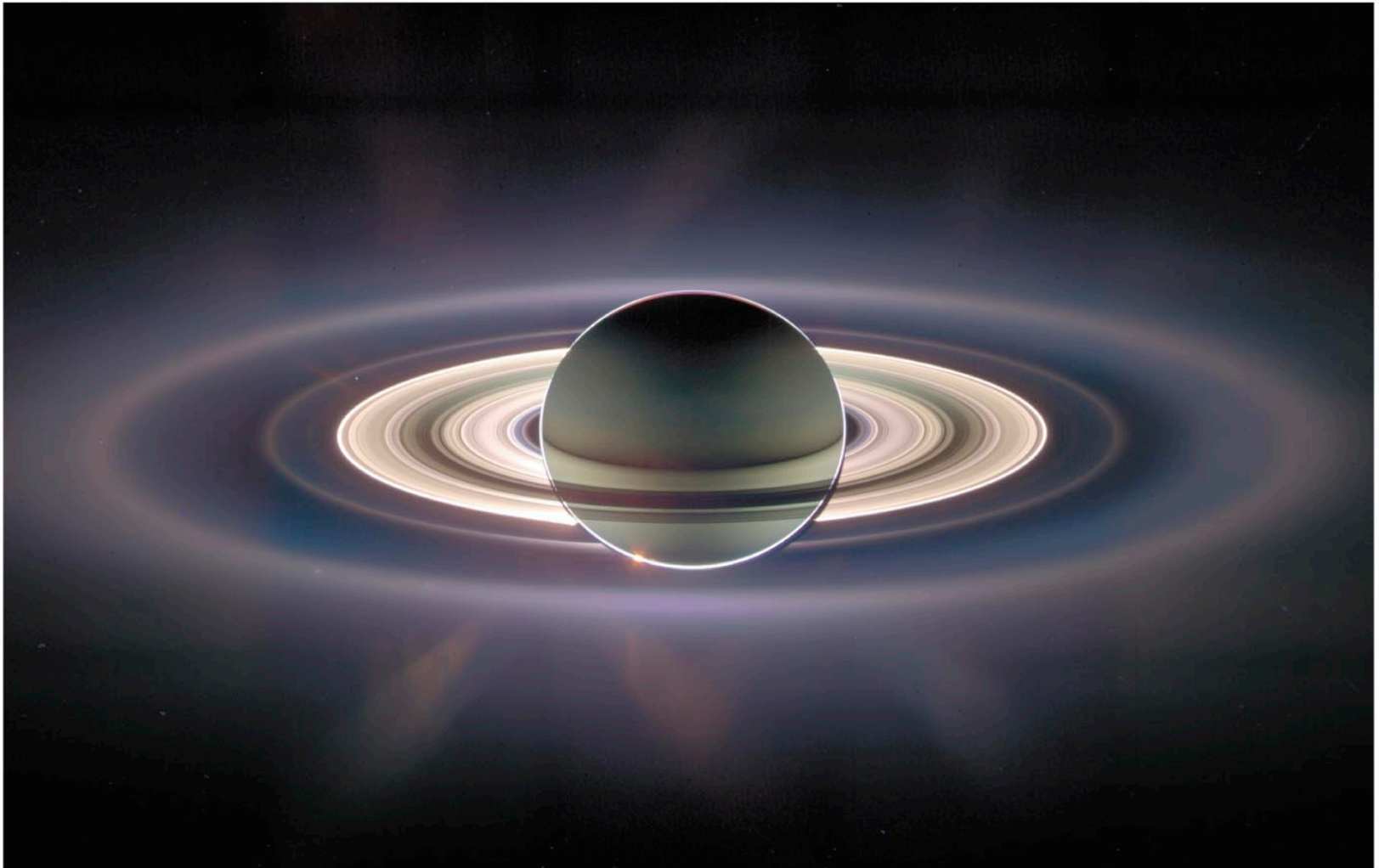


Chapter 11: Giant Planets and Their Satellites



11.1 A Different Kind of Planet

Our goals for learning:

- Are jovian (“giant”) 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?

- Discovery of Uranus, Neptune, Pluto

- Uranus: William Herschel, 1781

- Seen with a telescope

- Neptune: Urbain Leverrier and John Adams, 1846

- *Predicted* to exist, based on slight inconsistencies with Uranus's orbit, then confirmed with telescope

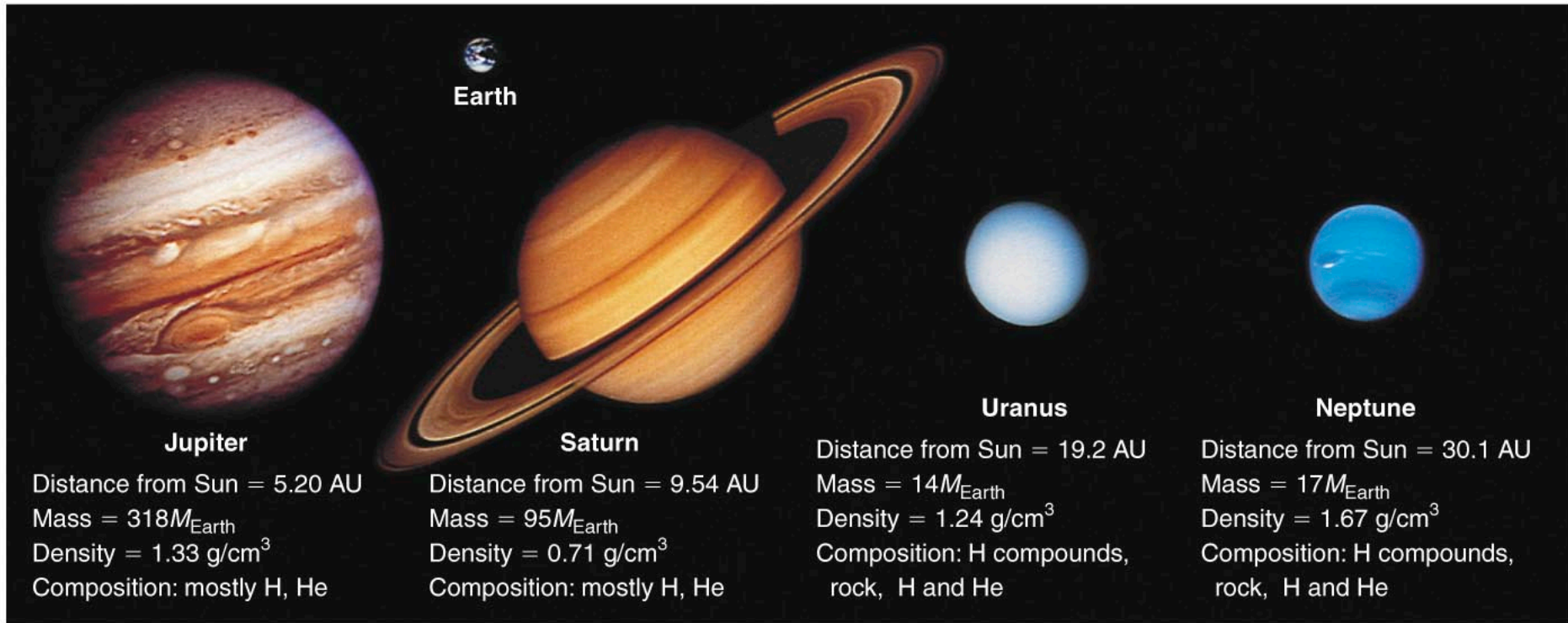
- Massive fight between England and France

- Pluto: Clyde Tombaugh

- Shoddily predicted, then seen w/ telescope



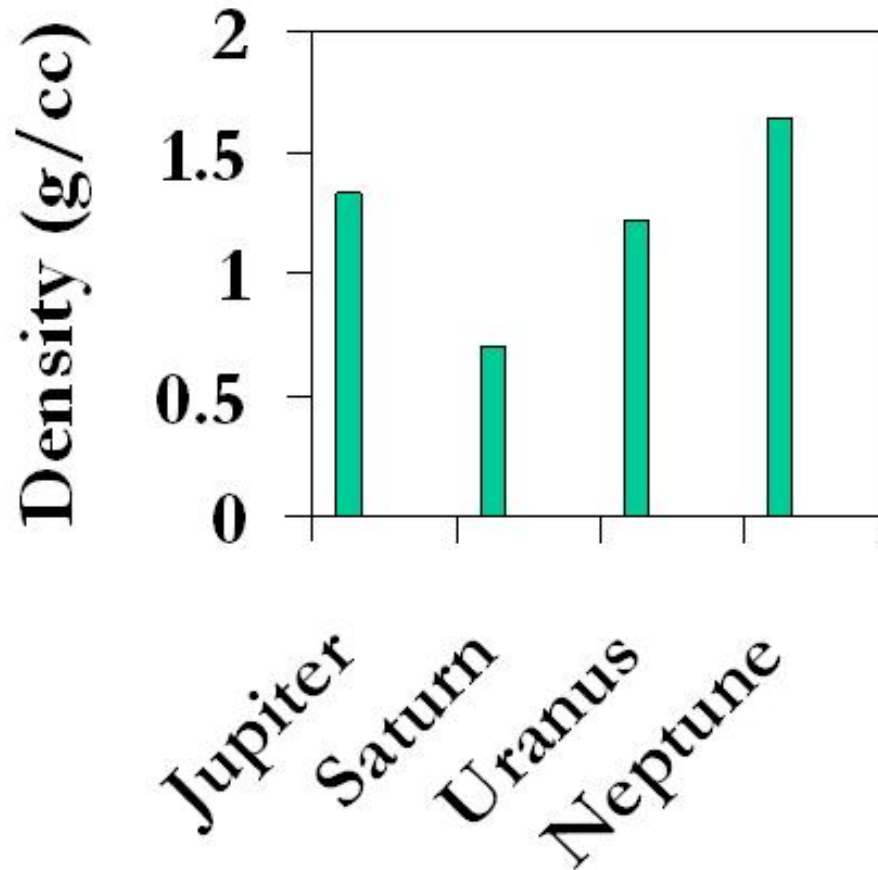
Are jovian planets all alike?



Jovian Planet Composition

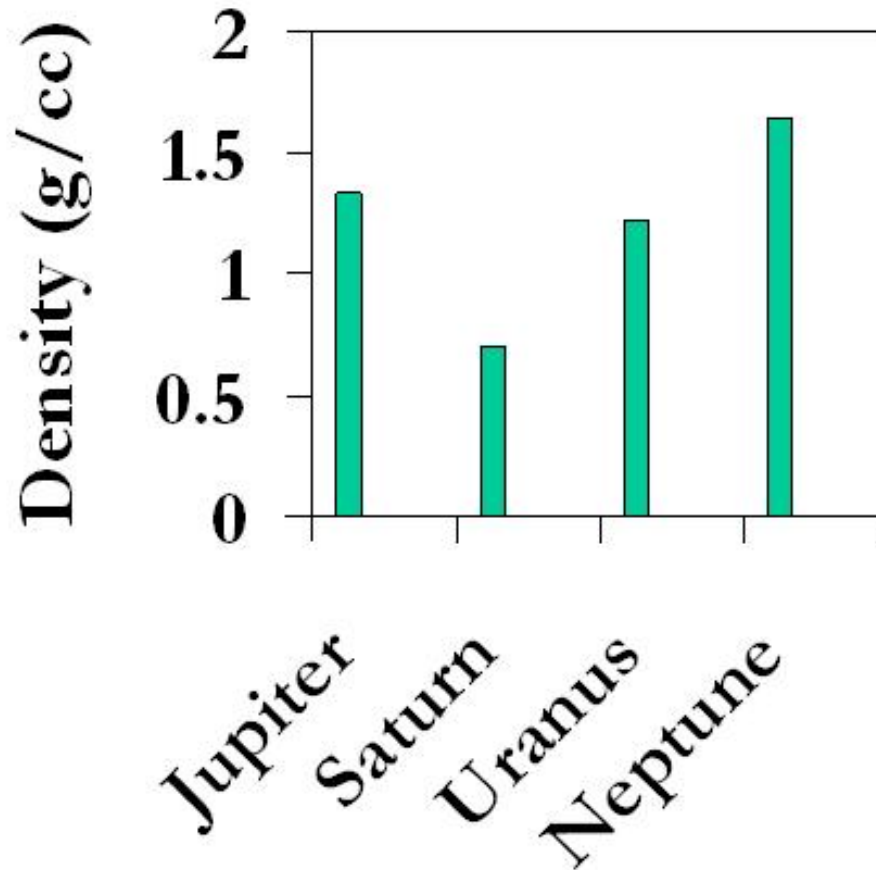
- Jupiter and Saturn
 - Mostly H and He gas, compressed to high density
- Uranus and Neptune
 - Mostly hydrogen compounds: water (H_2O), methane (CH_4), ammonia (NH_3)
 - Some H, He, and rock

Density Differences



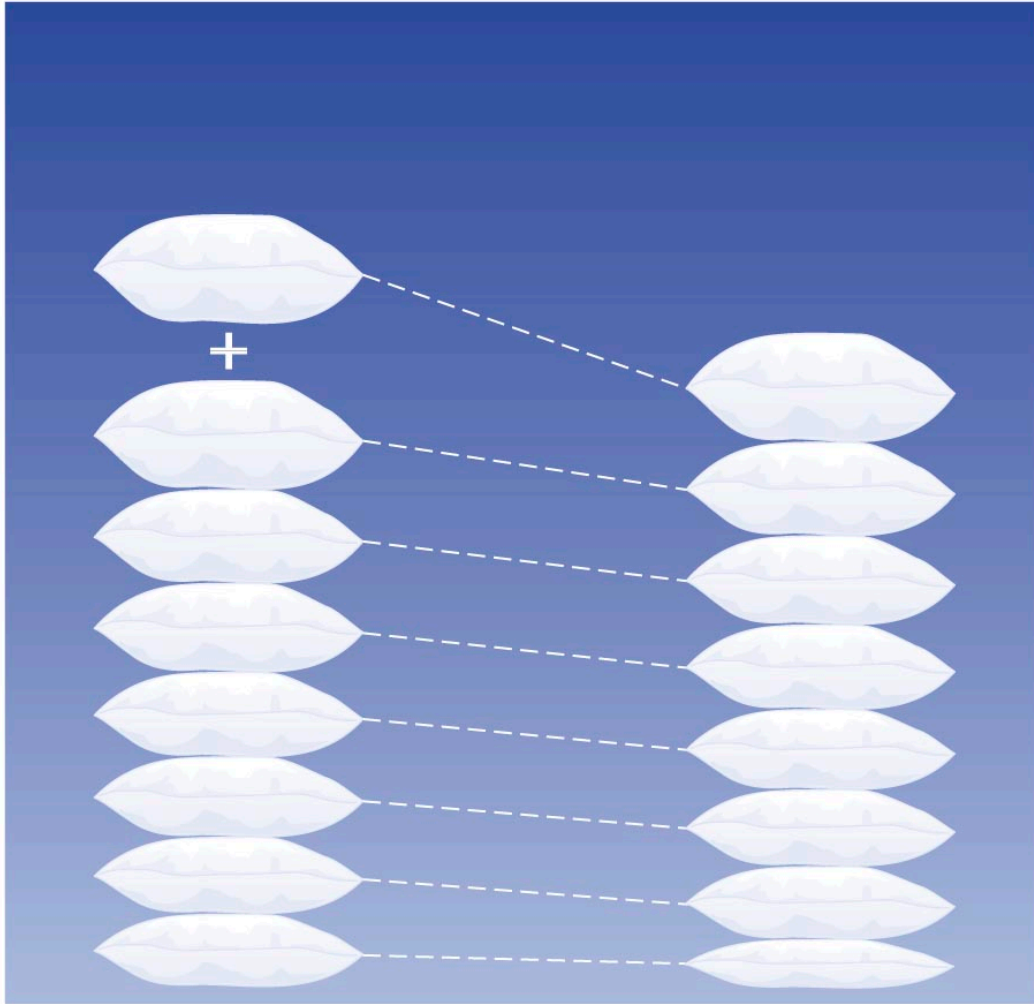
- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately.

Density Differences



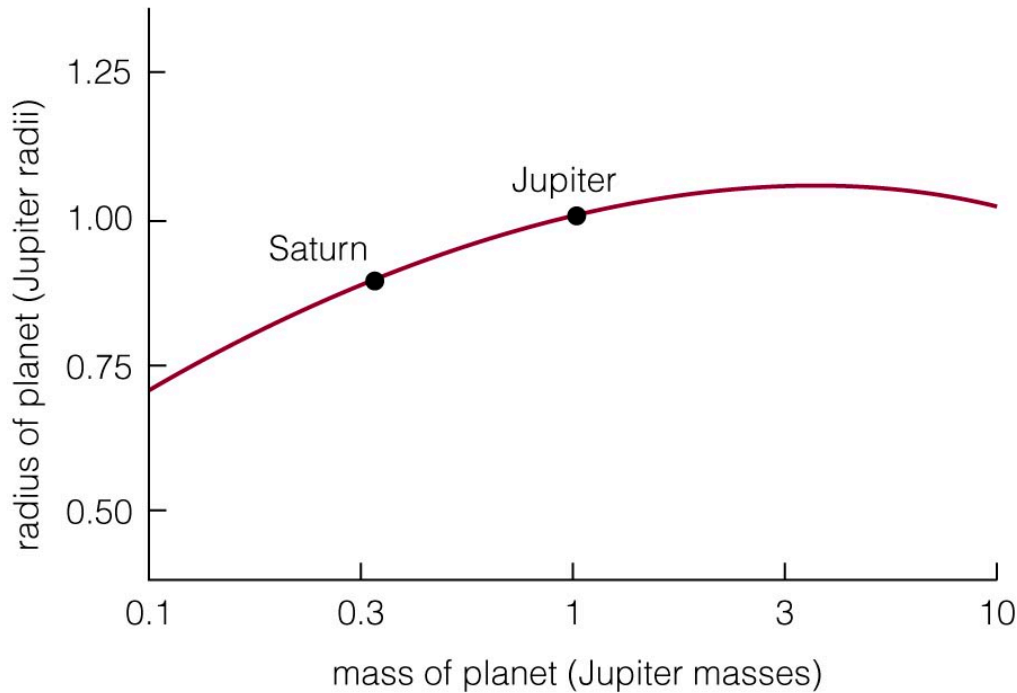
- But that explanation doesn't work for Jupiter....

Sizes of Jovian Planets

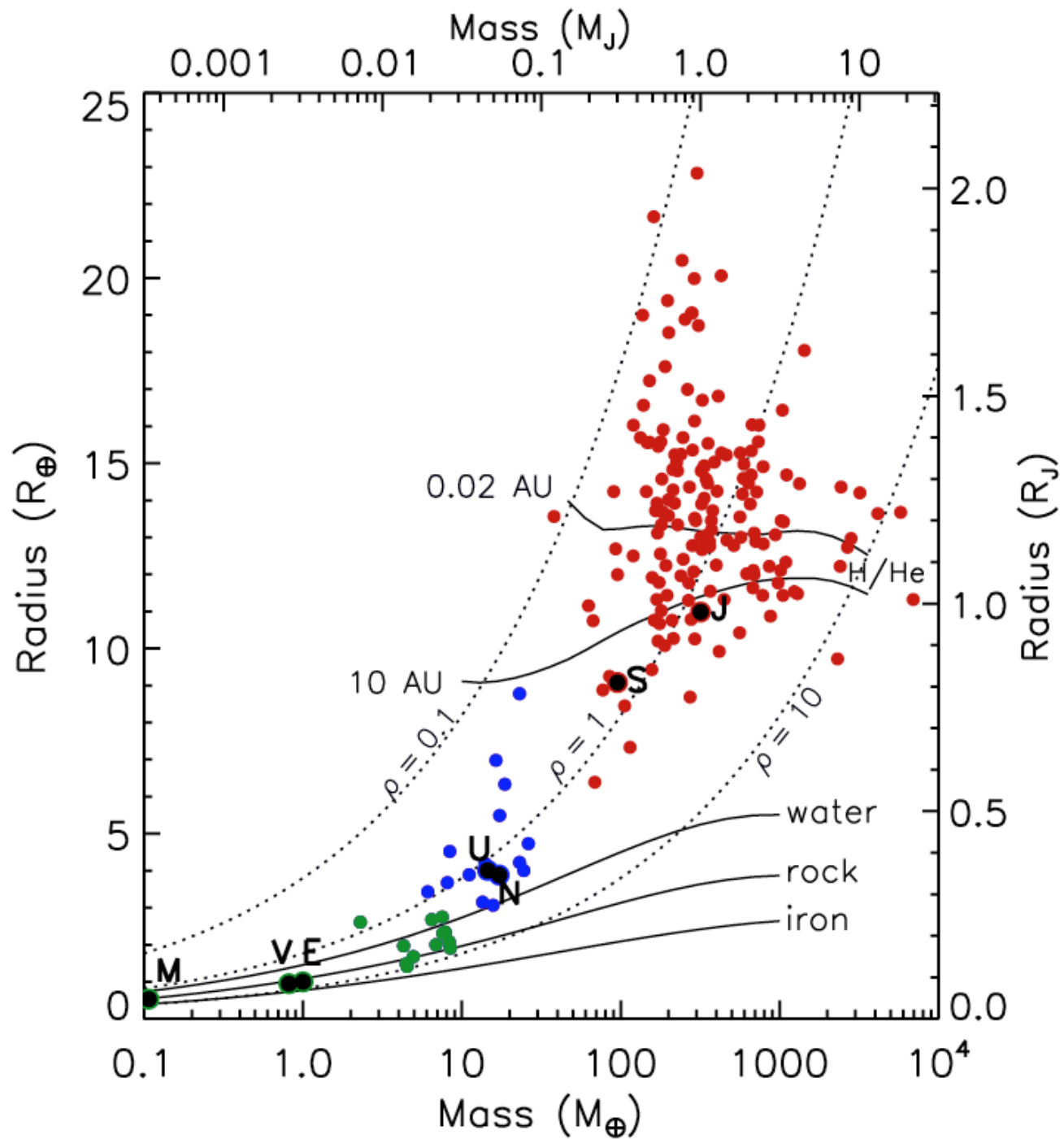


- Adding mass to a jovian planet compresses the underlying gas layers.

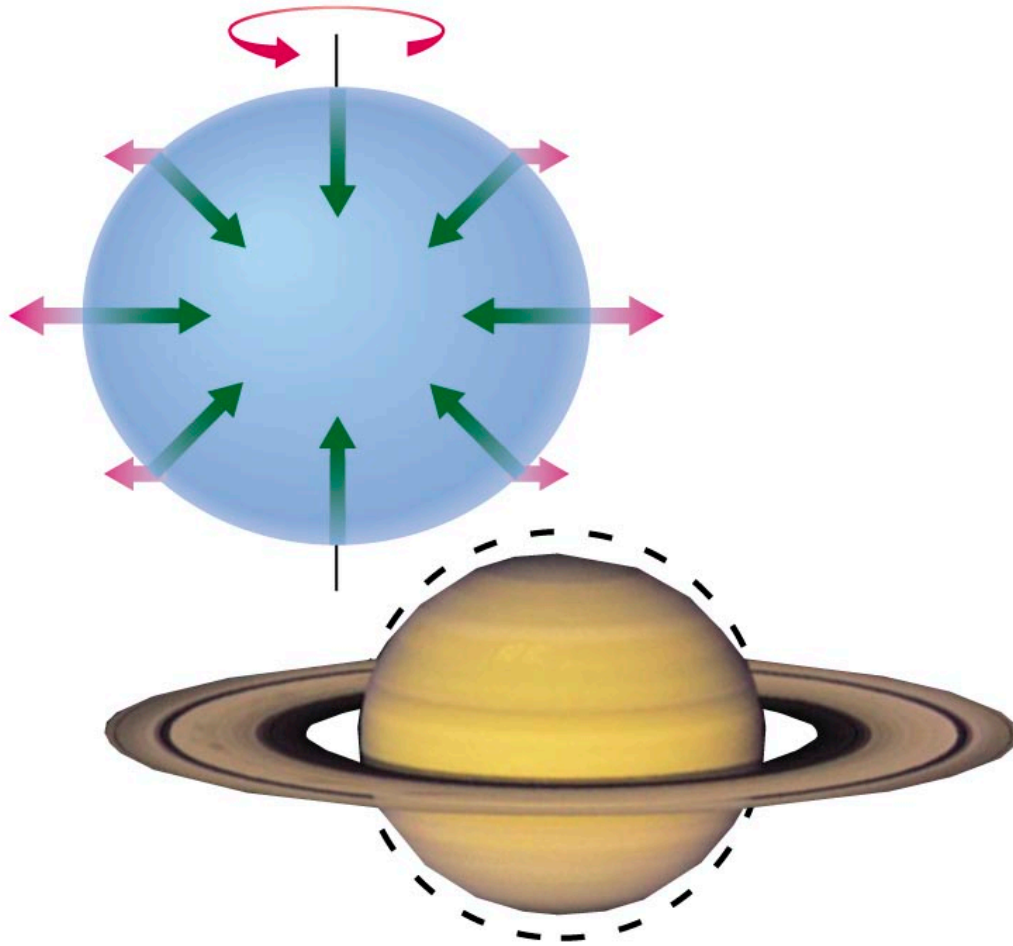
Sizes of Jovian Planets



- 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.

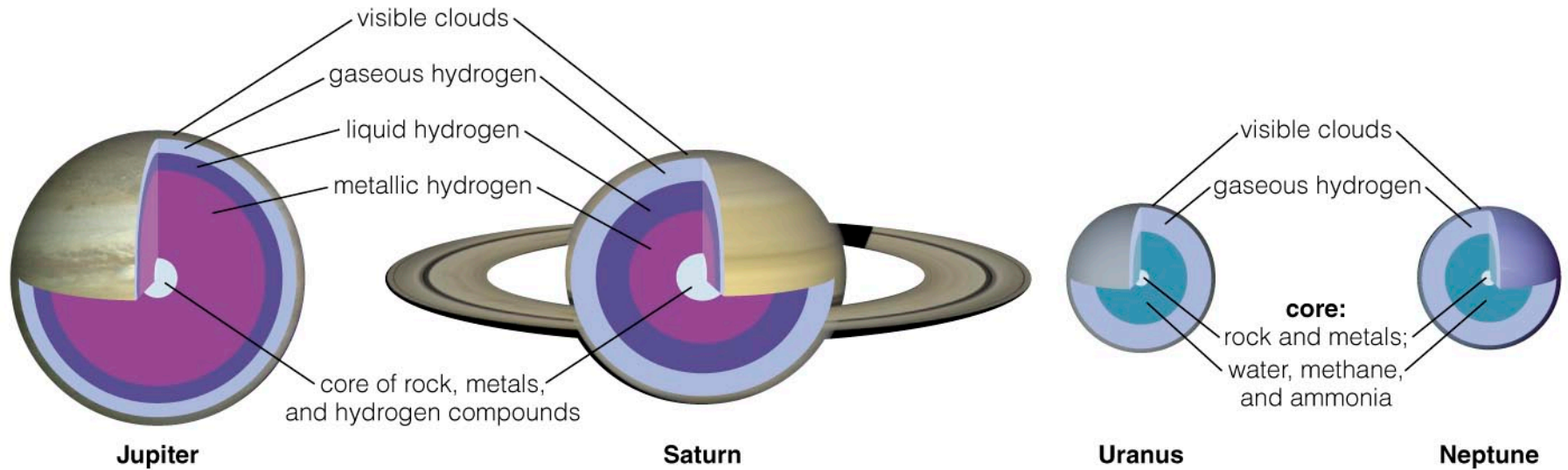


Rotation and Shape



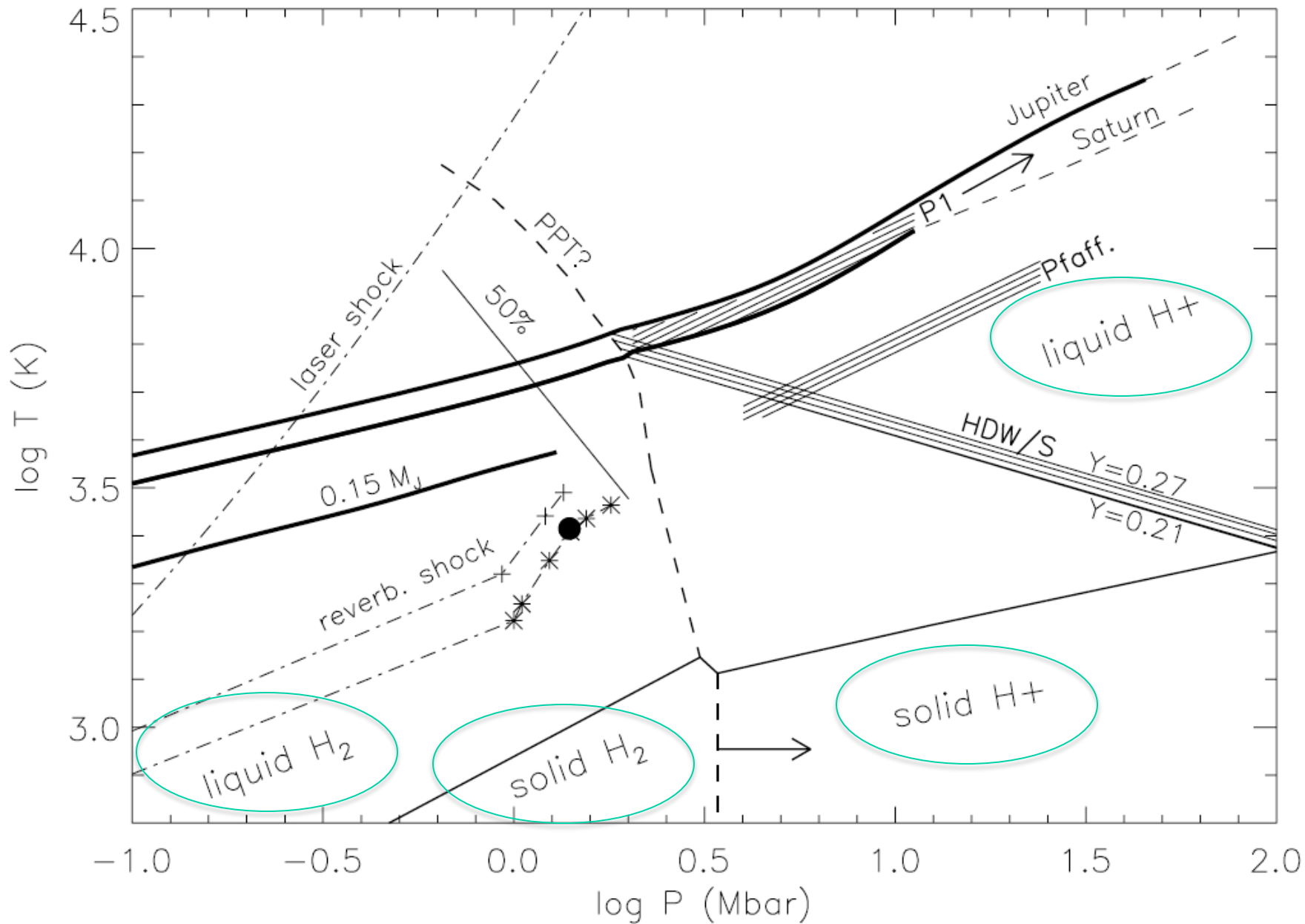
- Jovian planets are not quite spherical because of their rapid rotation.
- This is very helpful because we can probe their gravity field to understand density vs. radius

What are jovian planets like on the inside?

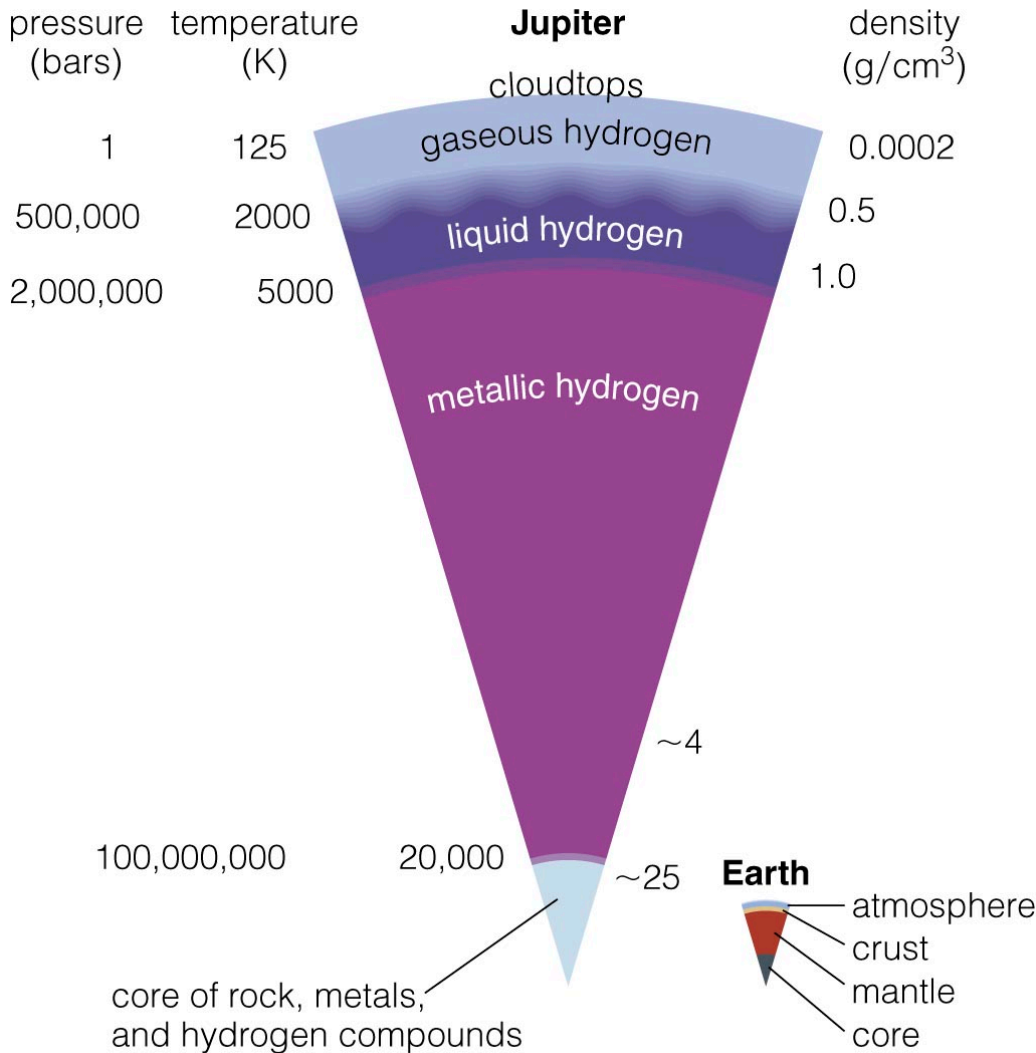


Interiors of Jovian Planets

- No solid surface
- Layers under high pressure and temperatures
- Cores (~10-15 Earth masses) made of hydrogen compounds, metals, and rock
- The layers are different for the different planets. WHY?

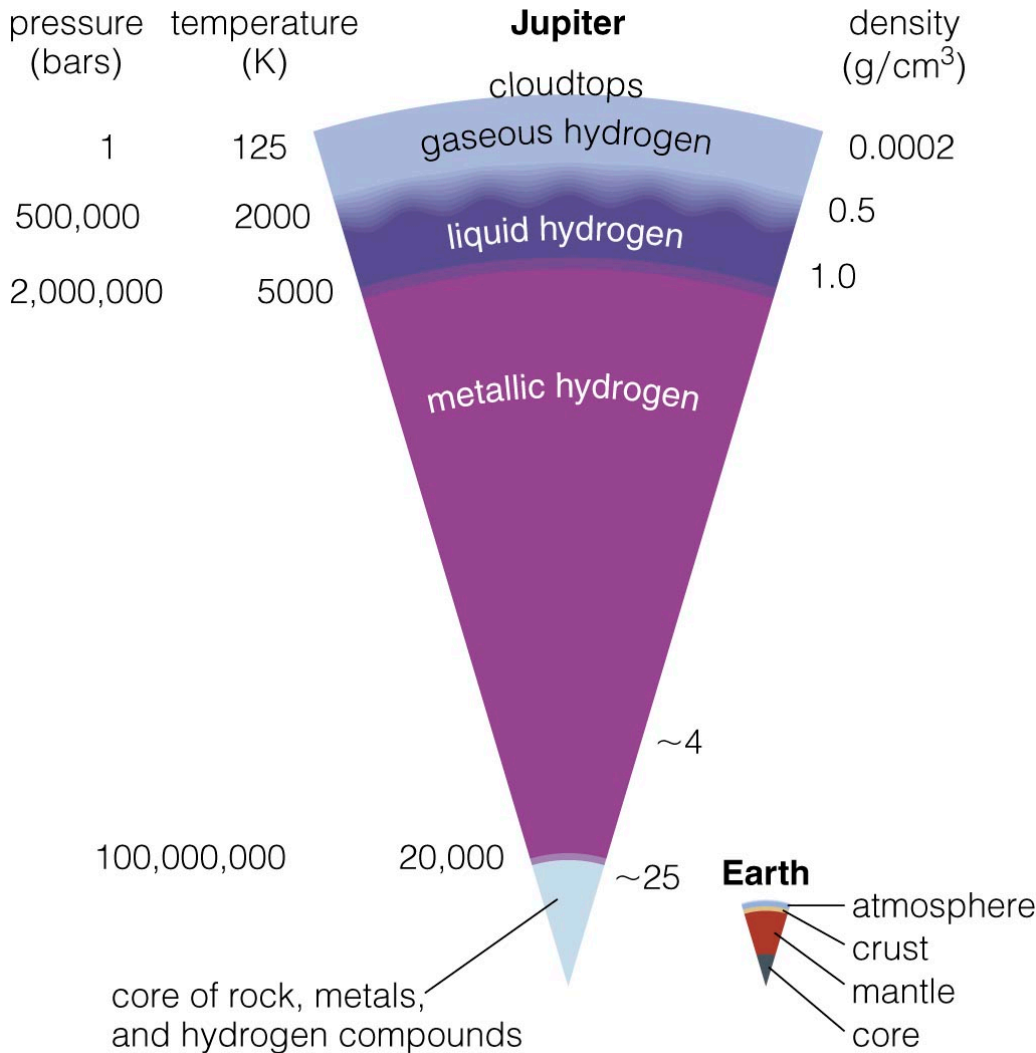


Inside Jupiter



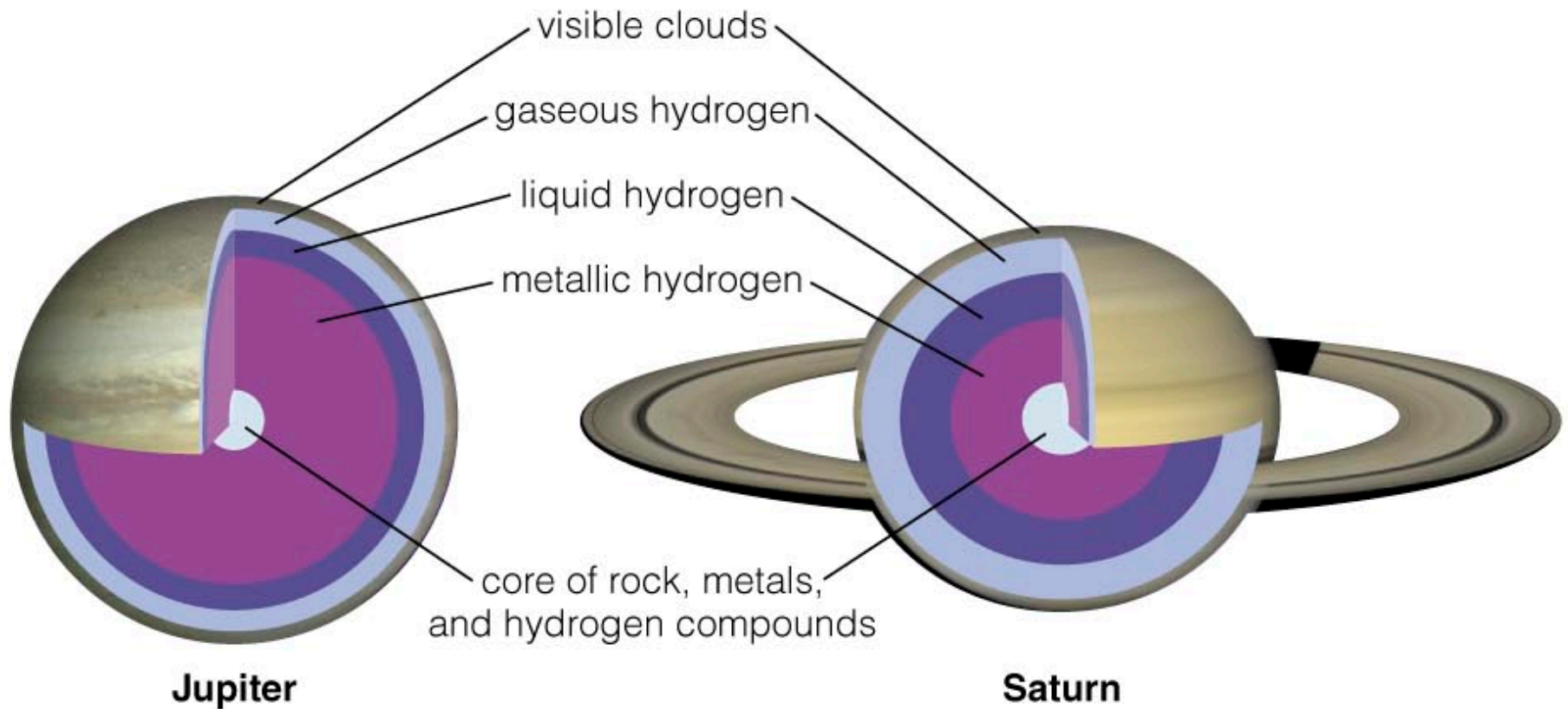
- High pressures inside Jupiter cause phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.

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.

Clicker Question:

Jupiter is about three times as massive as Saturn, but only slightly larger. Why?

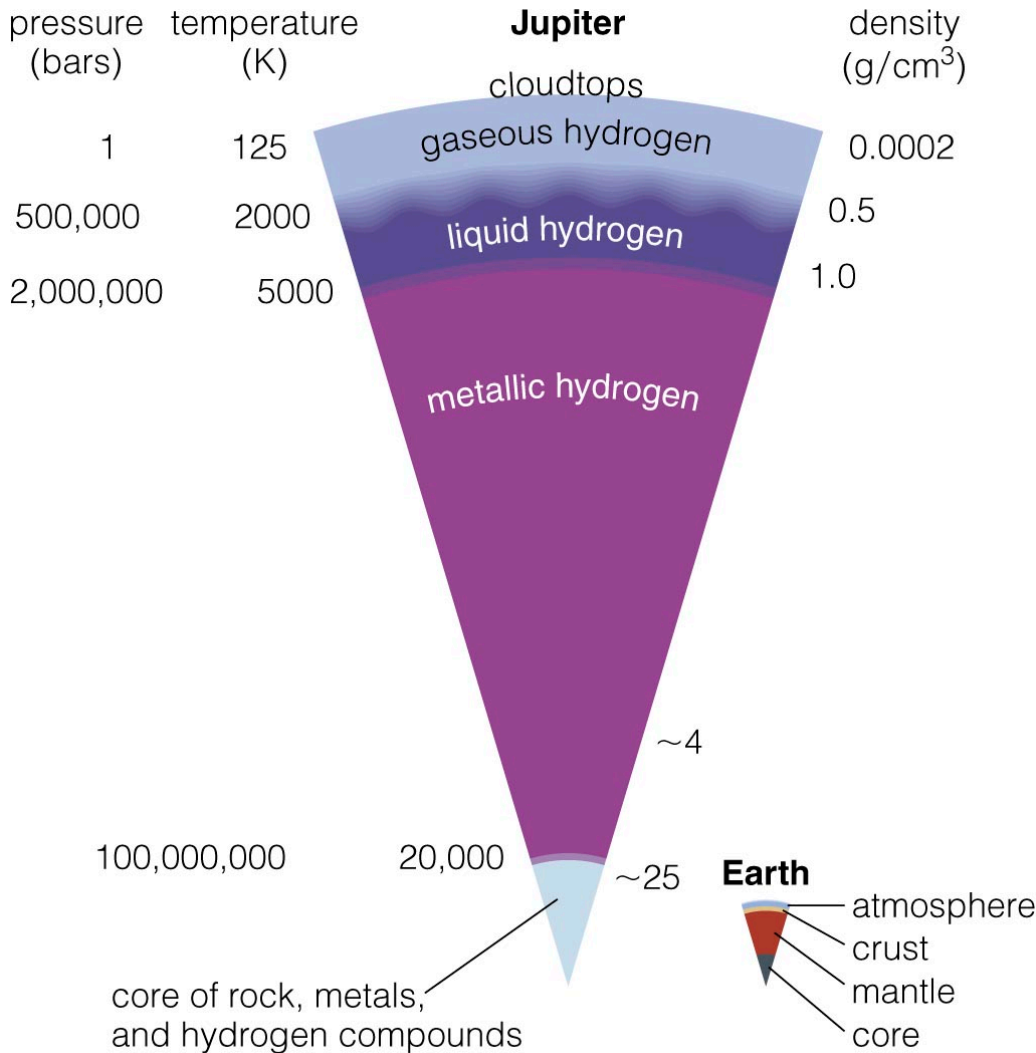
- A. It is made of inherently denser material.
- B. It is made of inherently less dense material.
- C. Adding mass increases gravity and compresses gasses.
- D. They are made of different gasses.
- E. none of the above

Clicker Question:

Jupiter is about three times as massive as Saturn, but only slightly larger. Why?

- A. It is made of denser material.
- B. It is made of less dense material.
- C. Adding mass increases gravity and compresses gasses.**
- D. They are made of different gasses.
- E. none of the above

Jupiter's Internal Heat



- Jupiter radiates twice as much energy as it receives from the Sun.
- Energy comes from conversion of gravitation potential energy into thermal energy—mostly in the past but a little today





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.
- Uranus, which is a lot like Neptune, has not detectable internal energy source

$P = 1 \text{ bar}, T \sim 140 \text{ K}$

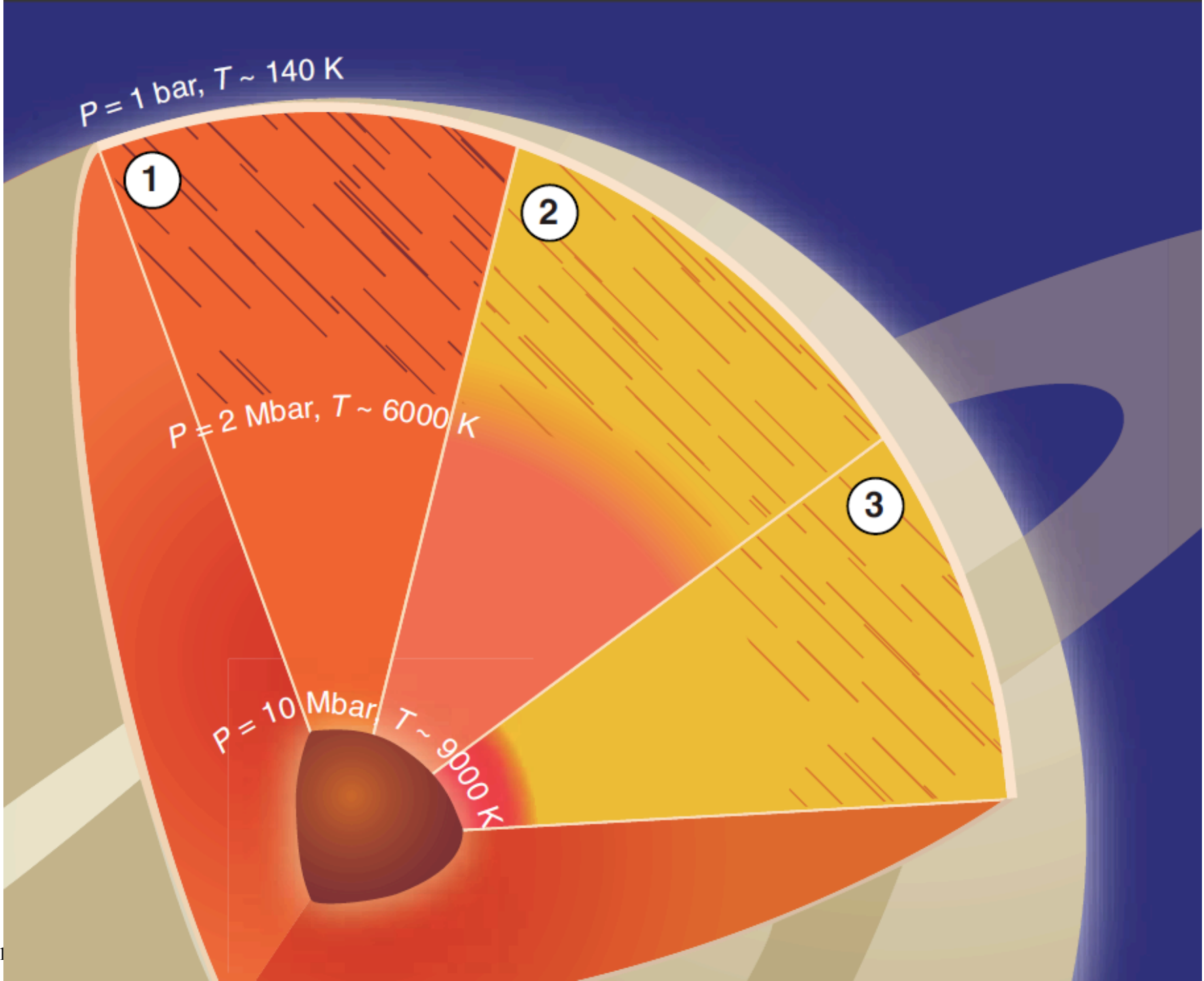
1

2

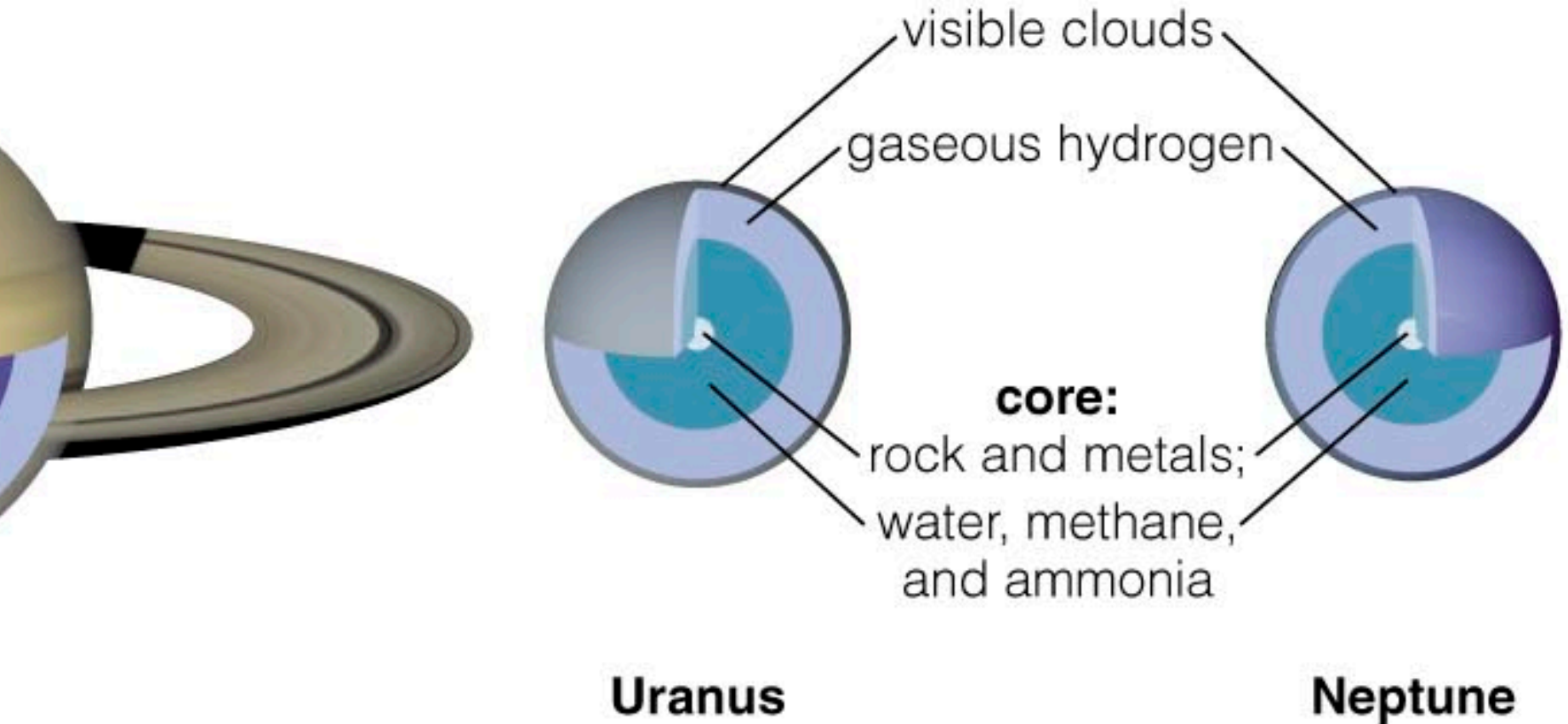
3

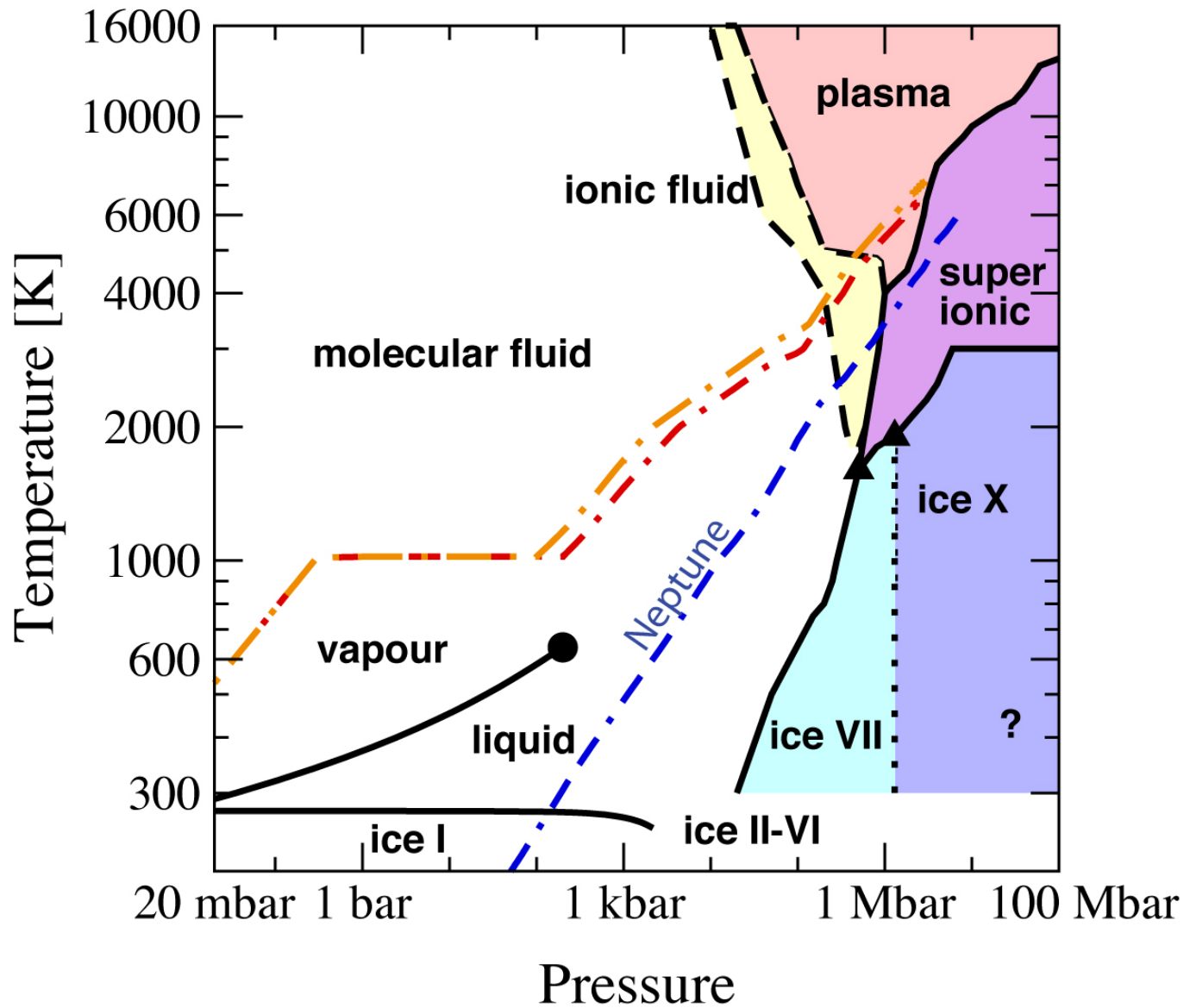
$P = 2 \text{ Mbar}, T \sim 6000 \text{ K}$

$P = 10 \text{ Mbar}, T \sim 9000 \text{ K}$

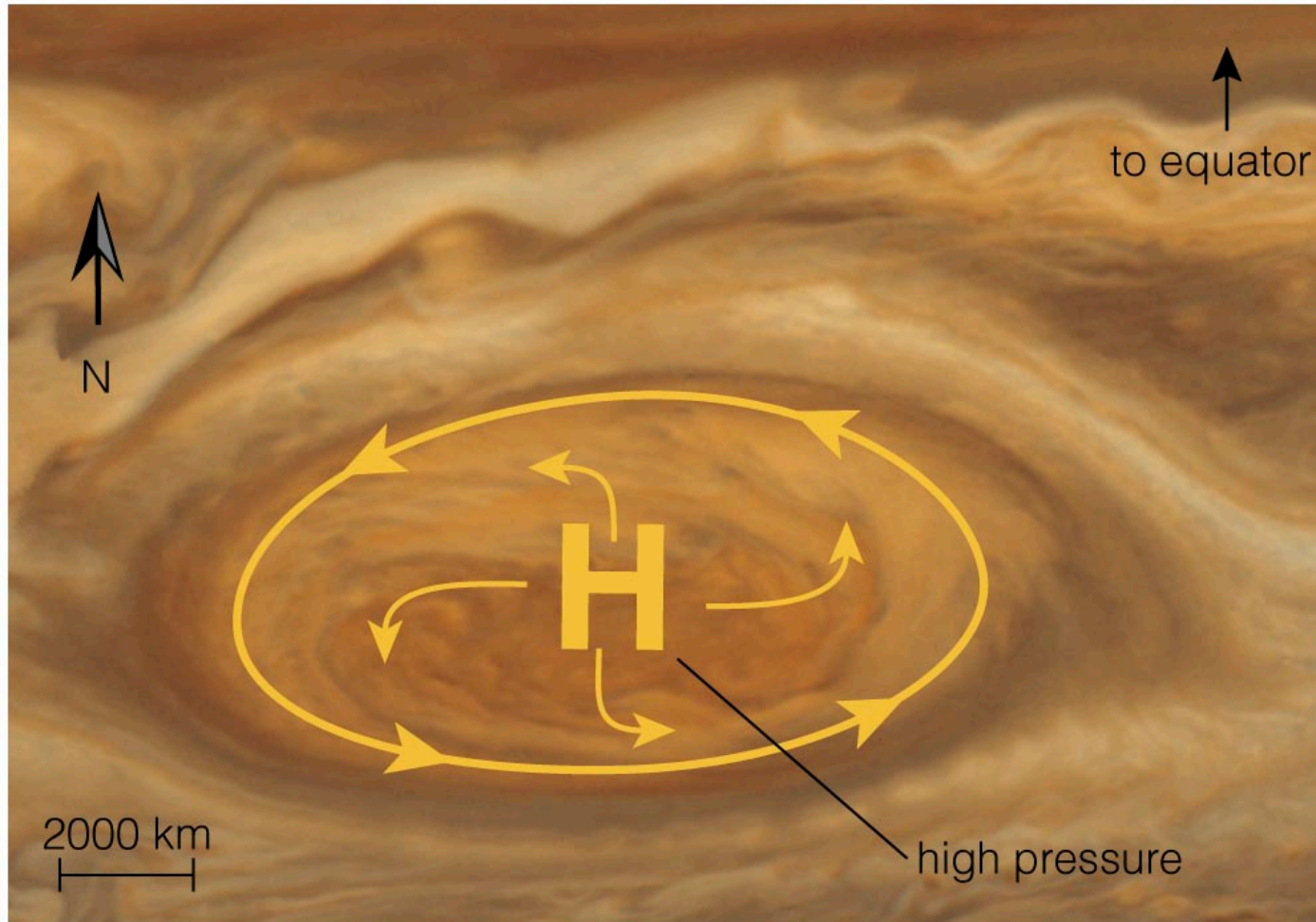


Comparing Jovian Interiors

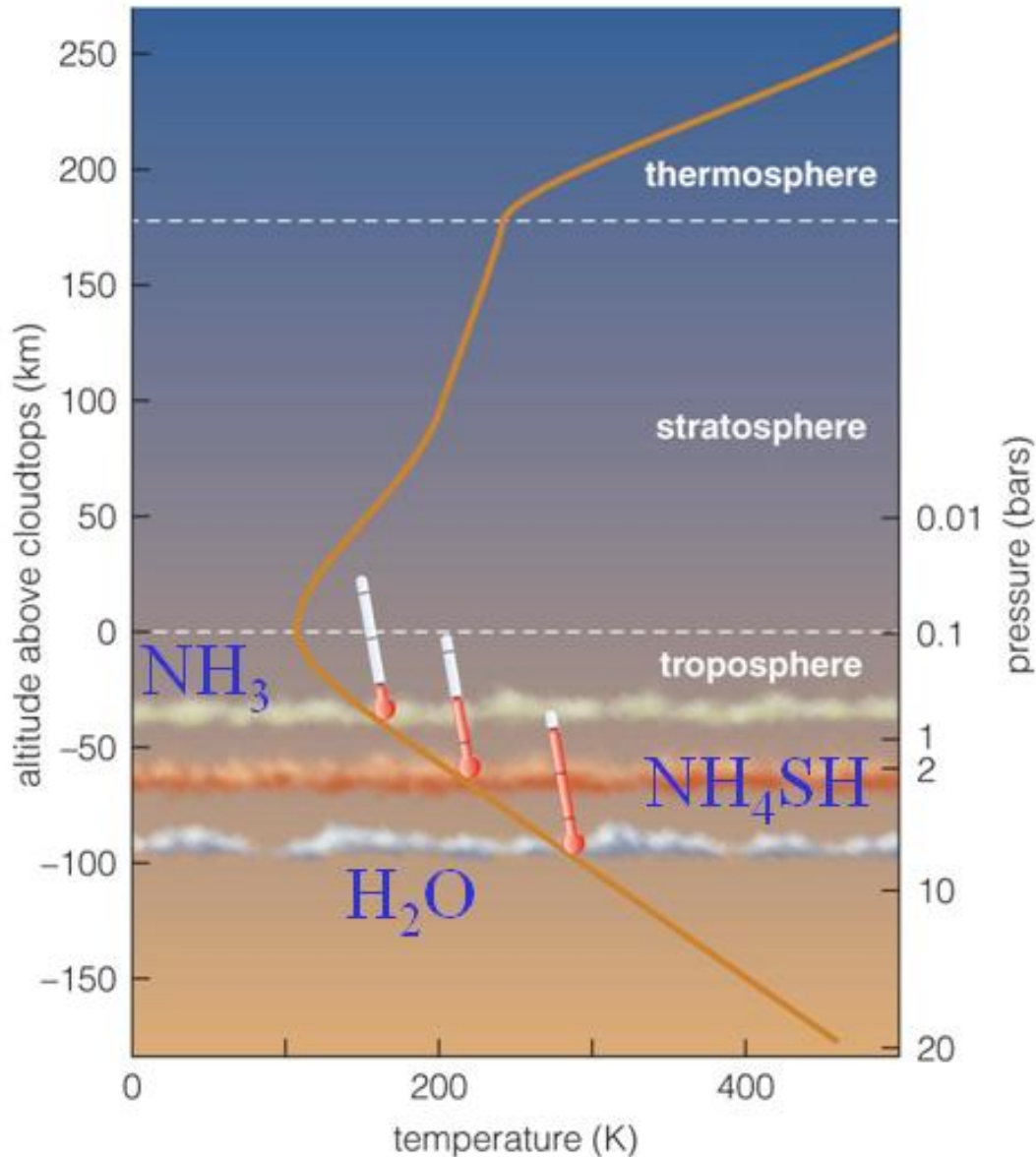




What is the weather like on jovian planets?

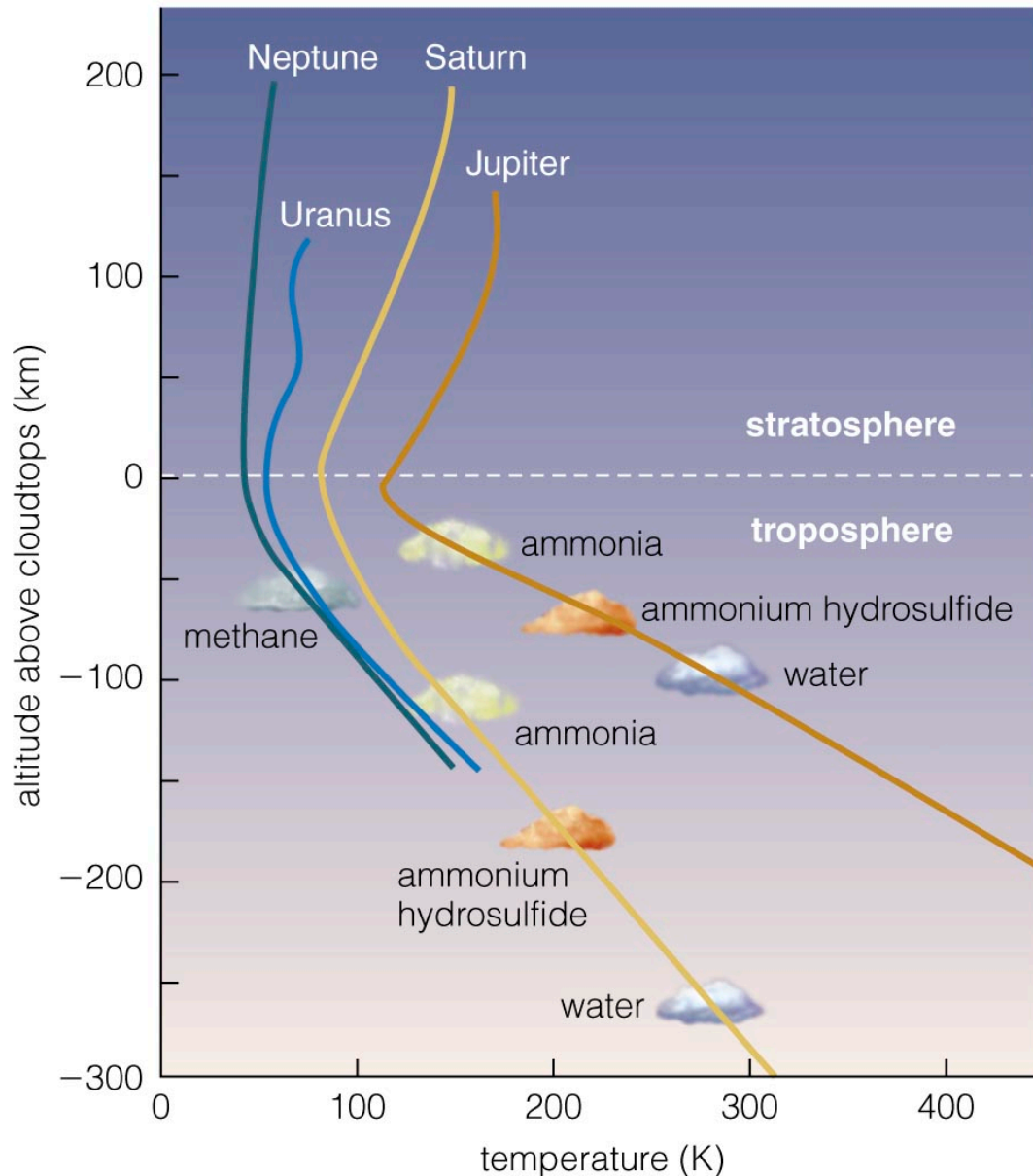


Jupiter's Atmosphere

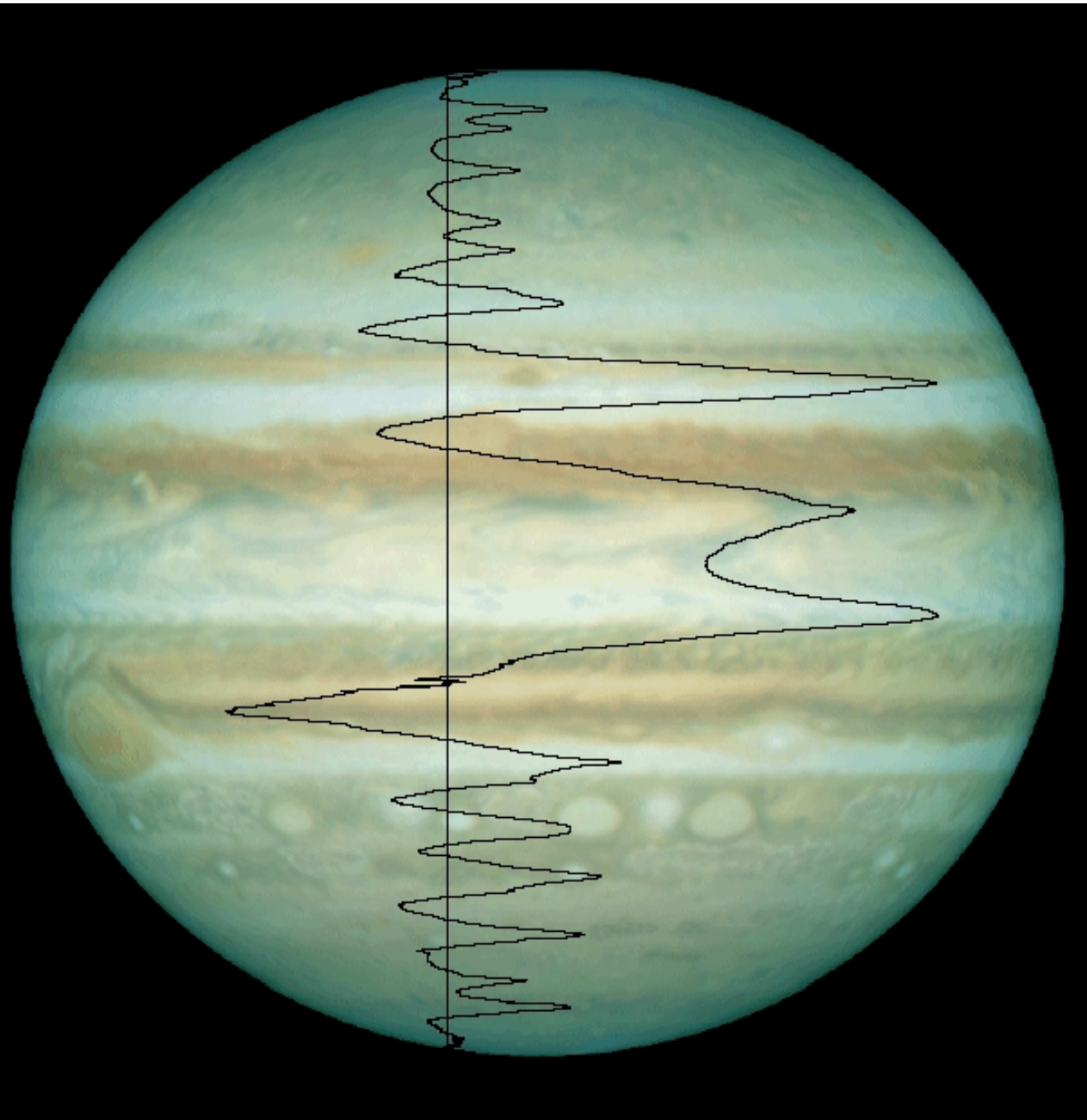


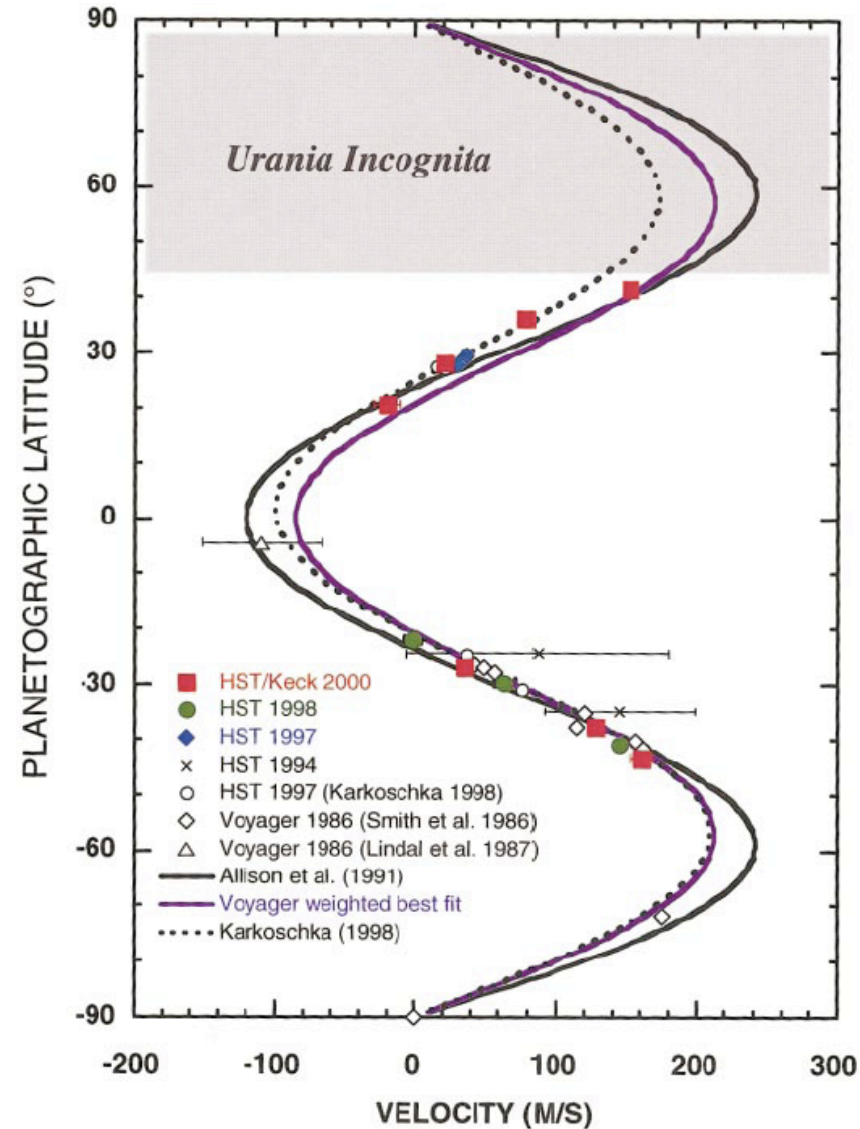
- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to freezing points of different hydrogen compounds.

Jovian Planet Atmospheres



- Other jovian planets have cloud layers similar to Jupiter's.
- Different compounds make clouds of different colors.
- If you go deep enough, you'd find clouds of iron and rock





New Measurements of the Winds of Uranus¹

H. B. Hammel

Space Science Institute, 3100 Marine Street, Suite A353, Boulder, Colorado 80303-1058

E-mail: hbh@alum.mit.edu

K. Rages

Space Physics Research Institute, Sunnyvale, California 94087

G. W. Lockwood

Lowell Observatory, 1400 West Mars Hill Road, Flagstaff, Arizona 86001

E. Karkoschka

University of Arizona, Lunar and Planetary Laboratory, Tucson, Arizona 85721-0092

and

I. de Pater

University of California, Astronomy Department, 601 Campbell Hall, Berkeley, California 94720-3411

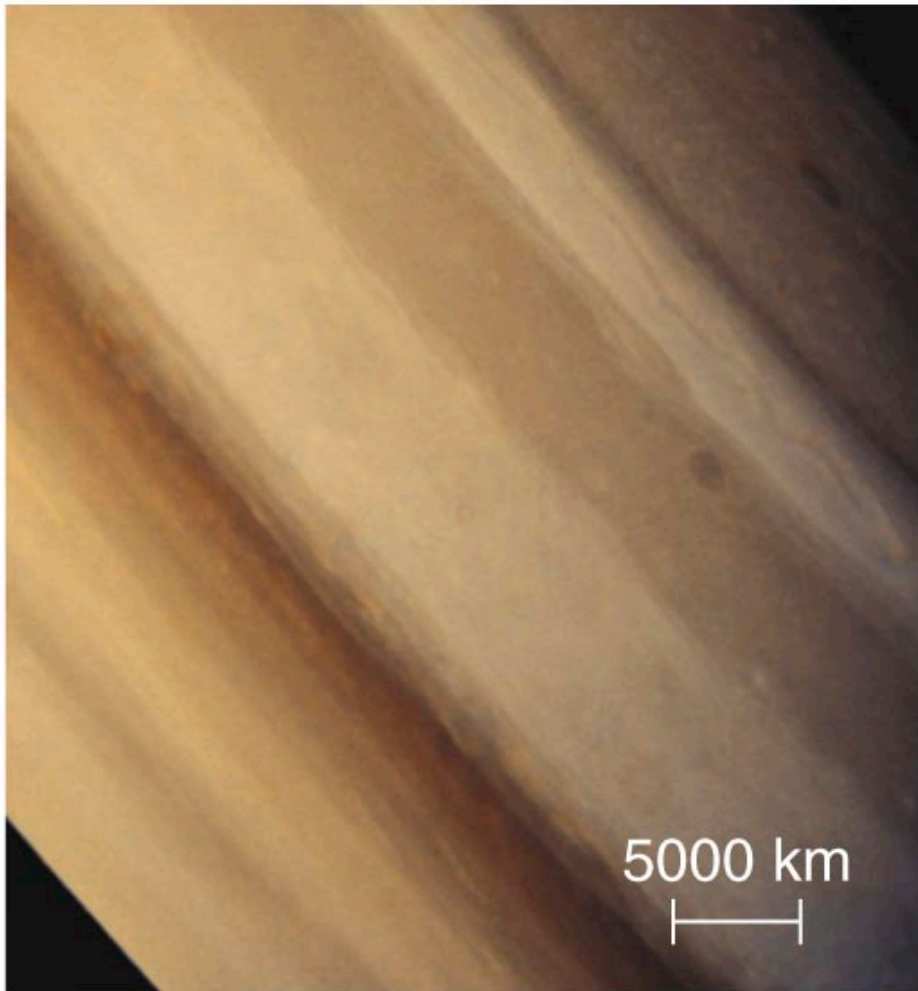
Received February 19, 2001; revised June 13, 2001

Jupiter's Colors



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

Saturn's Colors

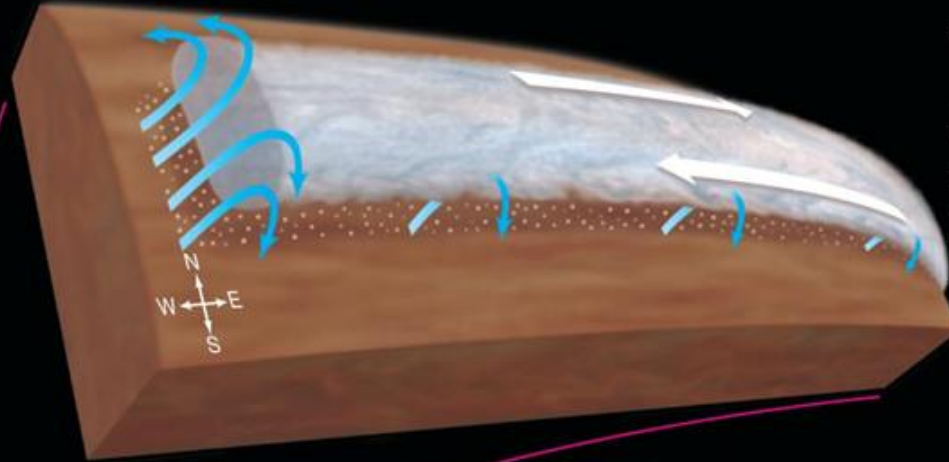


- Saturn's layers are similar, but deeper in and farther from the Sun (more subdued).

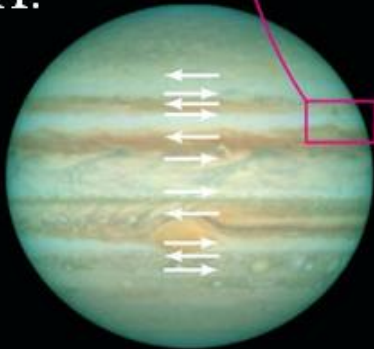
Jupiter's Bands

White ammonia clouds form where air rises.

Between white clouds, we see deeper reddish clouds of NH_4SH .



The Coriolis effect changes N-S flow to E-W winds.

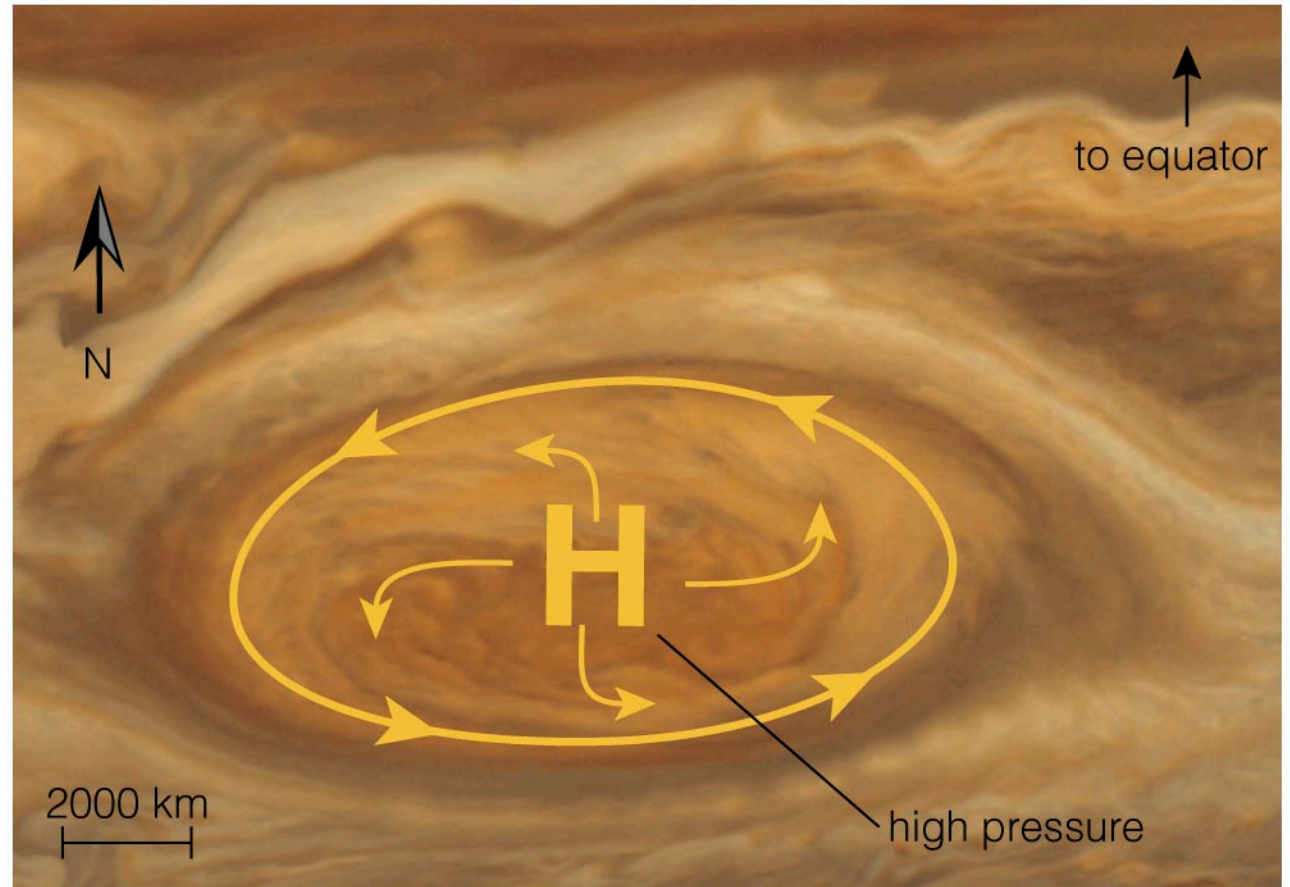


Warmer red bands are brighter in IR.



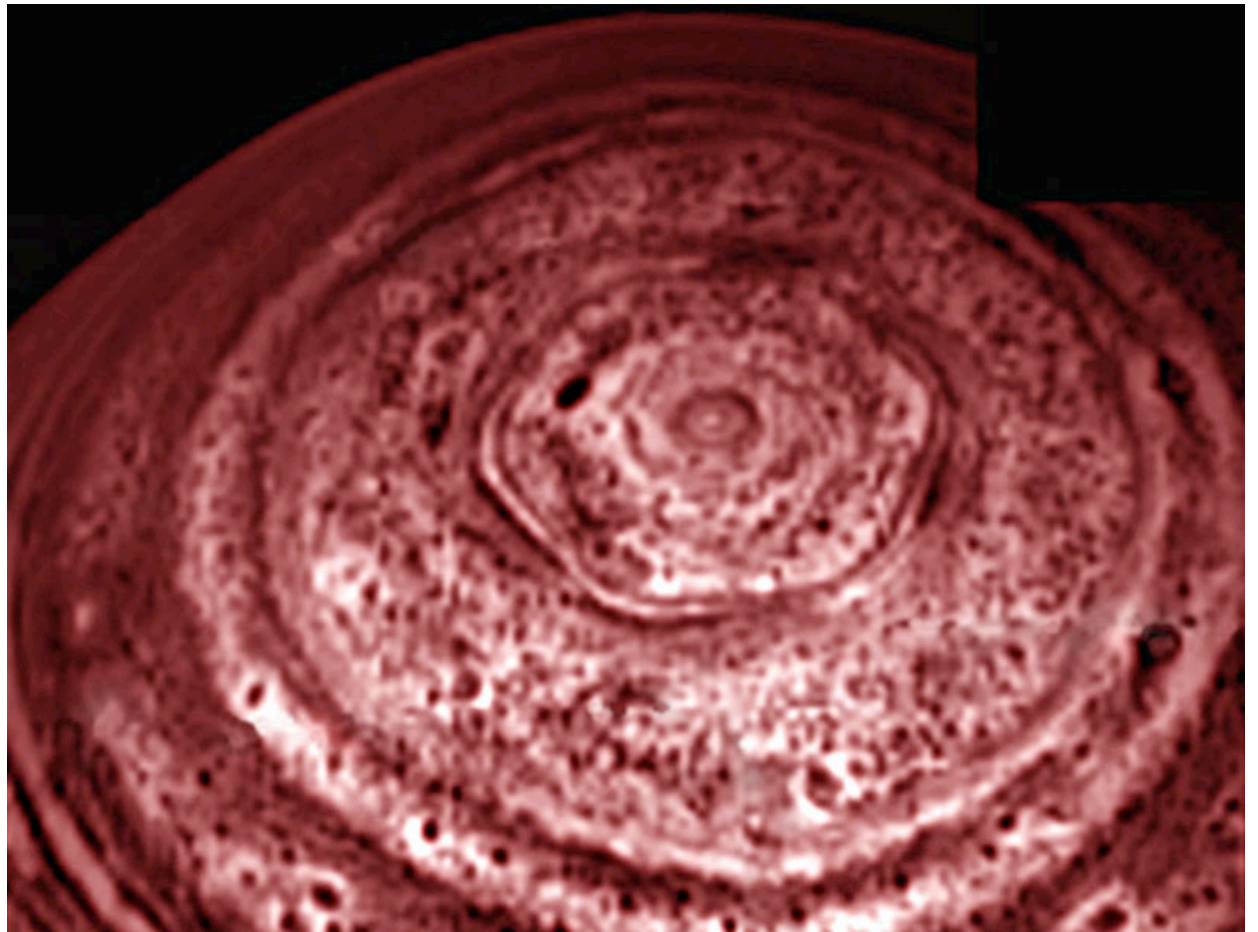
Interactive Figure 

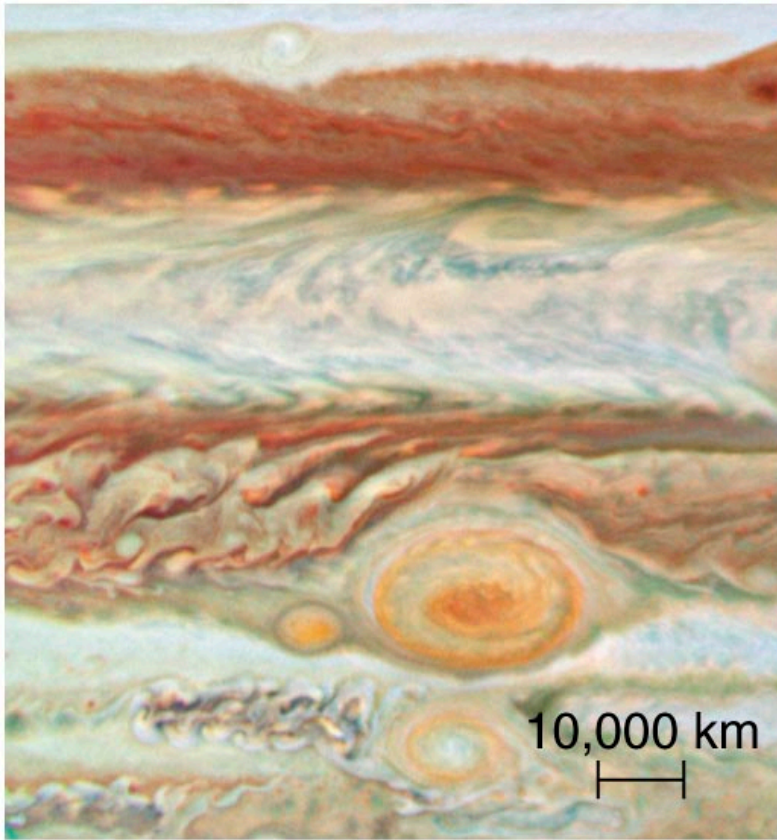
Jupiter's Great Red Spot



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

Saturn's North Pole Hexagon

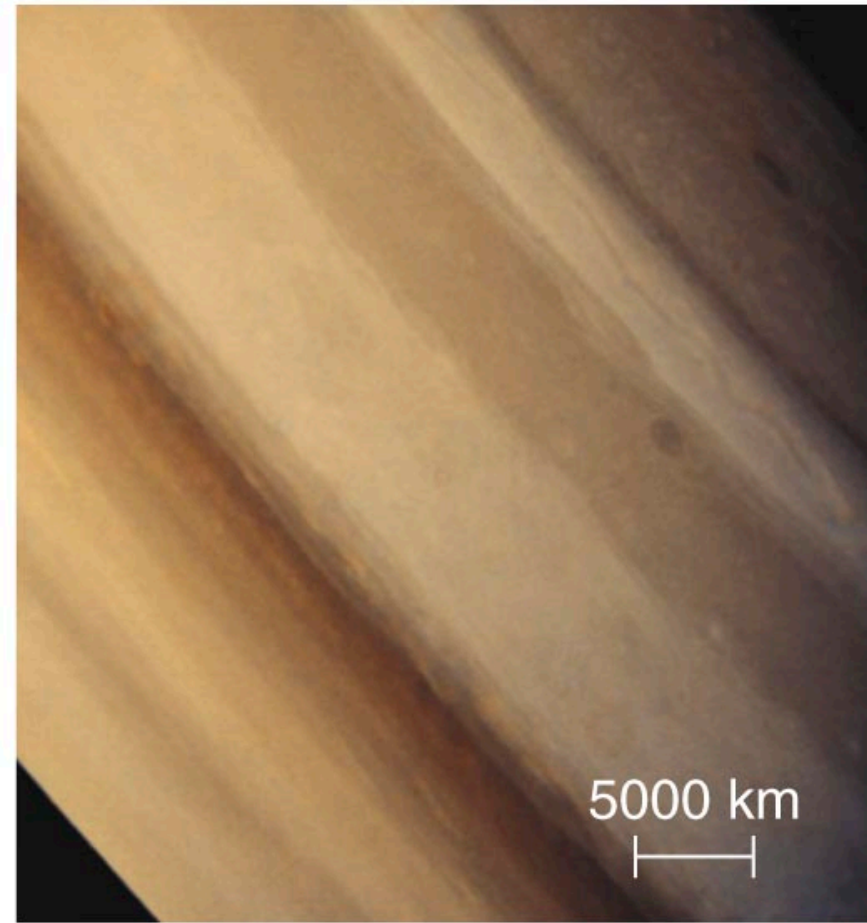




a This Hubble Space Telescope image shows Jupiter's southern hemisphere with the Great Red Spot, "Baby Red" (to its left), and "Red Jr." (below). Baby Red was torn apart by the Great Red Spot a few days later.

© 2010 Pearson Education, Inc.

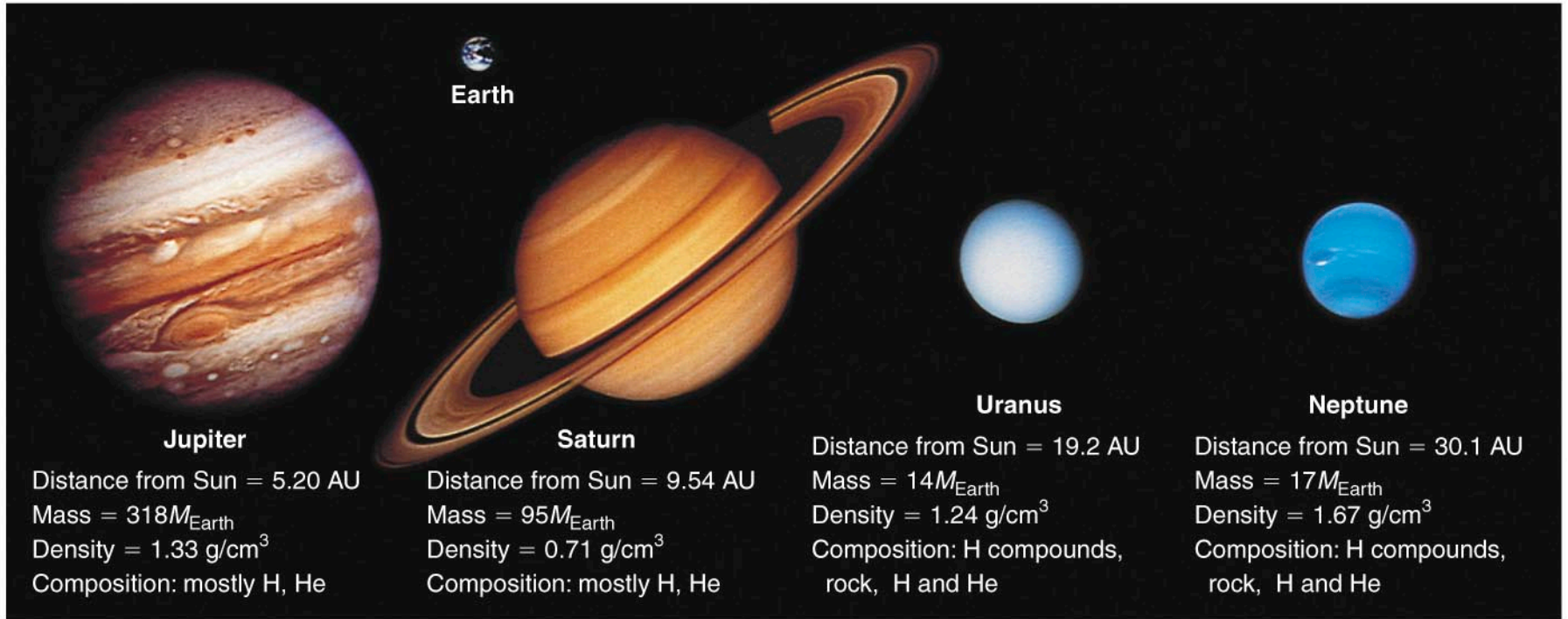
© 2010 Pearson Education, Inc.



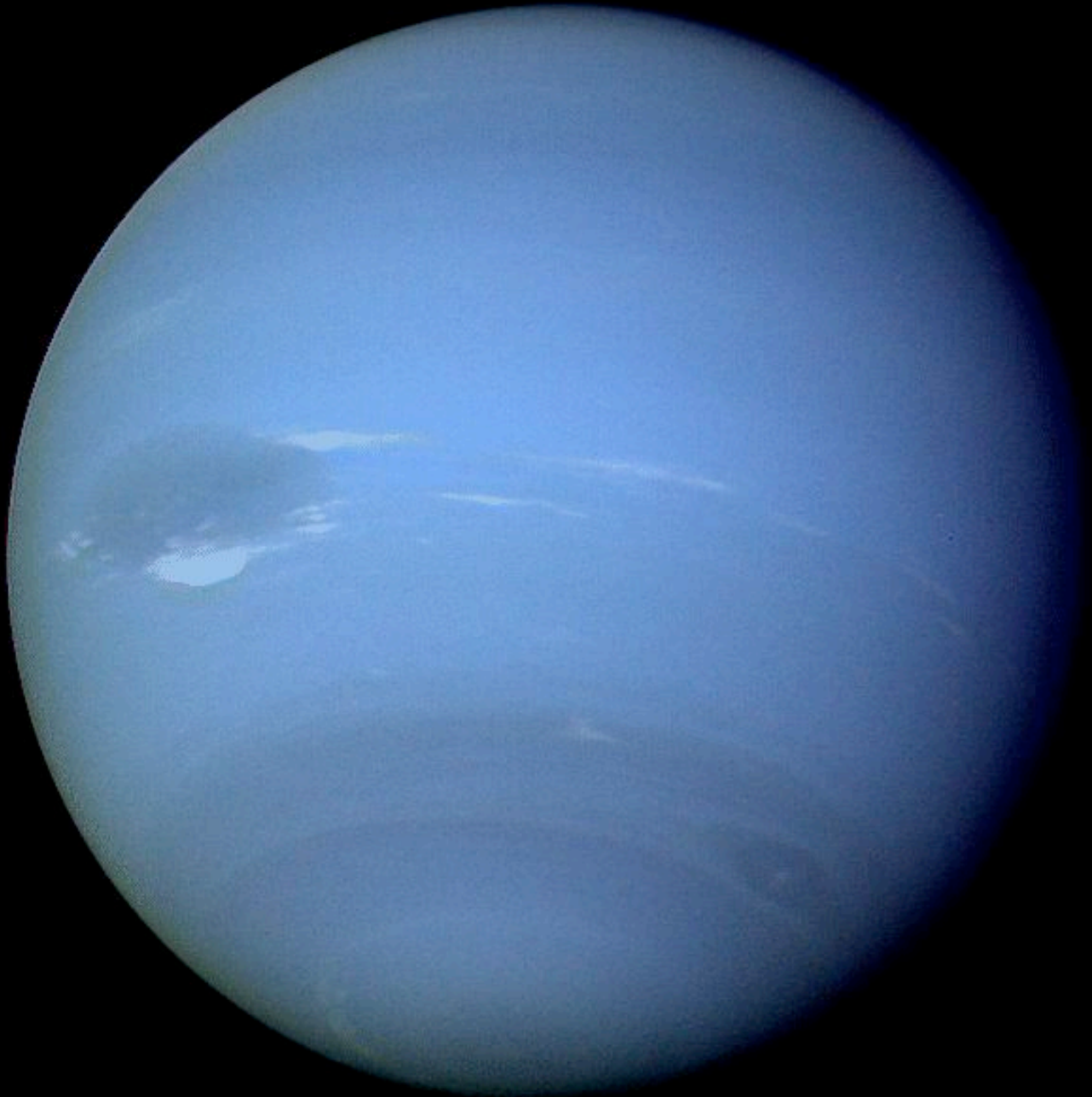
b Saturn's atmosphere, photographed by *Voyager 1*. Its banded appearance is very similar to that of Jupiter, but it has even faster winds.

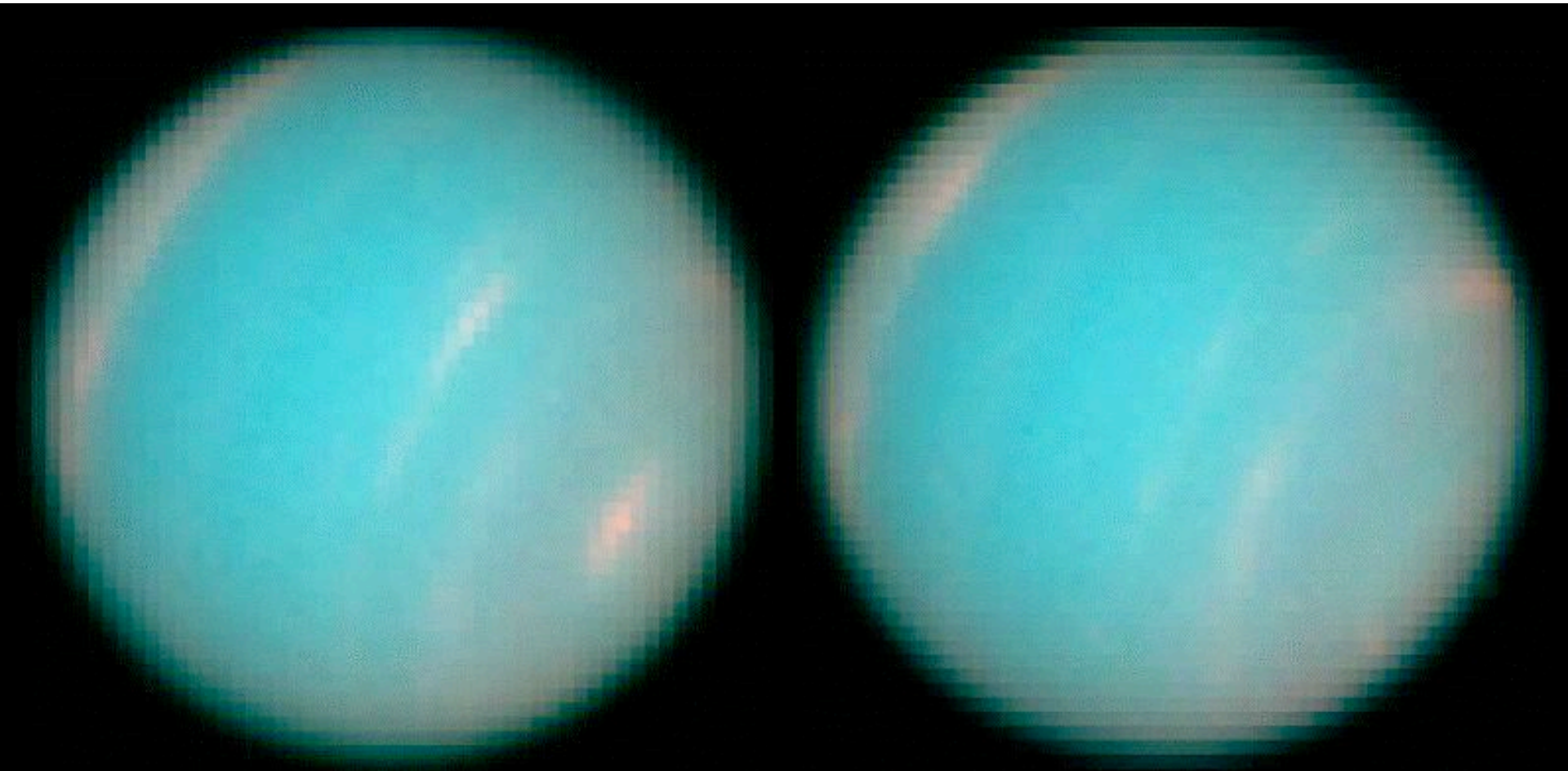
© 2010 Pearson Education, Inc.

Weather on Jovian Planets



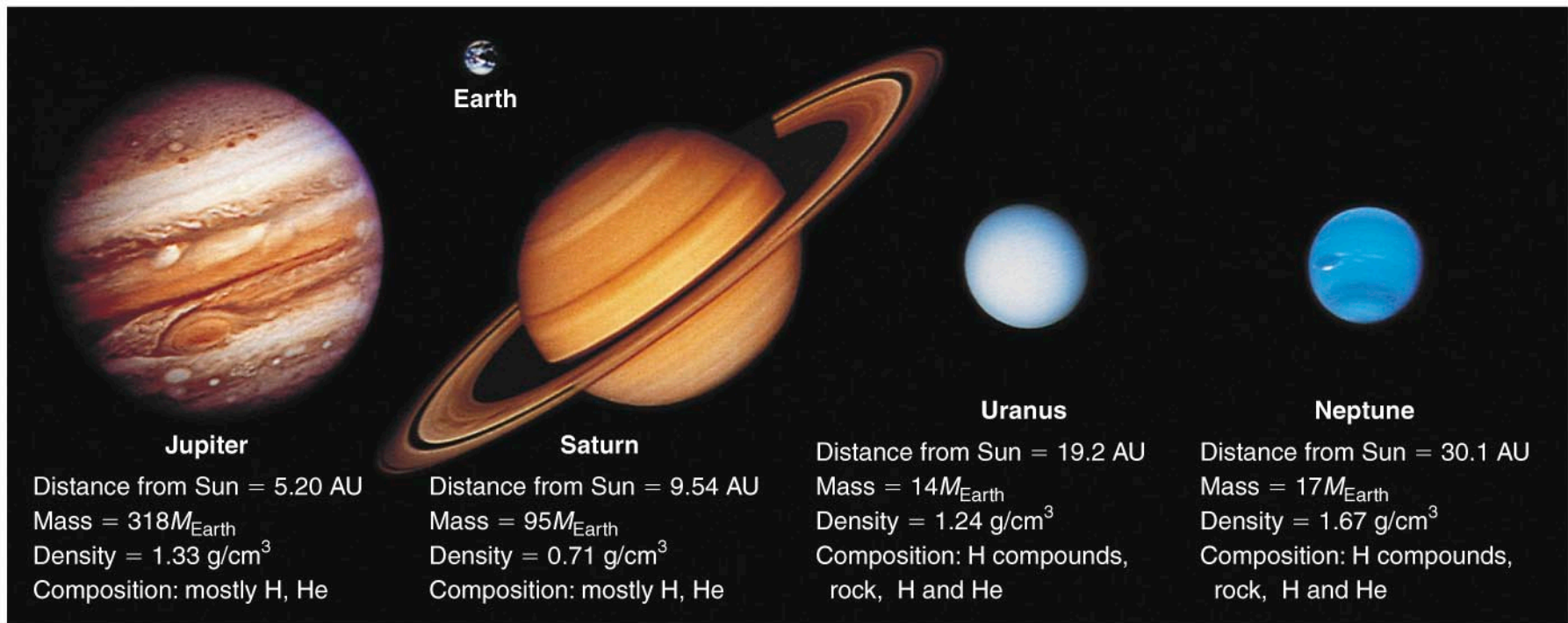
- All the jovian planets have strong winds and storms.



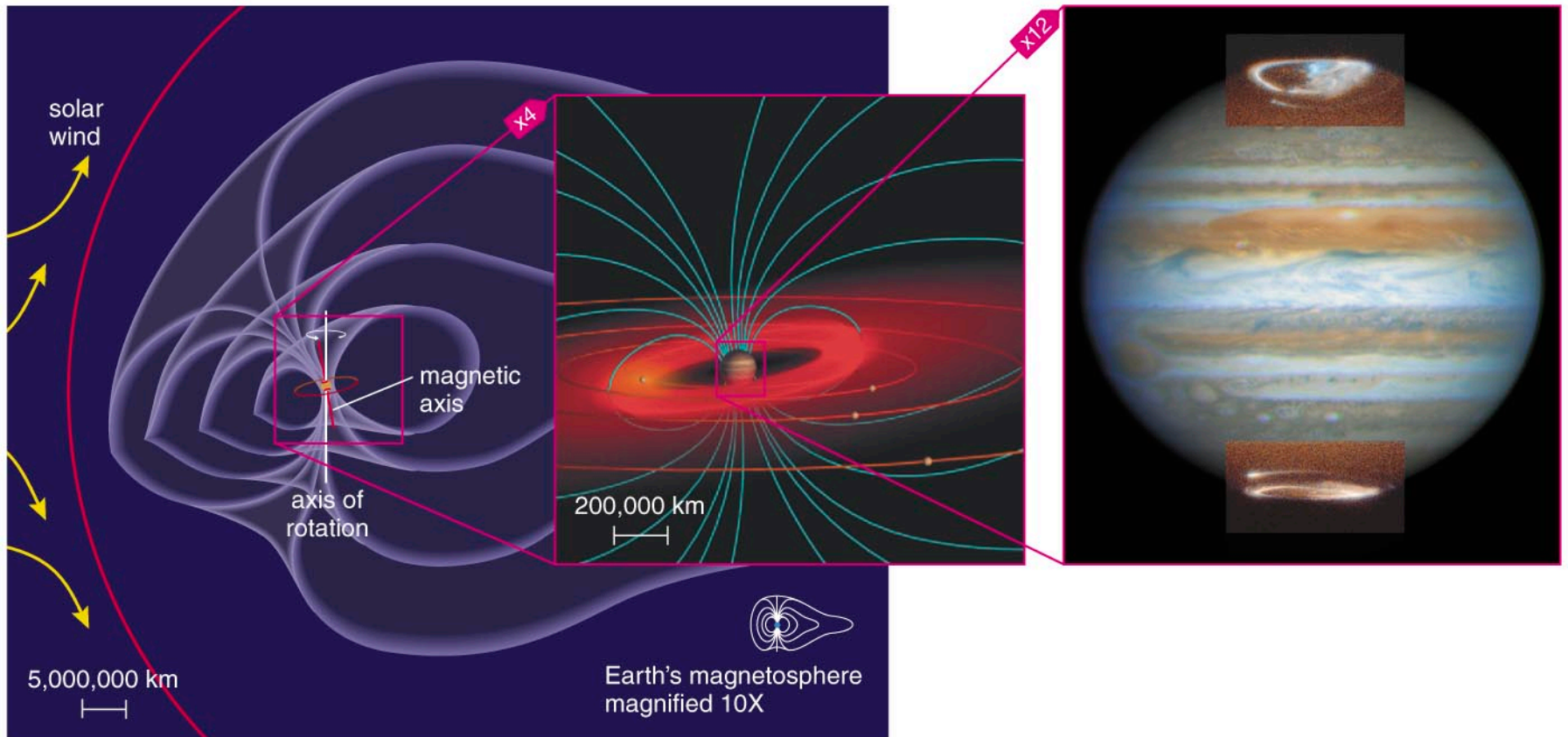


Methane on Uranus and Neptune

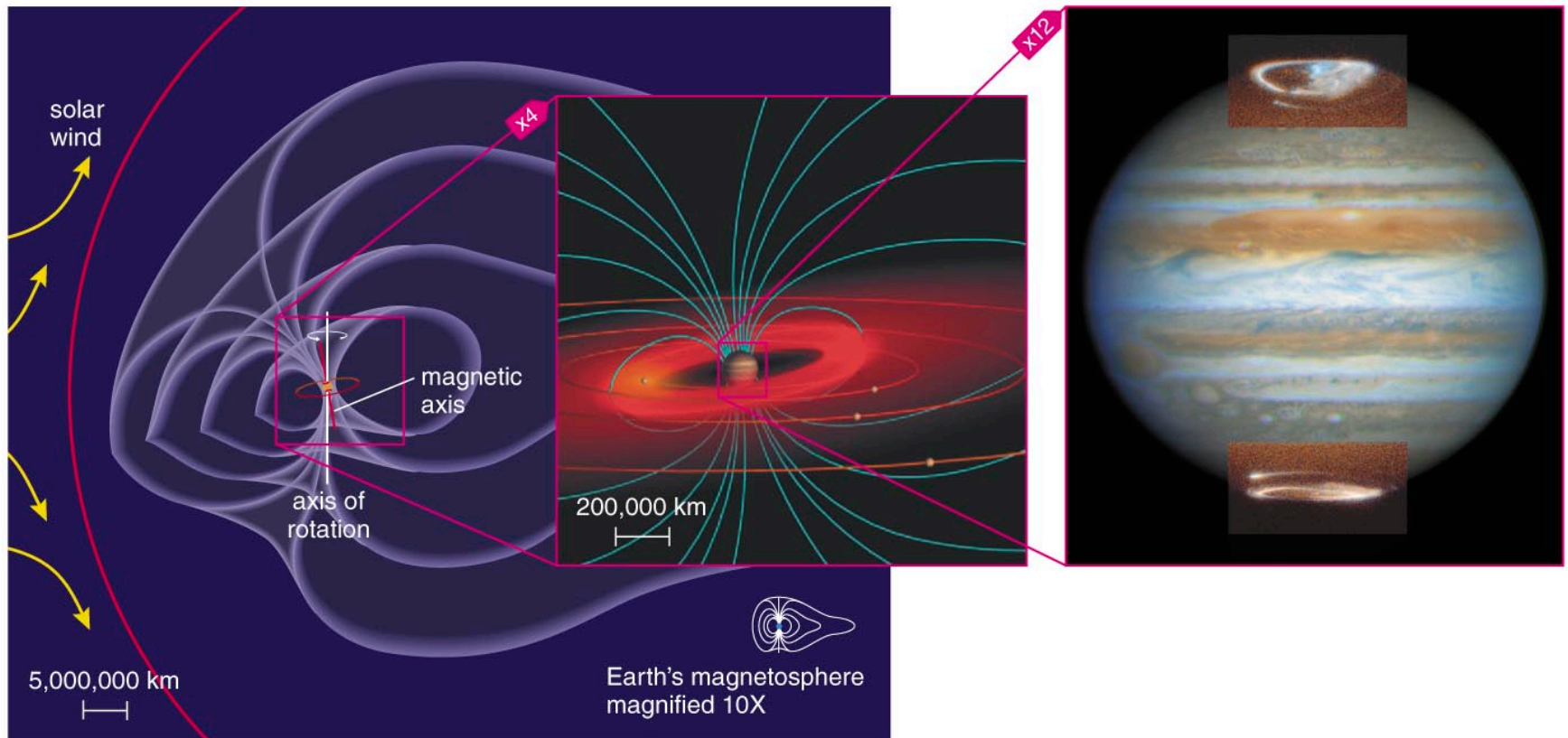
- Methane gas of Neptune and Uranus absorbs red light but transmits blue light.
- Blue light reflects off methane clouds, making those planets look blue.



Do jovian planets have magnetospheres like Earth's?

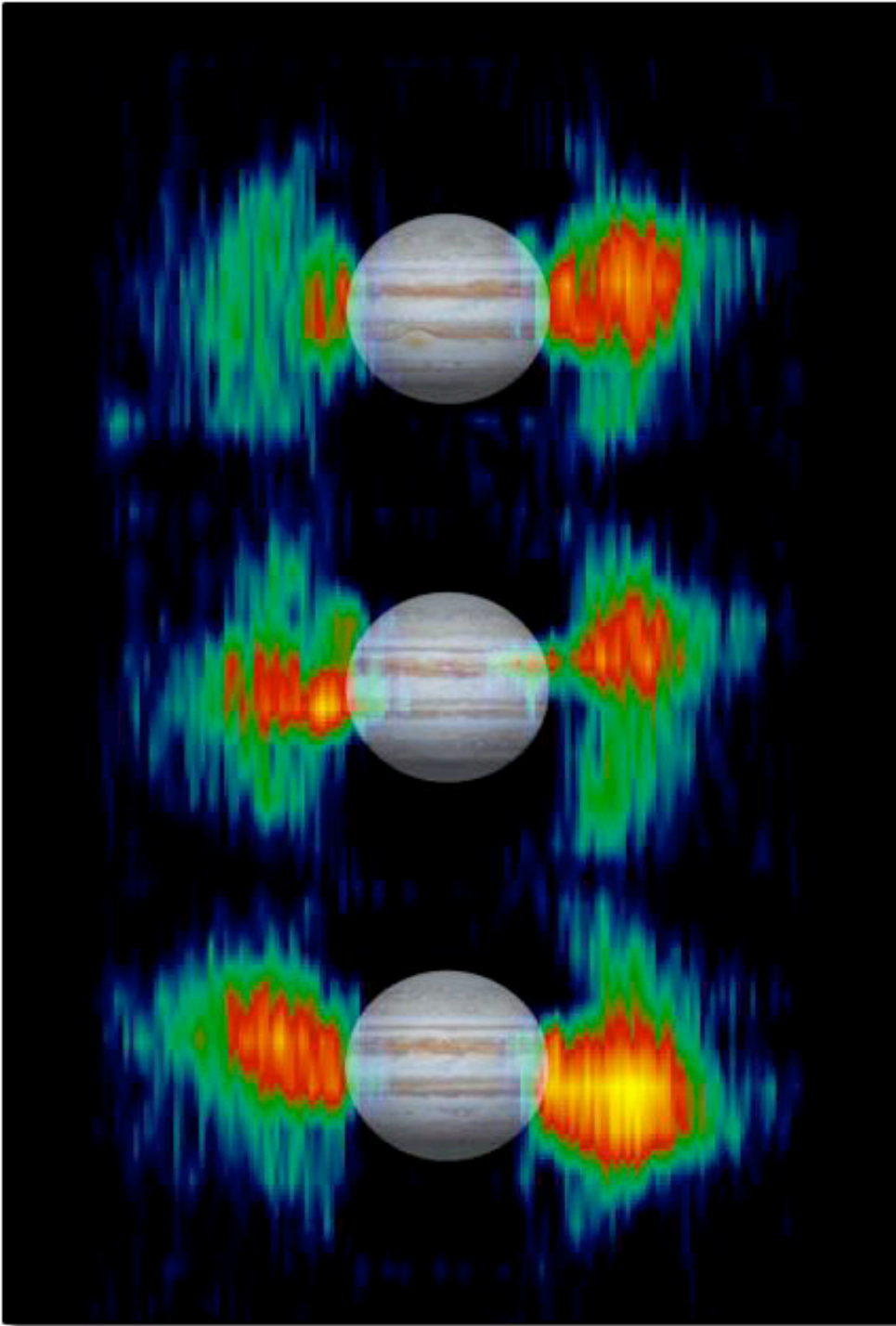


Jupiter's Magnetosphere



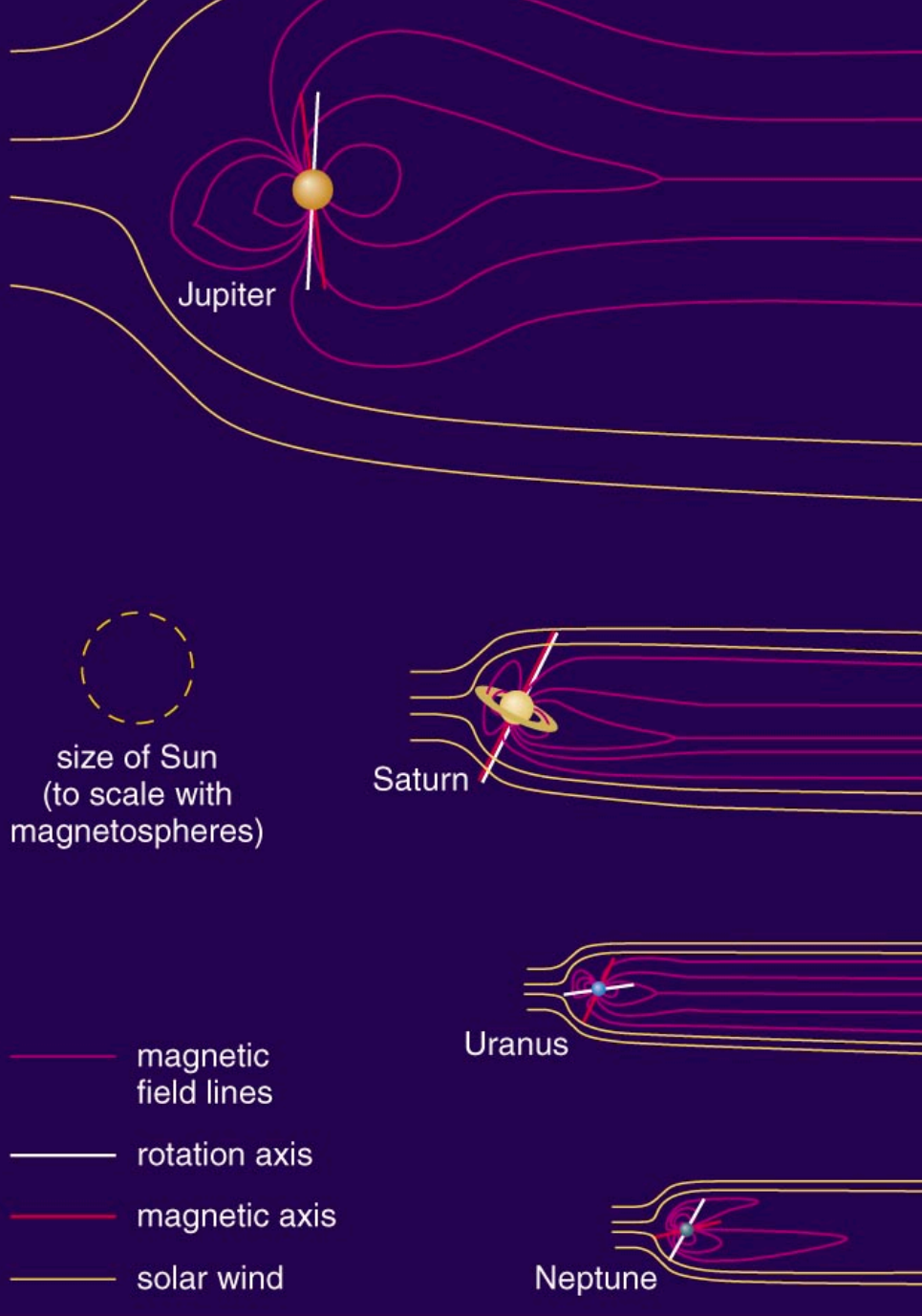
- Jupiter's strong magnetic field gives it an enormous magnetosphere.
- Gases escaping Io feed the donut-shaped Io torus.

Charged particles trapped in
Jupiter's magnetosphere
emit radio waves



Other Magnetospheres

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



Clicker Question

Jupiter does *not* have a large iron 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.

Clicker 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.

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.

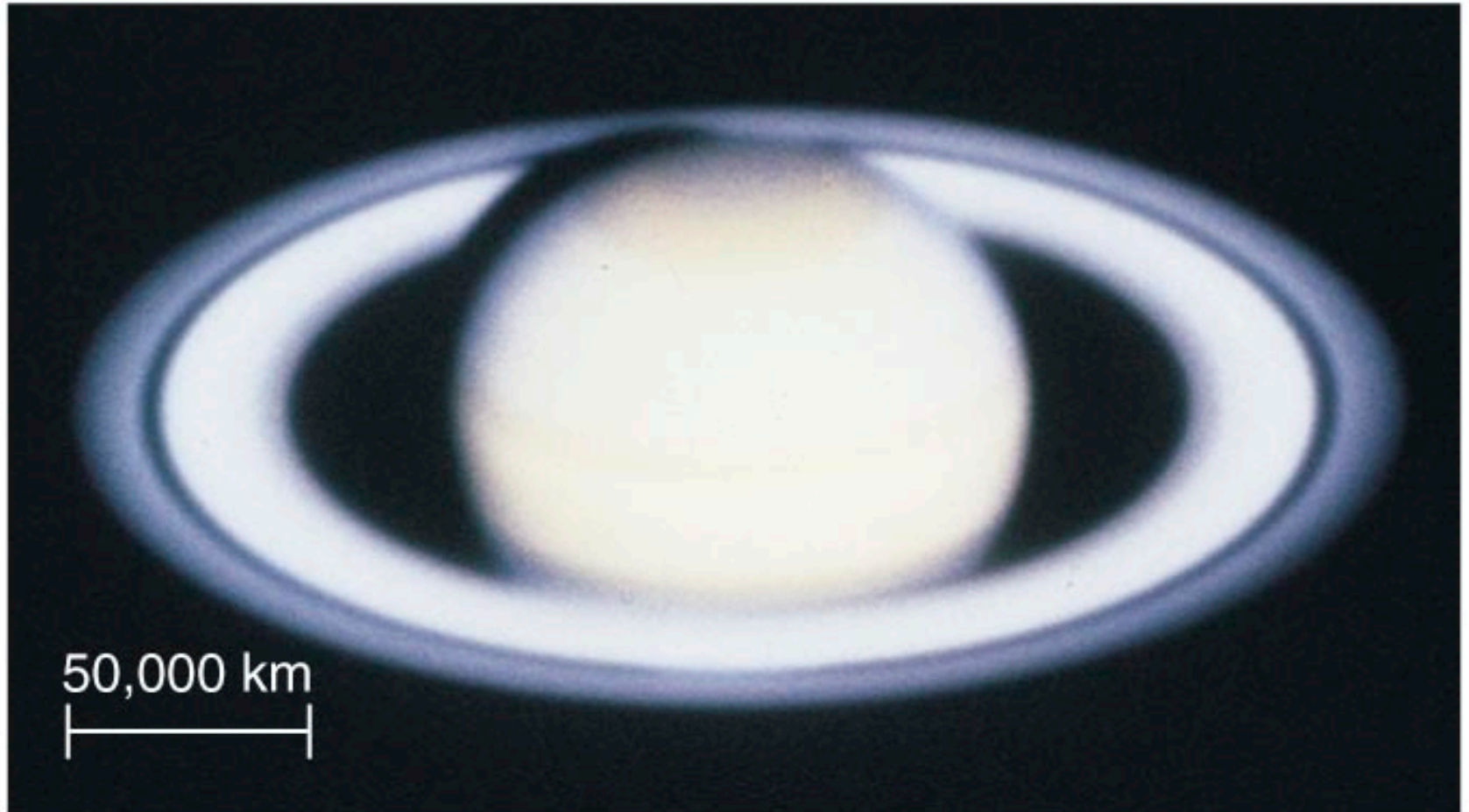
11.3 Jovian Planet Rings

(11.2 on Thursday)

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?

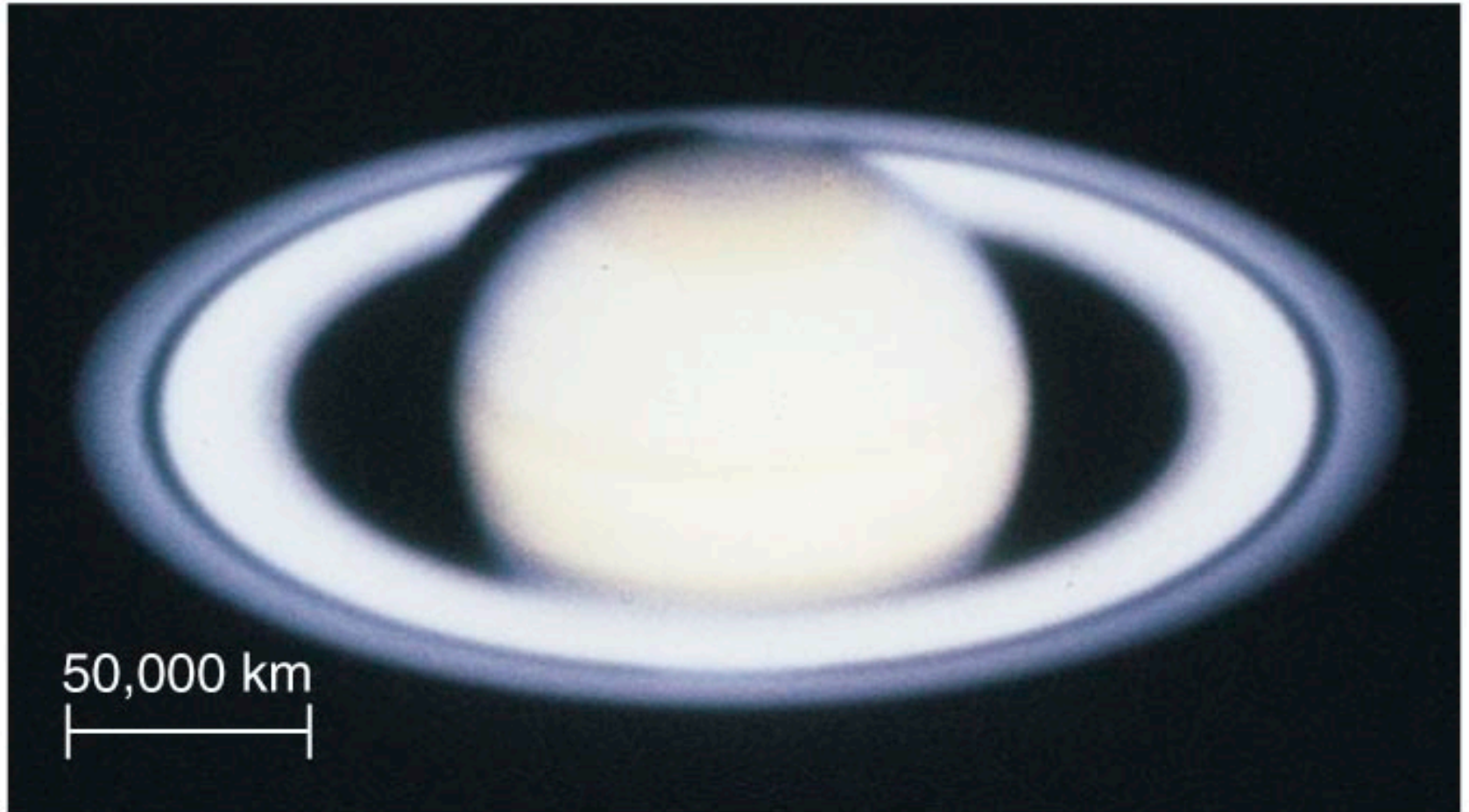
What are Saturn's rings like?



What are Saturn's rings like?

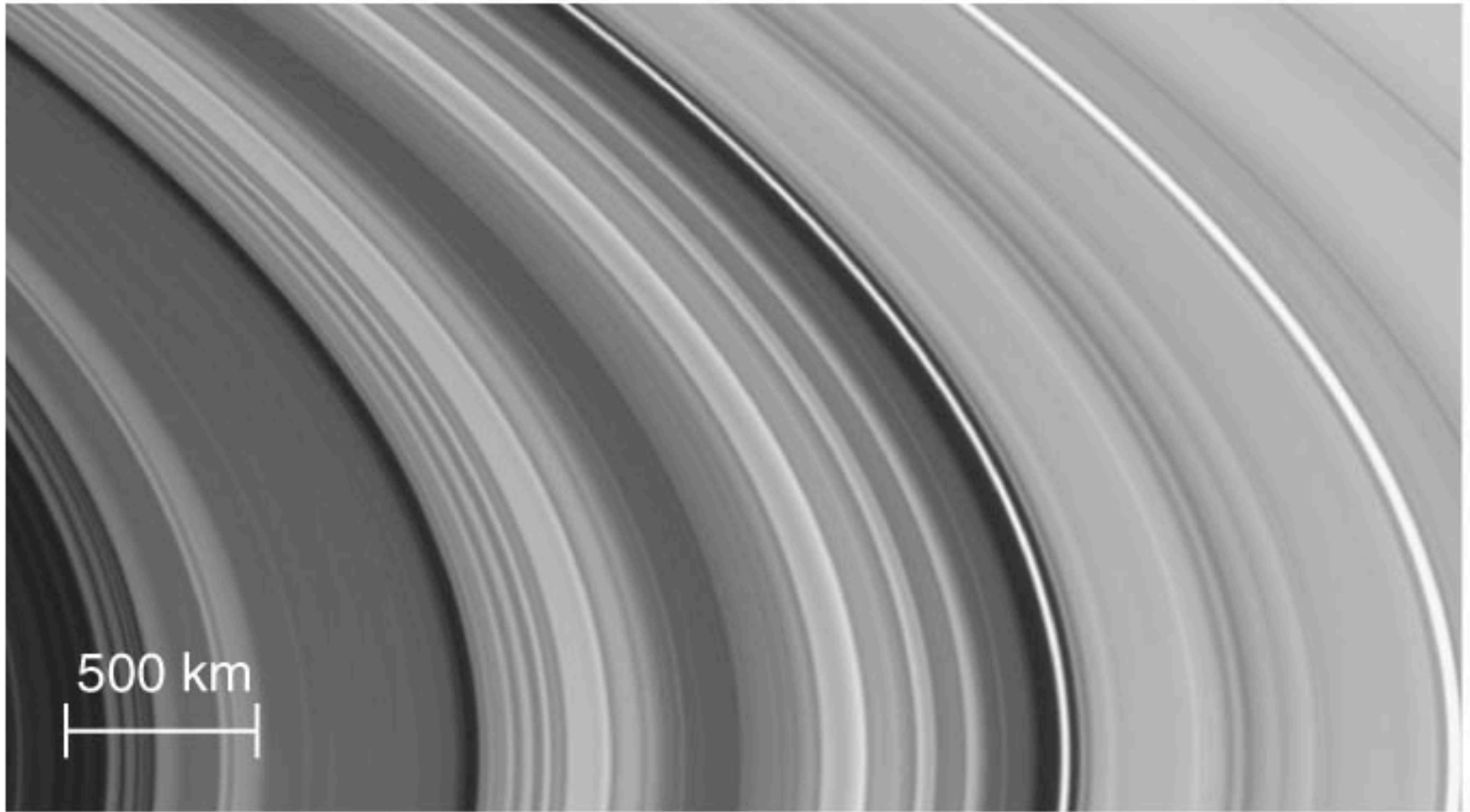
- They are made up of numerous, tiny individual particles.
- They orbit around Saturn's equator.
- They are very thin.

Earth-Based View of Saturn

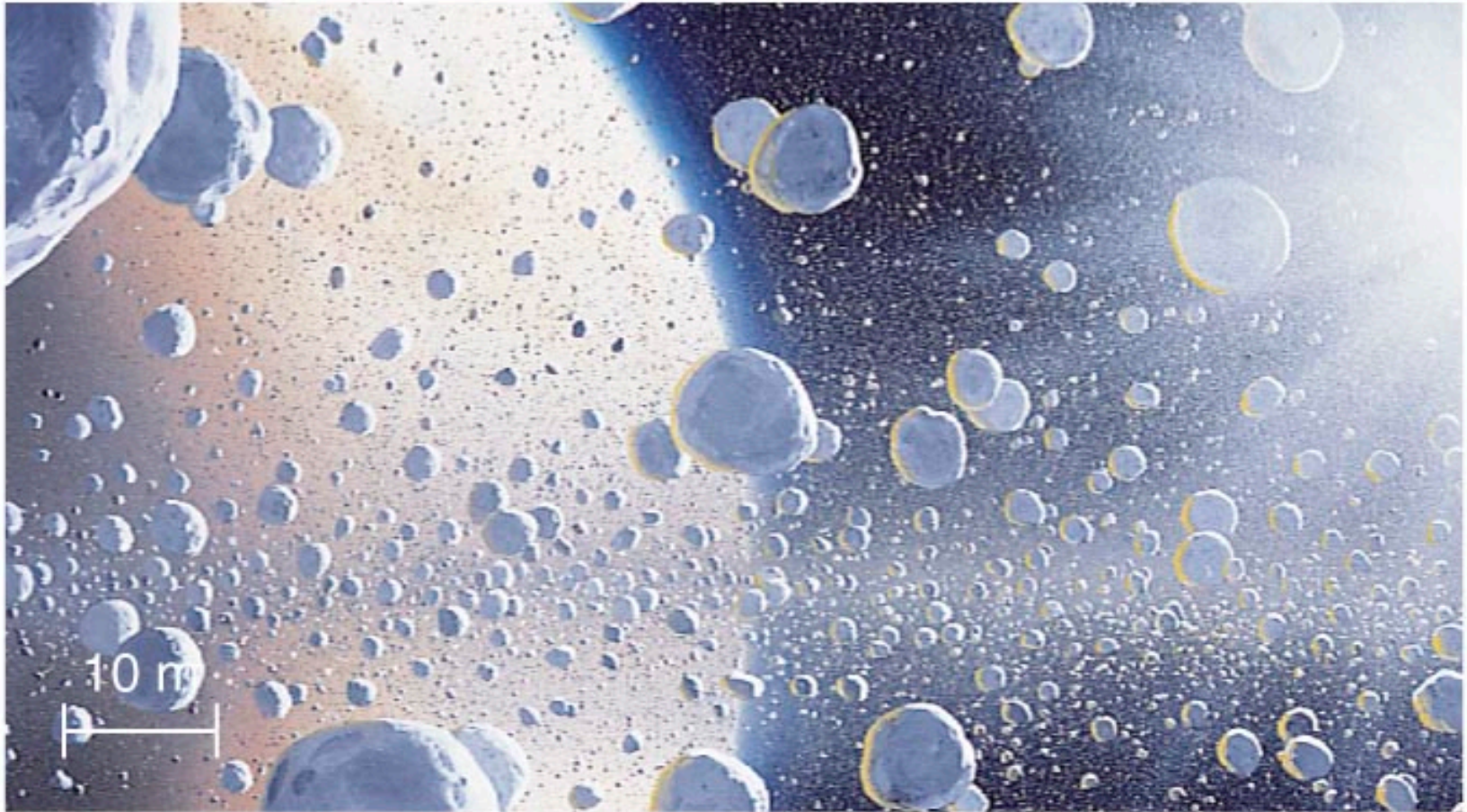


Interactive Figure 

Spacecraft View of Ring Gaps



Artist's Conception of Rings Close-Up



James Keeler, Lick Observatory
Director, 1898-1900

In 1895, proved that Saturn's
rings are not solid, but made up
of tiny particles

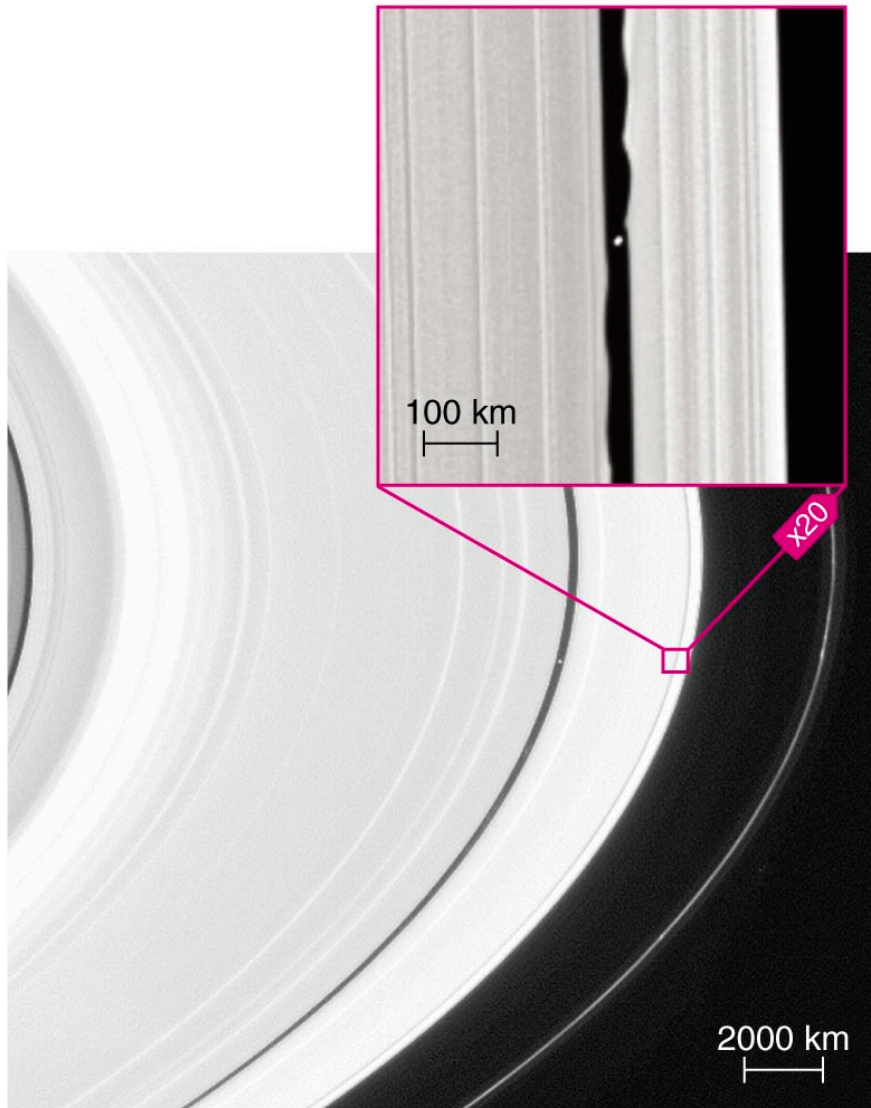
Used Kepler's 3rd law and the
Doppler Shift



J. E. Keeler

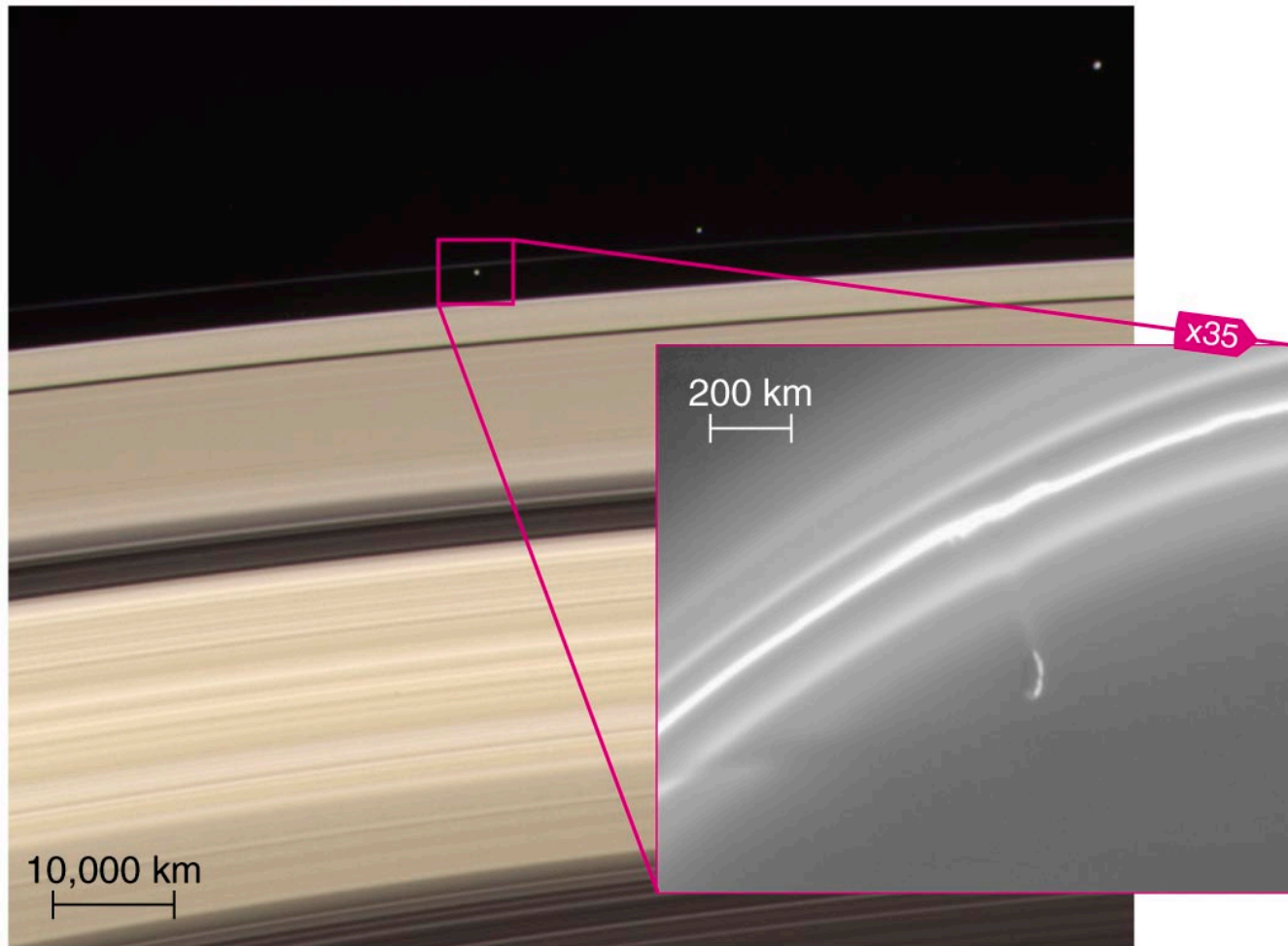


Gap Moons



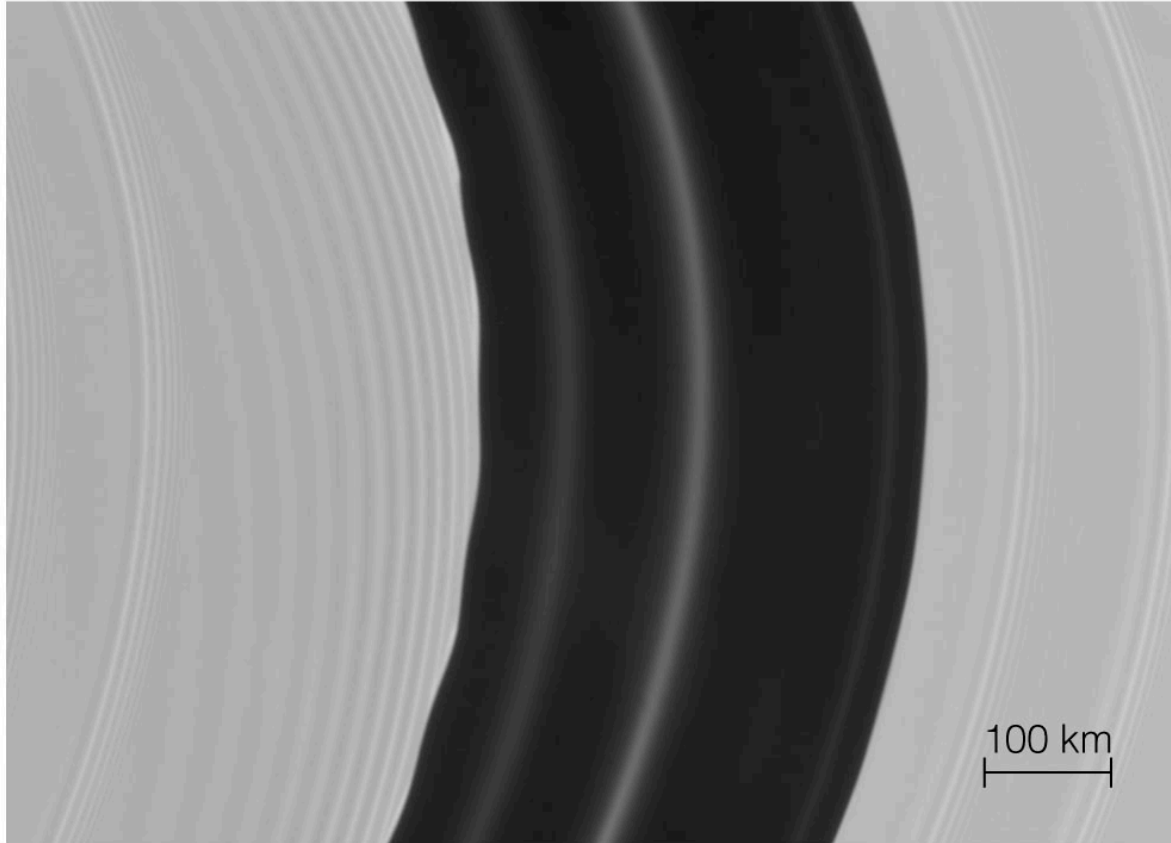
- Some small moons create gaps within rings.

Shepherd Moons

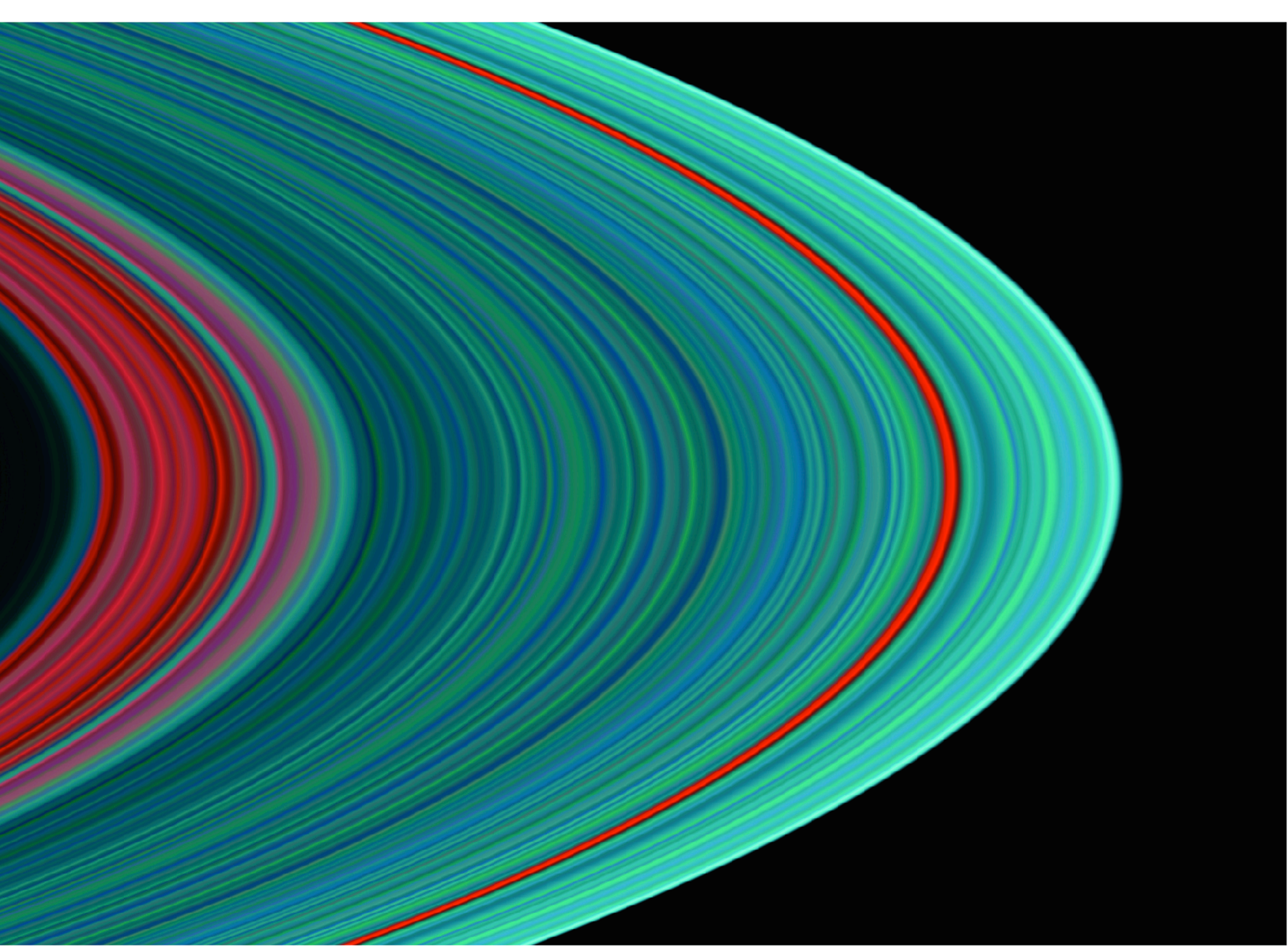


- A pair of small moons can force particles into a narrow ring.

Resonance Gaps



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



KRONOSEISMOLOGY: USING DENSITY WAVES IN SATURN'S C RING TO PROBE THE PLANET'S INTERIOR

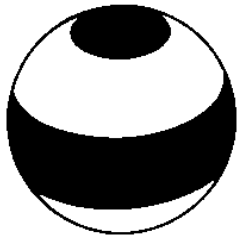
M. M. HEDMAN AND P. D. NICHOLSON

Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14850, USA; mmhedman@astro.cornell.edu

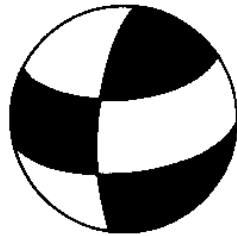
Received 2013 March 15; accepted 2013 April 12; published 2013 June 11

ABSTRACT

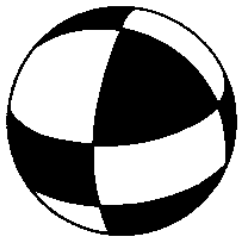
Saturn's C ring contains multiple spiral patterns that appear to be density waves driven by periodic gravitational perturbations. In other parts of Saturn's rings, such waves are generated by Lindblad resonances with Saturn's various moons, but most of the wave-like C-ring features are not situated near any strong resonance with any known moon. Using stellar occultation data obtained by the Visual and Infrared Mapping Spectrometer on board the *Cassini* spacecraft, we investigate the origin of six unidentified C-ring waves located between 80,900 and 87,200 km from Saturn's center. By measuring differences in the waves' phases among the different occultations, we are able to determine both the number of arms in each spiral pattern and the speeds at which these patterns rotate around the planet. We find that all six of these waves have between two and four arms and pattern speeds between $1660^\circ \text{ day}^{-1}$ and $1861^\circ \text{ day}^{-1}$. These speeds are too large to be attributed to any satellite resonance. Instead, they



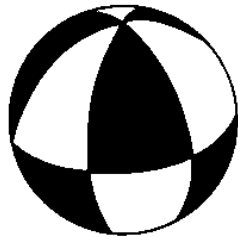
$m = 0$



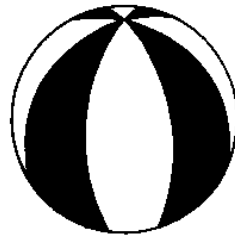
$|m| = 1$



$|m| = 2$



$|m| = 3$

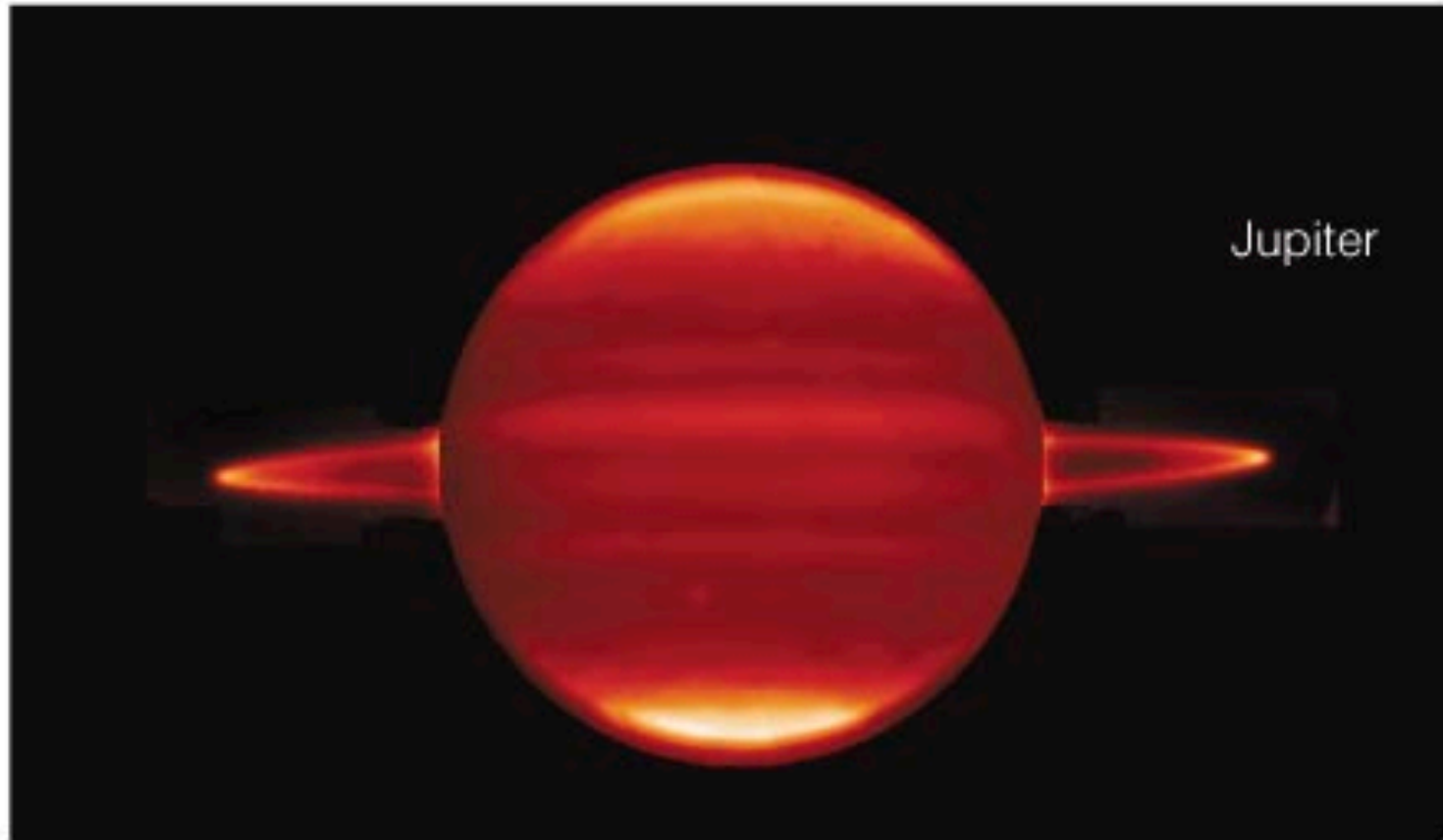


$|m| = 4$

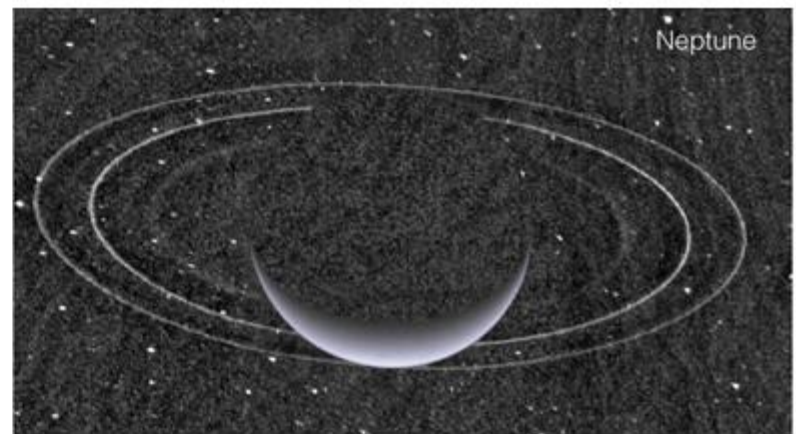
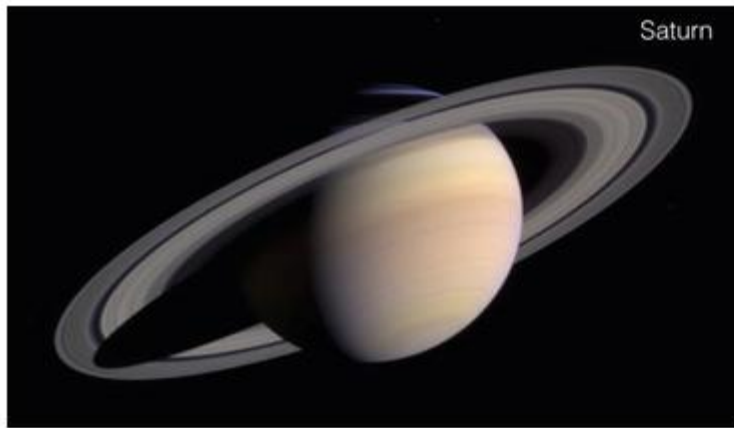
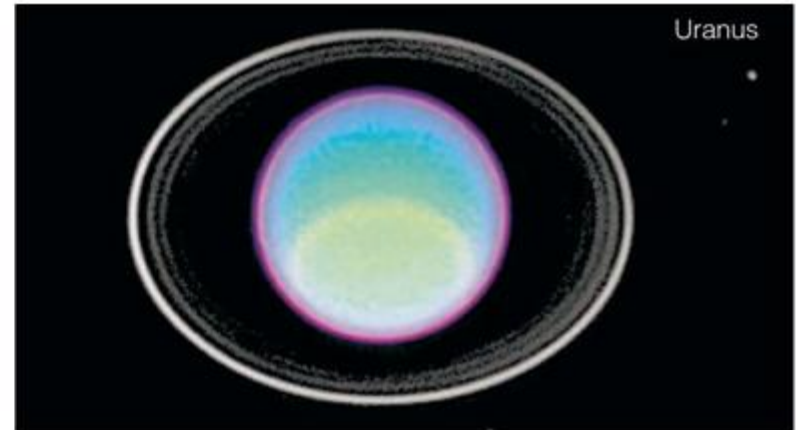
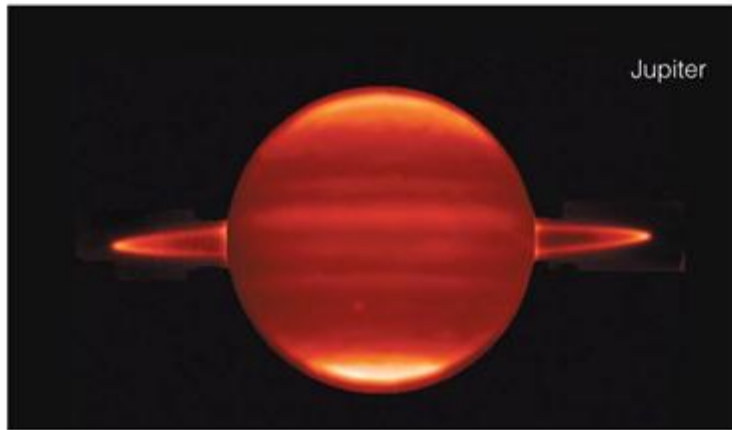
FIG. 1. Illustration of spherical harmonics for degree $l = 4$.

Saturn's Rings as a Seismograph

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?

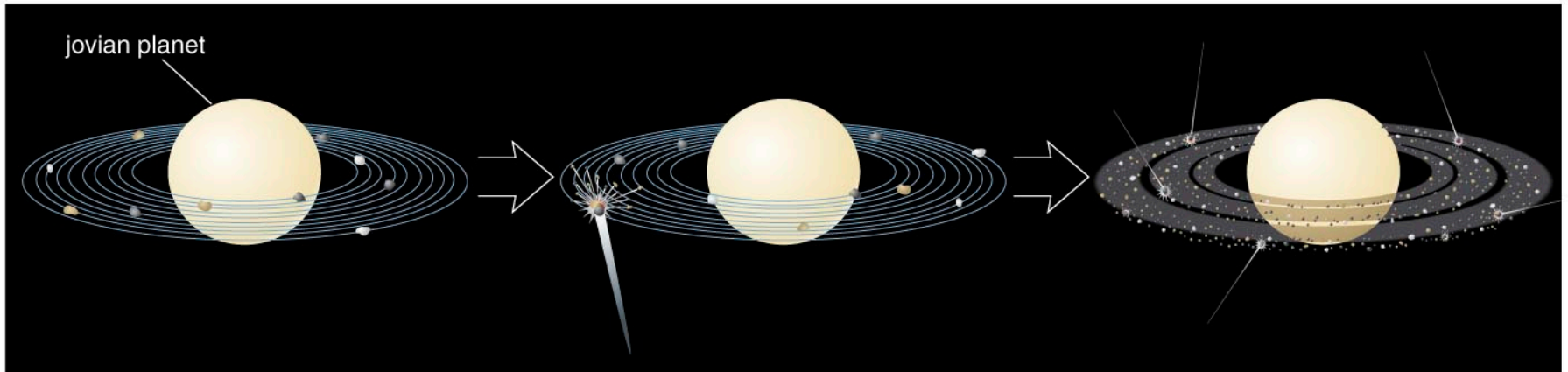
- They formed from dust created in impacts on moons orbiting those planets.

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.