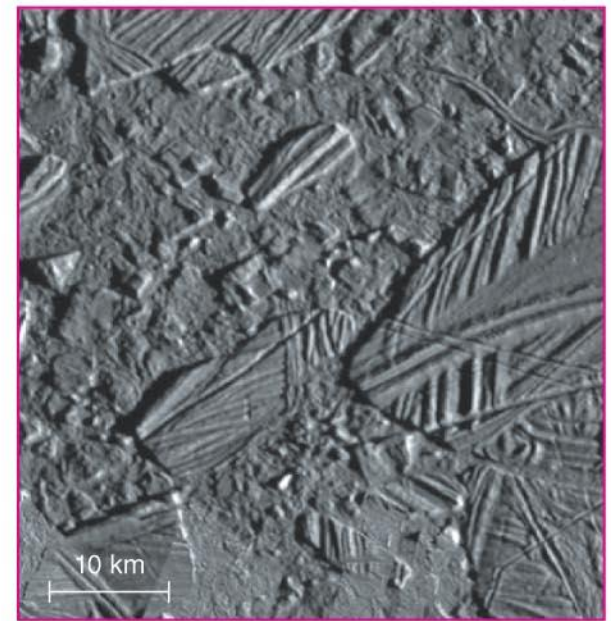
Europa's interior also warmed by tidal heating.



Europa may have a 100-km-thick ocean under an icy crust.

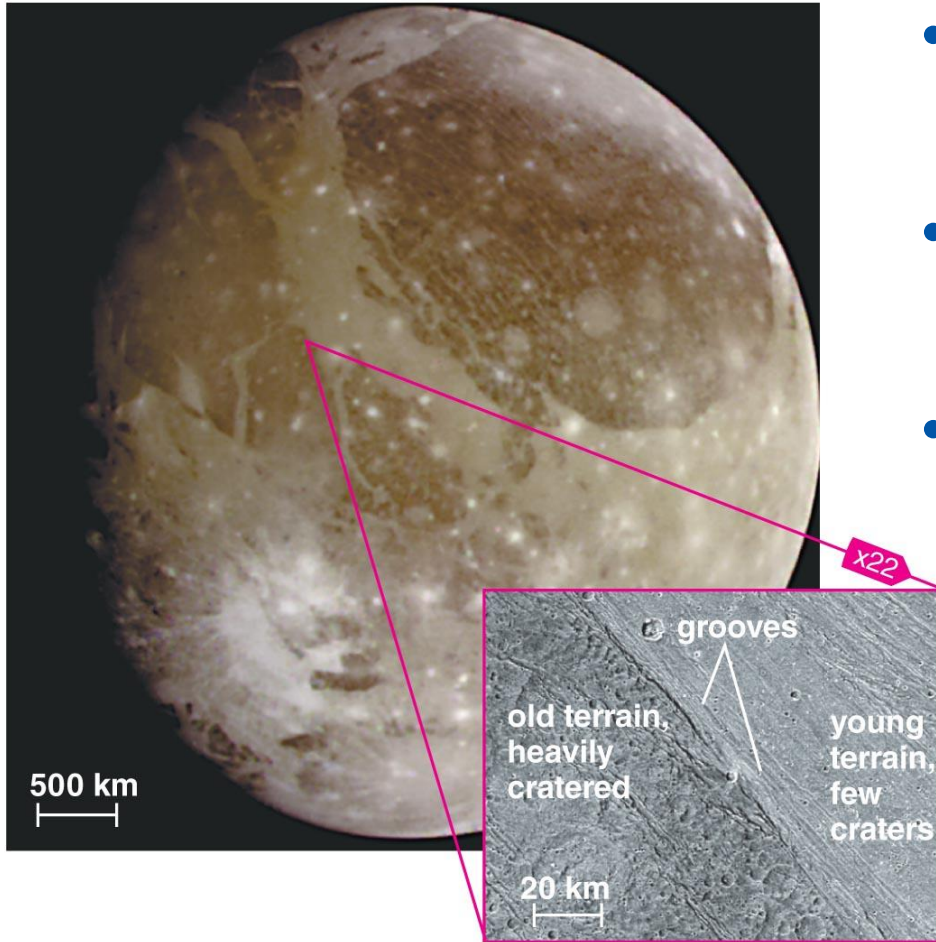


Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .



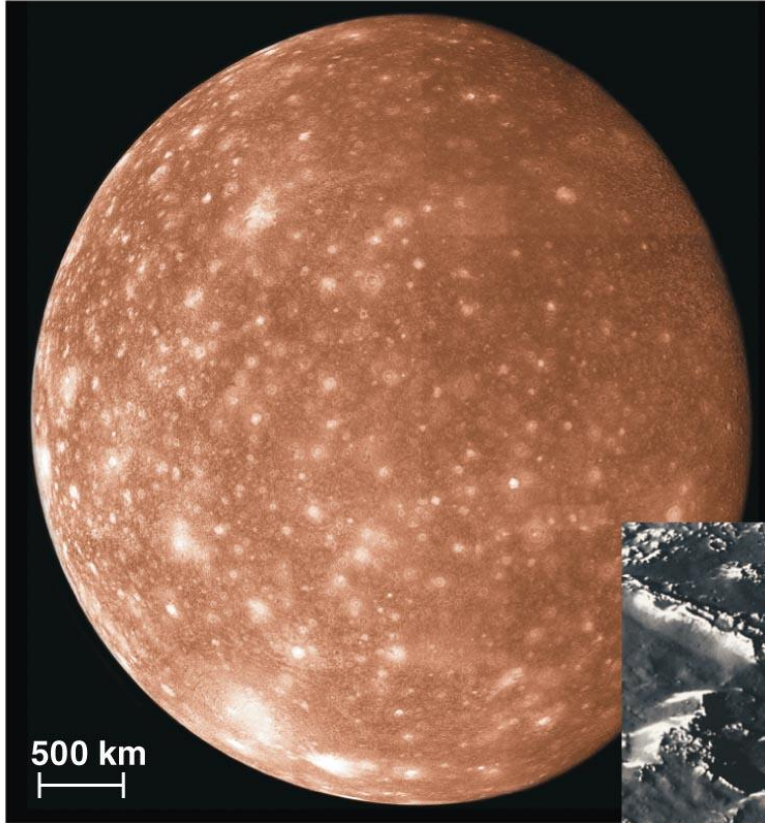
. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

Ganymede

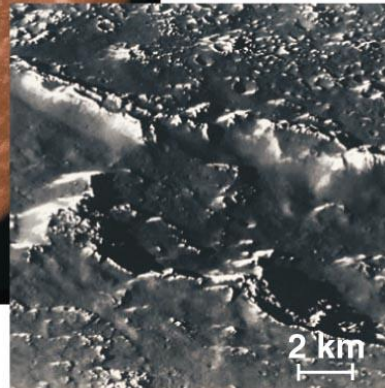


- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?

Callisto



Callisto is heavily cratered, indicating an old surface that nonetheless may hide a deeply buried ocean.



Close-up photo shows a dark powder overlaying the low areas of the surface.

- "Classic" cratered iceball
- No tidal heating, no orbital resonances
- But it has a magnetic field!?

Thought Question

How does Io get heated by Jupiter?

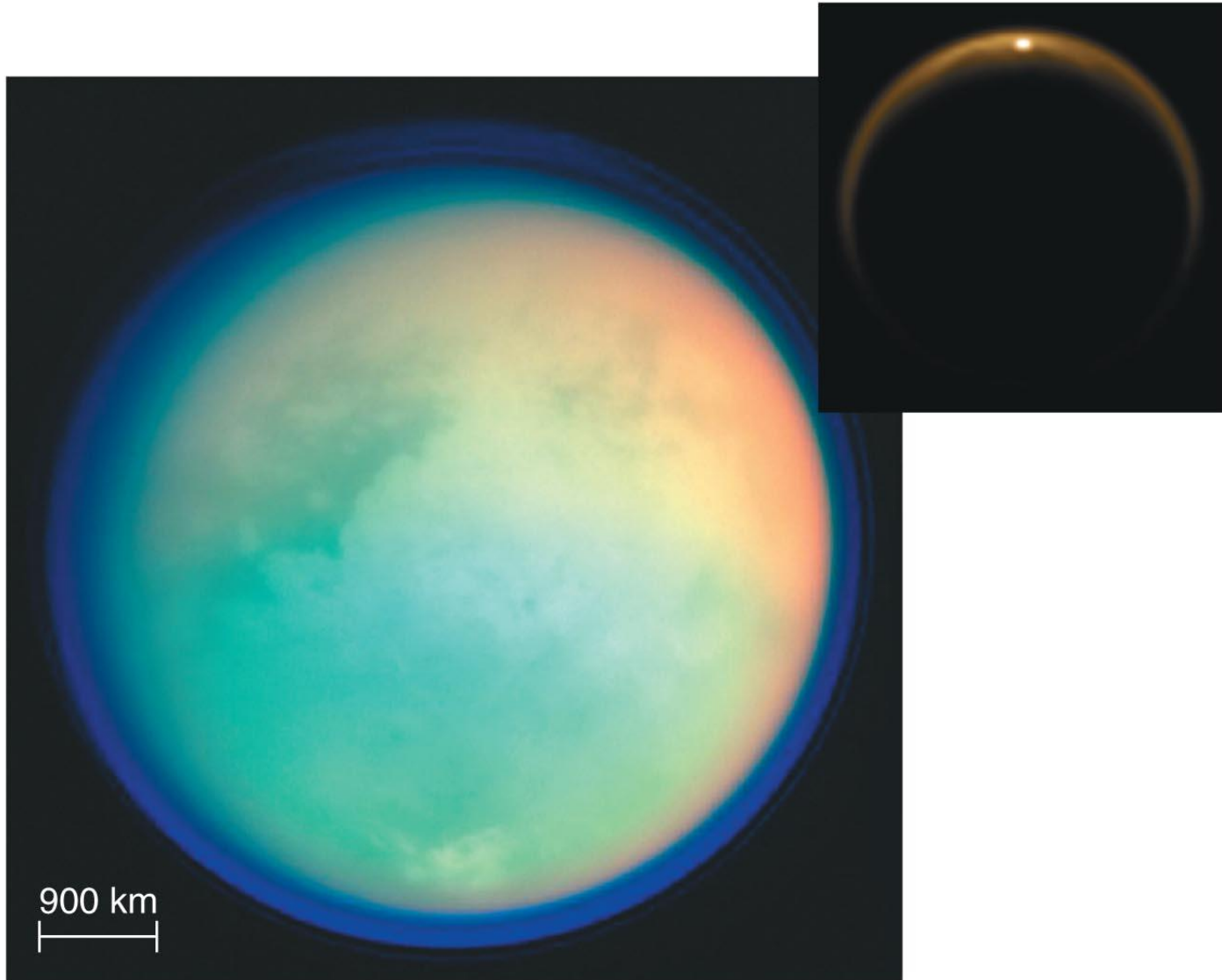
- a) auroras
- b) infrared light
- c) tidal resonance
- d) volcanoes

Thought Question

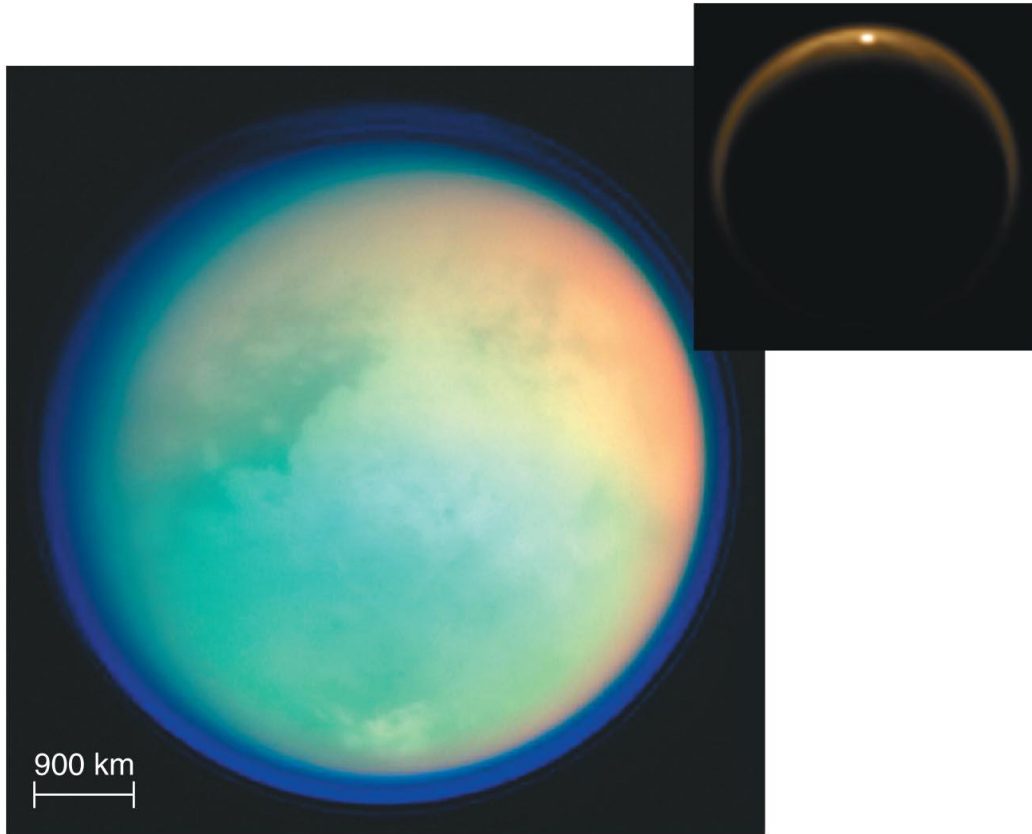
How does Io get heated by Jupiter?

- a) auroras
- b) infrared light
- c) tidal resonance**
- d) volcanoes

What geological activity do we see on Titan and other distant moons?

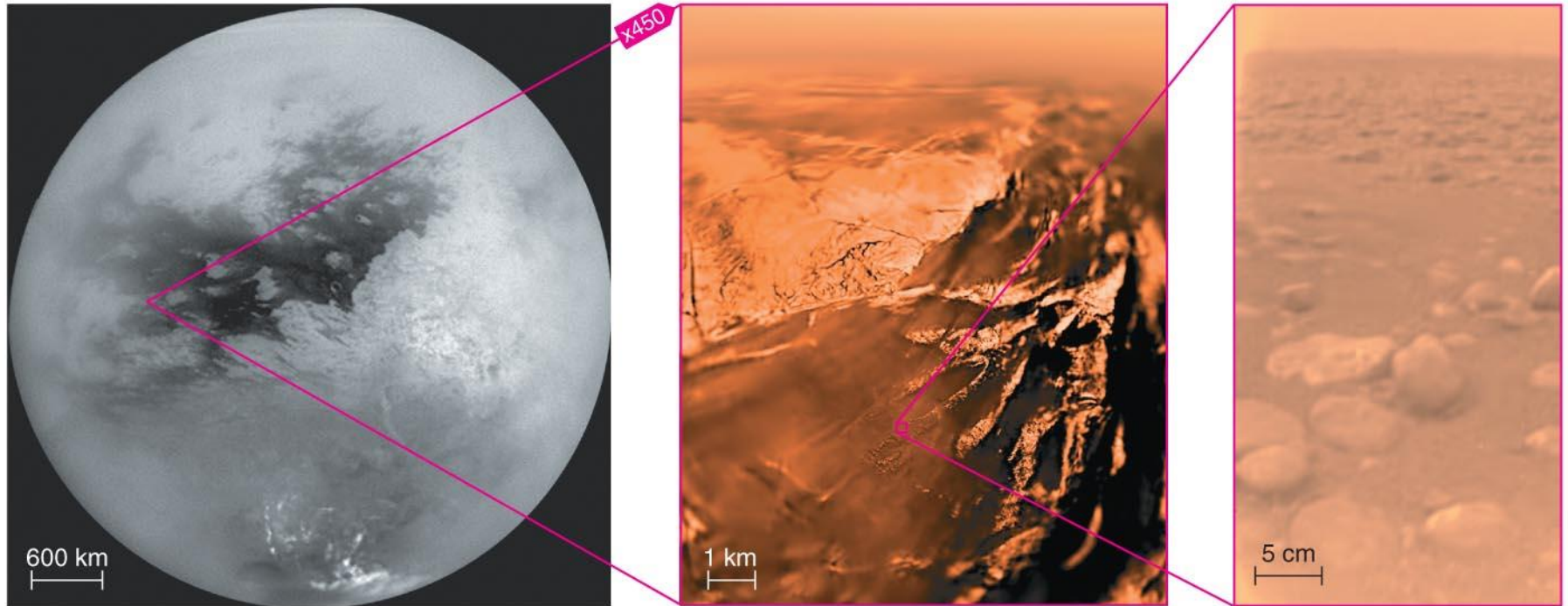


Titan's Atmosphere



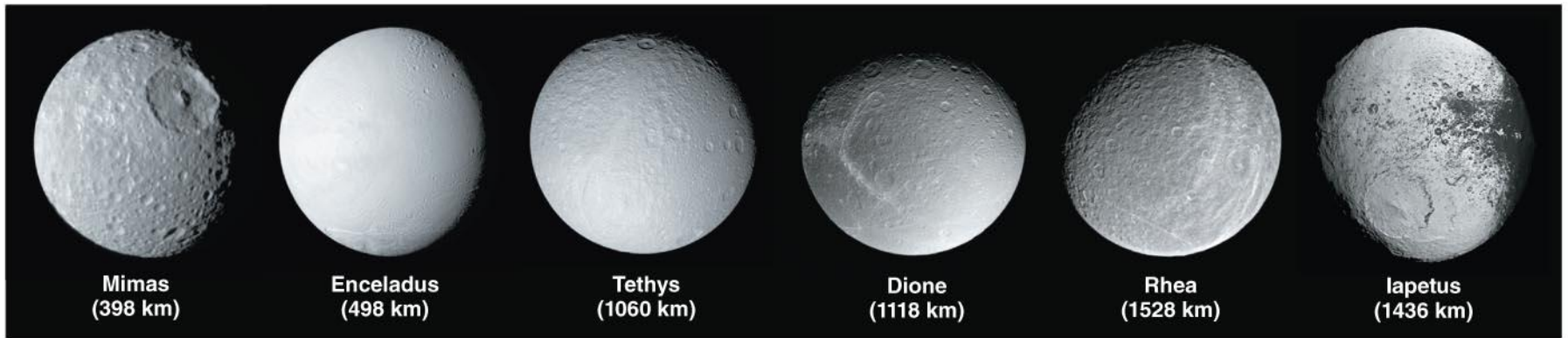
- Titan is the only moon in the solar system to have a thick atmosphere.
- It consists mostly of nitrogen with some argon, methane, and ethane.

Titan's Surface



- *Huygens* probe provided first look at Titan's surface in early 2005.
- It found liquid methane and "rocks" made of ice.

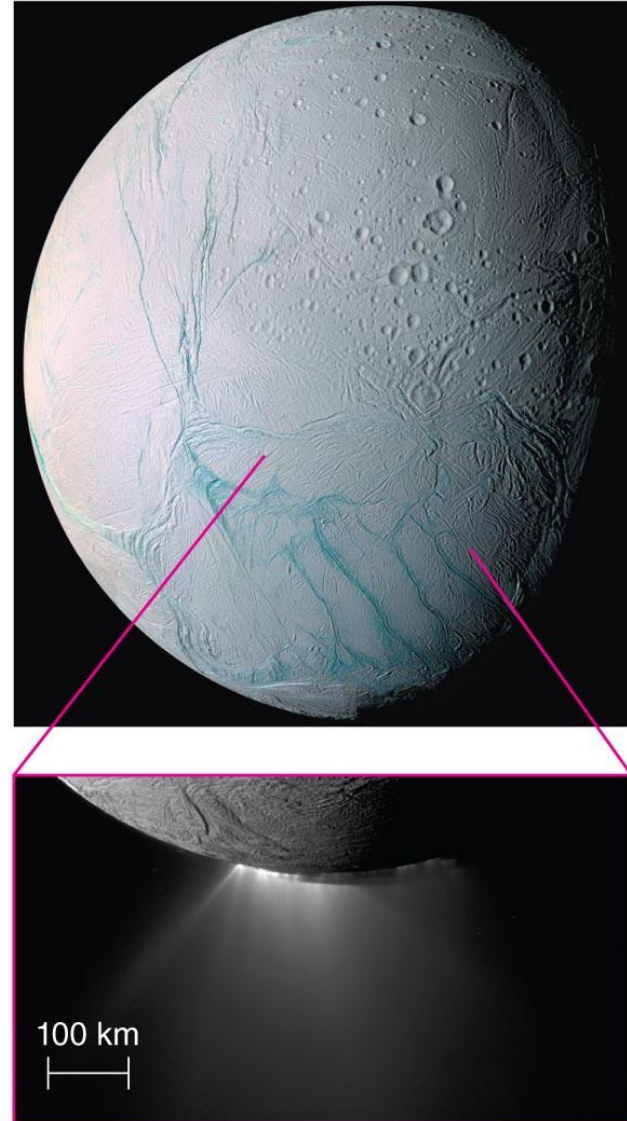
Medium Moons of Saturn



- Almost all of them show evidence of past volcanism and/or tectonics.

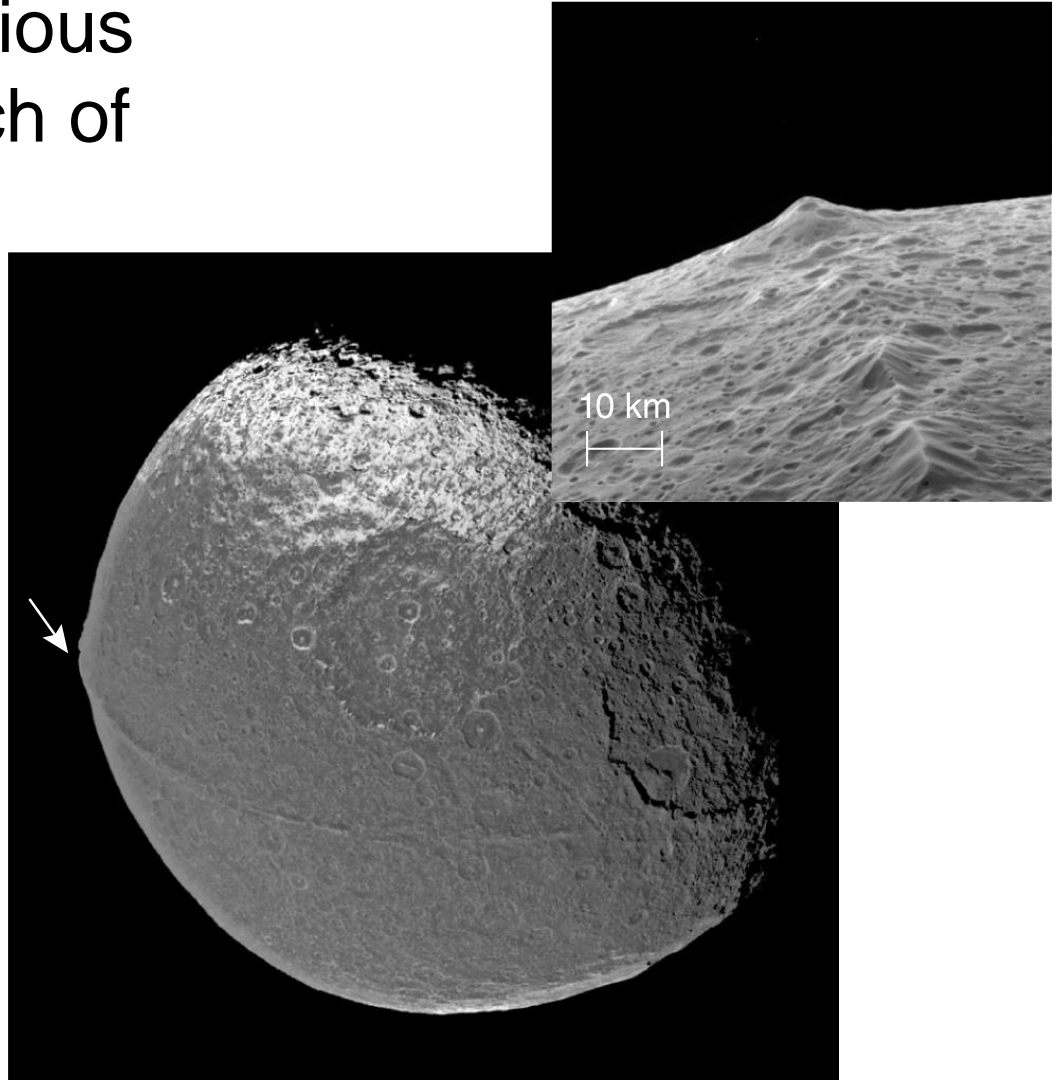
Medium Moons of Saturn

- Ice fountains of Enceladus suggest it may have a subsurface ocean.

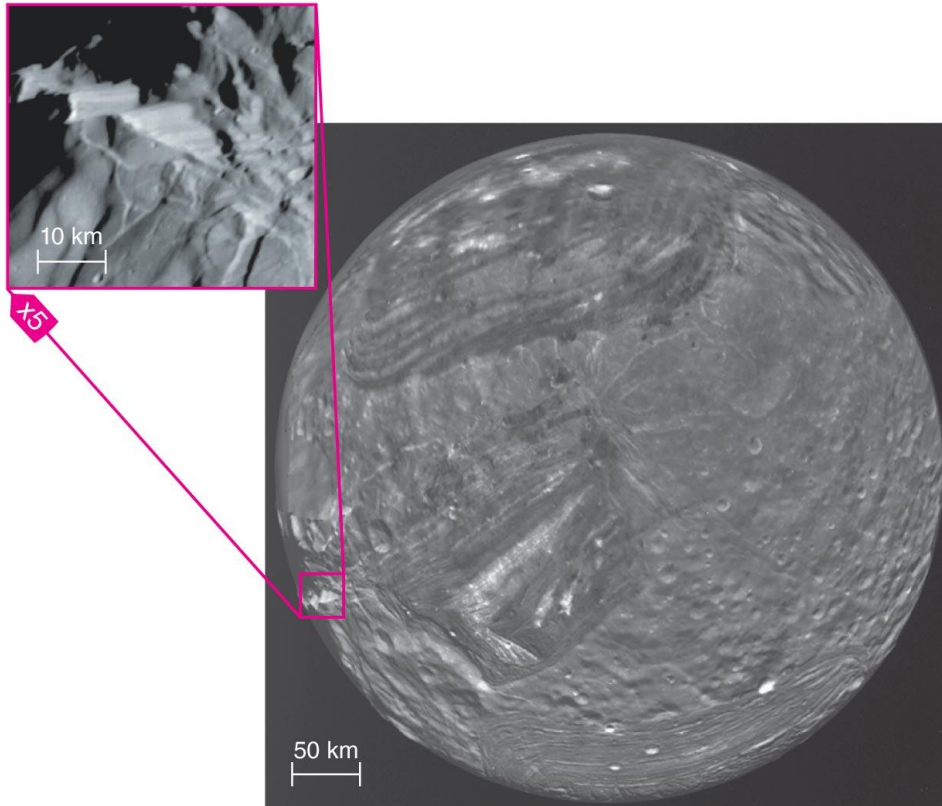


Medium Moons of Saturn

- Iapetus has a curious ridge around much of its equator

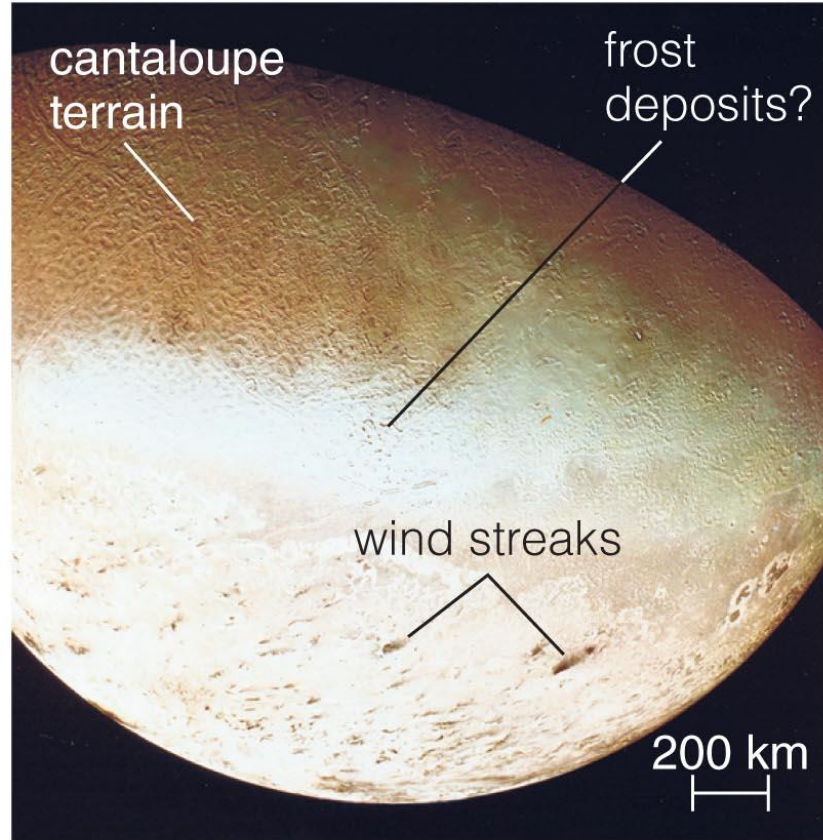


Medium Moons of Uranus

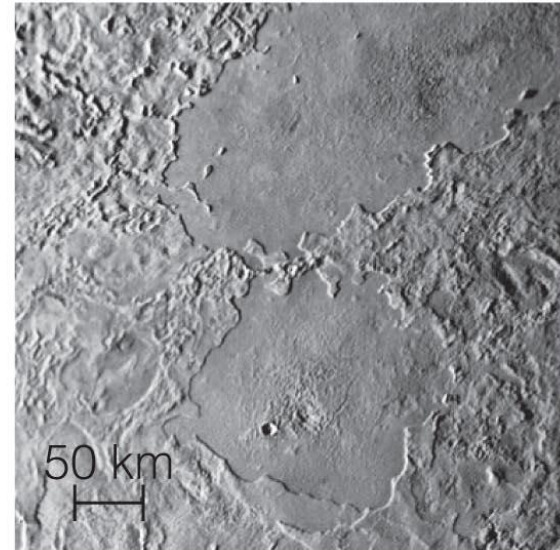


- They have varying amounts of geological activity – many unsolved mysteries!
- Miranda has large tectonic features and few craters (possibly indicating an episode of tidal heating in past).

Neptune's Moon Triton



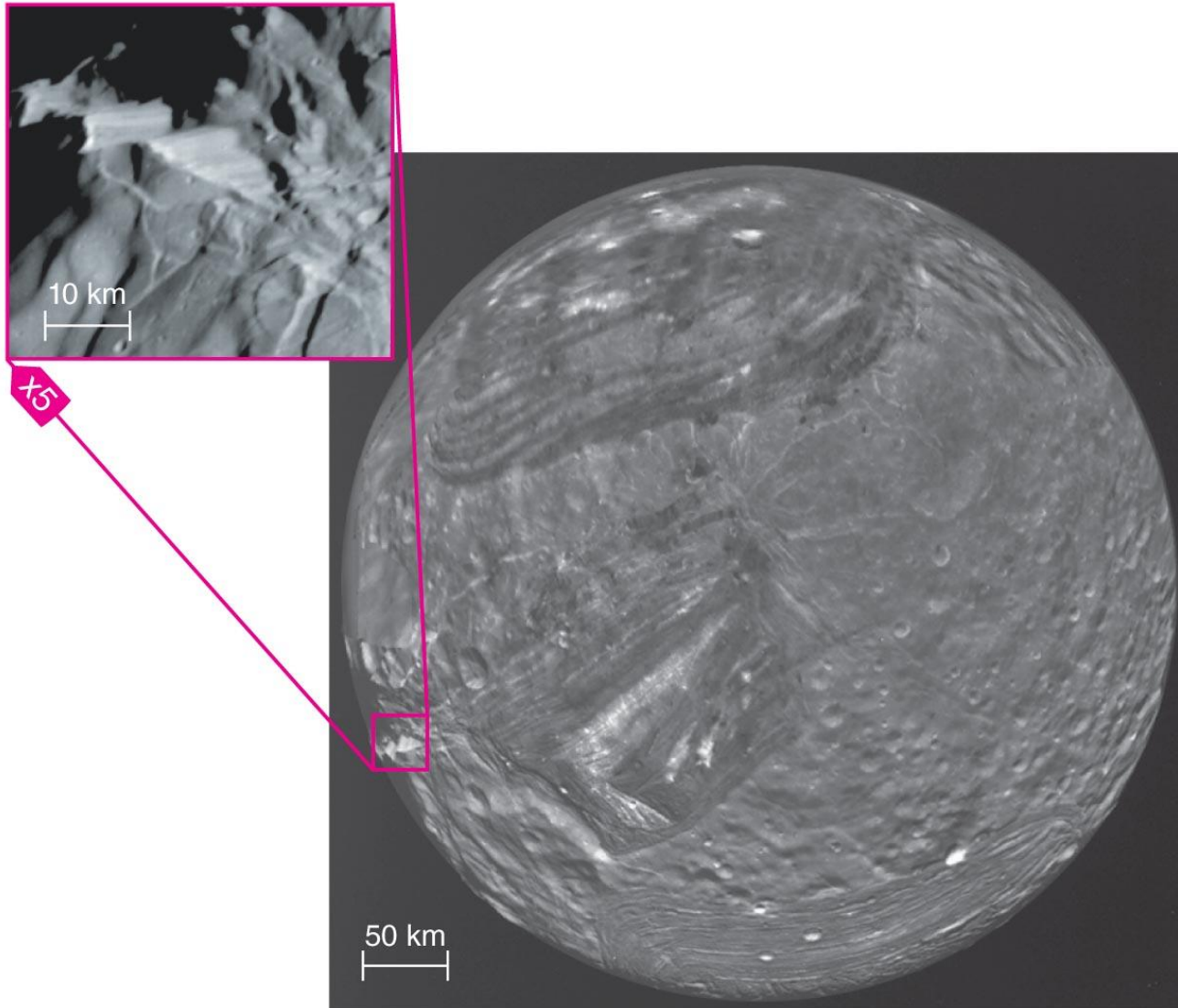
Triton's southern hemisphere as seen by *Voyager 2*.



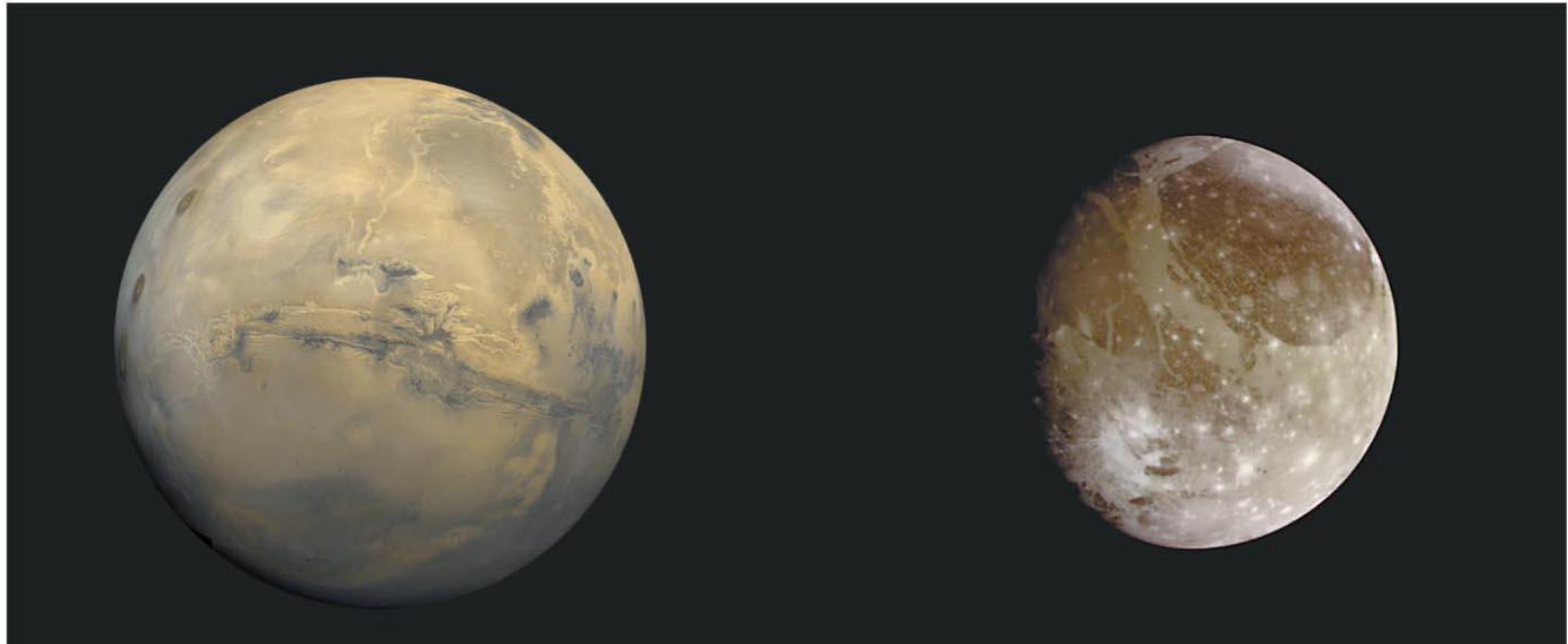
This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

- Likely captured Kuiper belt object
- Evidence of past geological activity

Why are small icy moons more geologically active than small rocky planets?



Rocky Planets versus Icy Moons



- Rock melts at higher temperatures.
- Only large rocky planets have enough heat for activity.
- Ice melts at lower temperatures.
- Tidal heating can melt internal ice, driving activity.

What have we learned?

- **What kinds of moons orbit the jovian planets?**
 - Moons come in many sizes.
 - The level of geological activity depends on a moon's size.
- **Why are Jupiter's Galilean moons so geologically active?**
 - Tidal heating drives geological activity, leading to Io's volcanoes and ice geology on other moons.

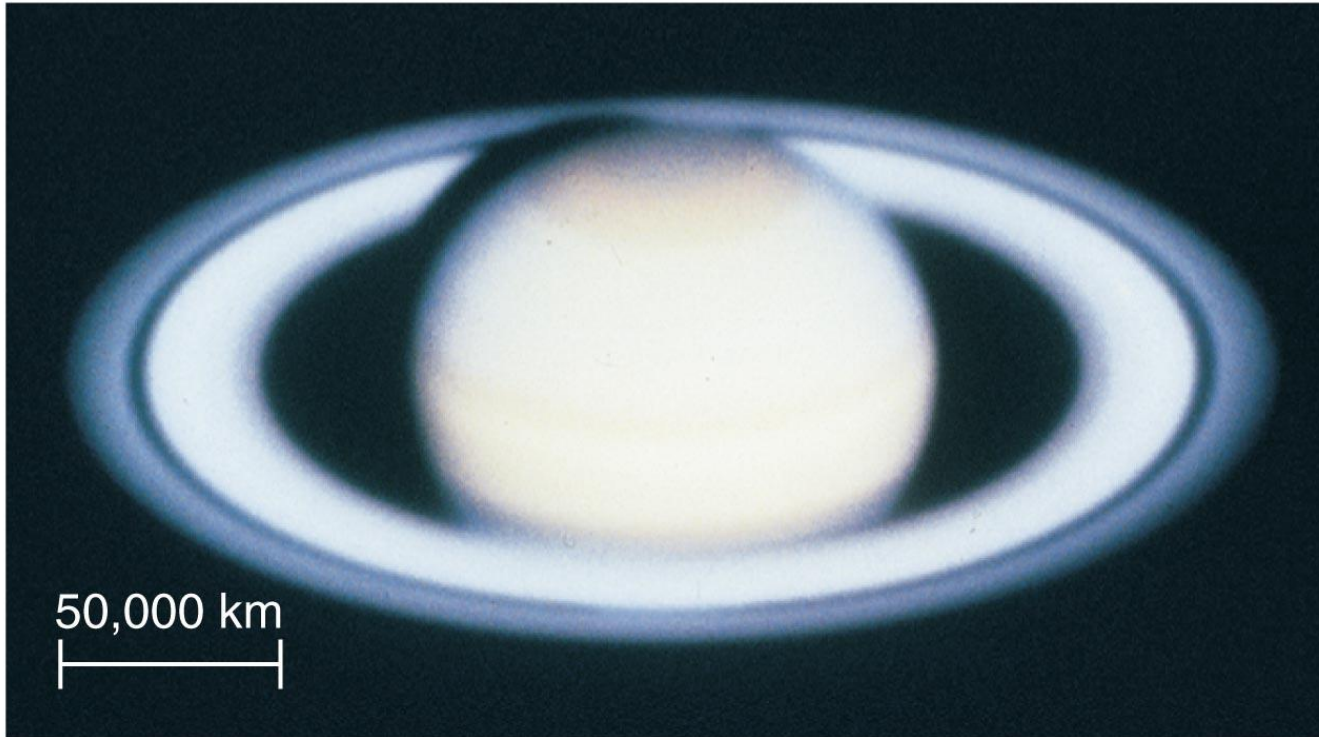
What have we learned?

- **What geological activity do we see on Titan and other distant moons?**
 - Titan is only moon with thick atmosphere.
 - Many other major moons show signs of geological activity.
- **Why are small icy moons more geologically active than small rocky planets?**
 - Ice melts and deforms at lower temperatures, enabling tidal heating to drive activity.

11.3 Jovian Planet Rings

- Our goals for learning:
 - **What are Saturn's rings like?**
 - **How do other jovian ring systems compare to Saturn's?**
 - **Why do the jovian planets have rings?**

What are Saturn's rings like?

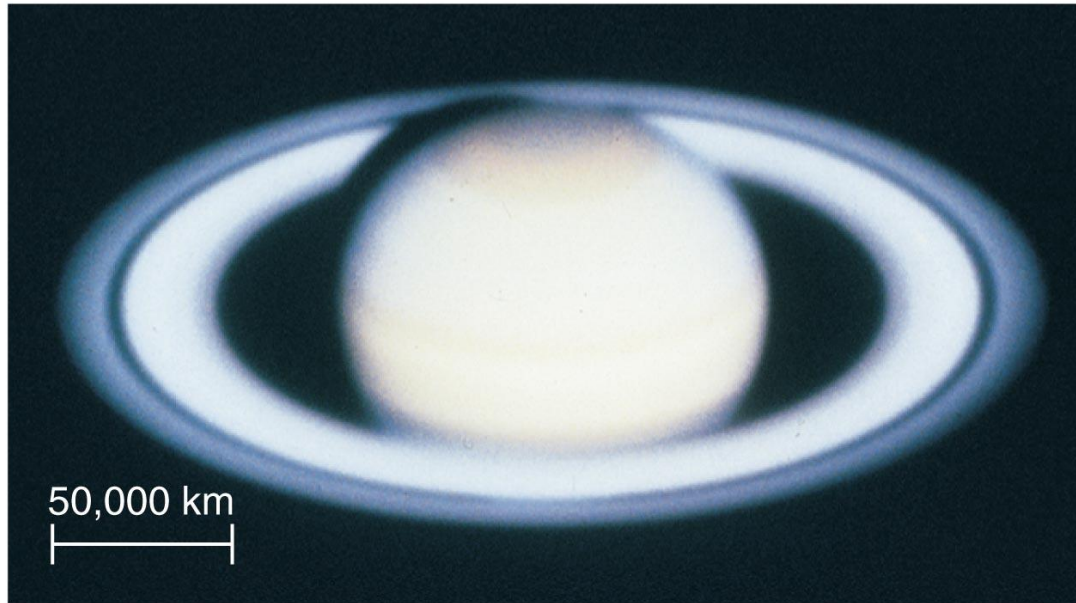


a This Earth-based telescopic view of Saturn makes the rings look like large, concentric sheets. The dark gap within the rings is called the *Cassini division*.

What are Saturn's rings like?

- They are made up of numerous, tiny individual particles.
- They orbit around Saturn's equator.
- They are very thin.

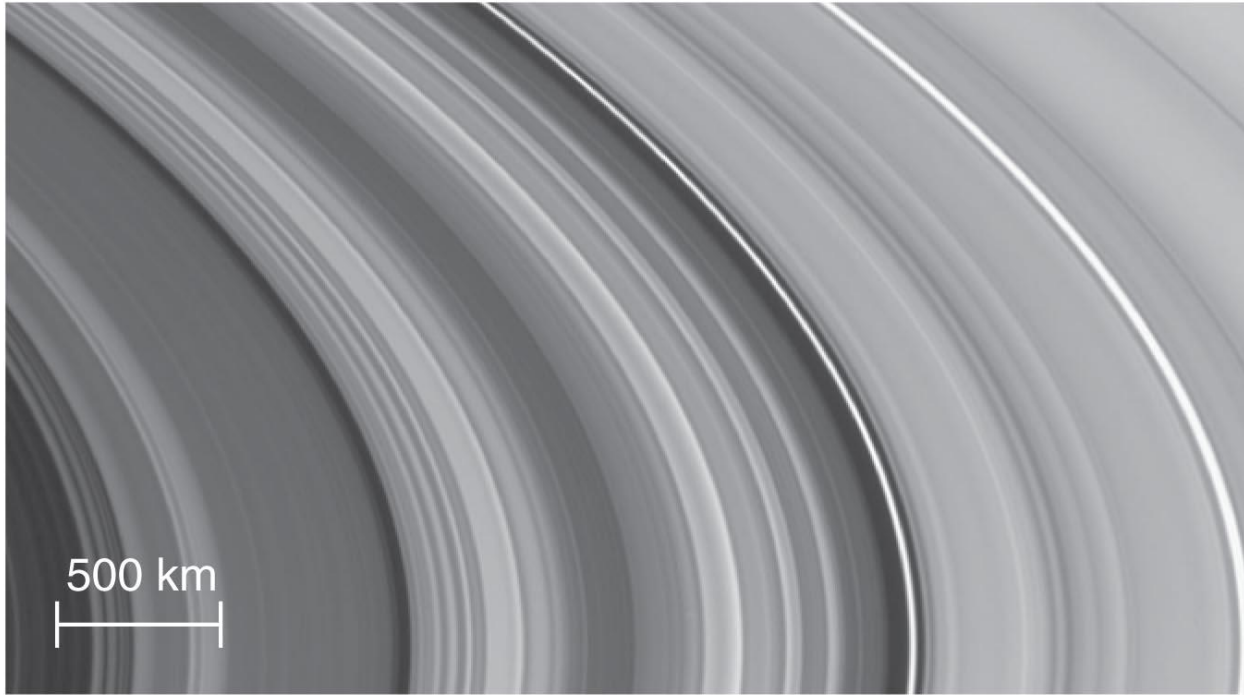
Earth-Based View of Saturn



a This Earth-based telescopic view of Saturn makes the rings look like large, concentric sheets. The dark gap within the rings is called the *Cassini division*.

- From Earth-based telescopes, the rings look like solid concentric sheets

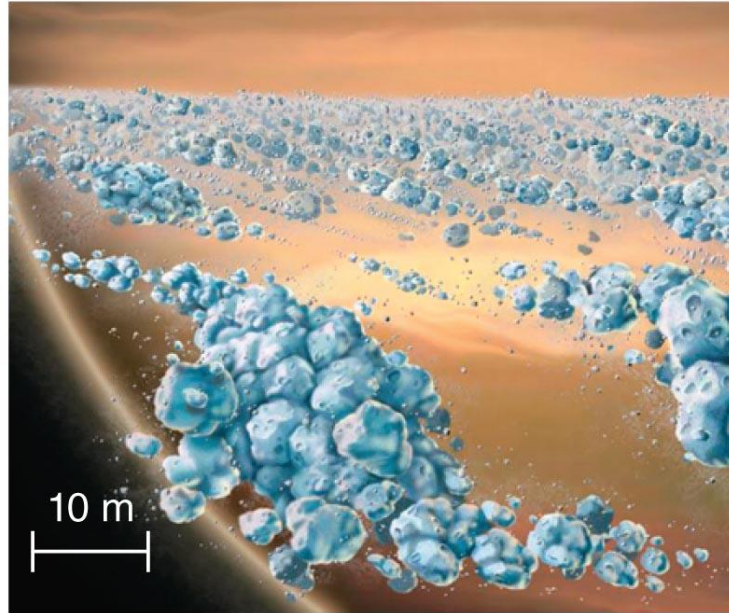
Spacecraft View of Ring Gaps



b This image of Saturn's rings from the *Cassini* spacecraft reveals many individual rings separated by narrow gaps.

- The *Cassini* spacecraft reveals many concentric rings

Artist's Conception of Rings Close-Up

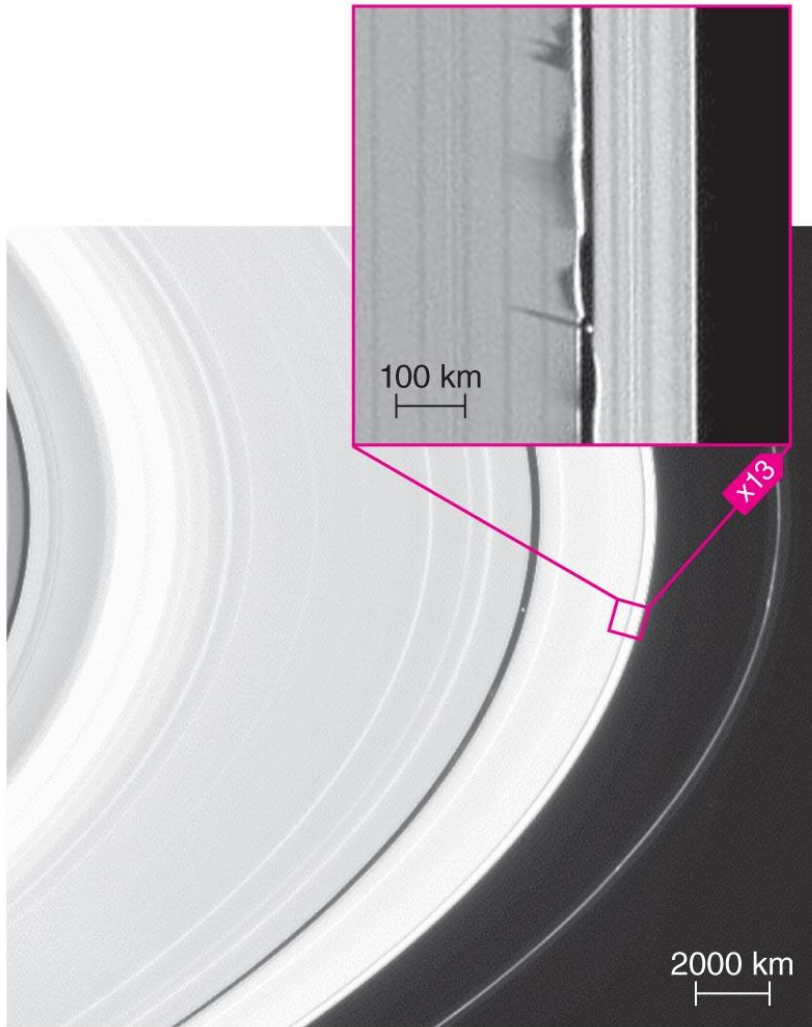


c Artist's conception of particles in a ring system. Particles clump together because of gravity, but small random velocities cause collisions that break them up.

- What we might see if we could get even closer...

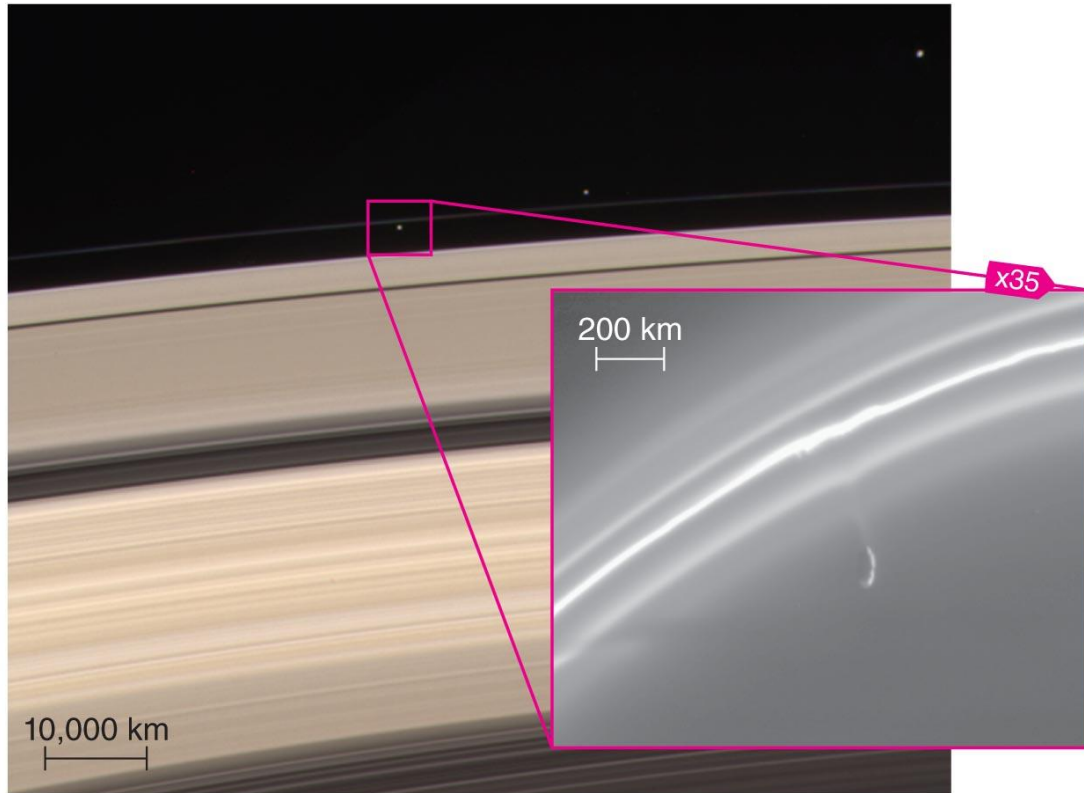
Gap Moons

- Some small moons create gaps within rings.



a Some small moons create gaps within the rings.

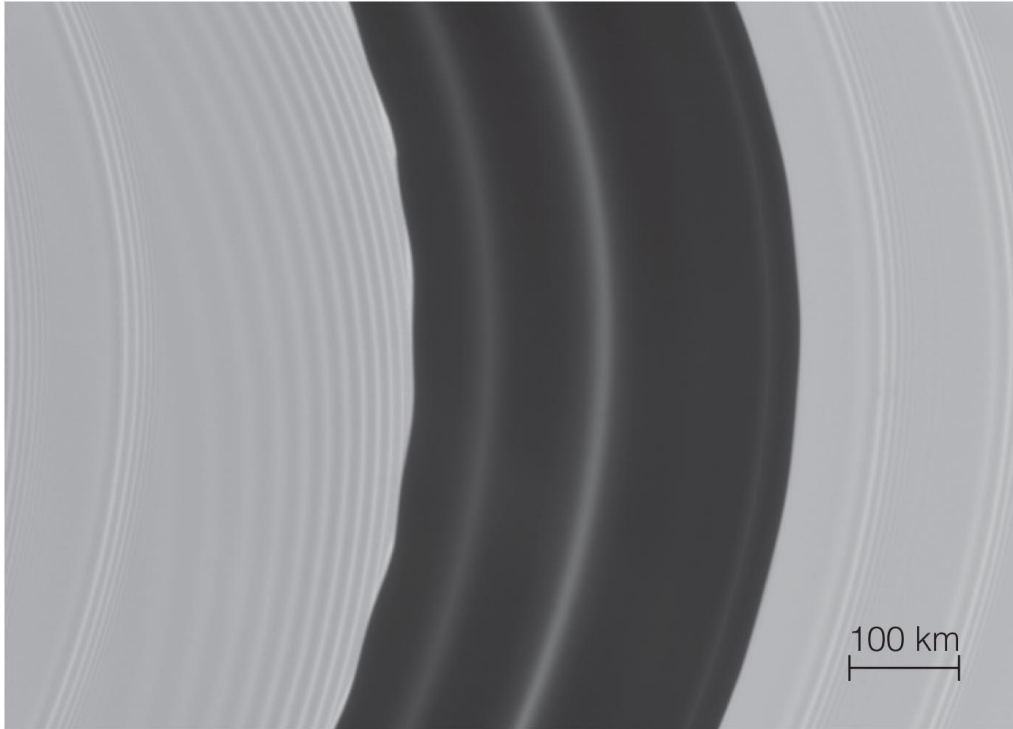
Shepherd Moons



- A pair of small moons can force particles into a narrow ring.

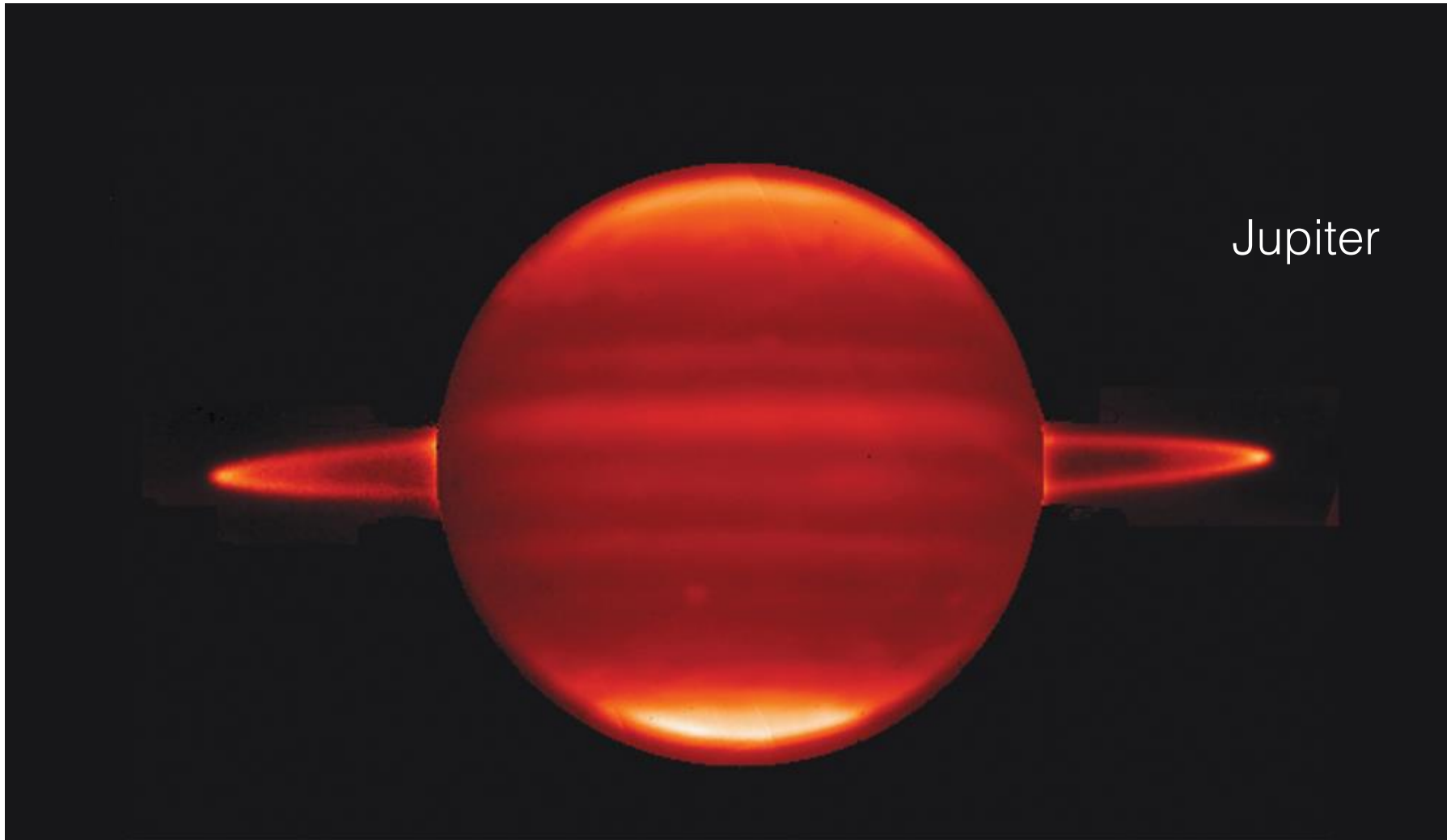
b Some moons force particles between them into a very narrow ring, as is the case with the two shepherd moons shown here. The inset shows a close-up of one of them.

Resonance Gaps

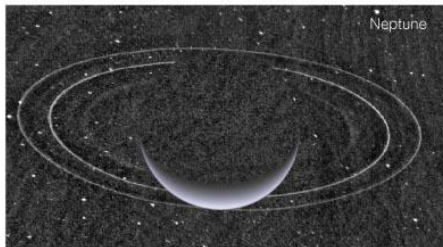
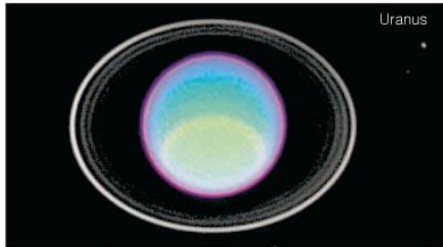
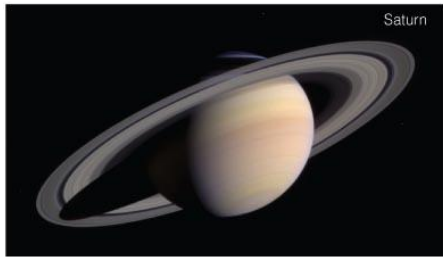
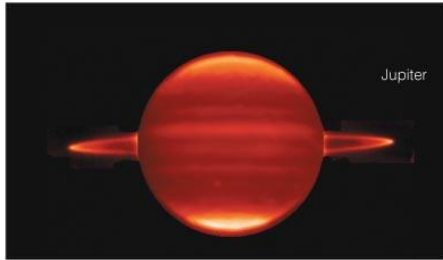


- Orbital resonance with a larger moon can also produce a gap.

How do other jovian ring systems compare to Saturn's?

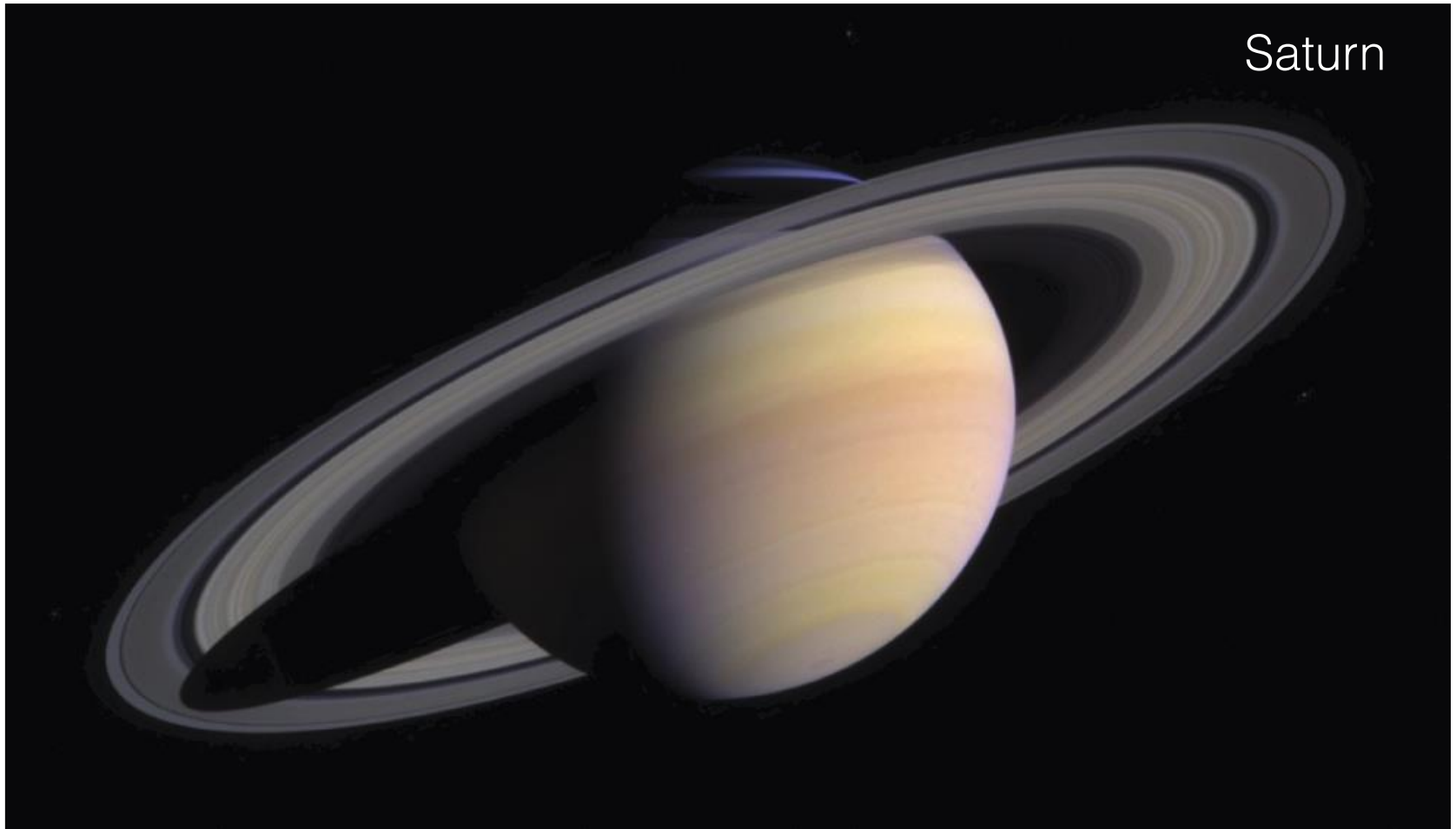


Jovian Ring Systems



- All four jovian planets have ring systems.
- Others have smaller, darker ring particles than Saturn.

Why do the jovian planets have rings?



Why do the jovian planets have rings?

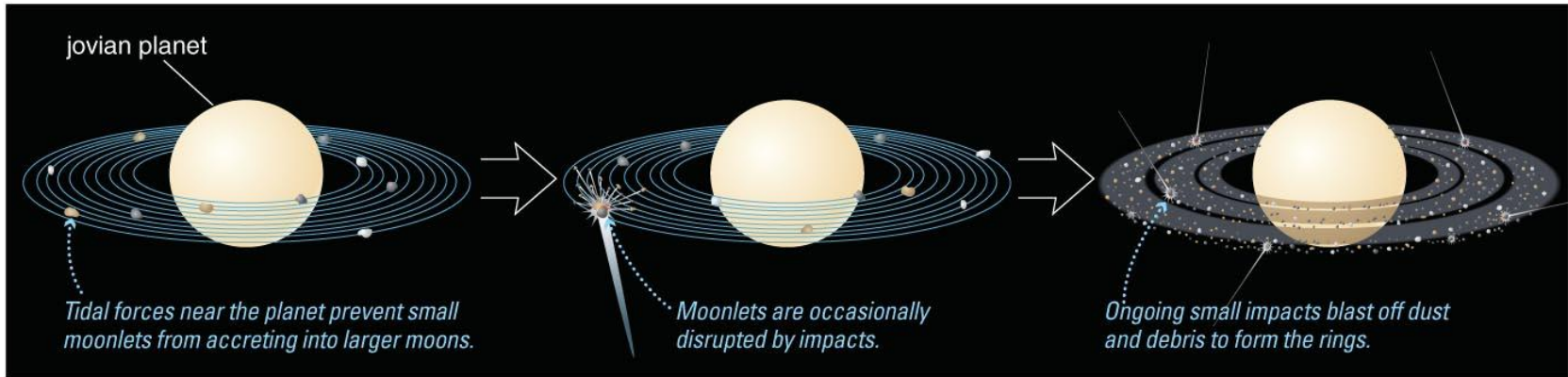
- They formed from dust created in impacts on moons orbiting those planets.

How do we know?

How do we know?

- Rings aren't leftover from planet formation because the particles are too small to have survived for so long.
- There must be a continuous replacement of tiny particles.
- The most likely source is impacts with jovian moons.

Ring Formation



- Jovian planets all have rings because they possess many small moons close in.
- Impacts on these moons are random.
- Saturn's incredible rings may be an "accident" of our time.

What have we learned?

- **What are Saturn's rings like?**
 - They are made up of countless individual ice particles.
 - They are extremely thin with many gaps.
- **How do other jovian ring systems compare to Saturn's?**
 - The other jovian planets have much fainter ring systems with smaller, darker, less numerous particles.
- **Why do the jovian planets have rings?**
 - Ring particles are probably debris from moons.