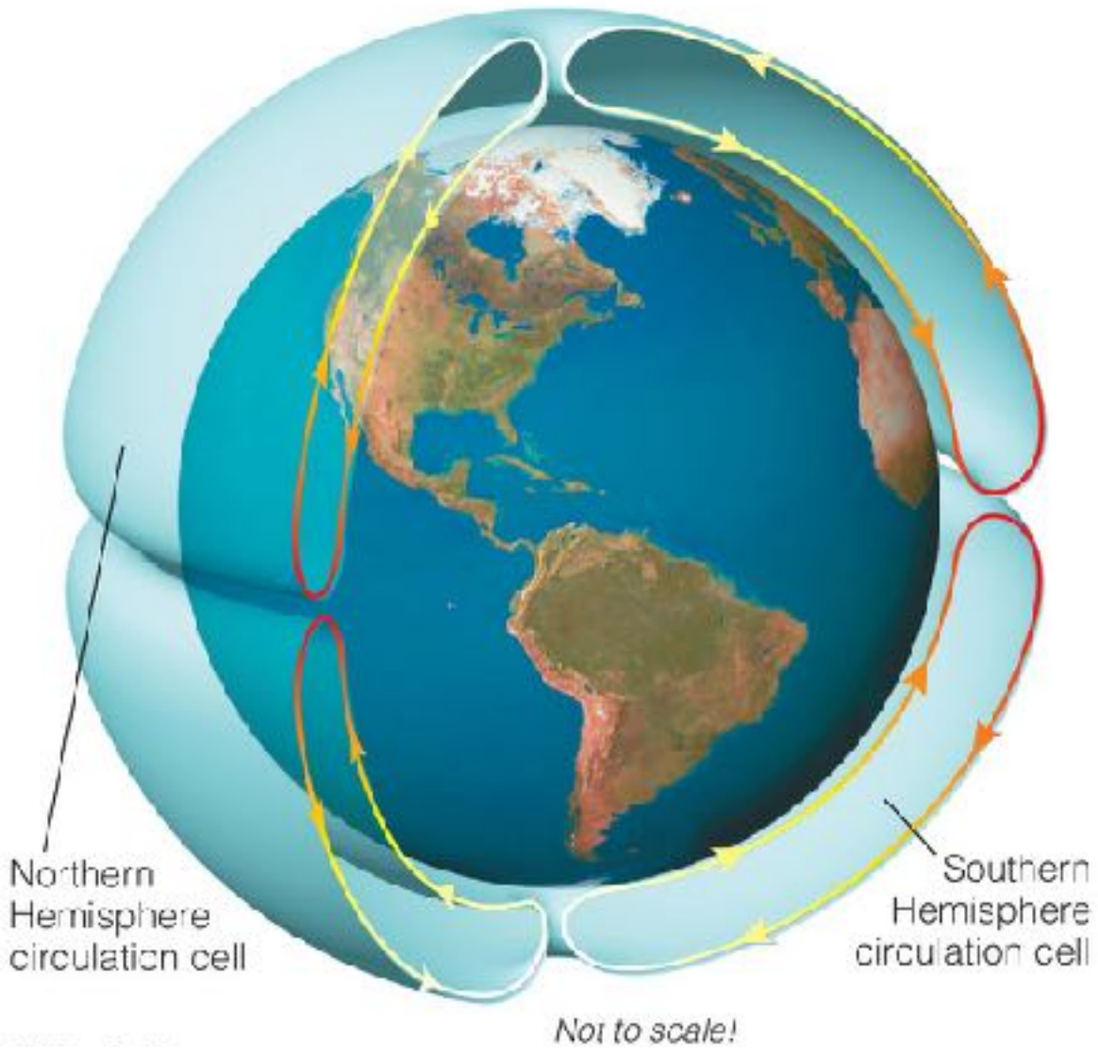
Today

- Jovian planets
- moons of the Jovian planets

Global Wind Patterns

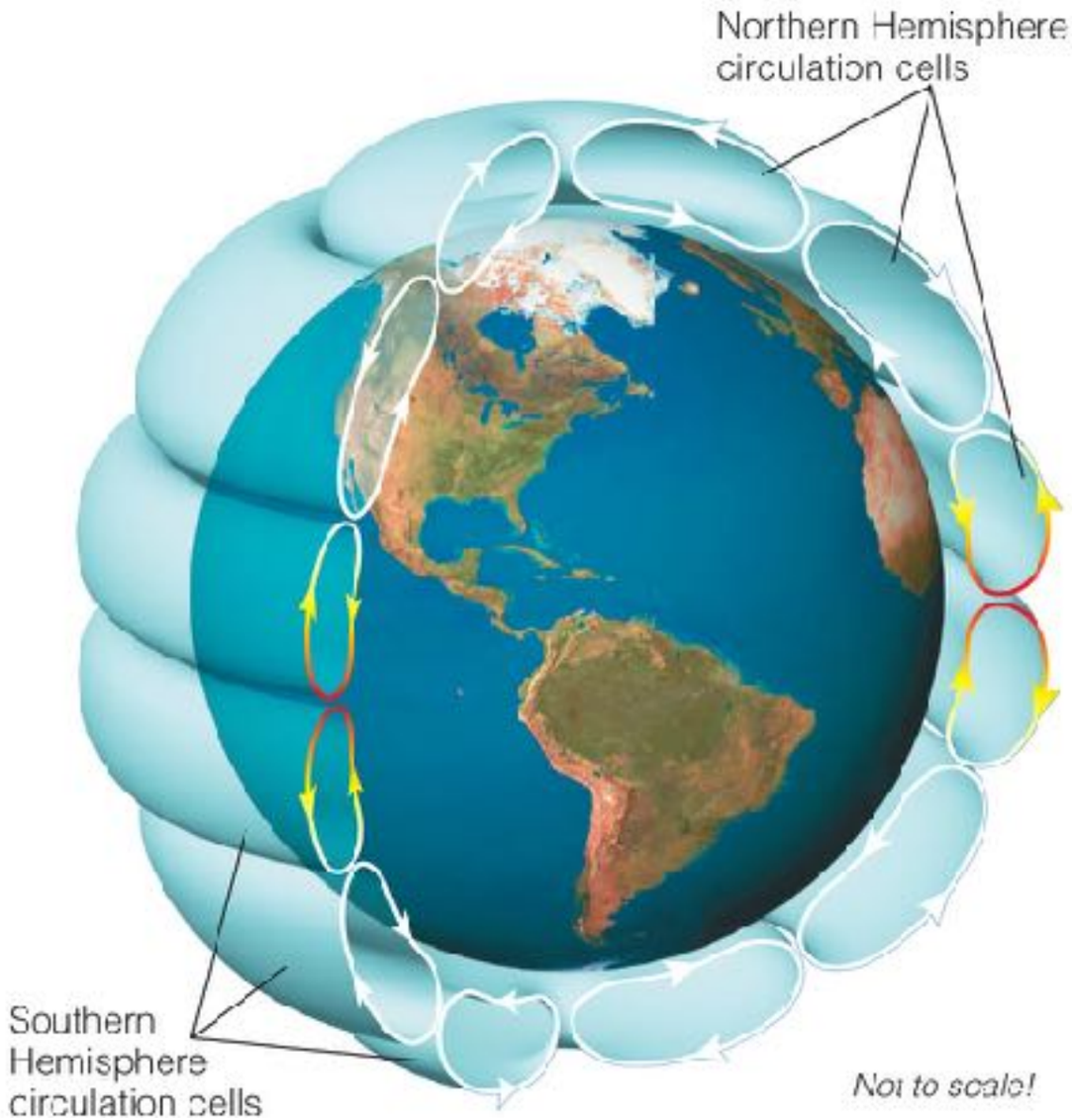
- Heat transport
- Global winds blow in distinctive patterns:
  - Equatorial: E to W
  - Mid-latitudes: W to E
  - High latitudes: E to W

Circulation Cells: No Rotation



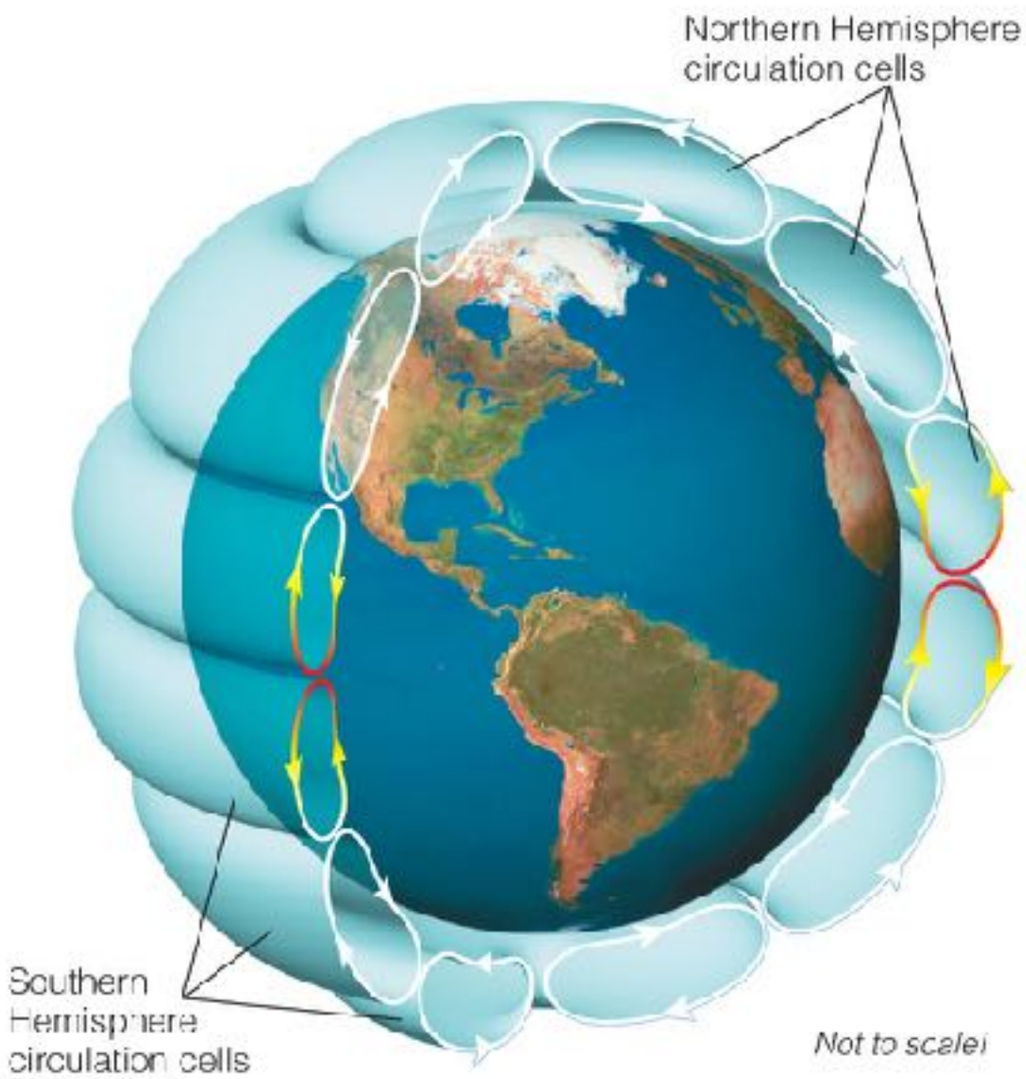
- Heated air rises at equator.
- Cooler air descends at poles.
- Without rotation, these motions would produce two large circulation cells.

Circulation Cells with Rotation



- Coriolis effect deflects north-south winds into east-west winds.
- Deflection breaks each of the two large "no-rotation" cells into three smaller cells in each hemisphere.
  - Tropical
  - Mid-latitude
  - Polar

Prevailing Winds



- Prevailing surface winds at mid-latitudes blow from W to E because the Coriolis effect deflects the S to N surface flow of mid-latitude circulation cells.

Coriolis Effect on Earth

a Low-pressure regions ("L") draw in air from surrounding areas, and the Coriolis effect causes this air to circulate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Interactive Figure

IF_10_15

- Air moving from a pole to the equator is going farther from Earth's axis and begins to lag behind Earth's rotation.
- Air moving from the equator to a pole moves closer to the axis and travels ahead of Earth's rotation.

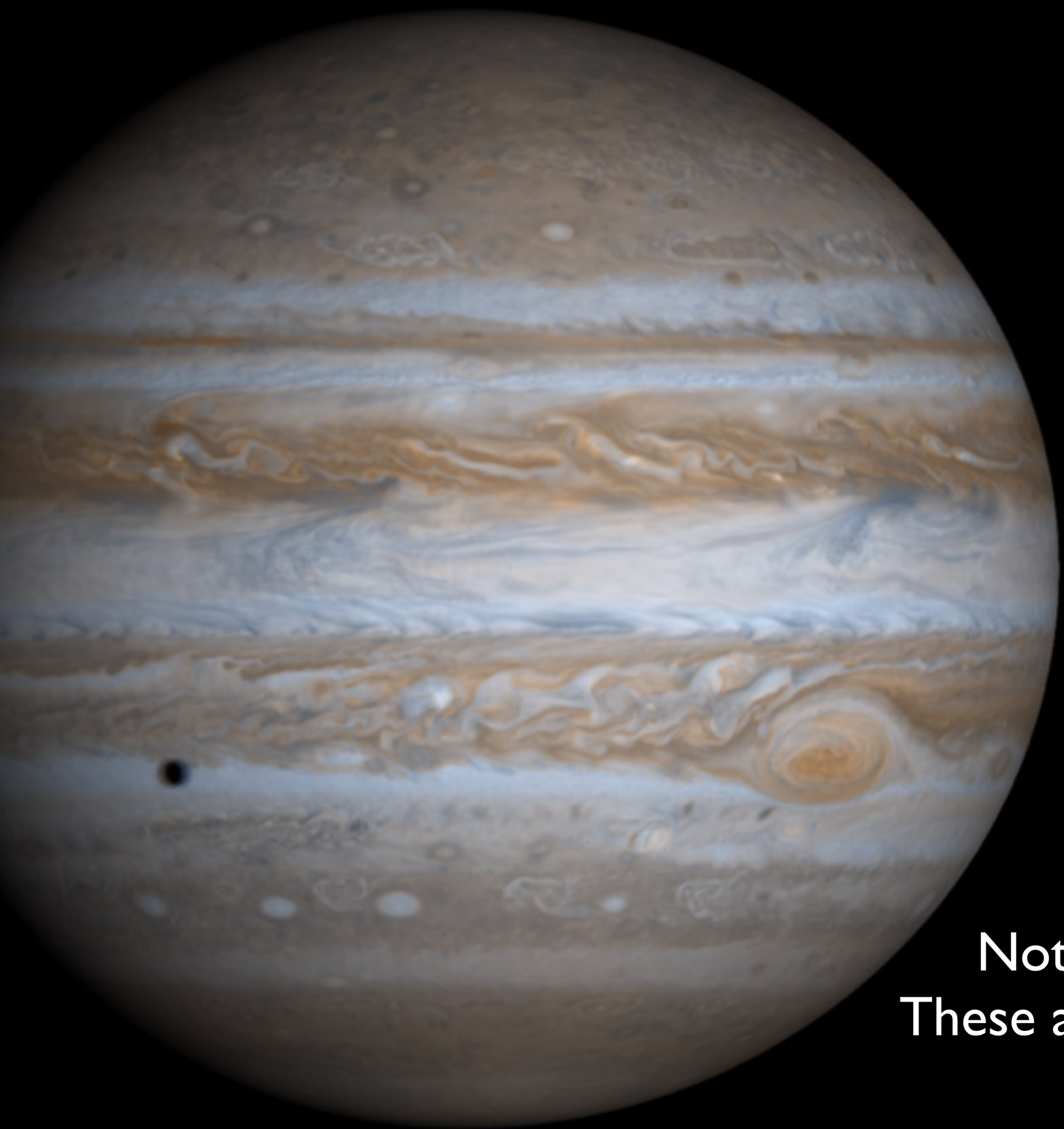
https://www.youtube.com/watch?v=tlQHki79K84&sns=em

Coriolis Effect on Earth

- Conservation of angular momentum causes large storms to swirl.

- Direction of circulation depends on hemisphere:
  - N: counterclockwise
    - right hand rule
  - S: clockwise

b This photograph shows the opposite directions of storm circulation in the two hemispheres.



- Jovian planets
  - Jupiter
  - Saturn
  - Uranus
  - Neptune

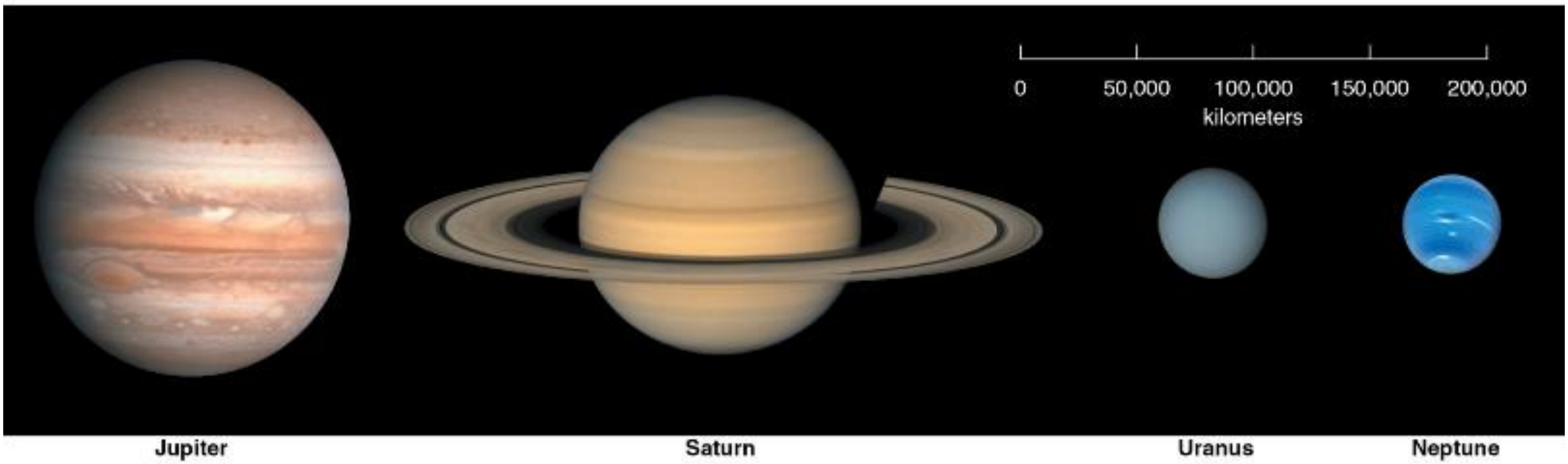
Note horizontal bands
These are circulation cells
Jovian day: $9^h\ 56^m$

The Giant Planets

- Jupiter, Saturn, Uranus, and Neptune are the giant planets.

  - Jupiter and Saturn: mainly hydrogen and helium (like the sun).
    - Hundreds of Earth masses
    - Called gas giants.

  - Uranus and Neptune: more water, water ice, and other ices
    - Tens of Earth masses
    - Called ice giants



Jupiter

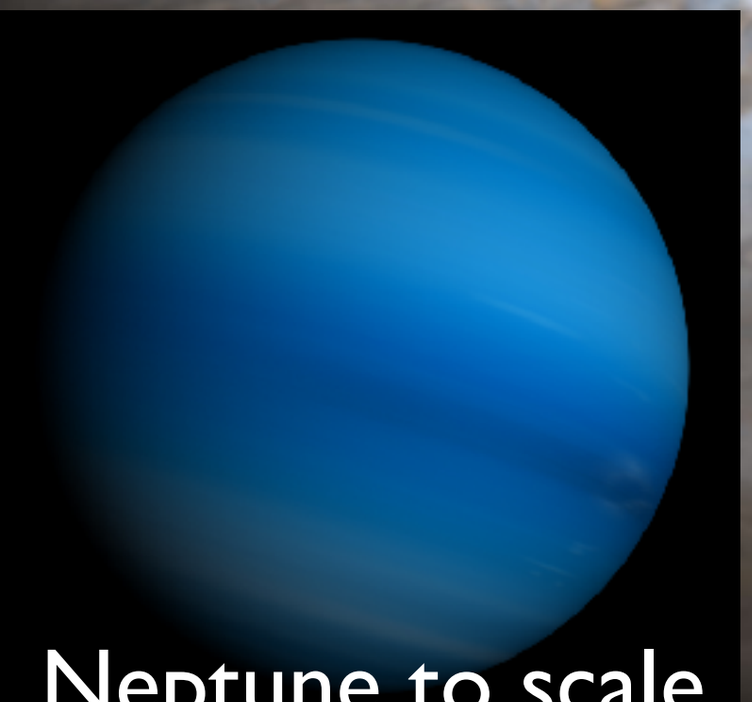
Many astronomers now distinguish between

Gas Giants
Jupiter, Saturn

and

Ice Giants
Uranus, Neptune

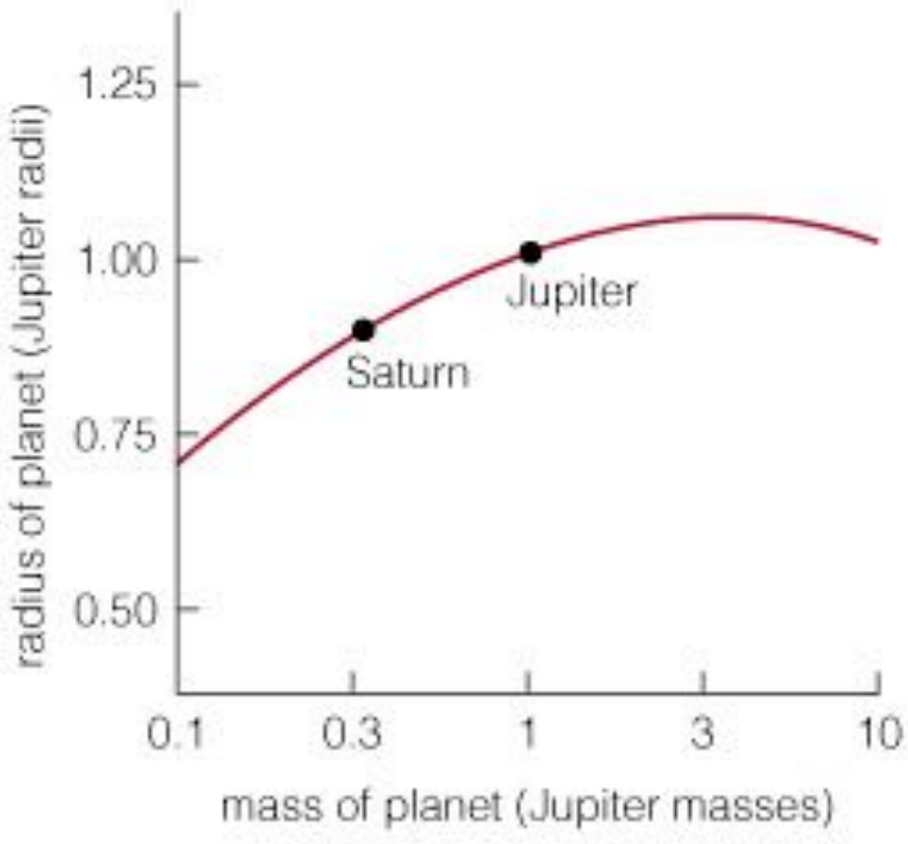
Expect more distinctions with new discoveries



Neptune to scale

Earth to scale

Sizes of Jovian Planets



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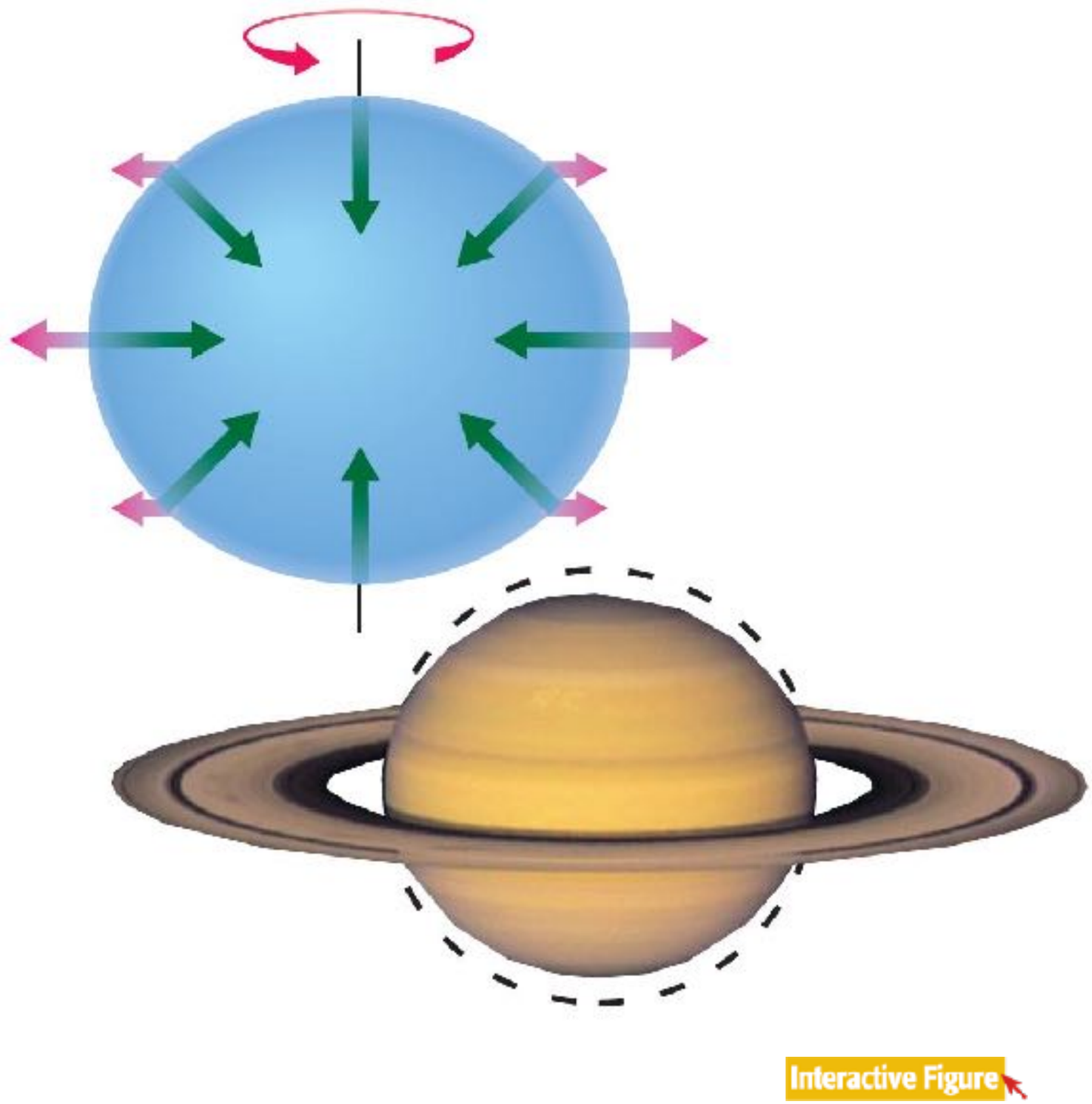
- Planets get larger as they get more massive
- up to a point...
- Planets more massive than Jupiter are expected to *shrink*.
- There comes a point where gravity wins: adding more mass causes *contraction*.

Rotation and Shape

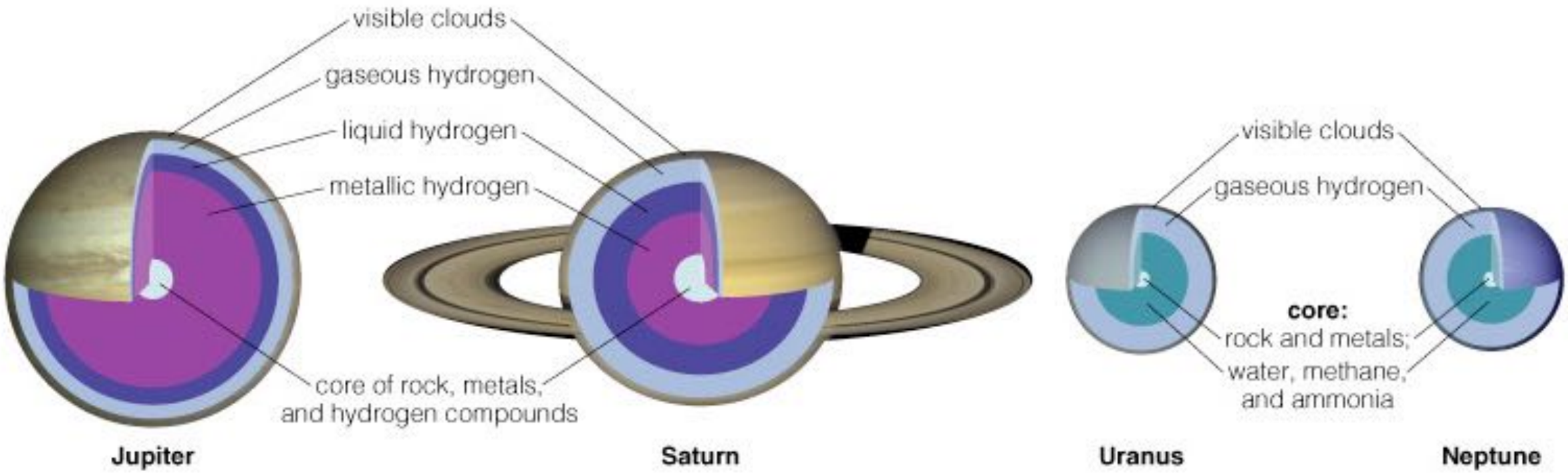


- Jovian planets are not quite spherical because of their rapid rotation.

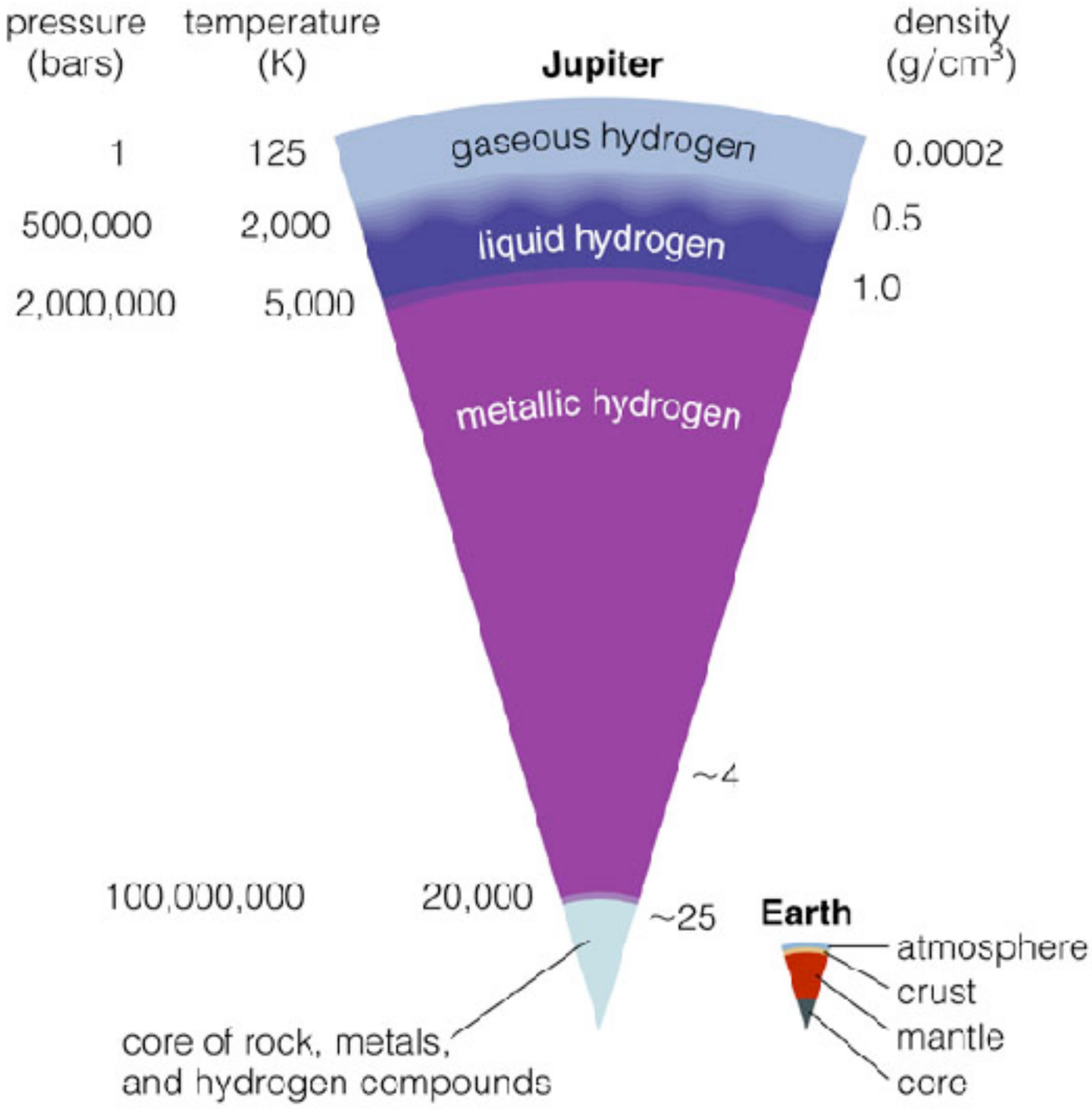
- "Oblate"

show Jovian Planet shapes

Interiors of Jovian Planets



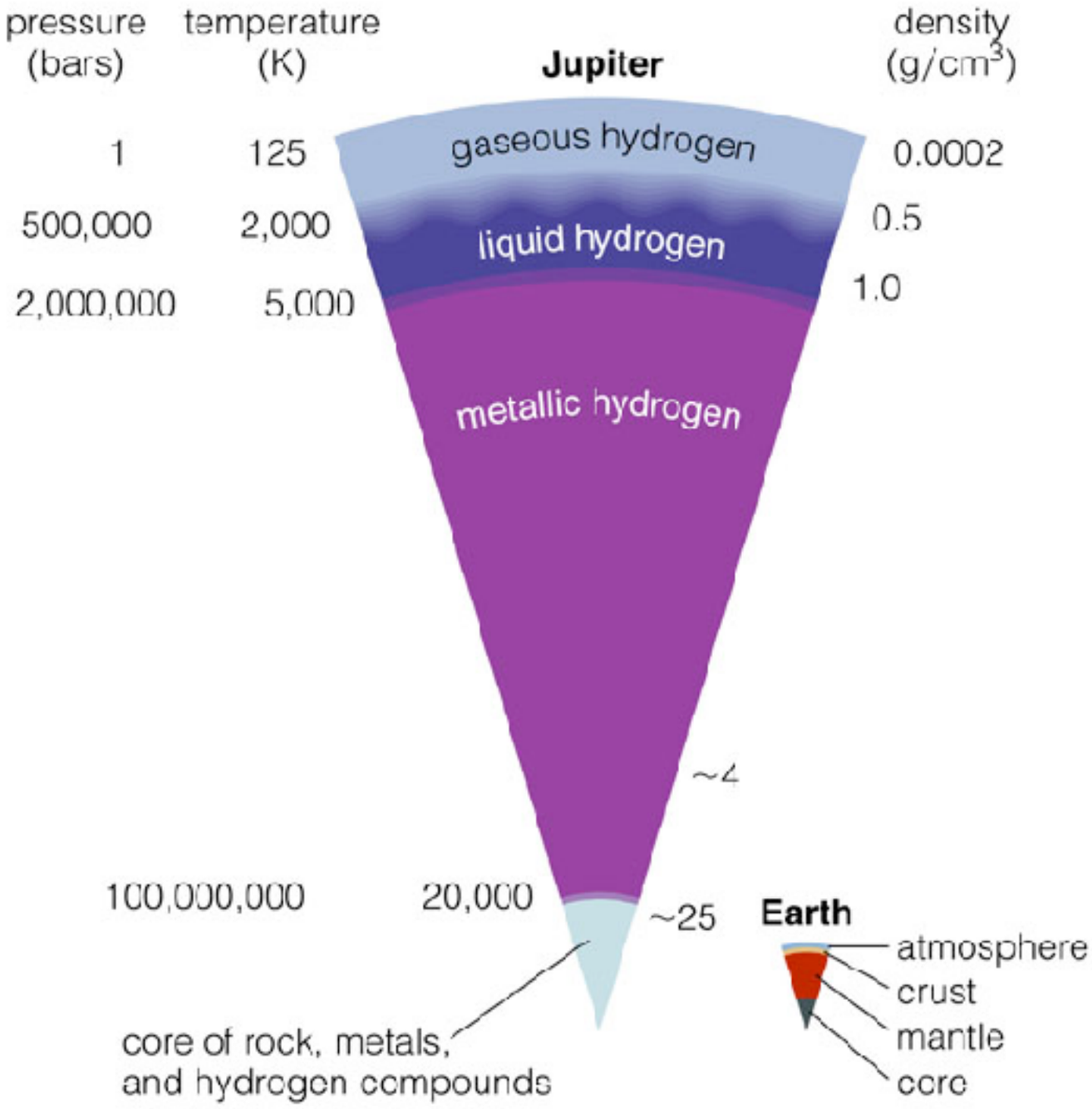
Inside Jupiter



- High pressure inside of Jupiter causes the phase of hydrogen to change with depth.

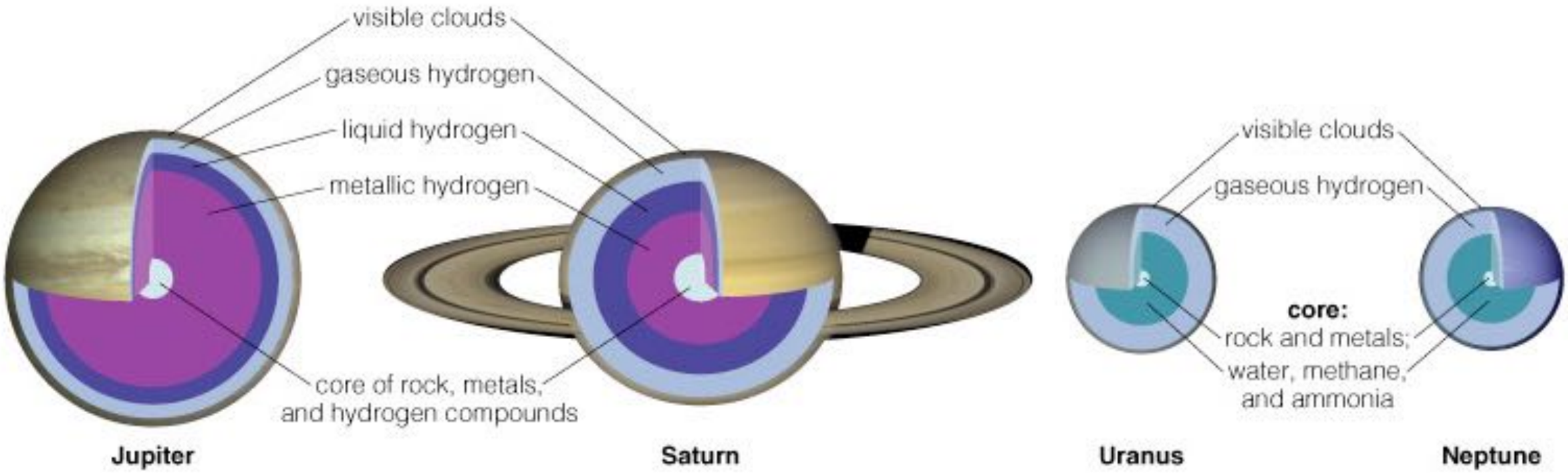
- Hydrogen acts like a metal at great depths because its electrons move freely.

Inside Jupiter



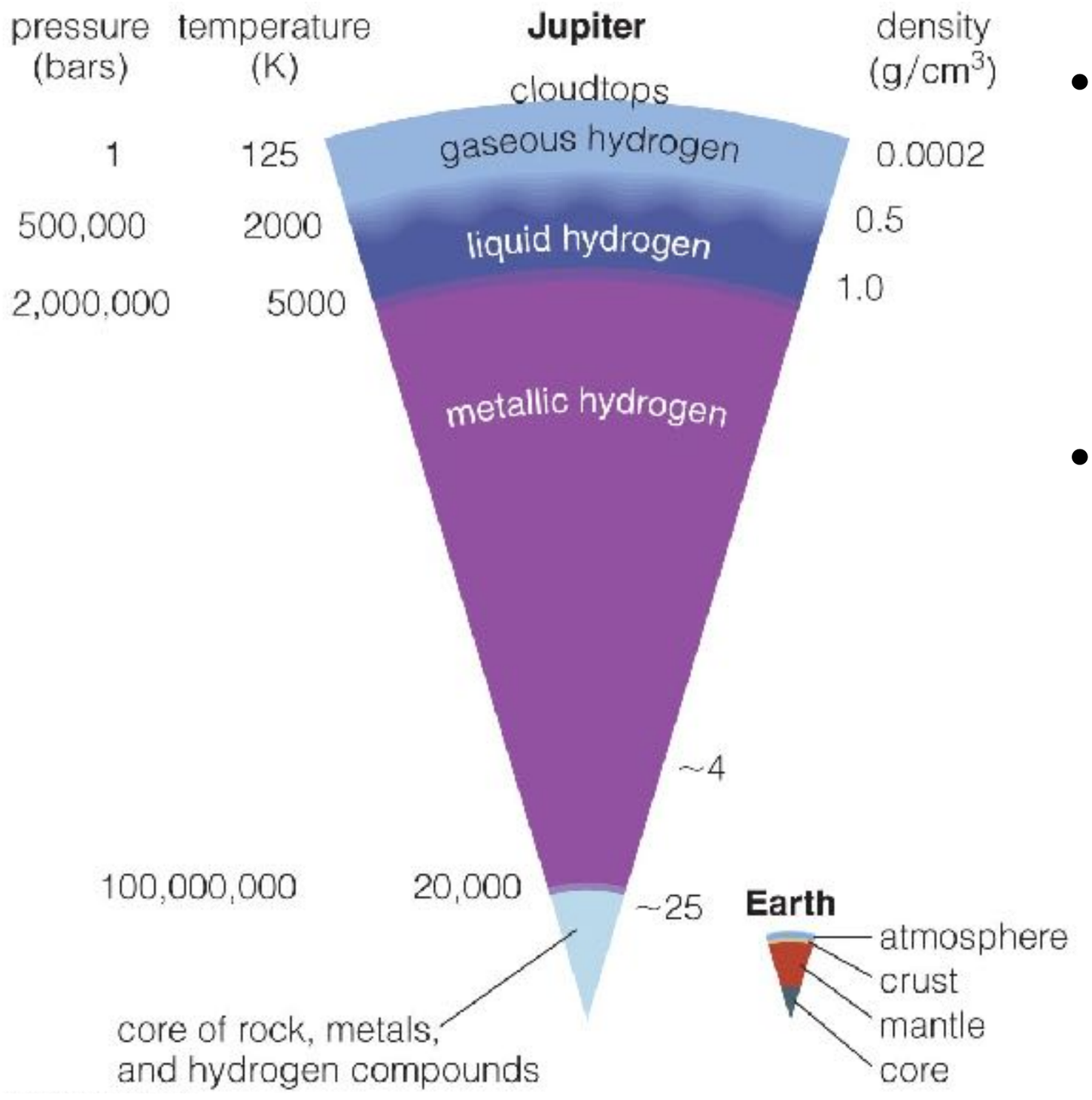
- The core is thought to be made of rock, metals, and hydrogen compounds.
- The core is about the same size as Earth but 10 times as massive.

Comparing Jovian Interiors



- Models suggest that 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 comes from the gradual gravitational contraction of the interior (releasing potential energy).

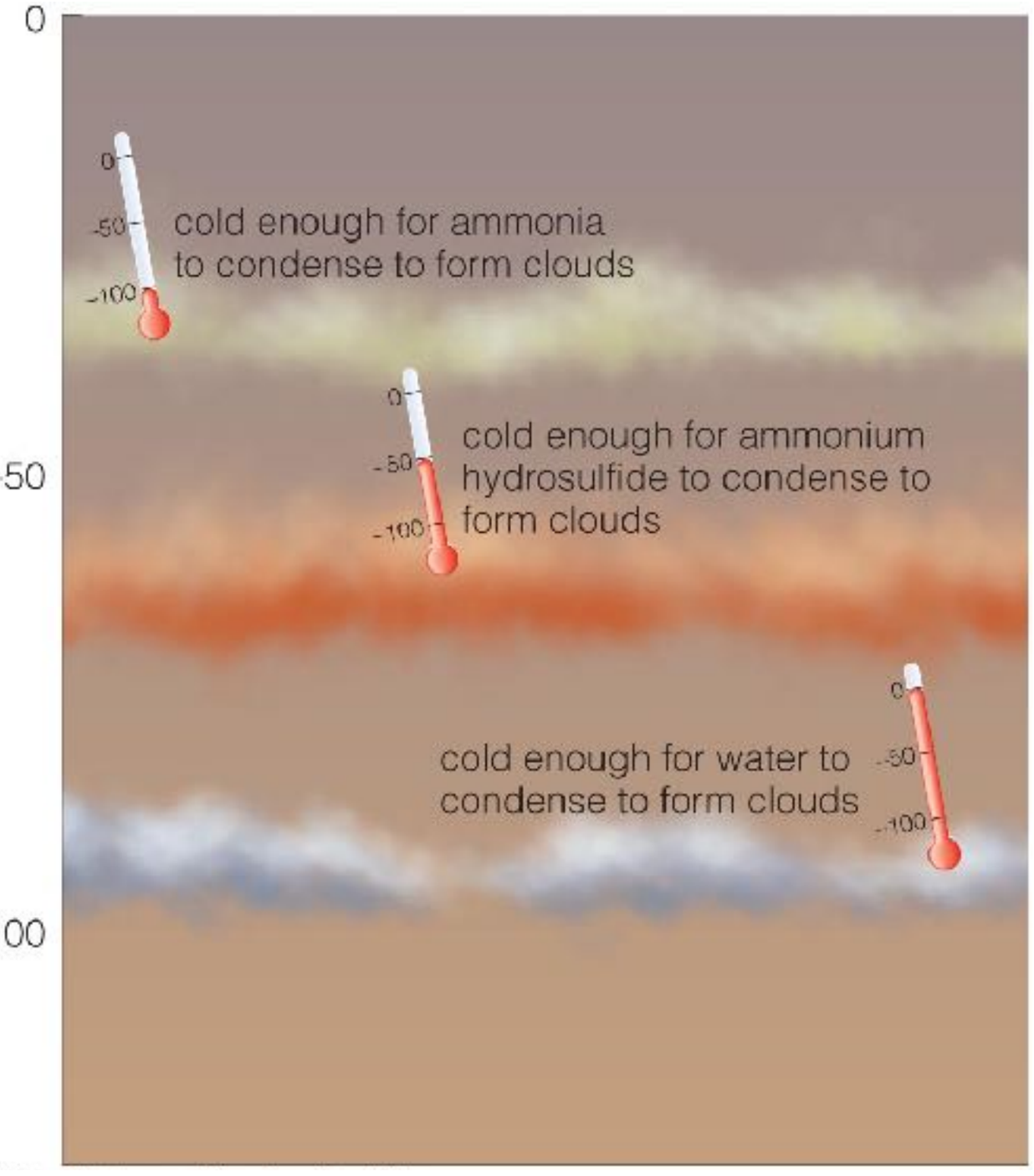
Internal Heat of Other Planets

- 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
  - also driven by gravitational contraction, but precise mechanism unclear.

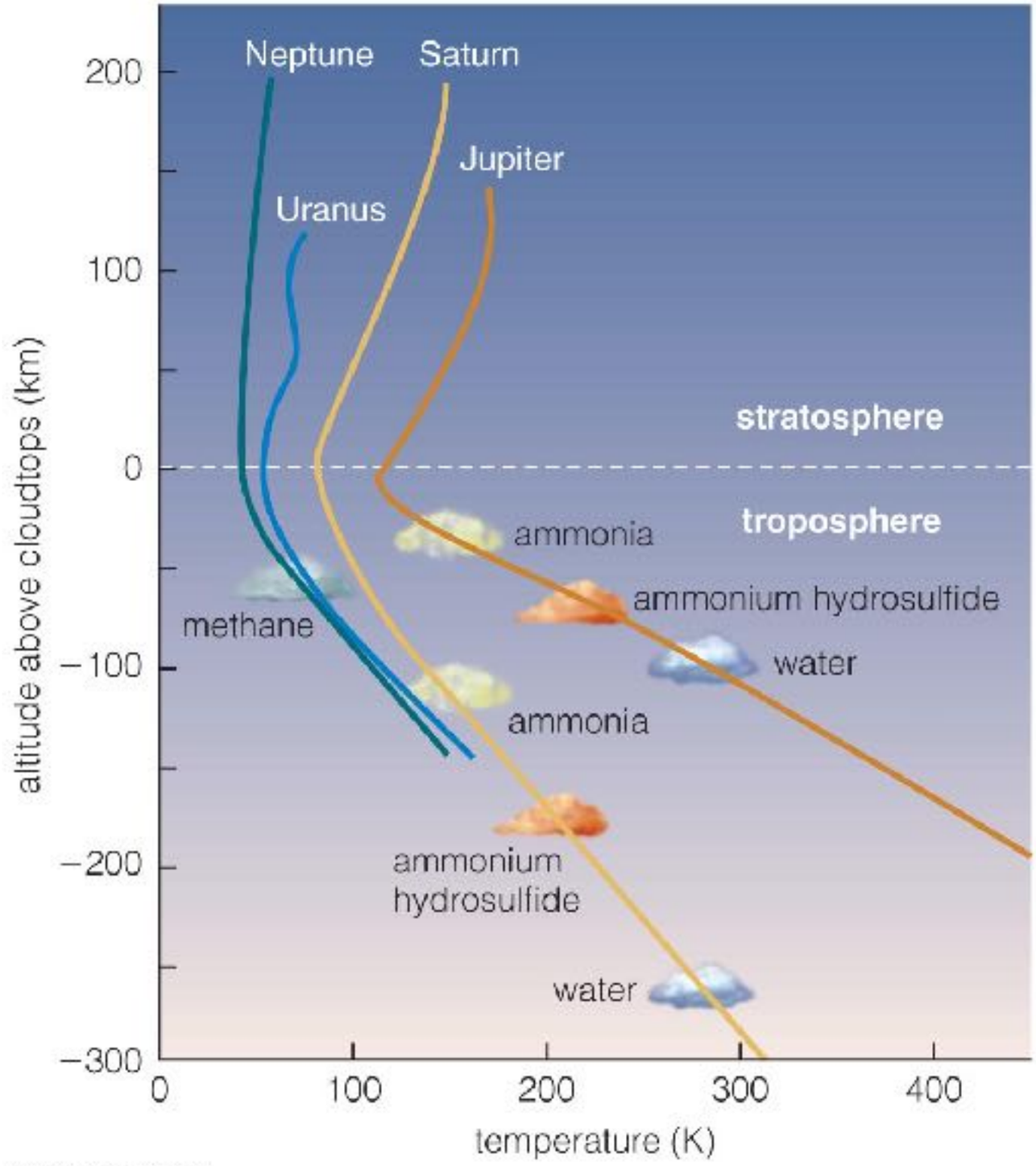
- Uranus does not radiate more than it receives.
  - no notable internal heat source

Jupiter's Atmosphere



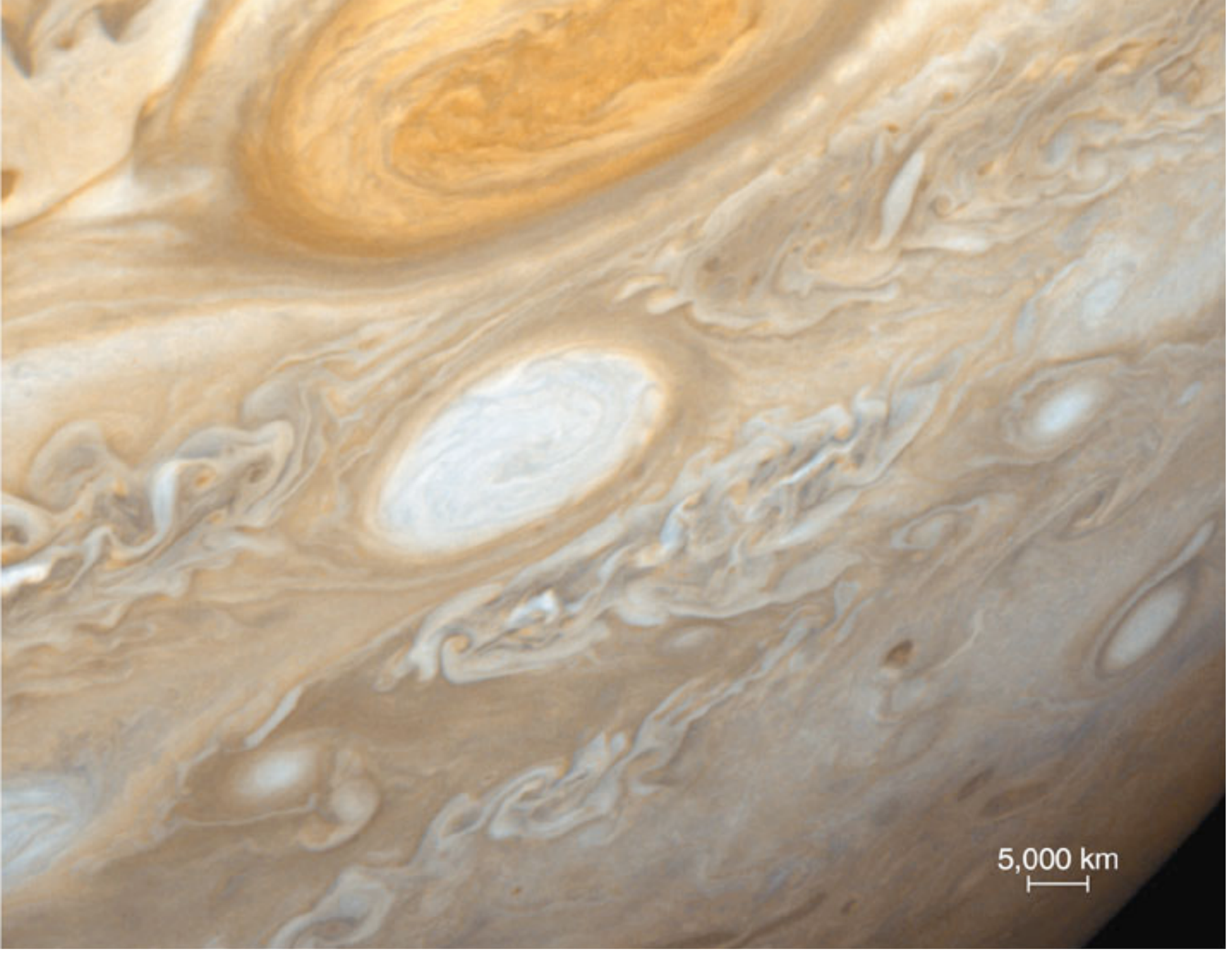
- Hydrogen compounds in Jupiter form clouds.
- Different cloud layers correspond to freezing points of different hydrogen compounds.
- Other jovian planets have similar cloud layers.

Jovian Planet Atmospheres

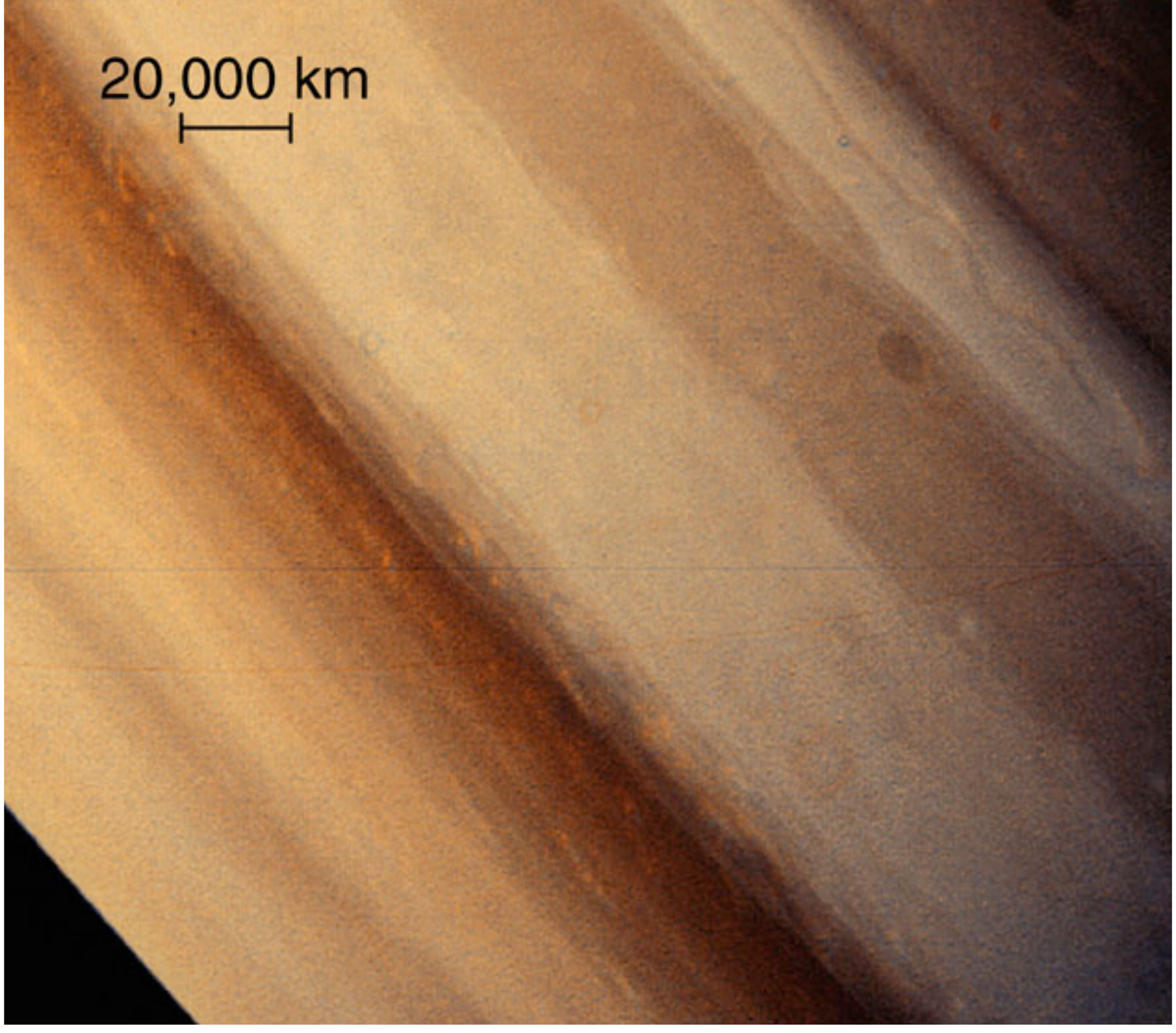


- Other jovian planets have cloud layers similar to Jupiter's.
- Different compounds make clouds of different colors.
- Reveal conditions to different depths in each planet

Jupiter's Colors



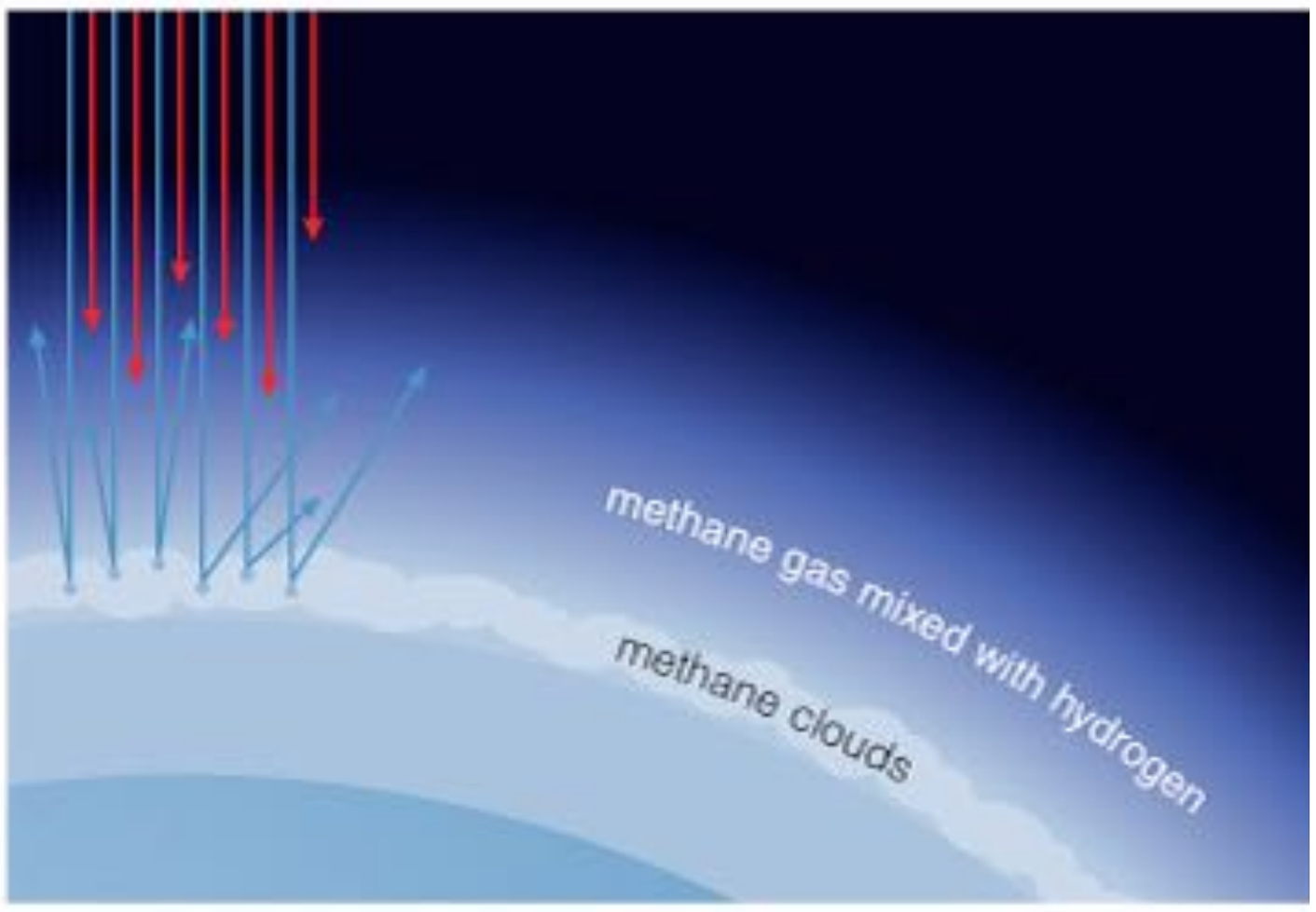
- Ammonium sulfide clouds (NH_4SH) reflect red/brown.
- Ammonia, the highest, coldest layer, reflects white.



Saturn's Colors

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

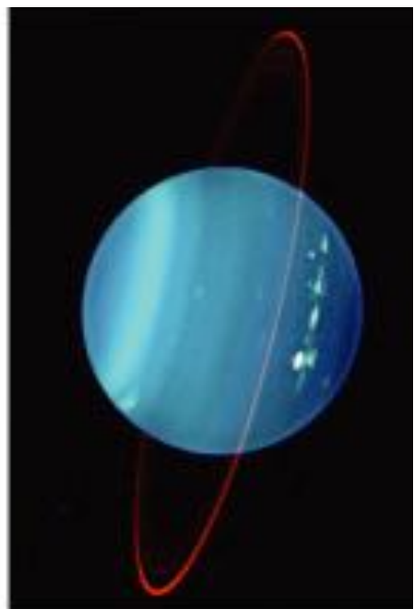
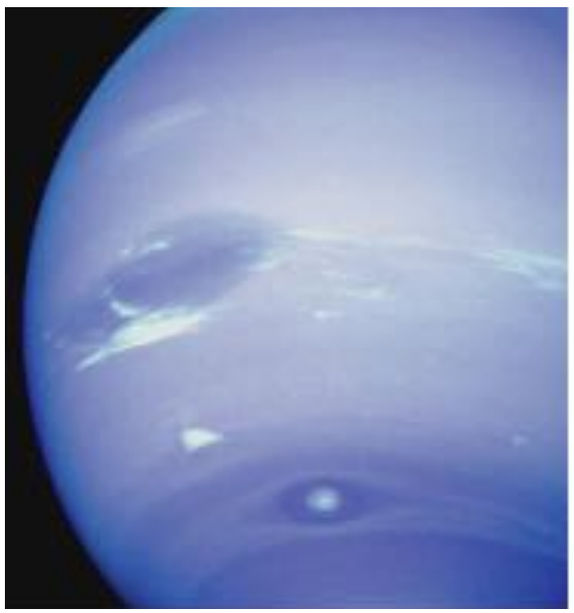
Methane on Uranus and Neptune



- Methane gas on Neptune and Uranus absorbs red light but reflects blue light.

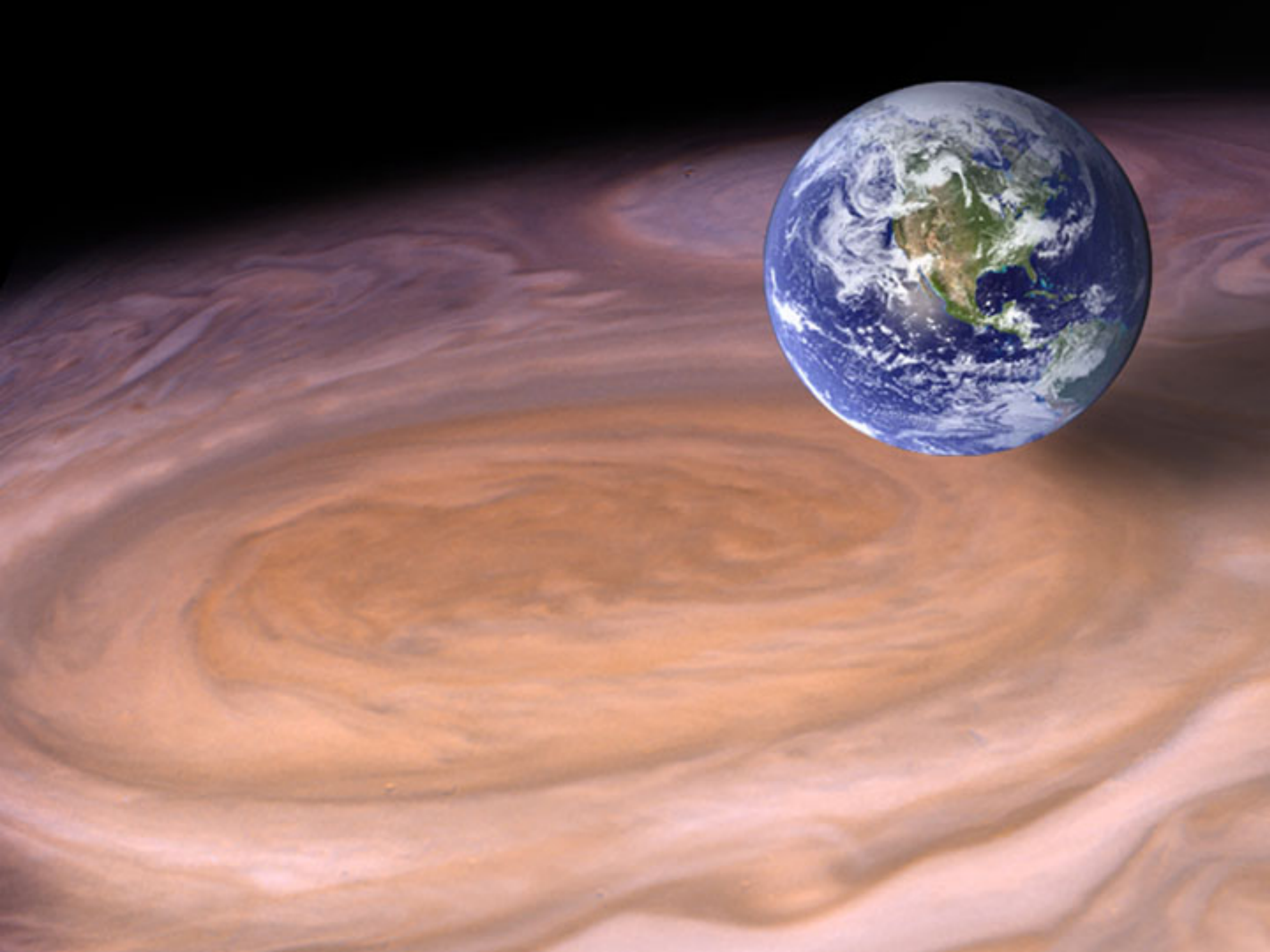
- Blue light reflects off methane clouds, making those planets look blue.

Weather on Jovian Planets

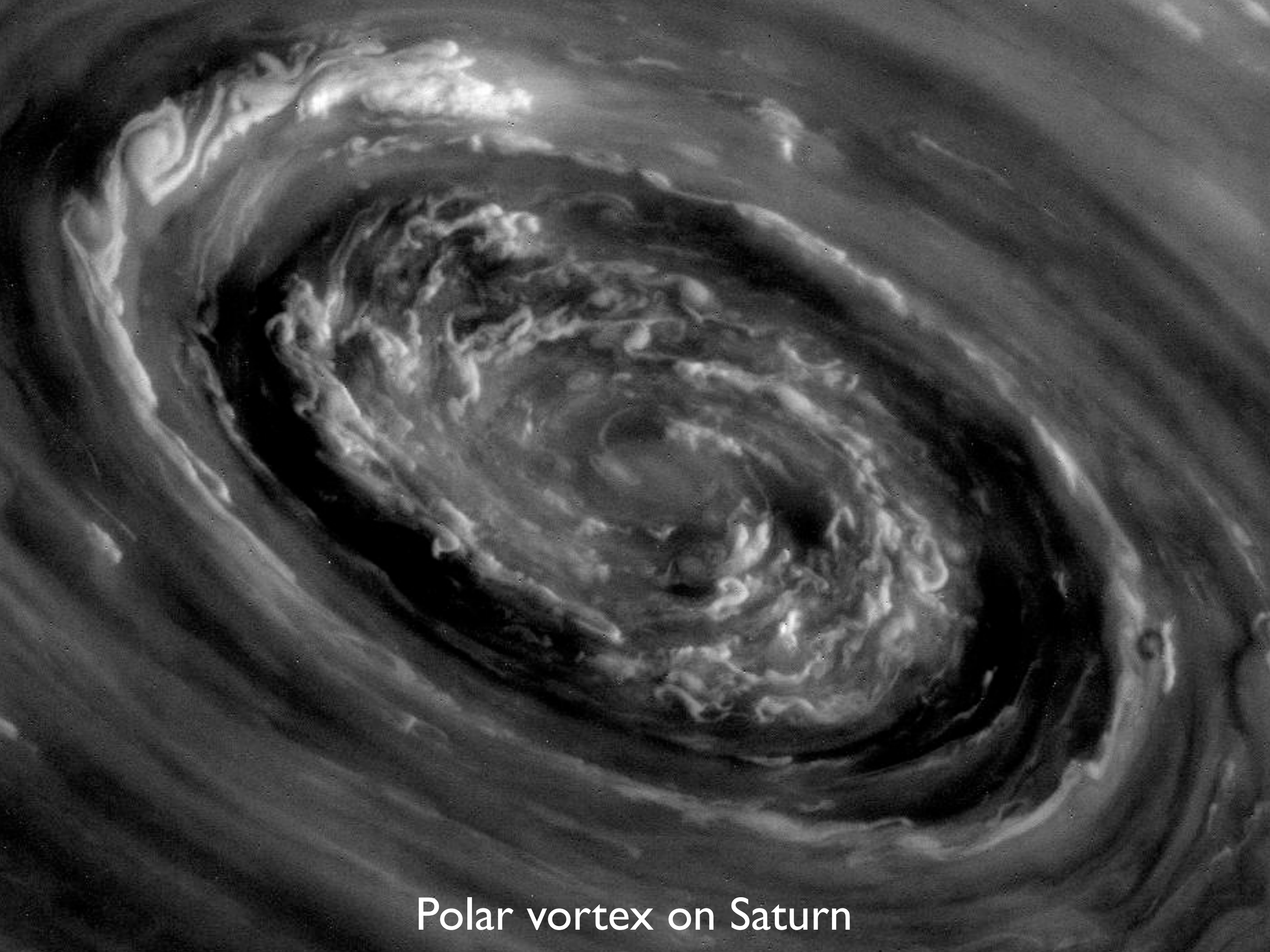



- All the jovian planets have strong winds and storms.

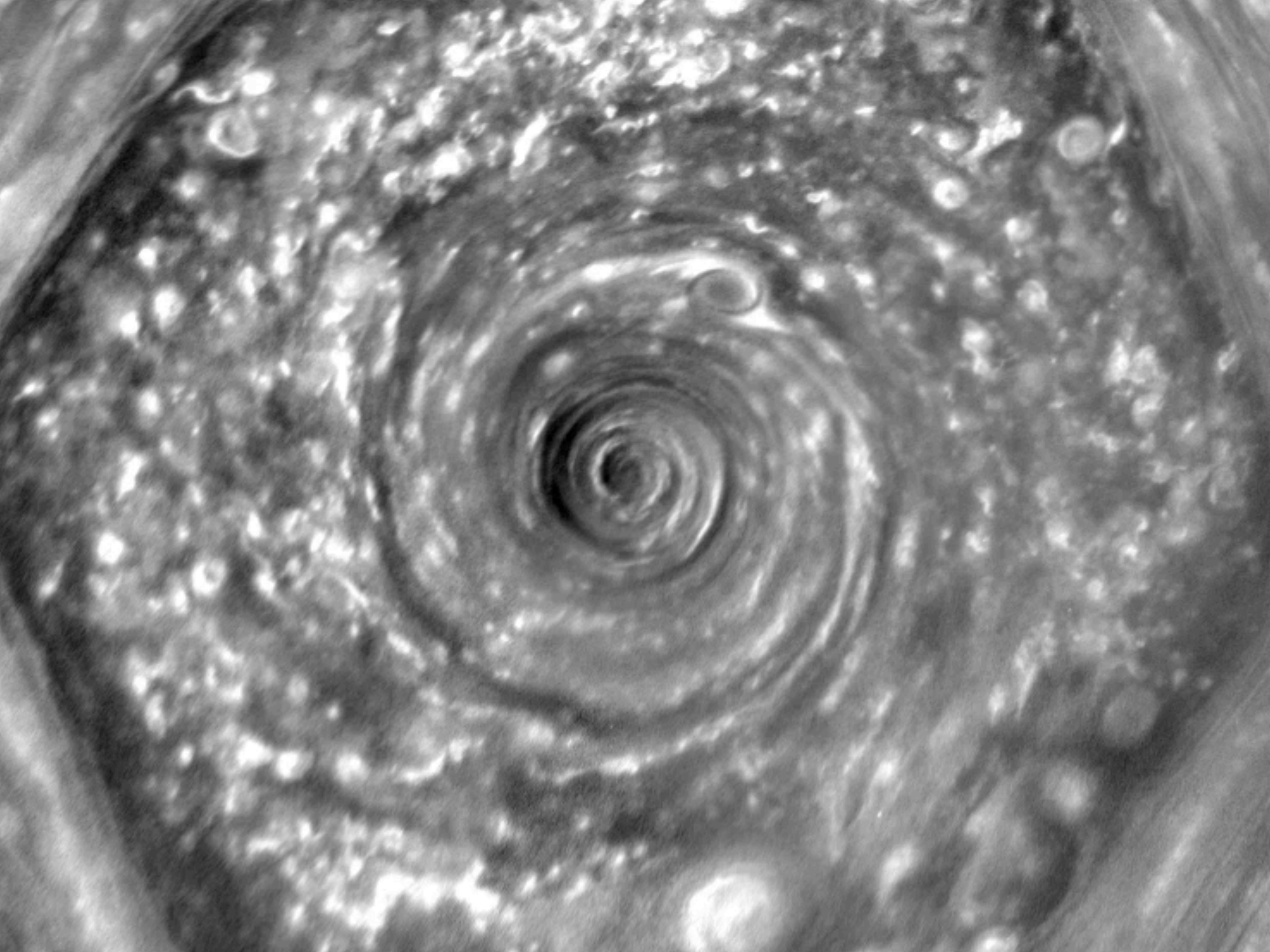
The great red spot on Jupiter is a storm larger than Earth that has persisted for centuries.



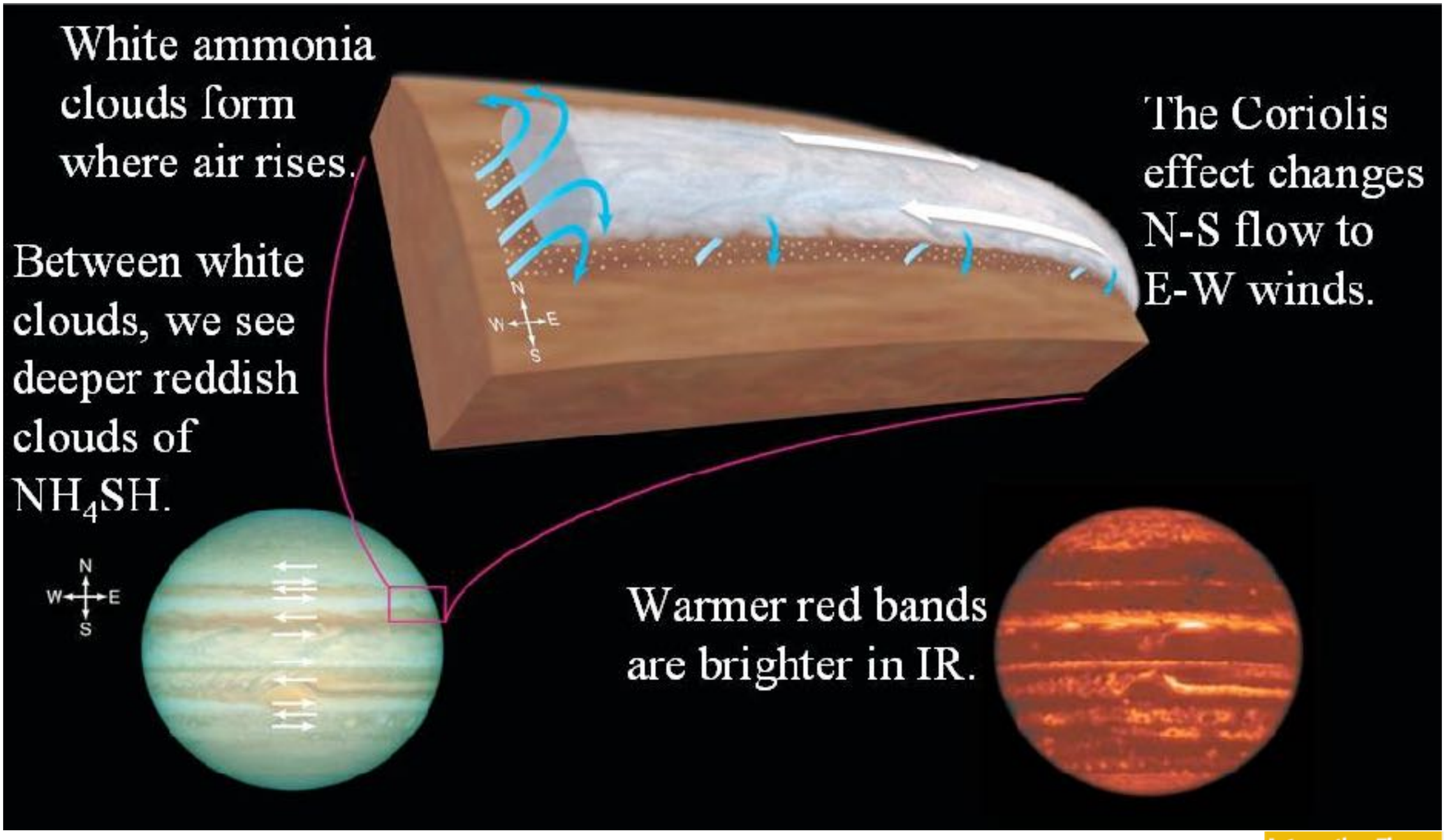
Polar vortex on Saturn



Polar vortex on Saturn



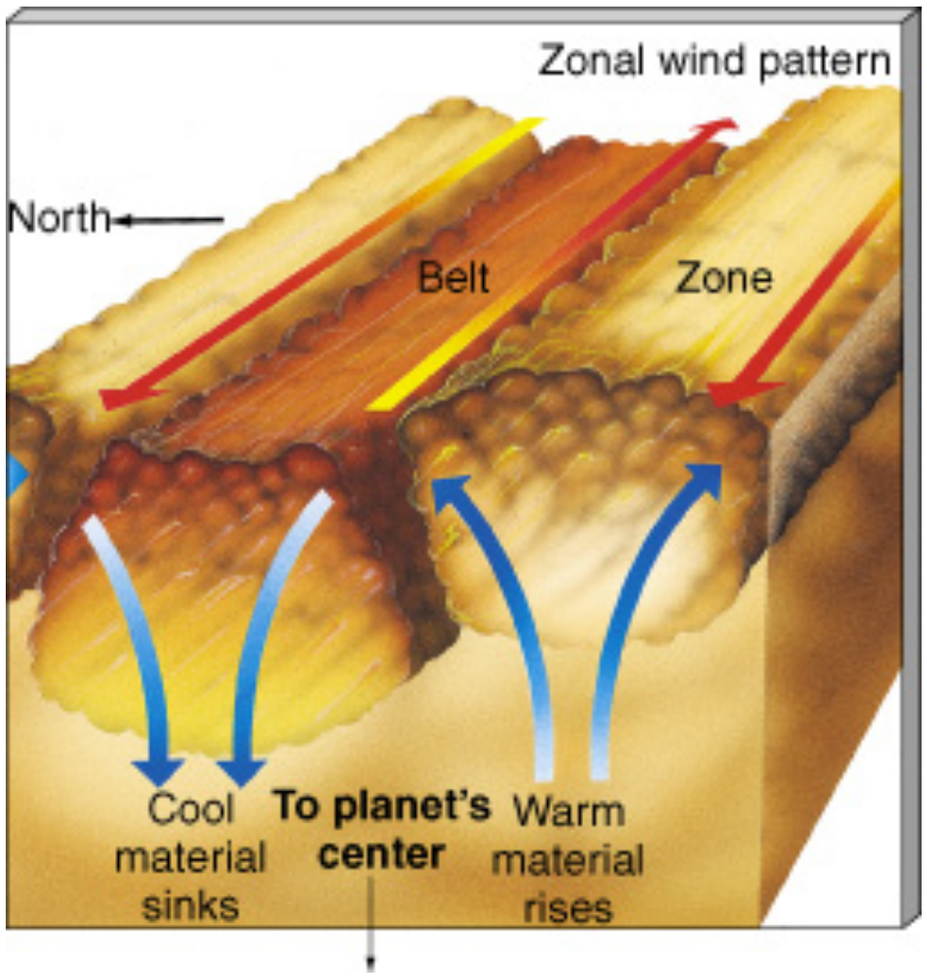
Jupiter's Bands



Interactive Figure

Zonal (band) structure in Jovian planet atmospheres

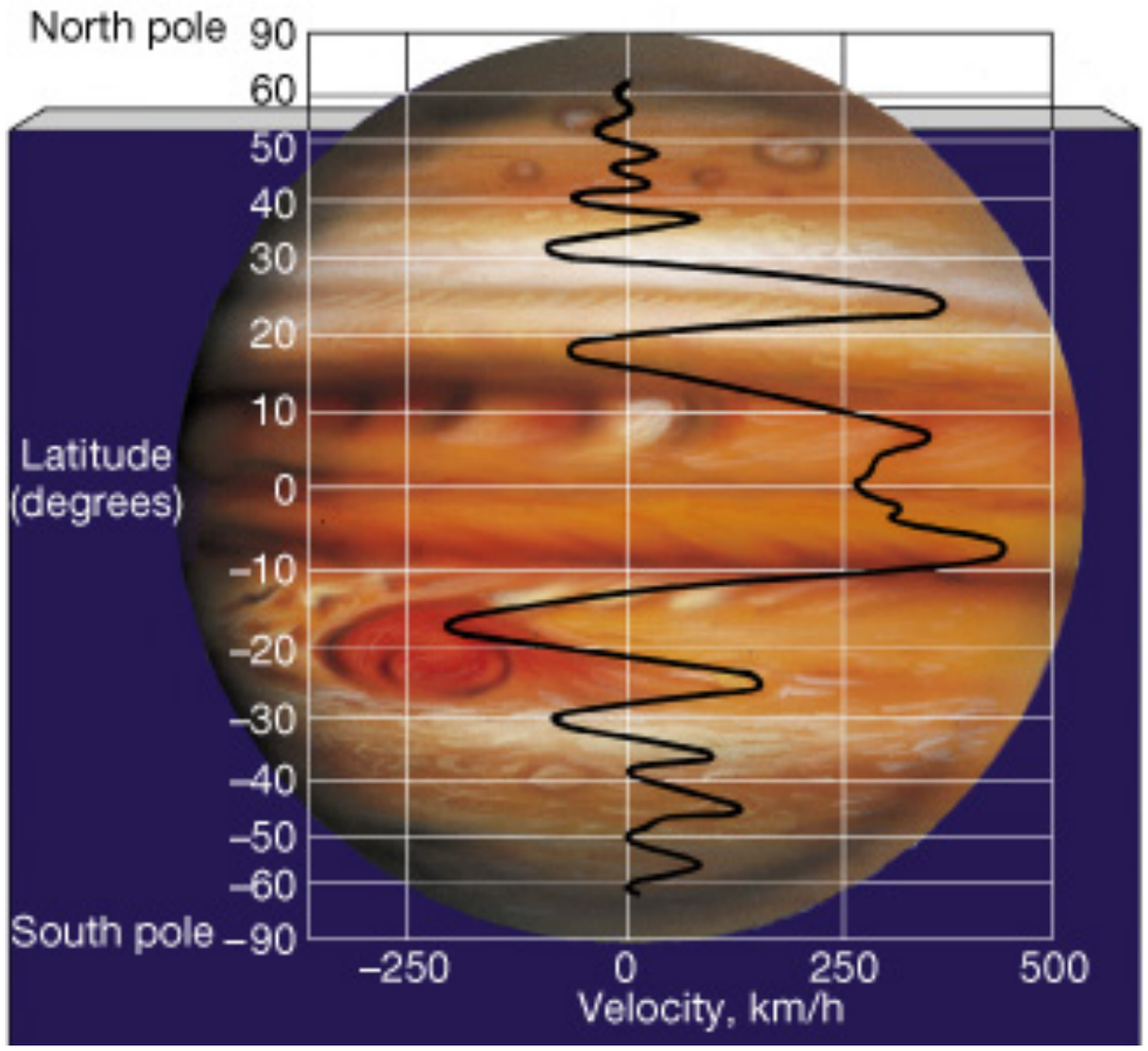
Zonal wind pattern



Hot rising and cool sinking material segregates into band structure

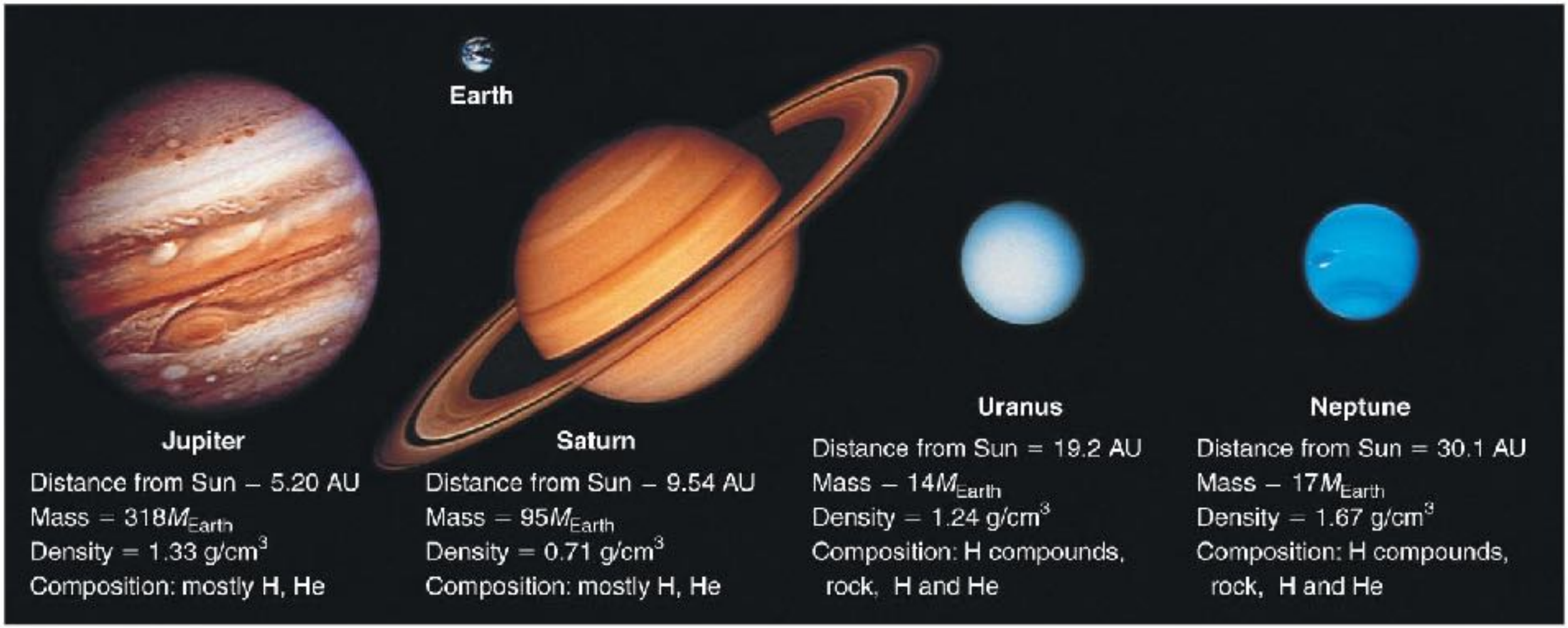
show Jovian cloud layers

Zonal wind speed



Rapid rotation causes many zones (more than Earth's 3) with high wind speeds

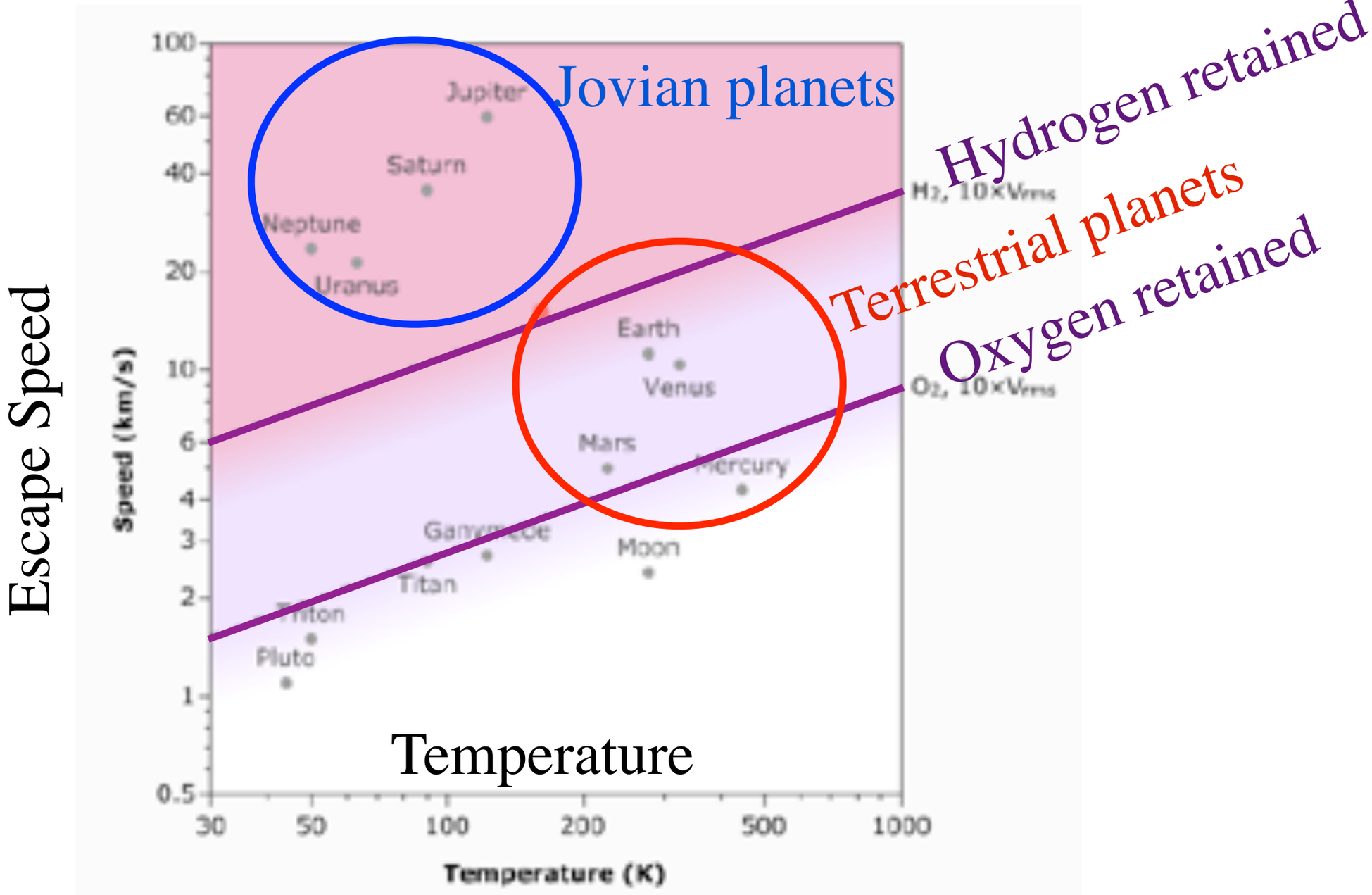
Weather on Jovian Planets



- All the jovian planets have strong winds and storms.

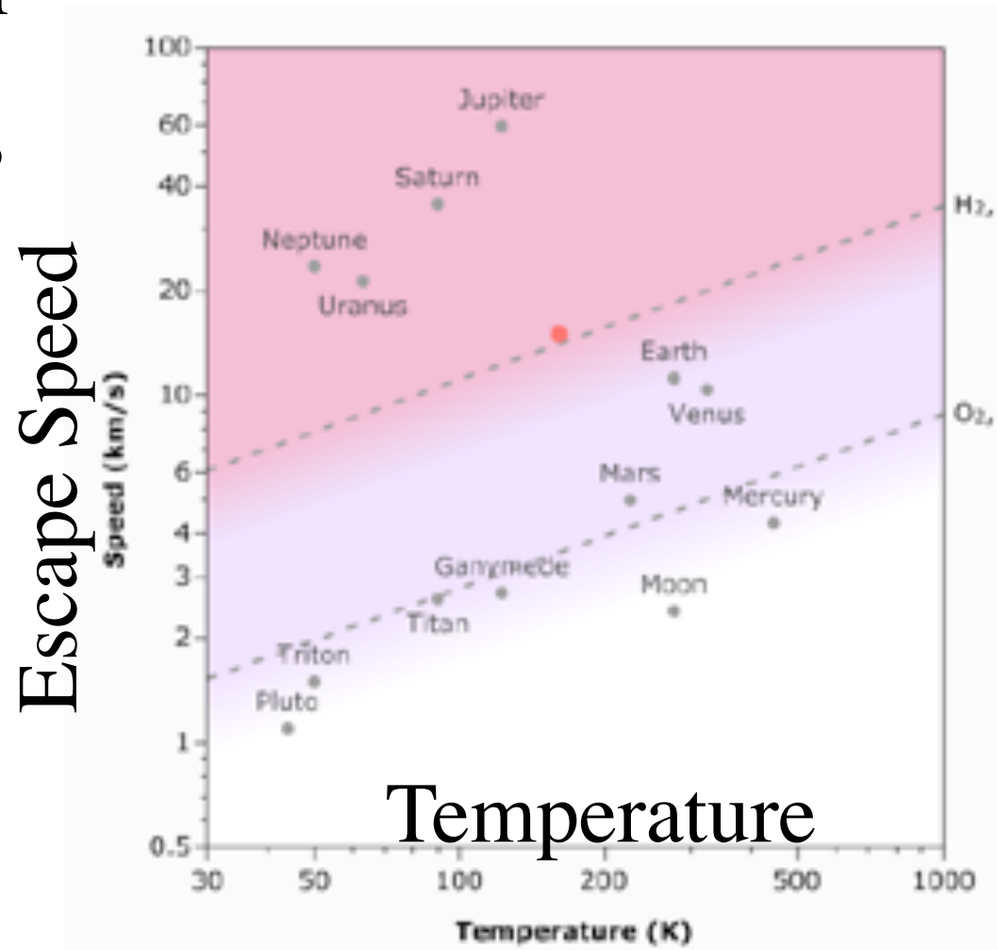
Jovian planets are

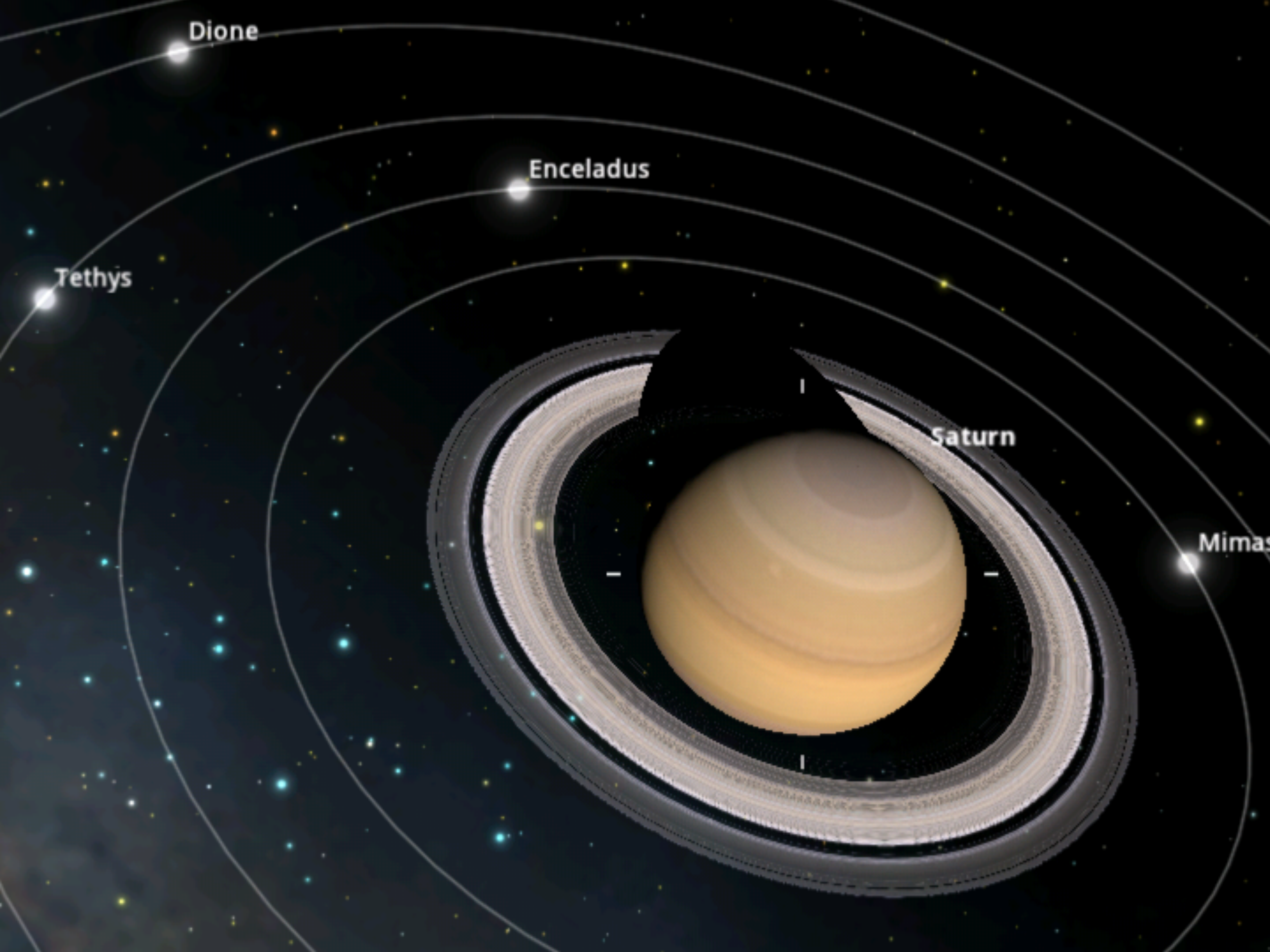
- Big
  - massive and cold, they can retain light elements like hydrogen and helium



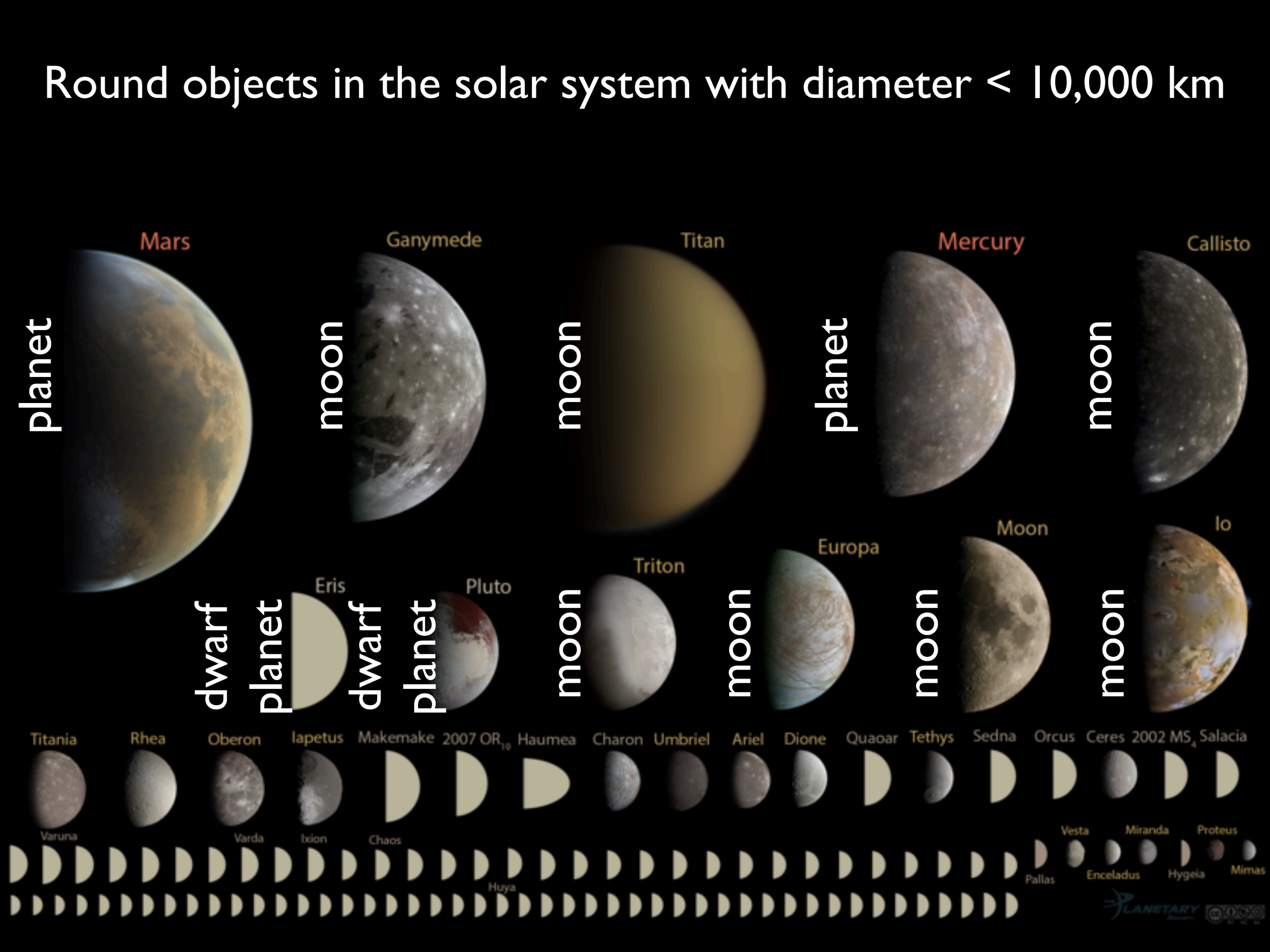
Jovian planets are

- Big
  - massive and cold, they can retain light elements like hydrogen and helium
  - their composition is like that of the stars
  - the smaller terrestrial planets are the abnormal planets in terms of composition
- Like miniature solar systems
  - moons
  - rings




Dione
Enceladus
Tethys
Saturn
Mimas

Round objects in the solar system with diameter < 10,000 km



Selected Moons of the Solar System, with Earth for Scale

Earth

Moon

Mars

Phobos

Deimos

Asteroid Ida

Dactyl

Jupiter

Io

Europa

Ganymede

Callisto

Saturn

Mimas

Enceladus

Tethys

Dione

Rhea

Titan

Hyperion

Iapetus

Phoebe

Uranus

Puck

Miranda

Ariel

Umbriel

Titania

Oberon

Neptune

Proteus

Triton

Nereid

Pluto

Charon

Eris

Dysnomia

Scale: 1 pixel = 25 km

Earth

Obvious Definition

- A moon is an object that orbits a planet

Sizes of Moons

- Small moons (< 300 km)
  - No geological activity
- Medium-sized moons (300–1,500 km)
  - Geological activity in past
- Large moons (> 1,500 km)
  - Ongoing geological activity

crudely speaking

Medium and Large Moons

- Enough self-gravity to be spherical
- Have substantial amounts of ice - as important as rock to overall composition
- Formed in orbit around jovian planets
- Circular orbits mostly in the same direction as

Rocks and metals condense,
hydrogen compounds stay vaporized.

Hydrogen compounds, rocks,
and metals condense.

frost line

Inside frost line: terrestrial planets

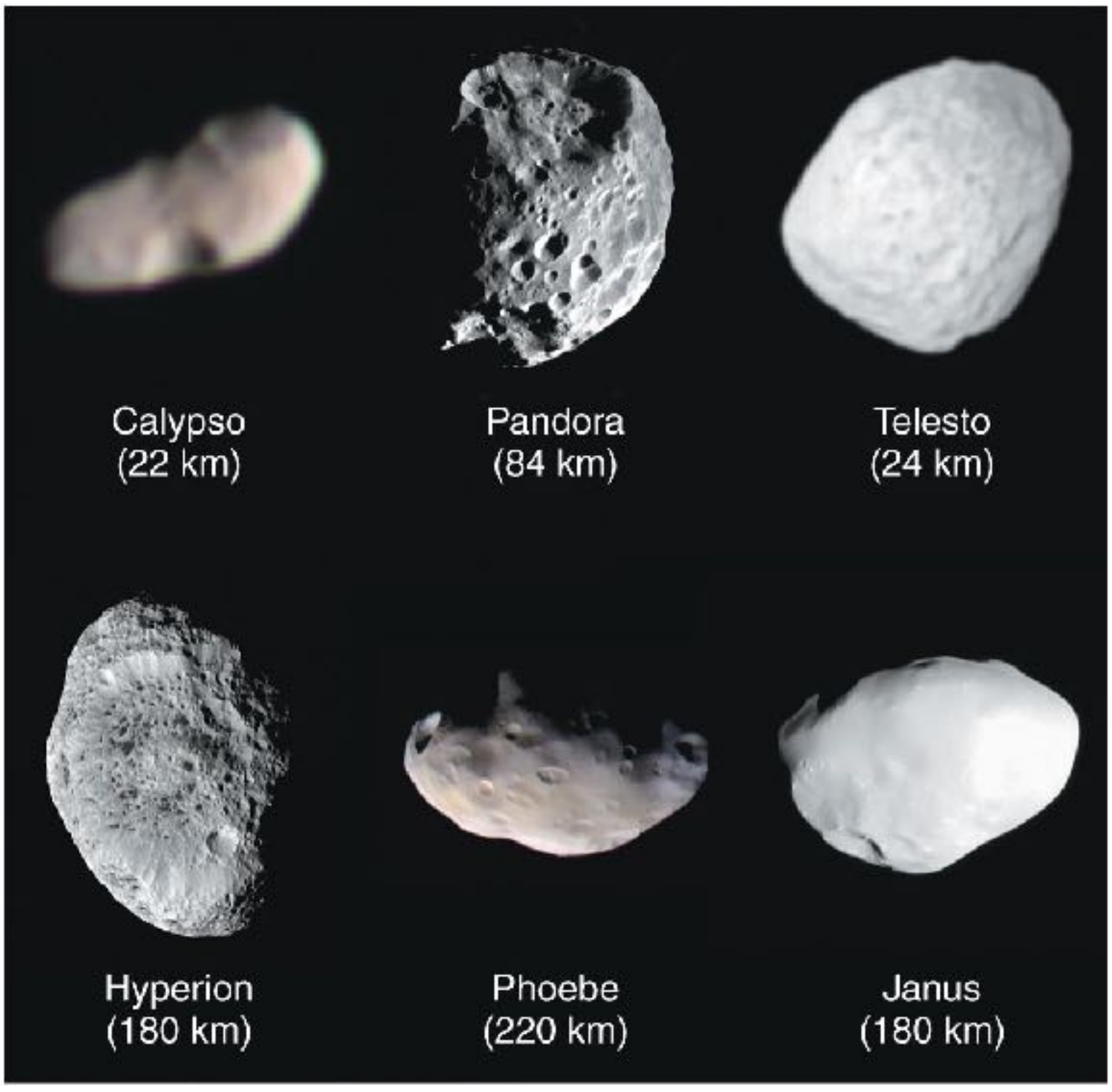
Beyond frost line: Gas giants, icy moons, dwarf planets, comets

Medium and Large Moons

- Density
  - low
  - typically ~2 g/cc
  - more than Gas giants
  - less than Terrestrials
- Composition
  - rock
  - ice / subsurface water

Ice is just another common "rock" mineral in the outer solar system.

Small Moons

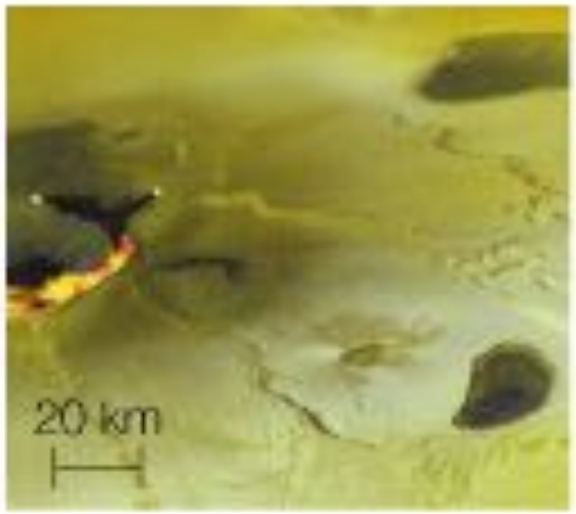


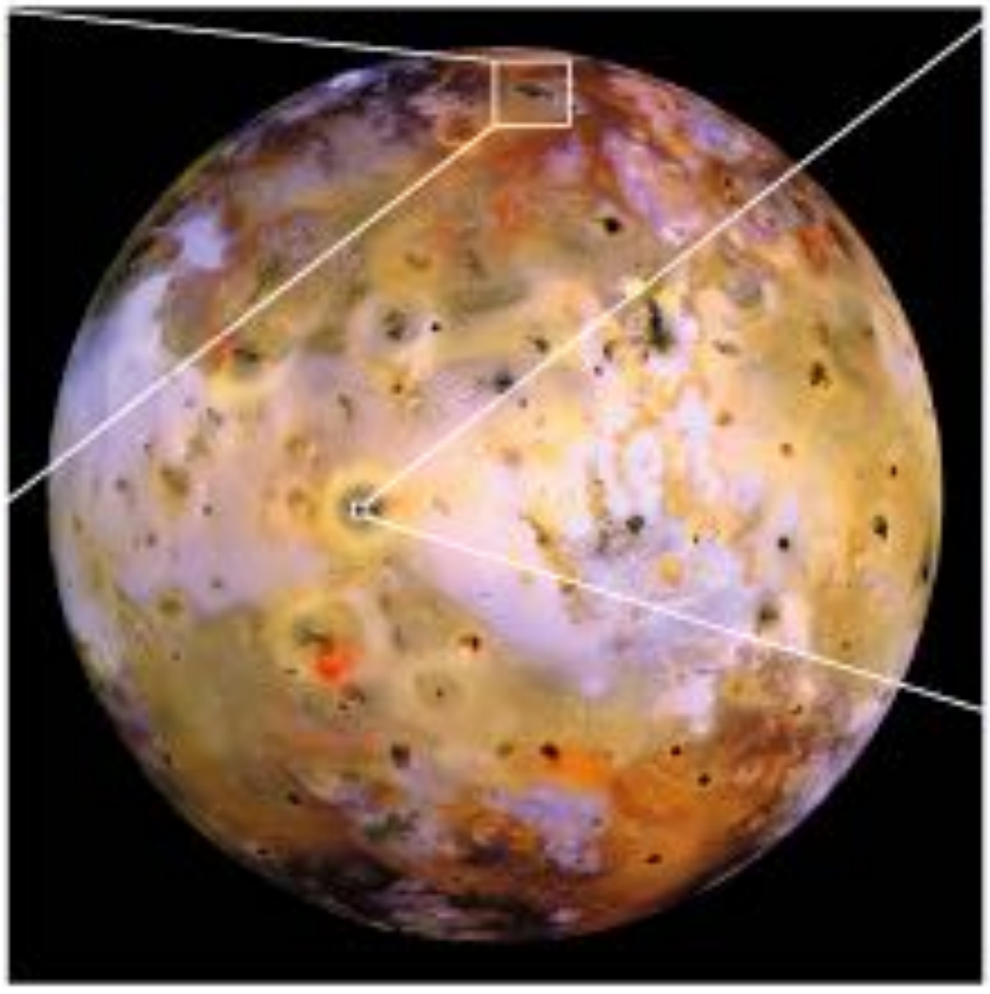
- Far more numerous than the medium and large moons
- Not enough gravity to be spherical: “potato-shaped”
- Often just captured asteroids

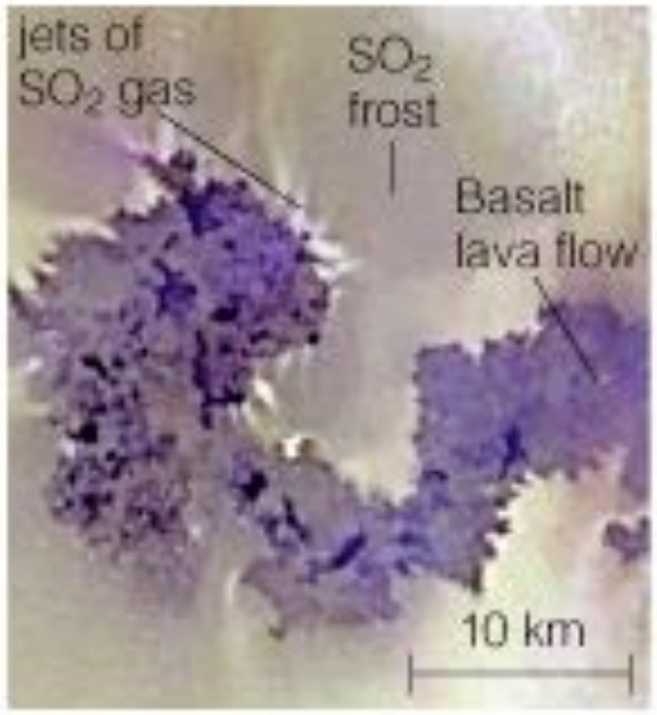
The moons of the Jovian planets

Galilean moons of Jupiter
("Medici stars")

Io





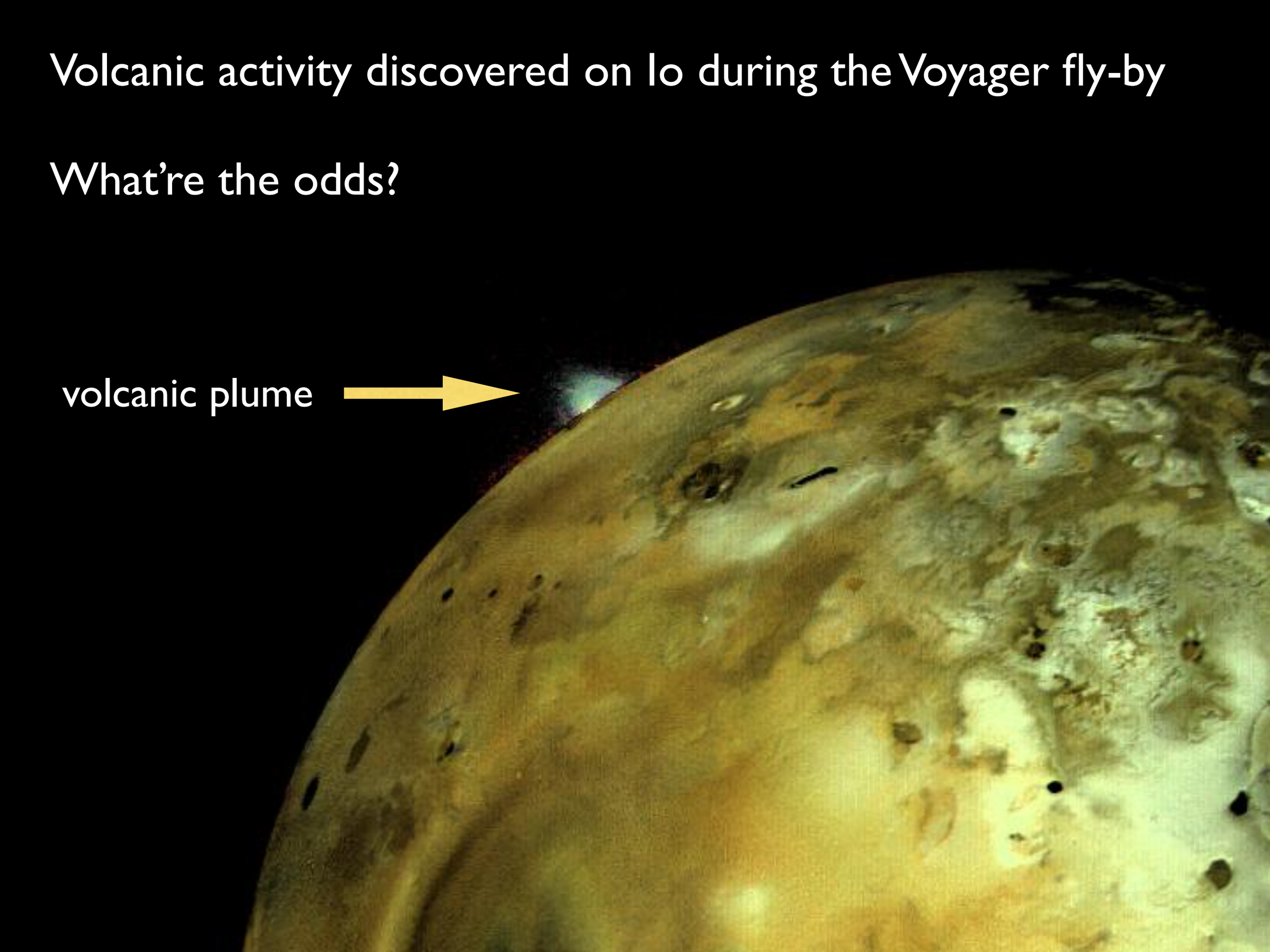


- Io is the most volcanically active body in the solar system.

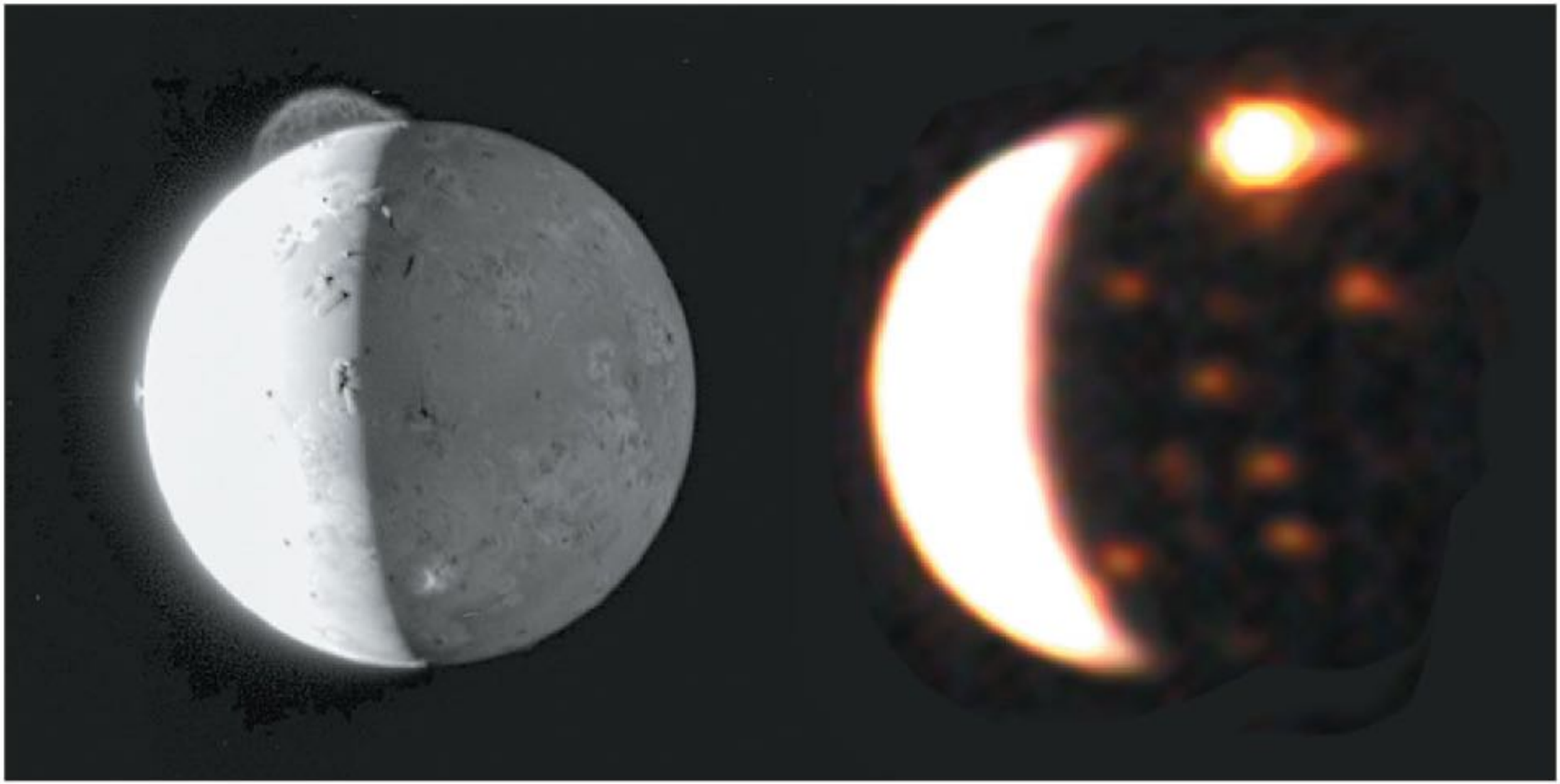
Volcanic activity discovered on Io during the Voyager fly-by

What're the odds?

volcanic plume



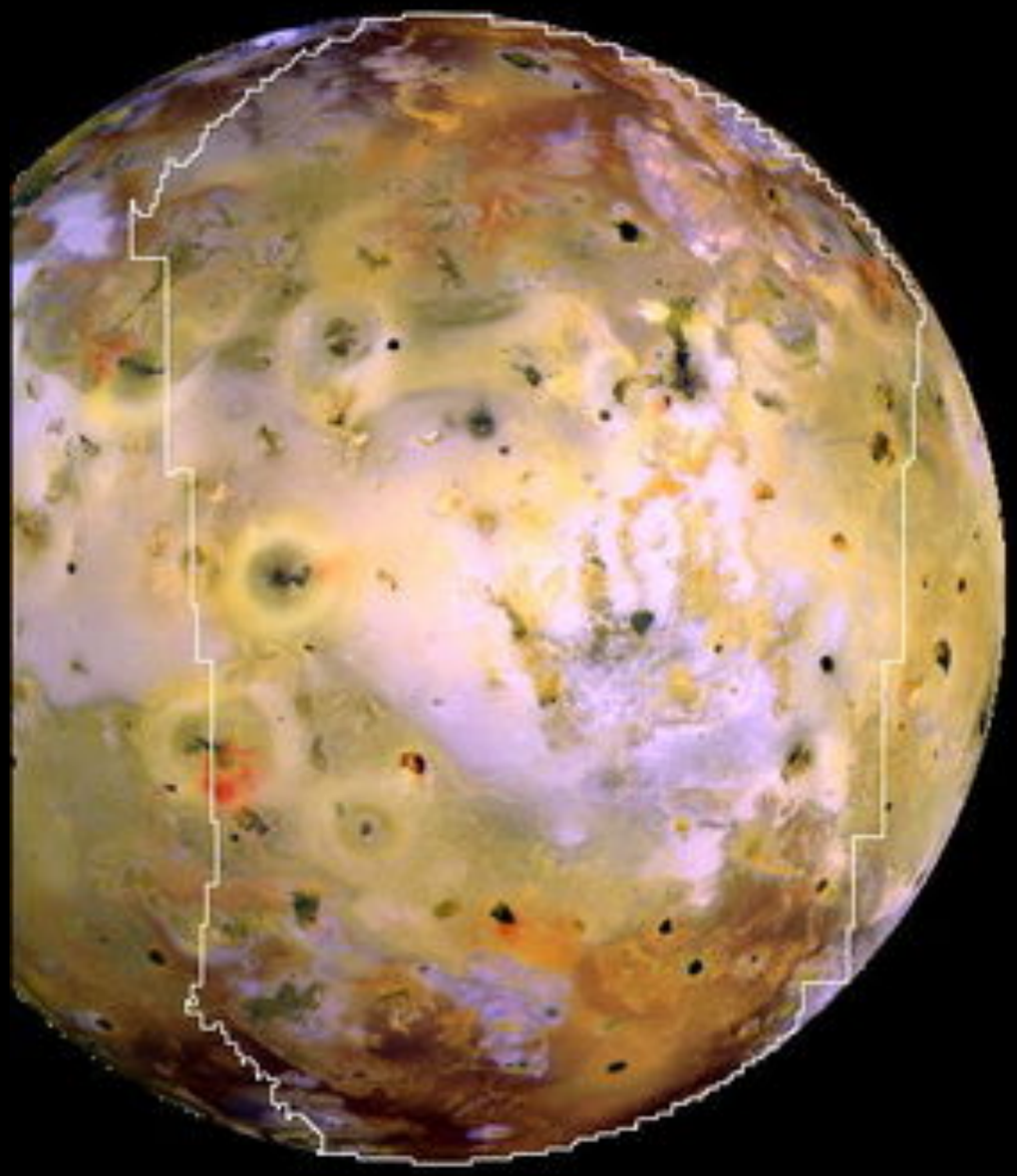
Io's Volcanoes

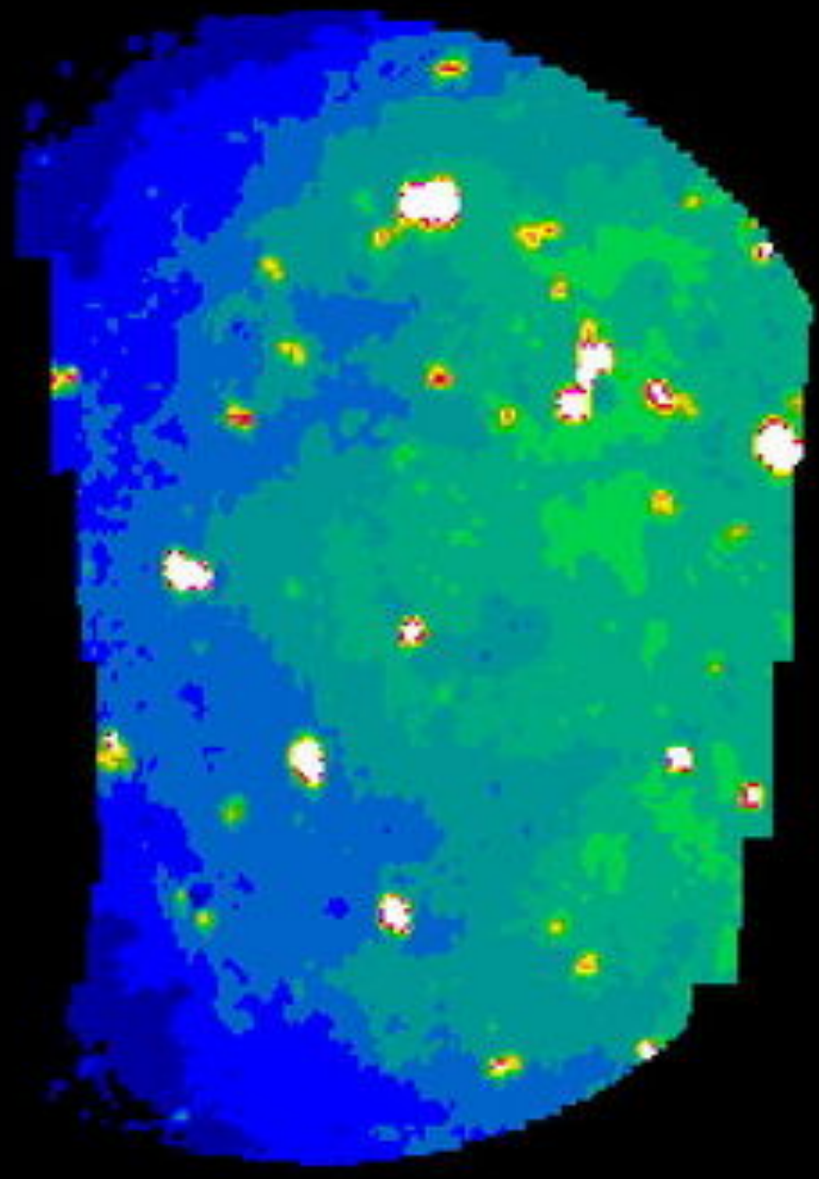


- Volcanic eruptions continue to change Io's surface.

optical

infrared



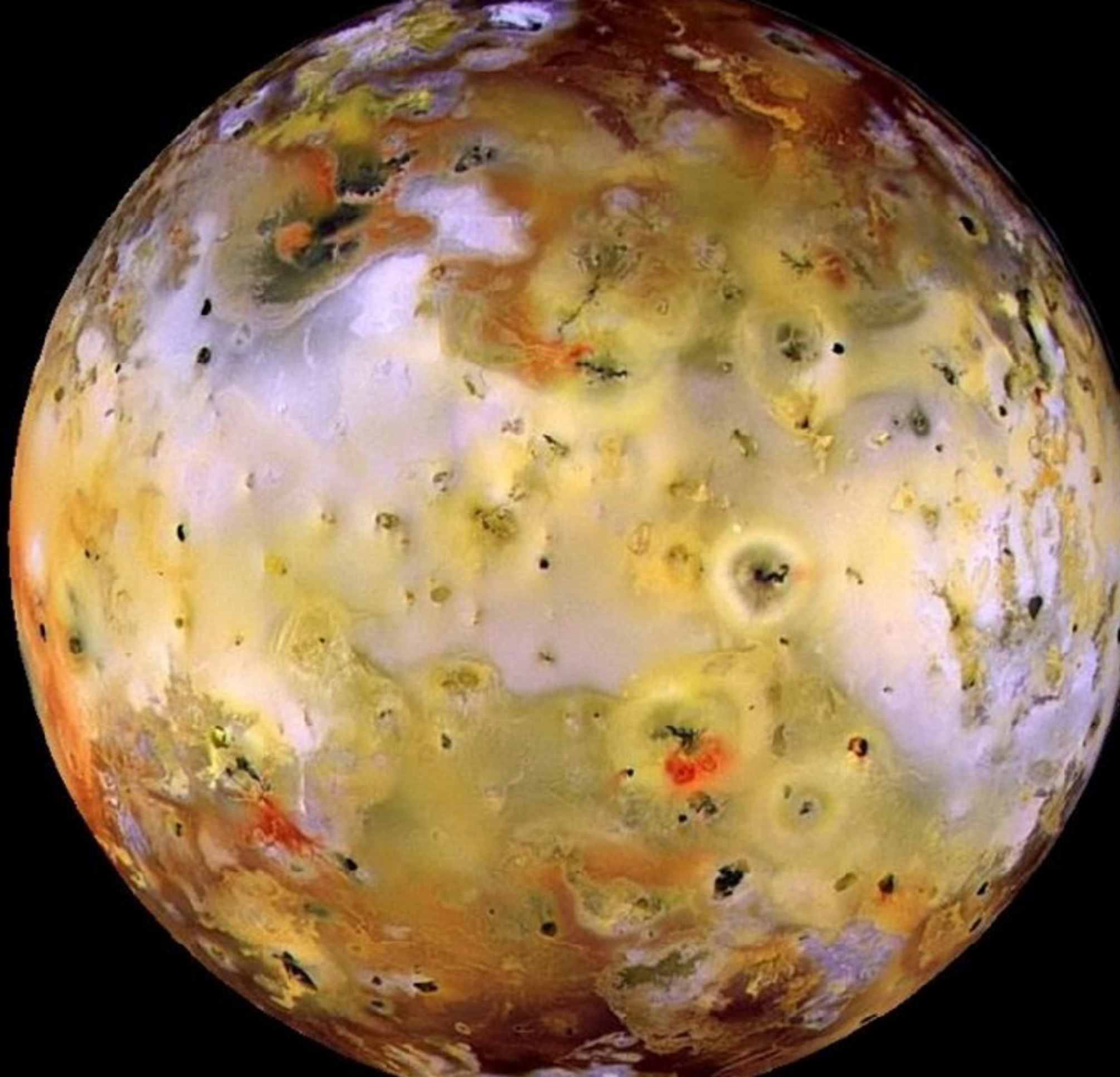


dark volcanic craters in the optical
correspond to hot spots in the infrared

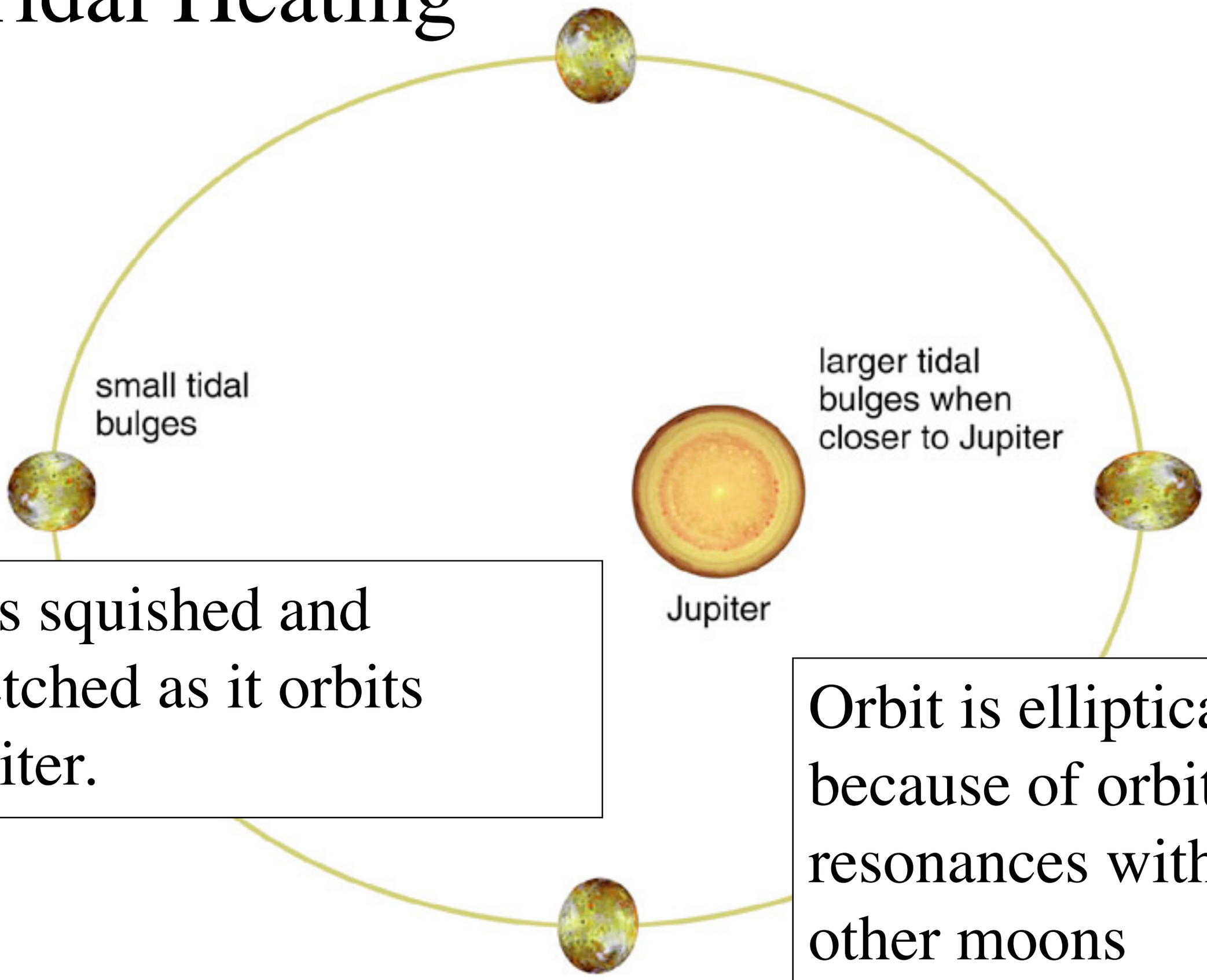
show interactive optical/IR image IF_11_17_IoVolcanoesIR

Io's surface very young

Constantly re-covered in fresh lava & sulfur dioxide snow



Tidal Heating

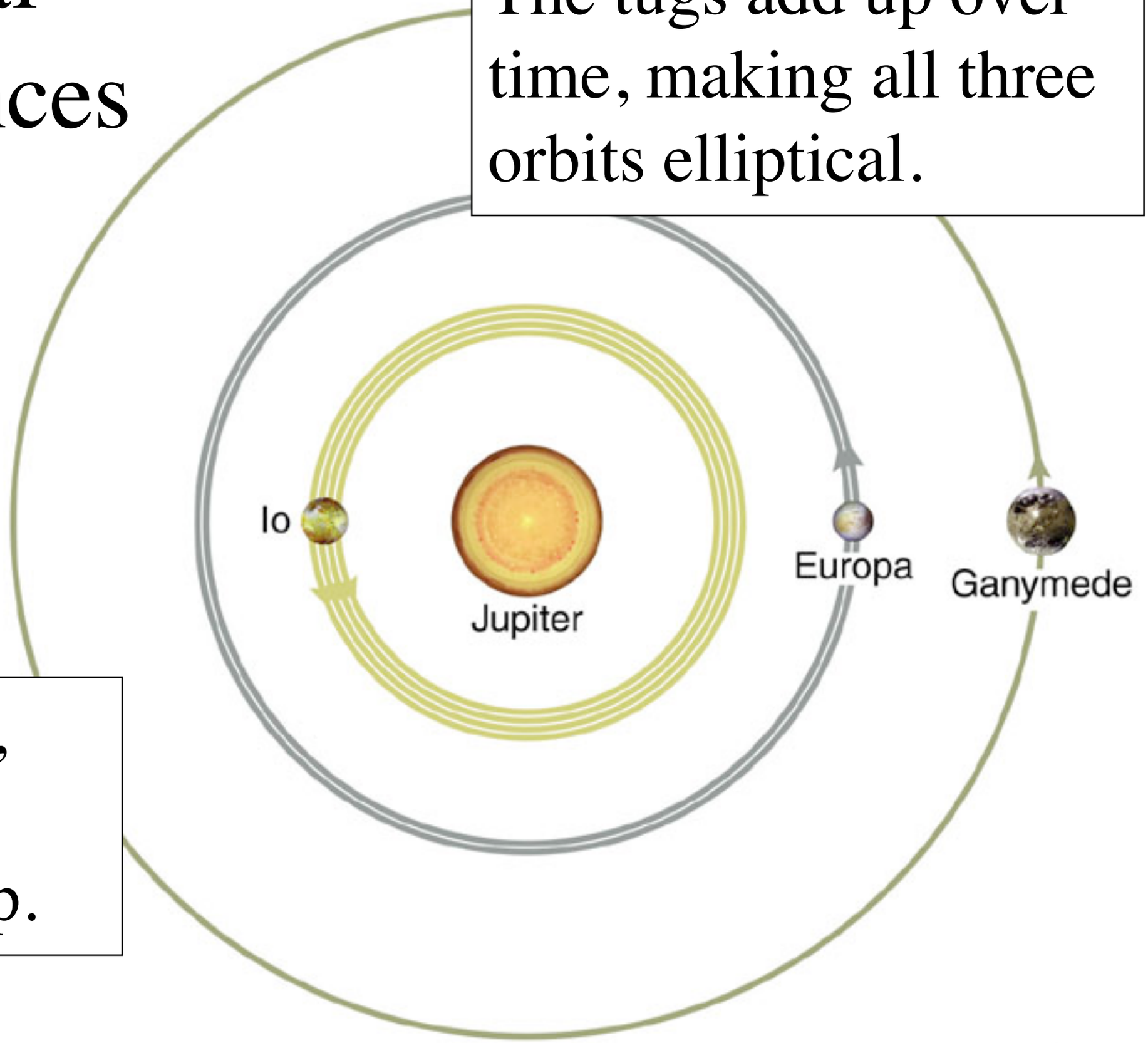


Io is squished and stretched as it orbits Jupiter.

Orbit is elliptical because of orbital resonances with other moons

Orbital Resonances

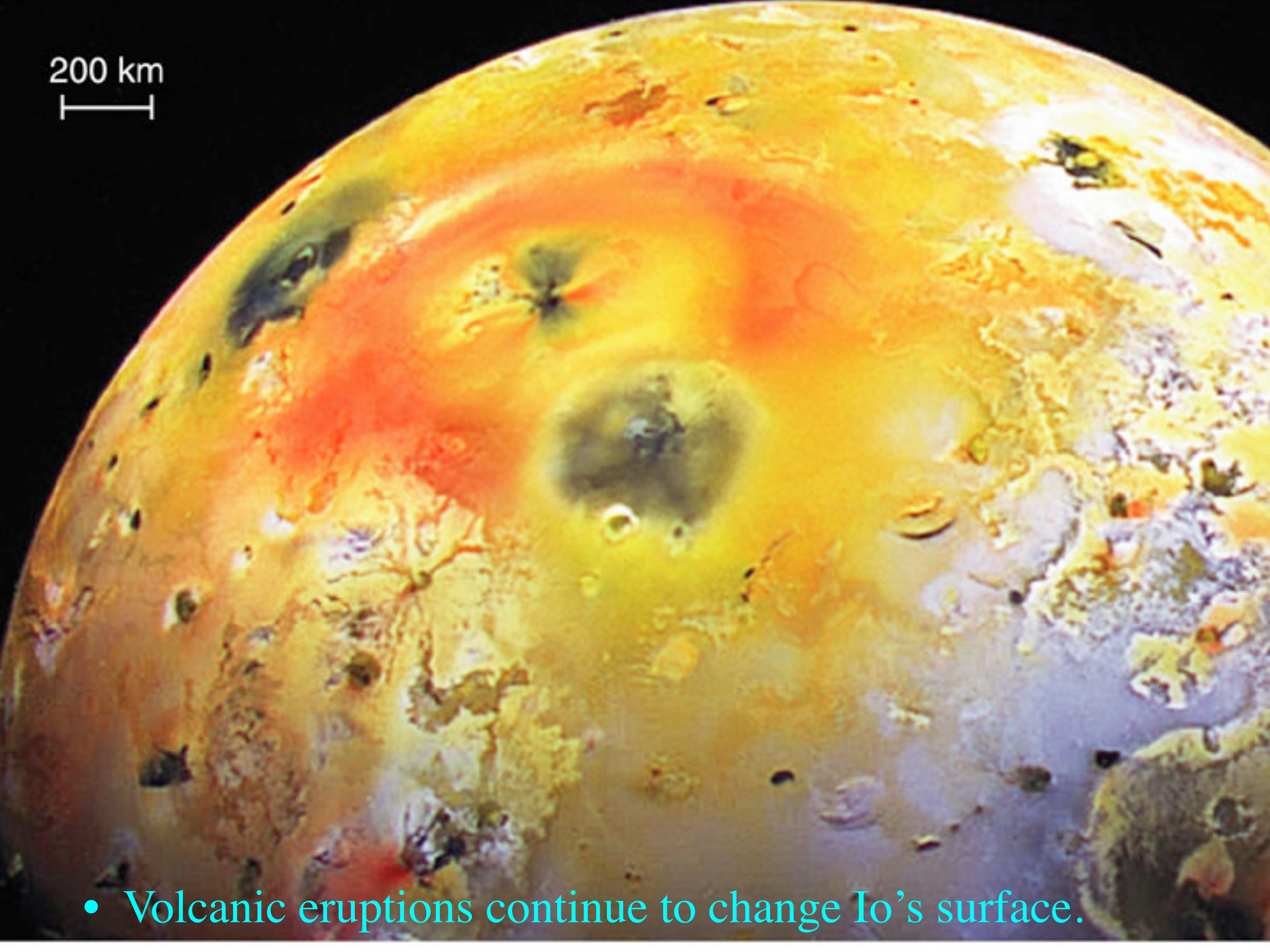
The tugs add up over time, making all three orbits elliptical.



Every 7 days, these three moons line up.

IF_11_19_TidalHeatingResonance

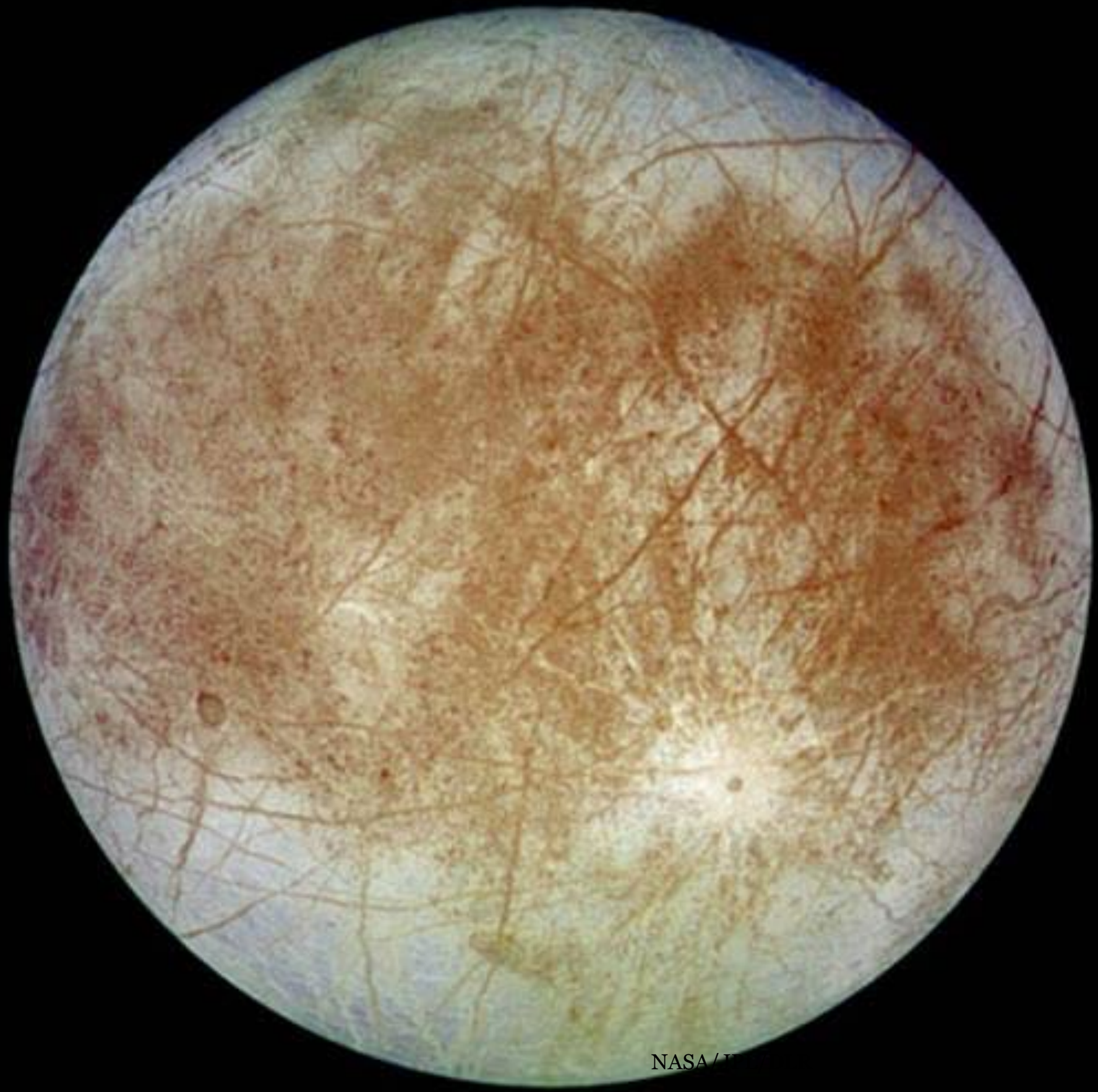
show interactive figure



- Volcanic eruptions continue to change Io's surface.

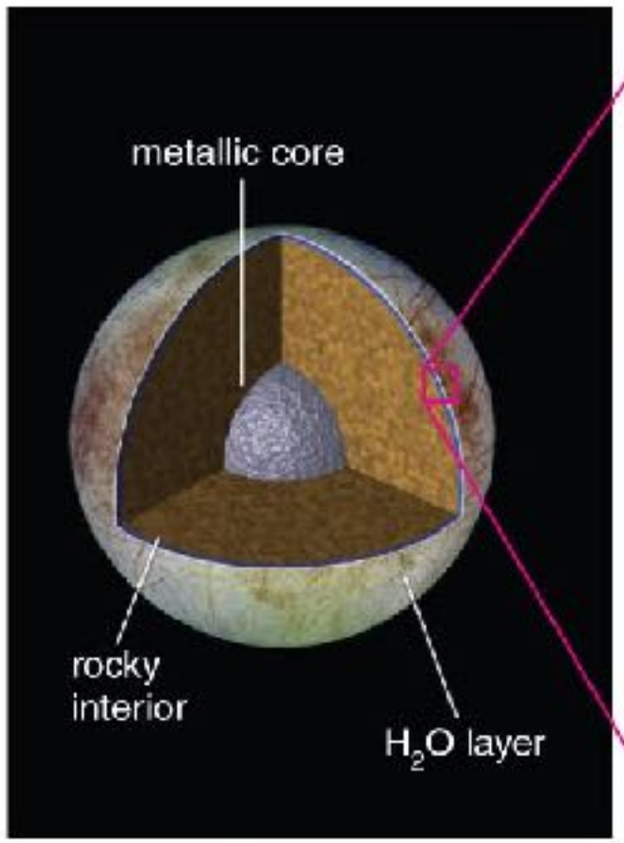
The moons of the Jovian planets

Europa

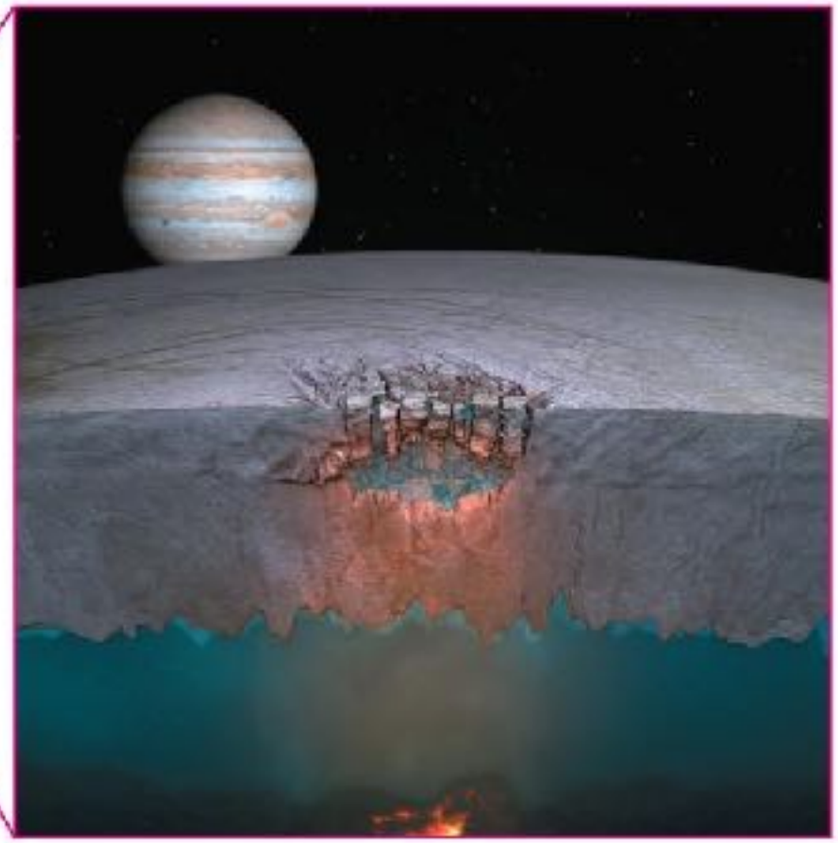


NASA /

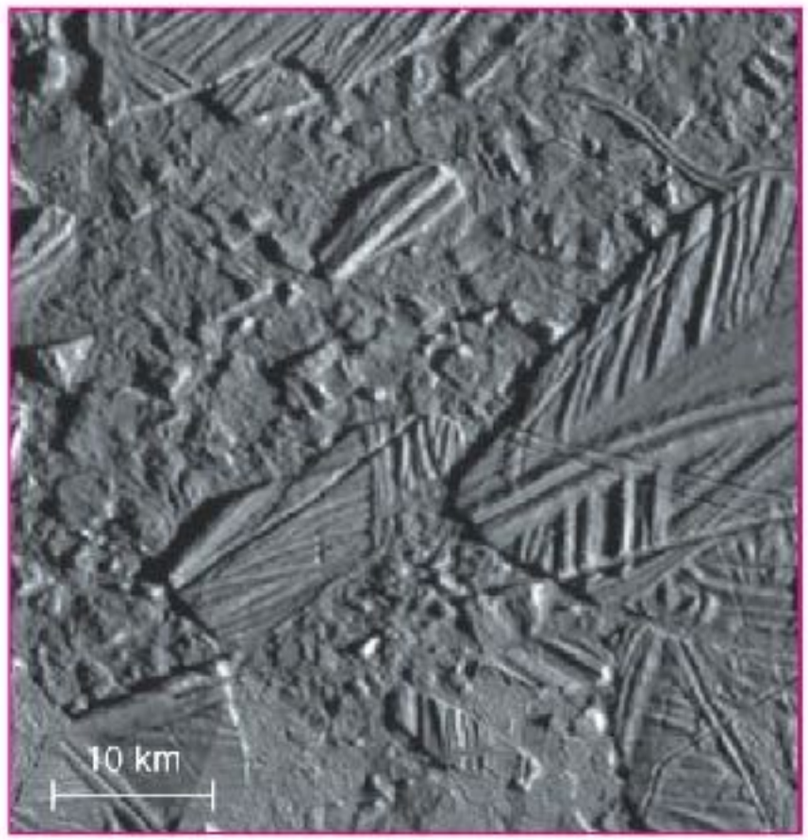
Europa's interior also warmed by tidal heating.



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

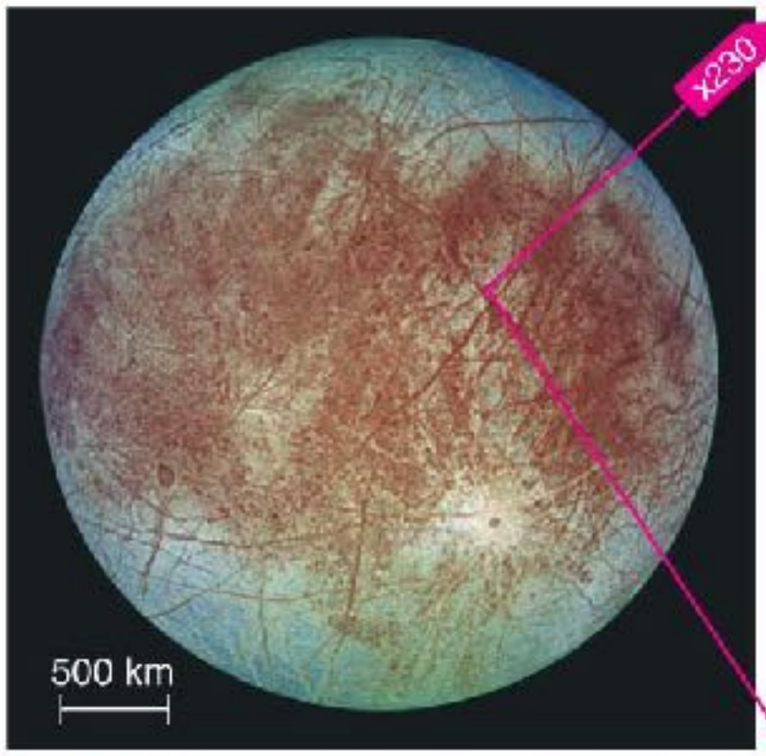


Rising plumes of warm water may sometimes create lakes within the ice, causing the crust above to crack . . .

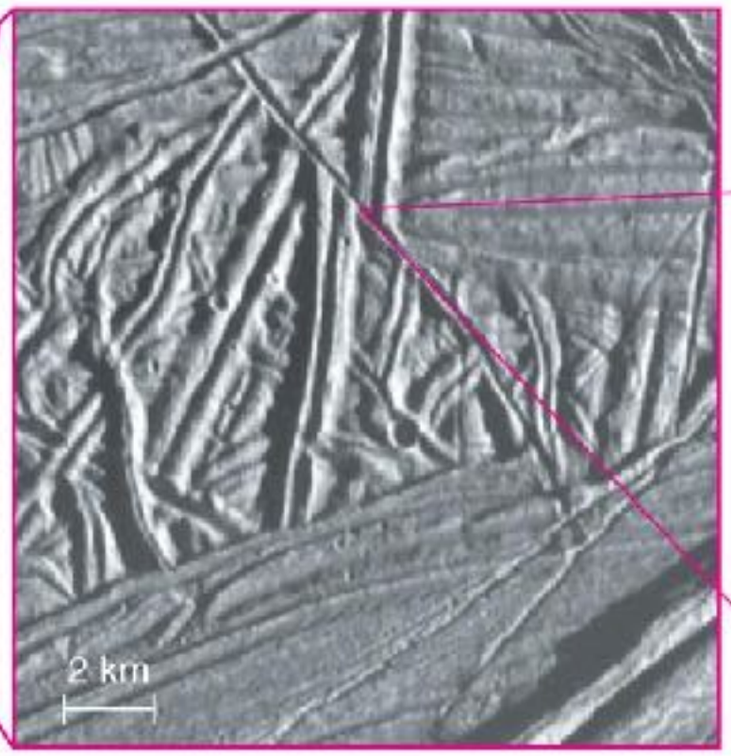


. . . explaining surface terrain that looks like a jumble of icebergs suspended in a place where liquid or slushy water froze.

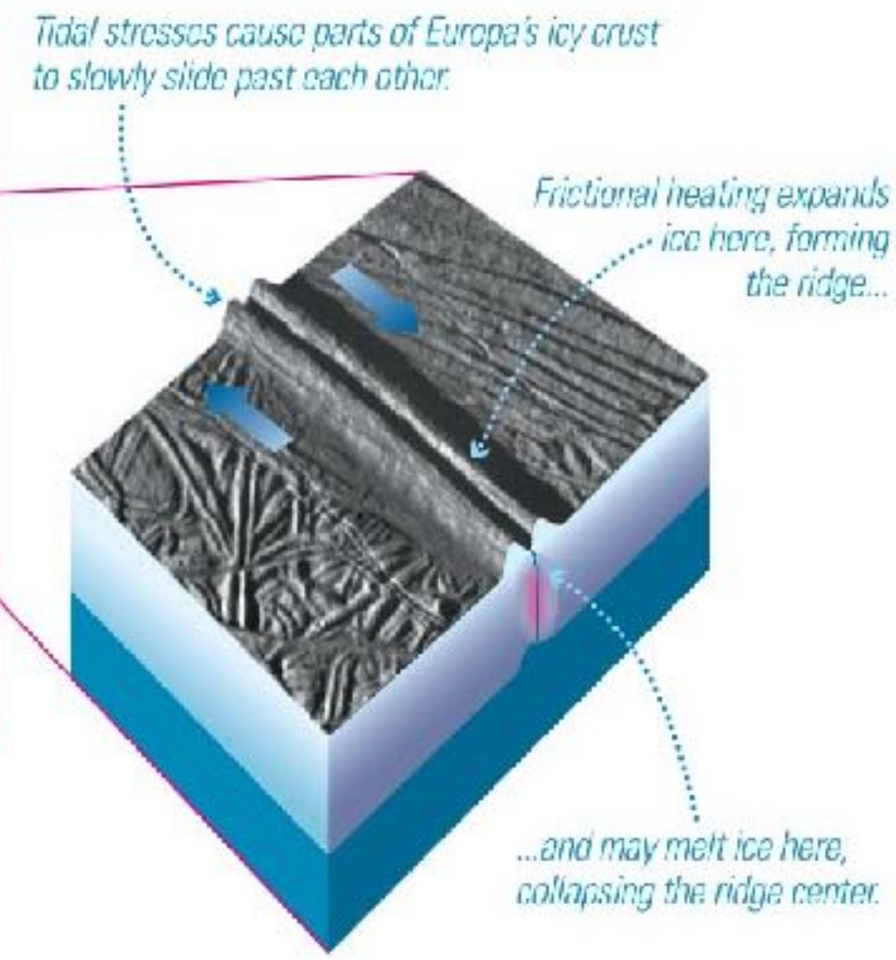
Tidal stresses crack Europa's surface ice.

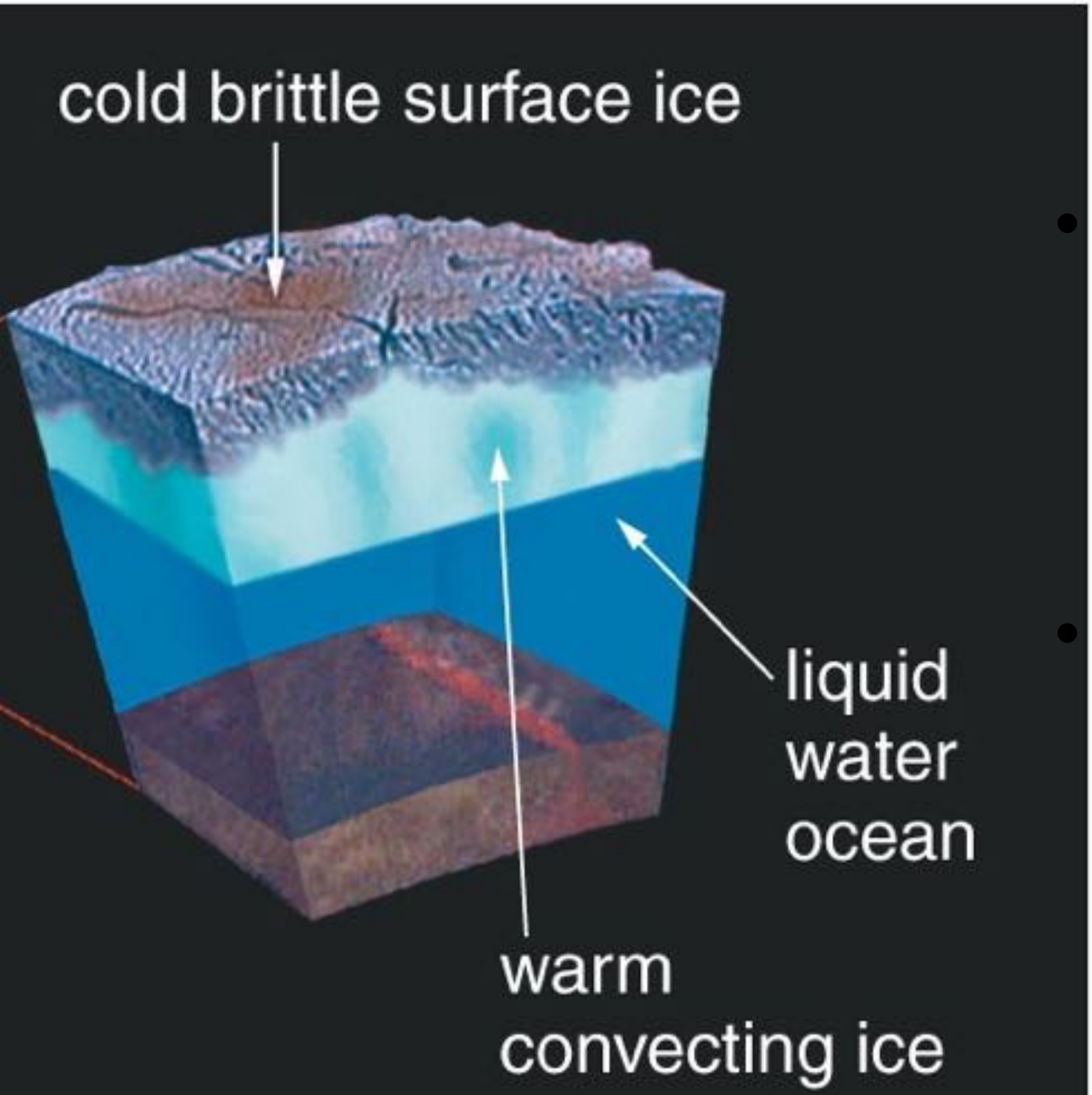


Europa's surface appears heavily cracked even from a distance.



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





Europa

- Icy surface
  - cracks driven by some "geological" activity
- Liquid ocean beneath?
  - popular spot to speculate about the potential for life