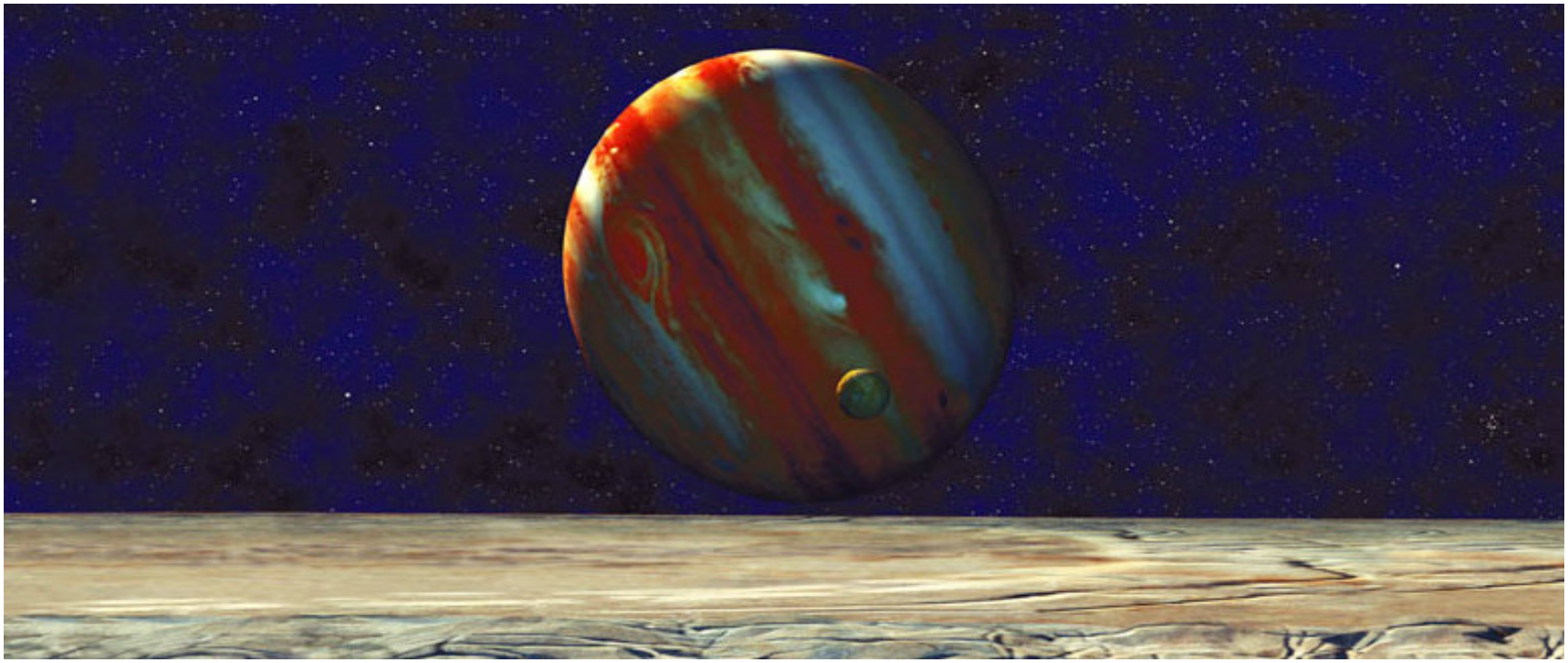
Chapter 11
Jovian Planet Systems



Agenda

- Announce:
  - Project Presentation Expectations
  - Don’t forget online assignments
  - Observation Dec 5/7
- Finish Ch. 9—Planetary Geology
- Start Ch. 11—Jovian Planets

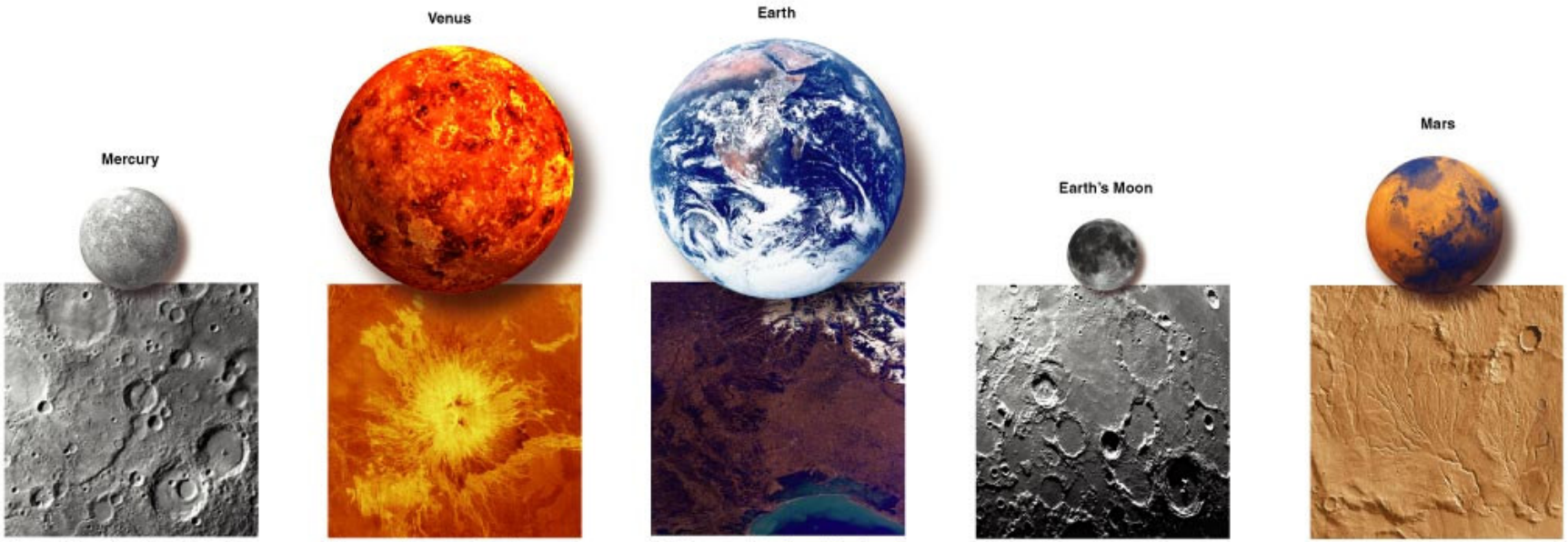
Project Expectations

- Professional:
  - Proper spelling/grammar
  - Formal tone
- Freedom:
  - Expression/belief
  - Form/perspective
- Interesting, captivating
- Focused, directed…you wanted to understand/answer something, and here's the answer
- Demonstrate ability to attack a research problem finding proper sources
- Each group should take no more than 5minutes/per group member

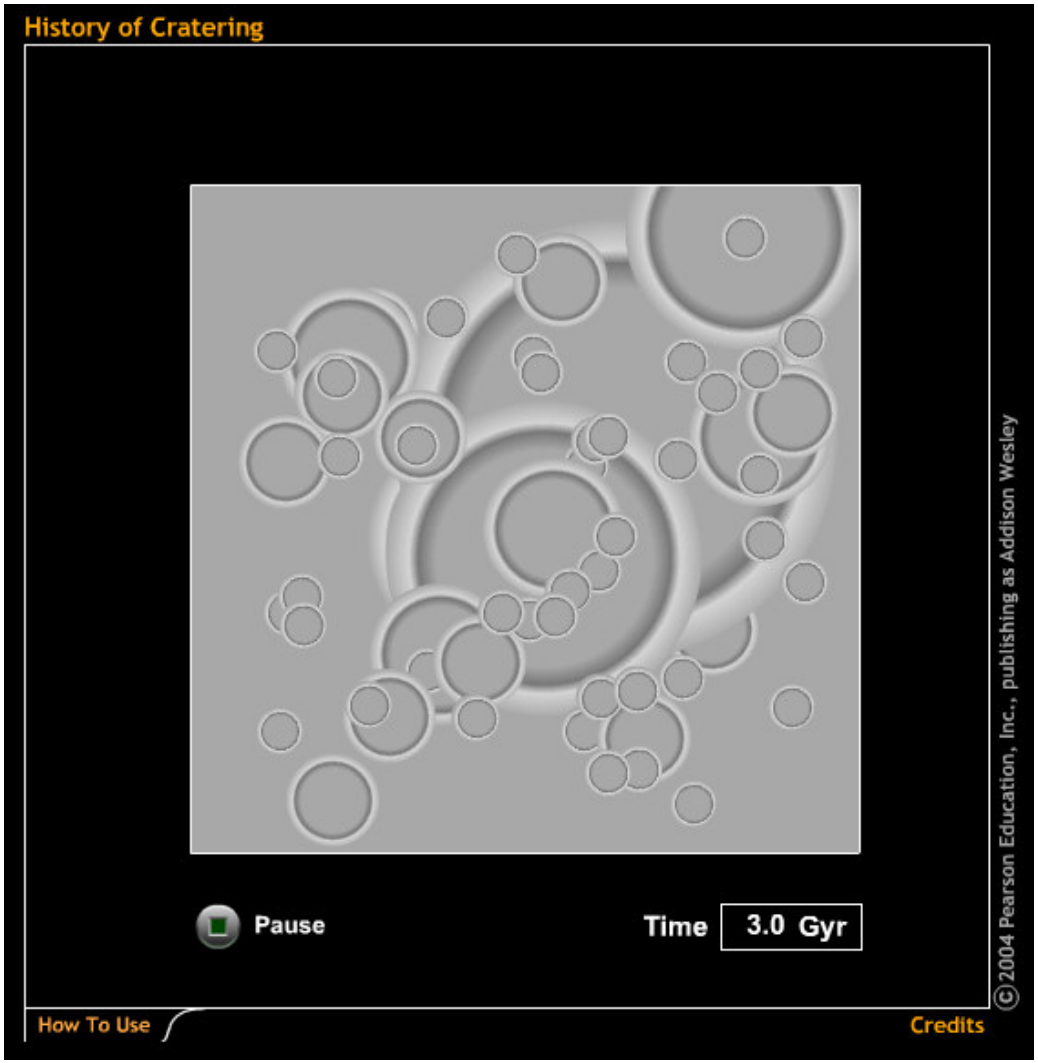
Powerpoint Tips

- Use colors that people can see
- Make sure presentation will work
- Avoid silly effects
- Don’t put sentences on slides
- Find good graphics as appropriate
- Don’t assume audience knows more than they do

How does a planet's surface reveal its geological age?

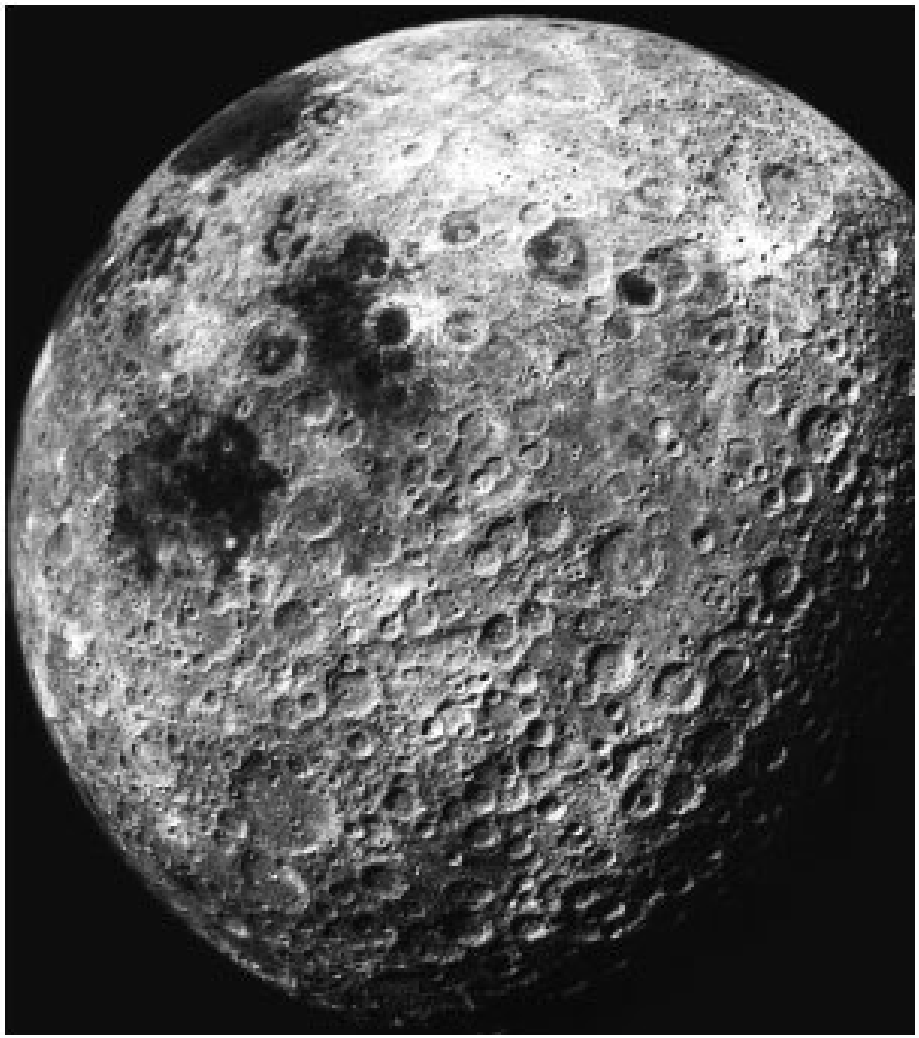


History of Cratering



- Most cratering happened in first billion years
- A surface with many craters has not changed much in 3 billion years

Cratering of Moon

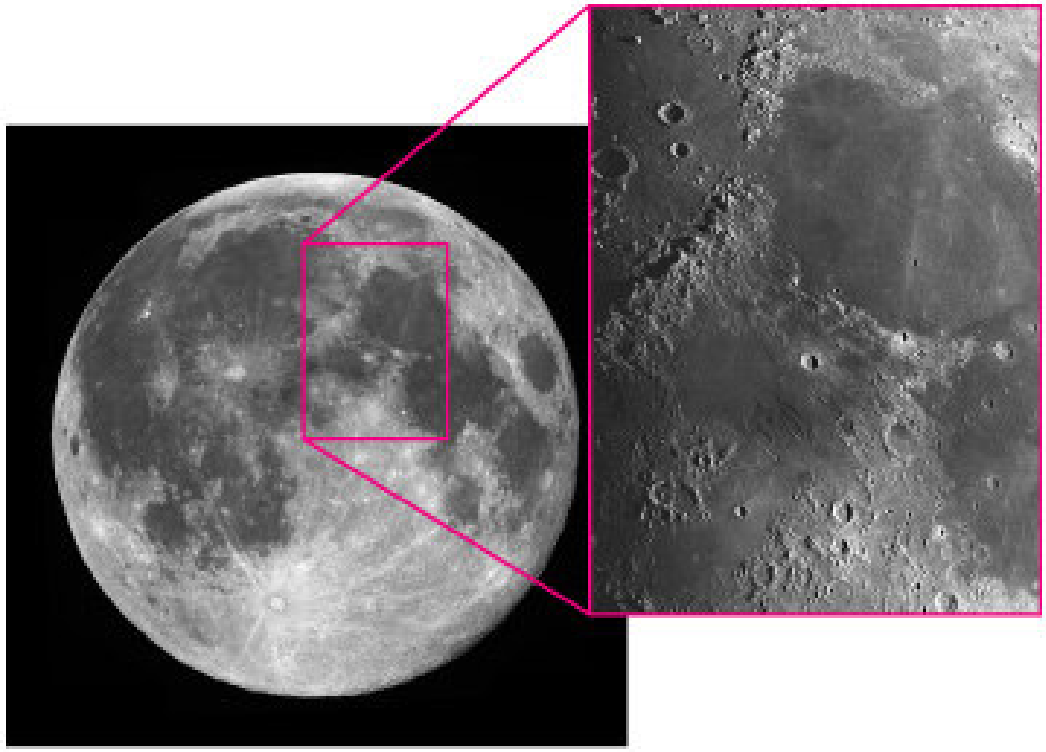


- Some areas of Moon are more heavily cratered than others
- Younger regions were flooded by lava after most cratering

9.3 Geology of the Moon and Mercury

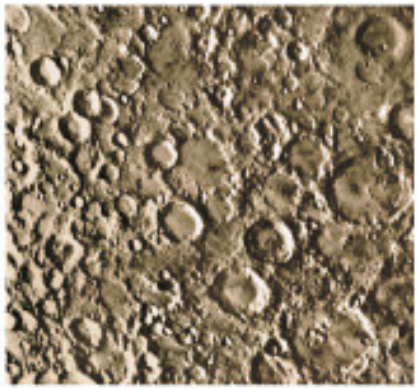
- Our goals for learning
- What geological processes shaped our Moon?
- What geological processes shaped Mercury?

Lunar Maria



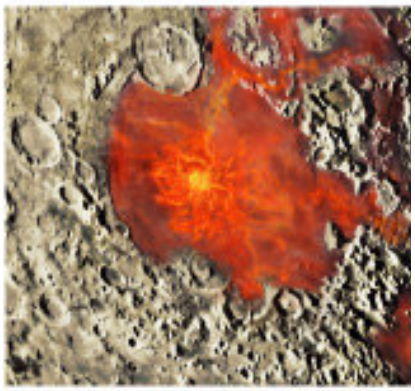
- Smooth, dark lunar maria are less heavily cratered than lunar highlands
- Maria were made by flood of runny lava

Formation of Lunar Maria

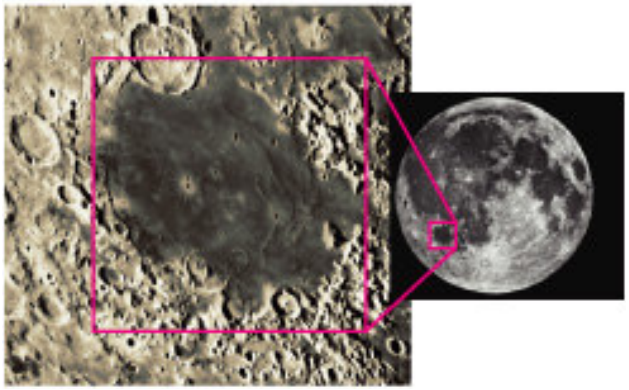


Early surface covered with craters

Large impact crater weakens crust

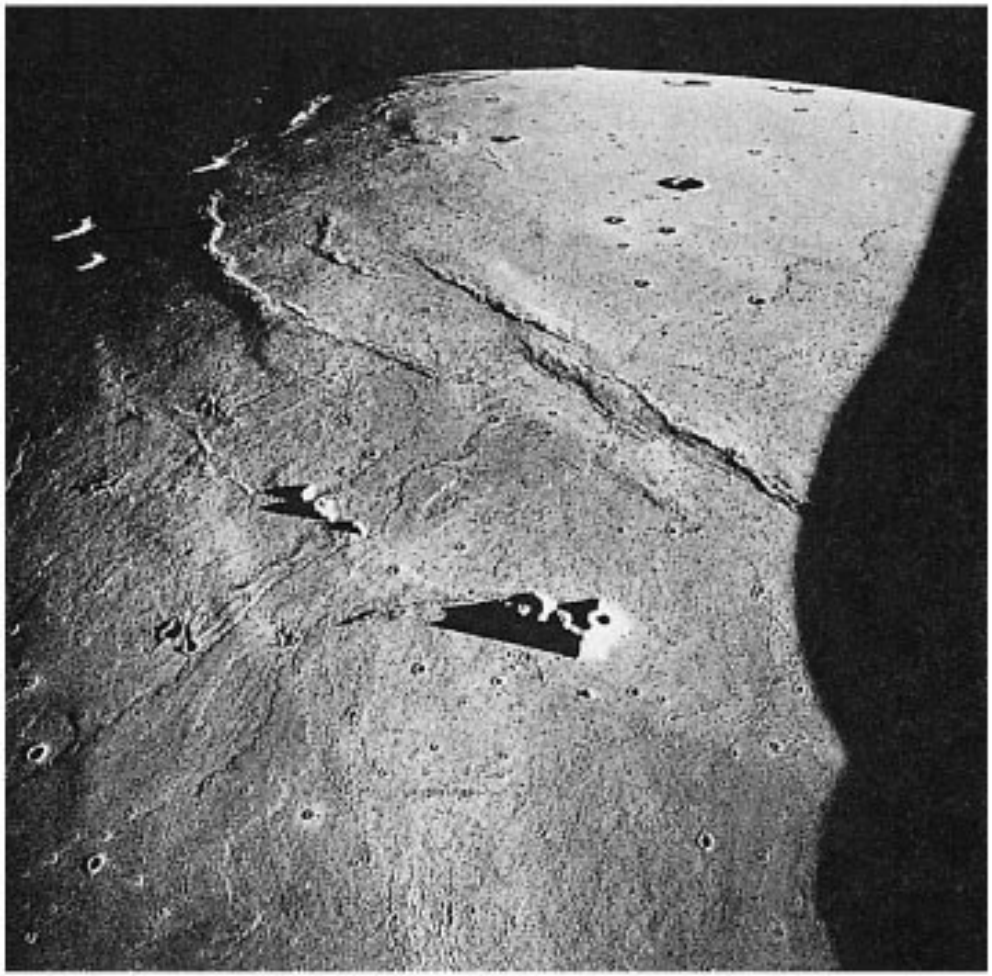


Heat build-up allows lava to well up to surface



Cooled lava is smoother and darker than surroundings

Tectonic Features

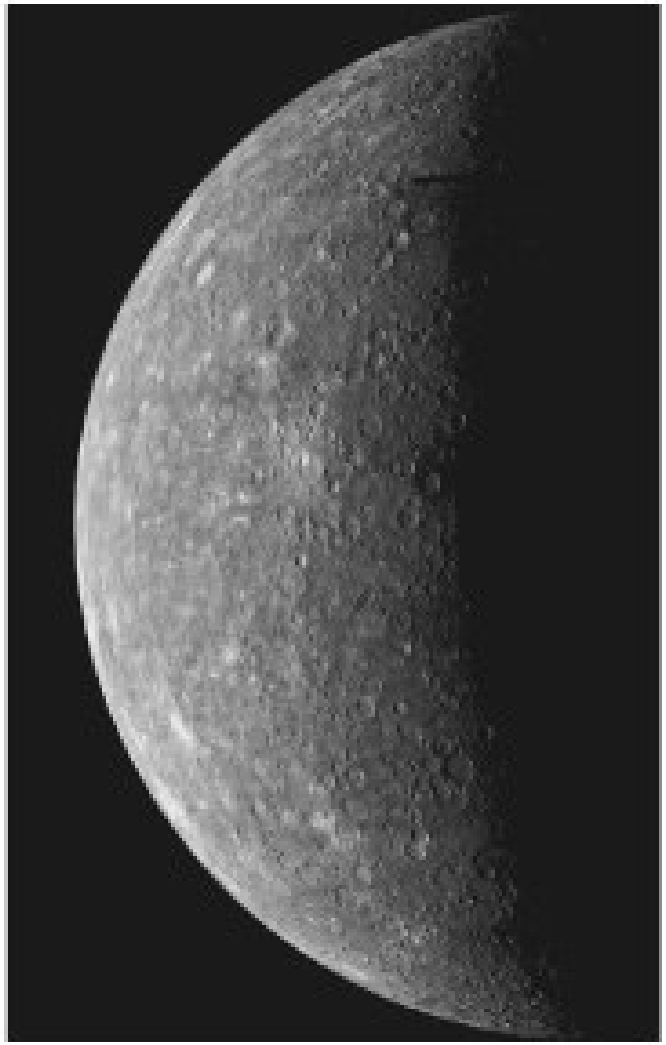


- Wrinkles arise from cooling and contraction of lava flood

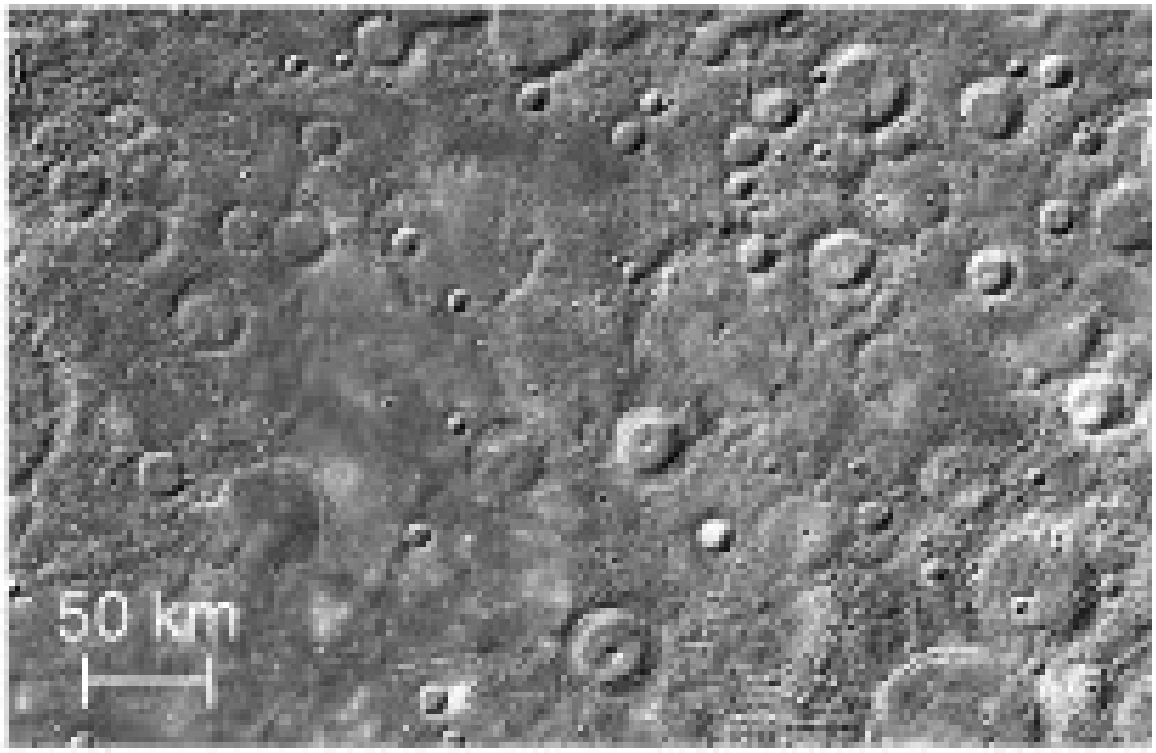
Geologically Dead

- Moon is considered geologically “dead” because geological processes have virtually stopped

What geological processes shaped Mercury?

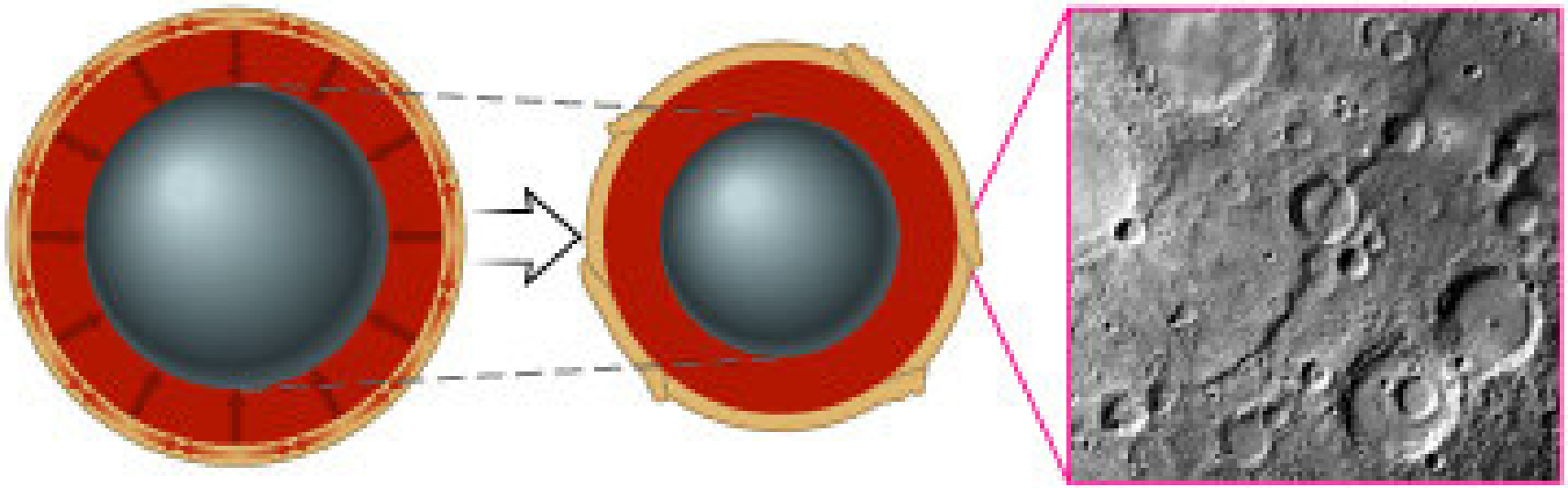


Cratering of Mercury



- A mixture of heavily cratered and smooth regions like the Moon
- Smooth regions are likely ancient lava flows

Tectonics on Mercury



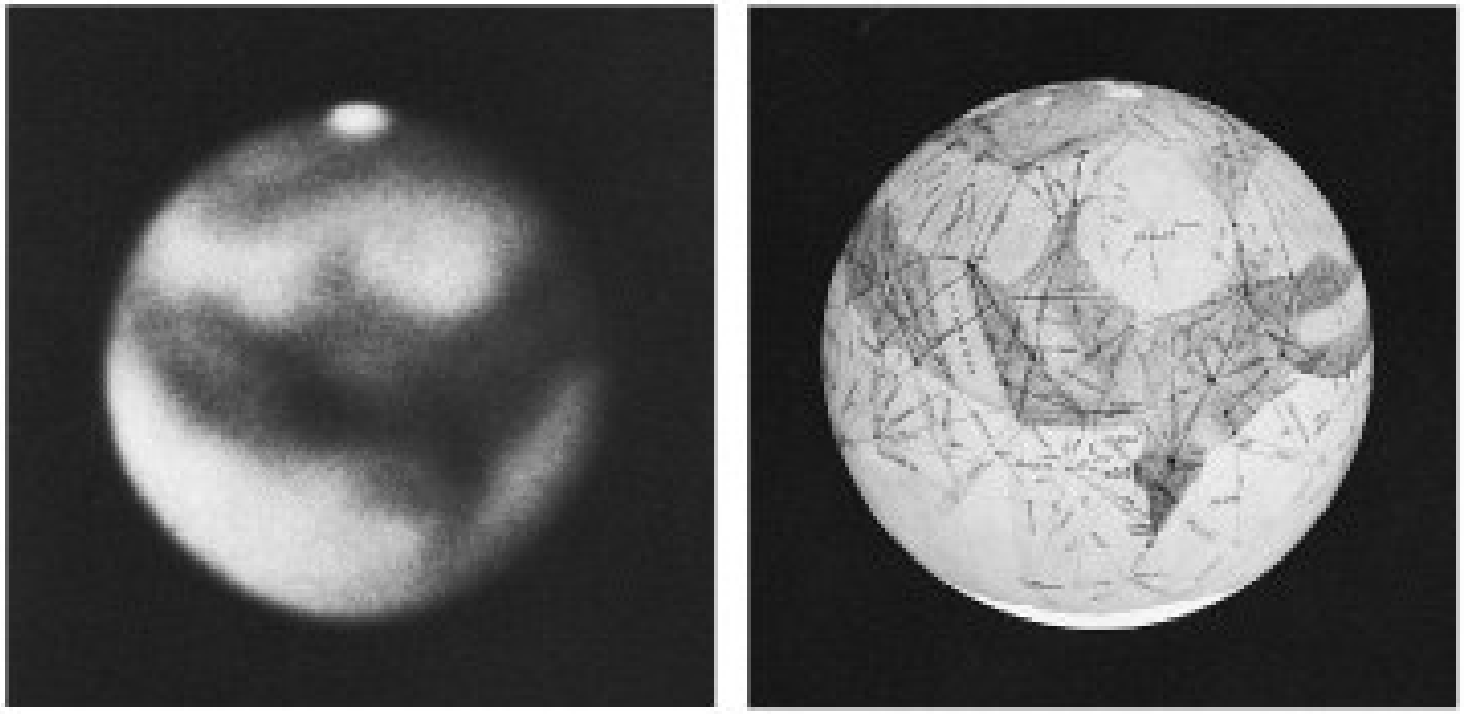
Shrinkage not to scale!

- Long cliffs indicate that Mercury shrank early in its history

9.4 Geology of Mars

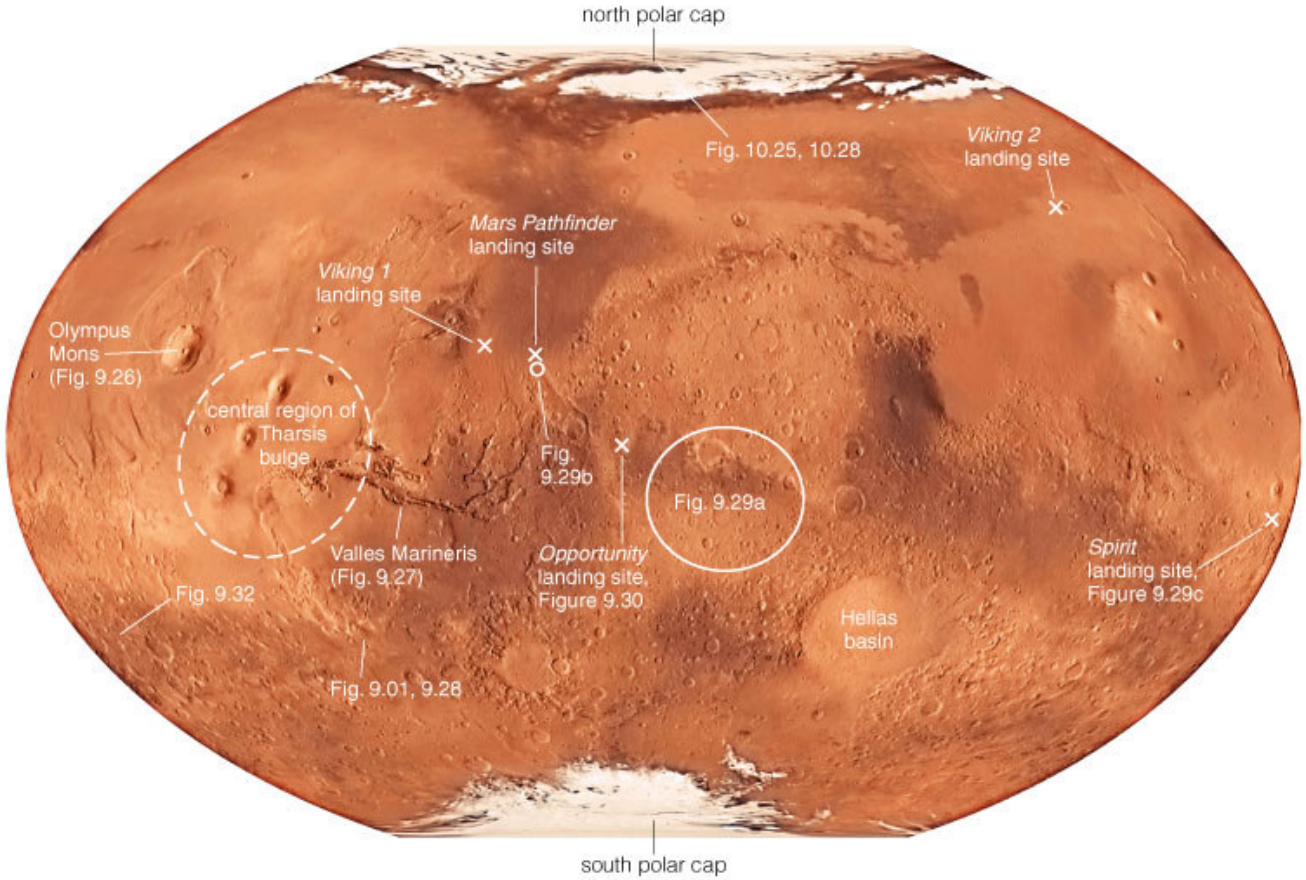
- Our goals for learning
- How did Martians invade popular culture?
- What are the major geological features of Mars?
- What geological evidence tells us that water once flowed on Mars?

“Canals” on Mars



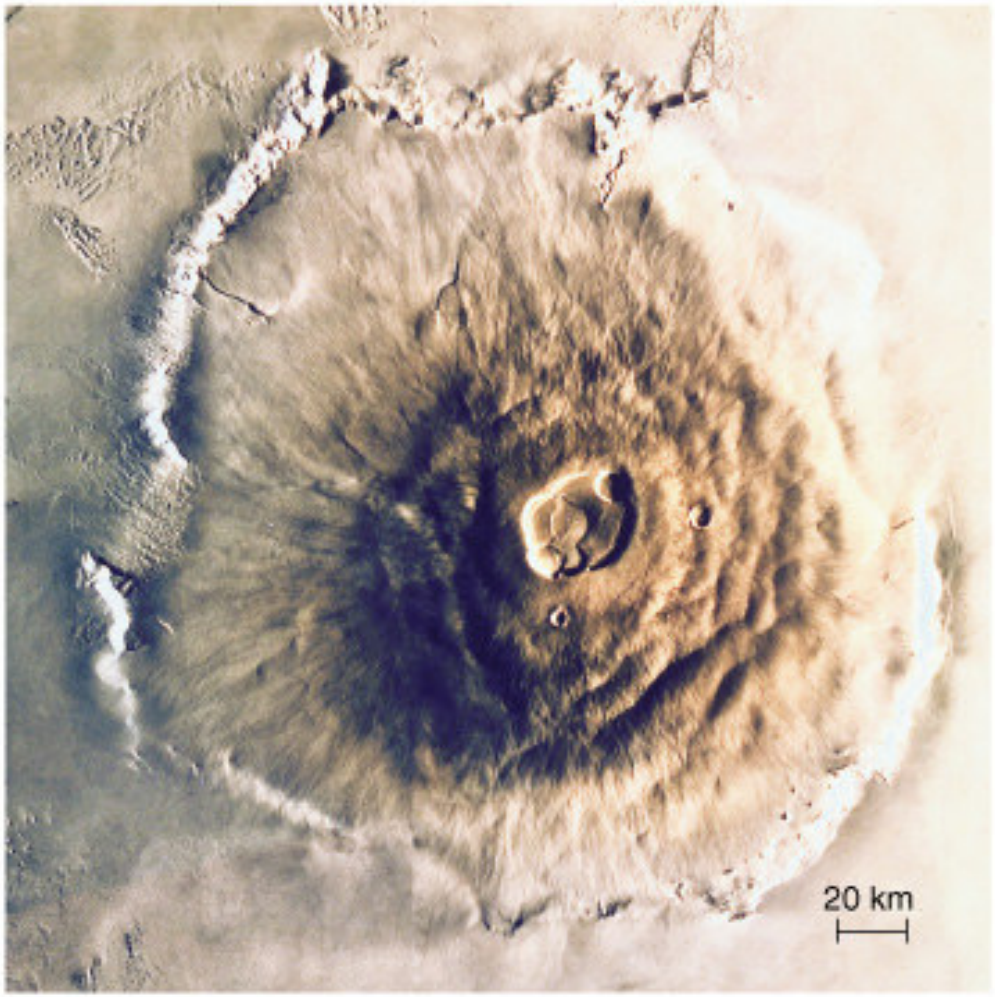
- Percival Lowell misinterpreted surface features seen in telescopic images of Mars

Cratering on Mars



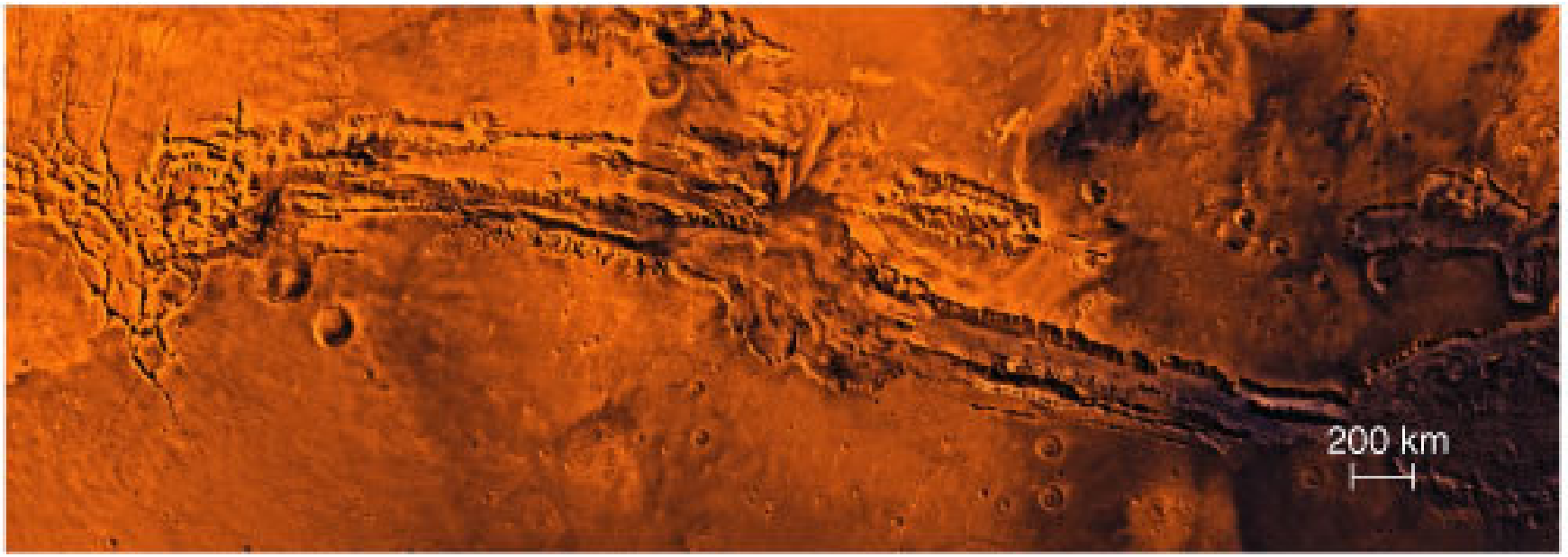
- Amount of cratering differs greatly across surface
- Many early craters have been erased

Volcanism on Mars



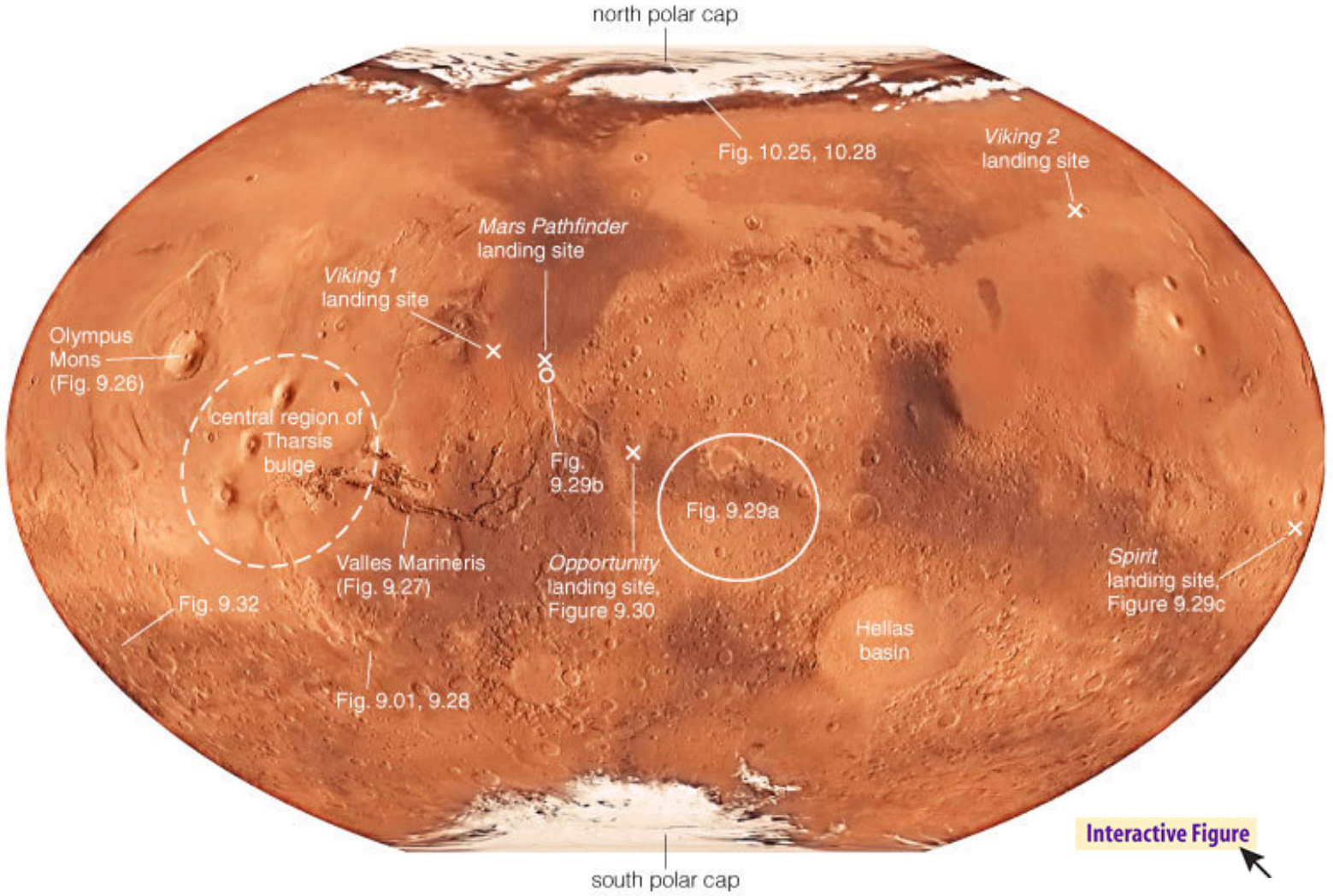
- Mars has many large shield volcanoes
- Olympus Mons is largest volcano in solar system

Tectonics on Mars

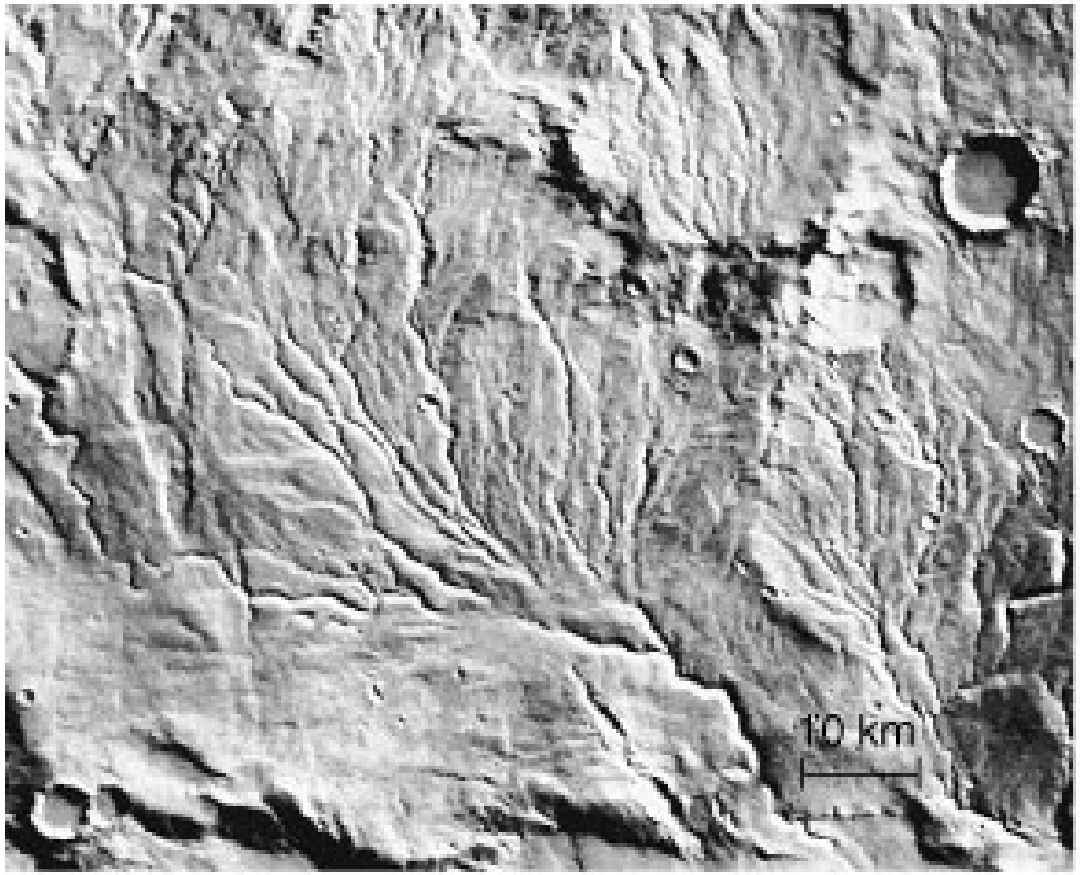


- System of valleys known as Valles Marineris thought to originate from tectonics

What geological evidence tells us that water once flowed on Mars?

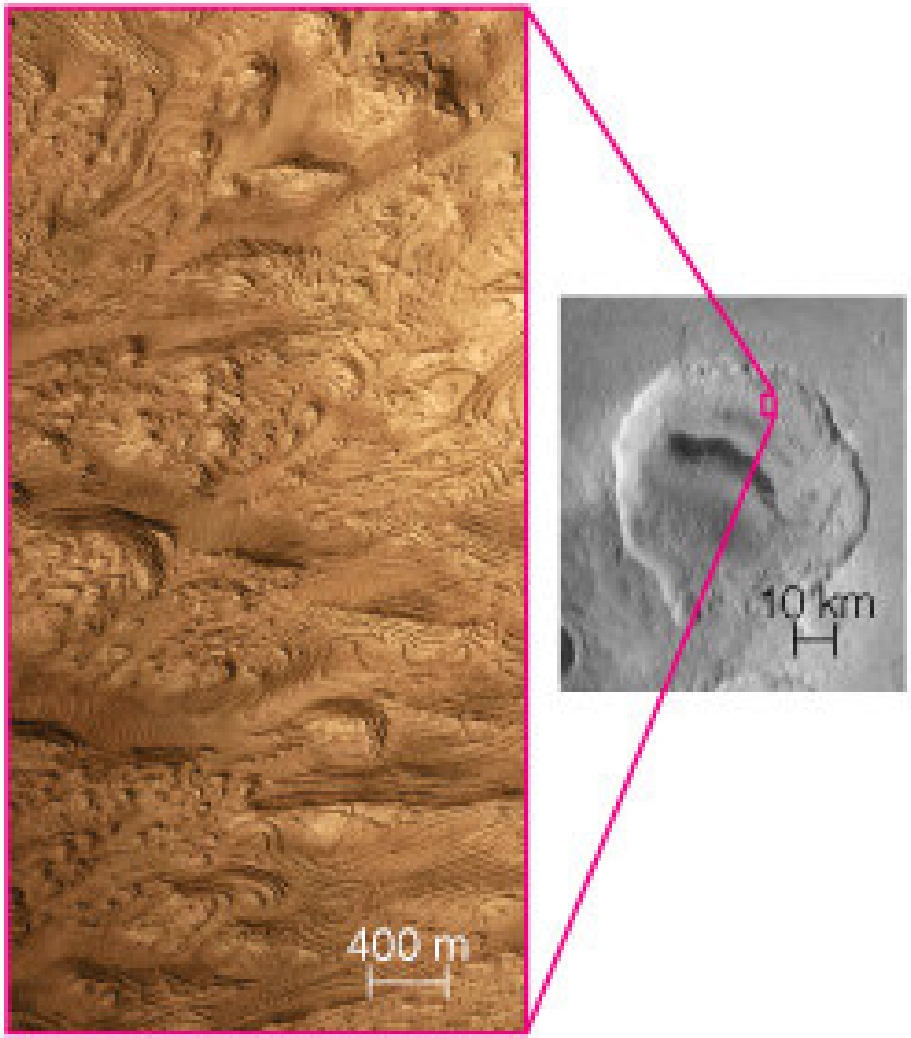


Dry Riverbeds?



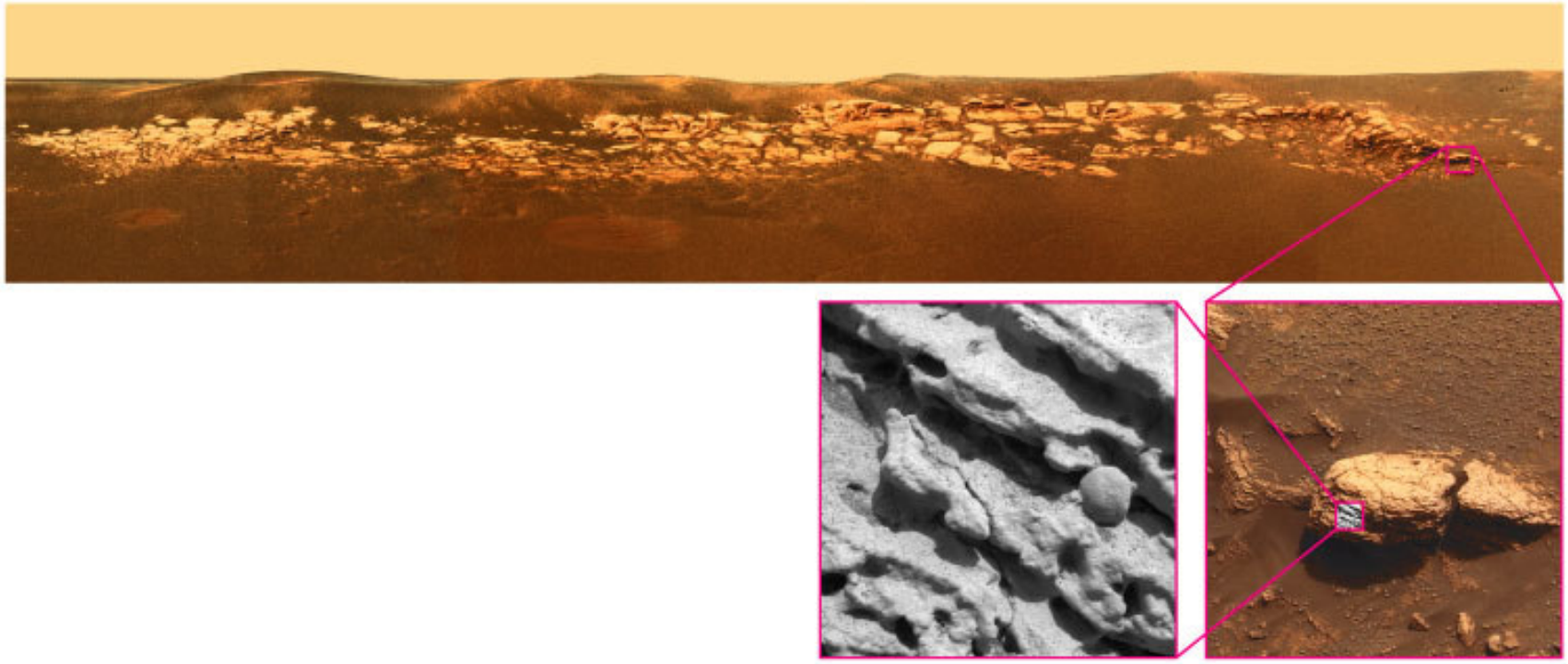
- Close-up photos of Mars show what appear to be dried-up riverbeds

Erosion of Craters



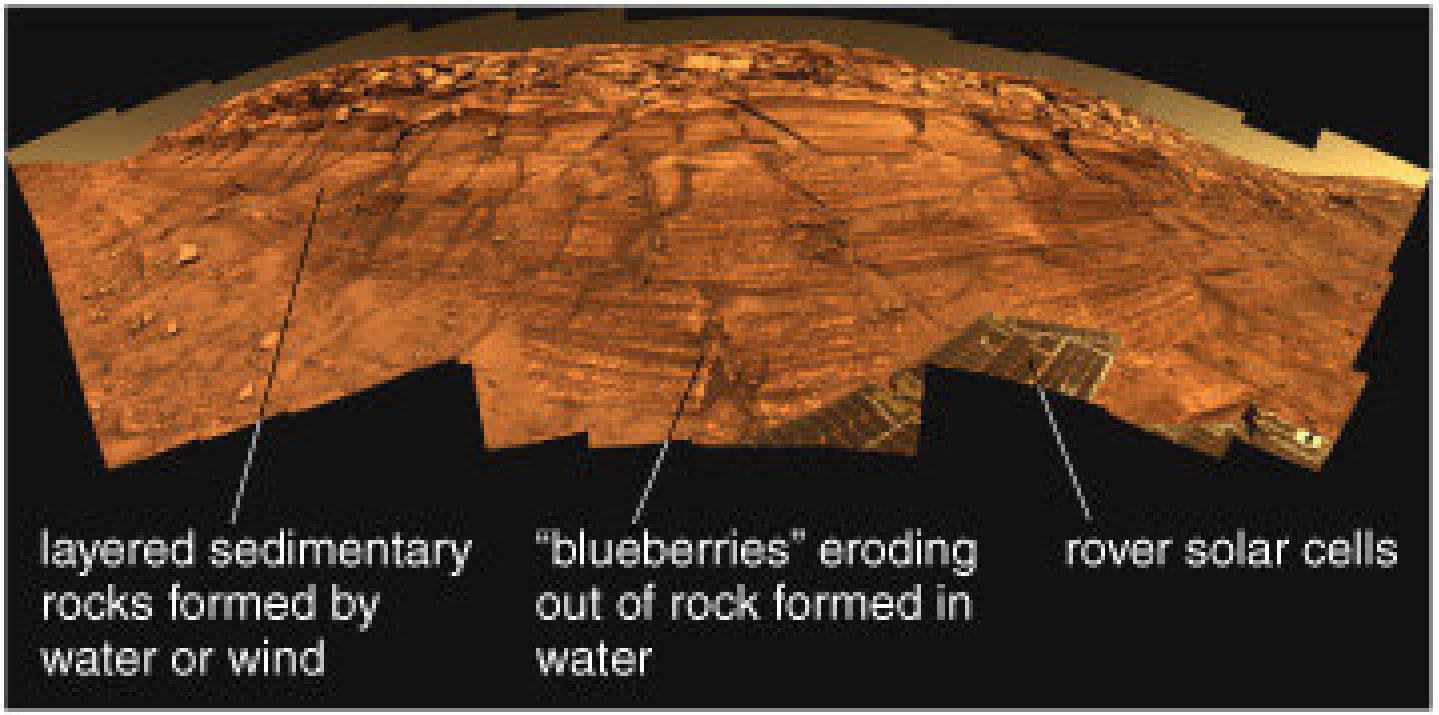
- Details of some craters suggest they were once filled with water

Martian Rocks



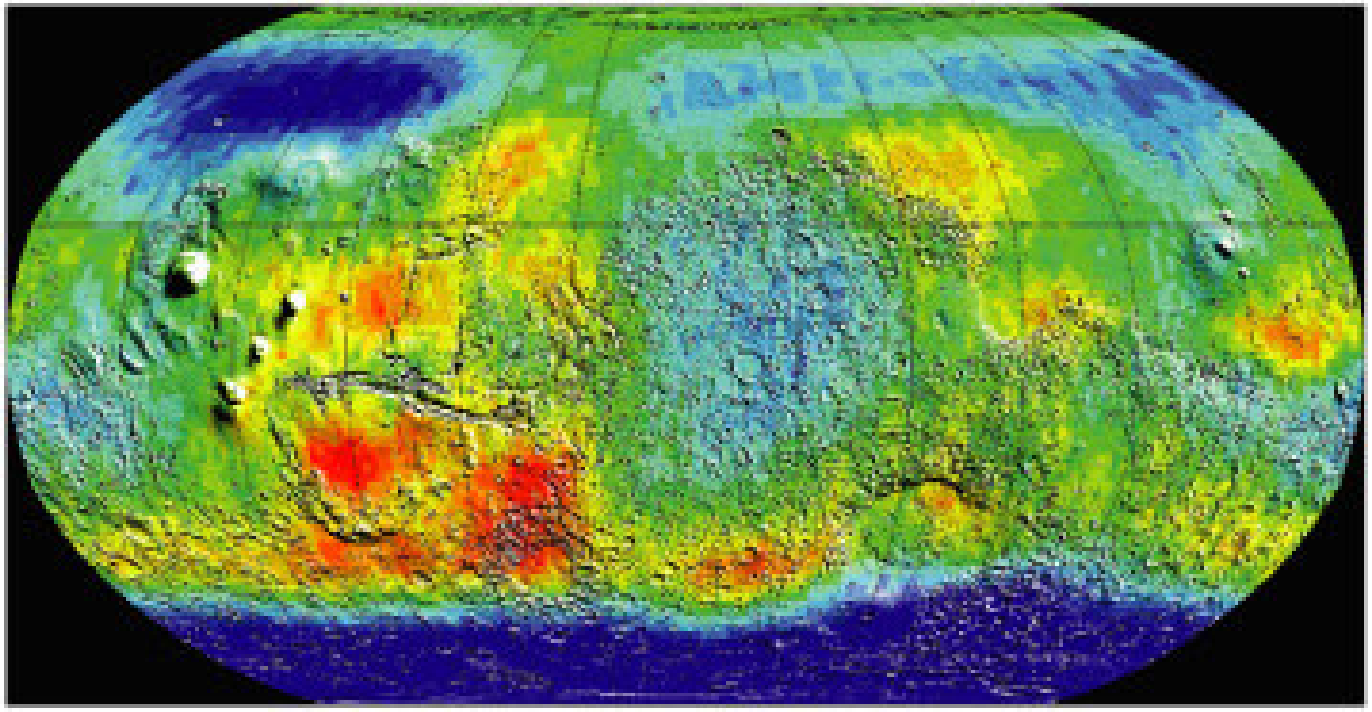
- Mars rovers have found rocks that appear to have formed in water

Martian Rocks



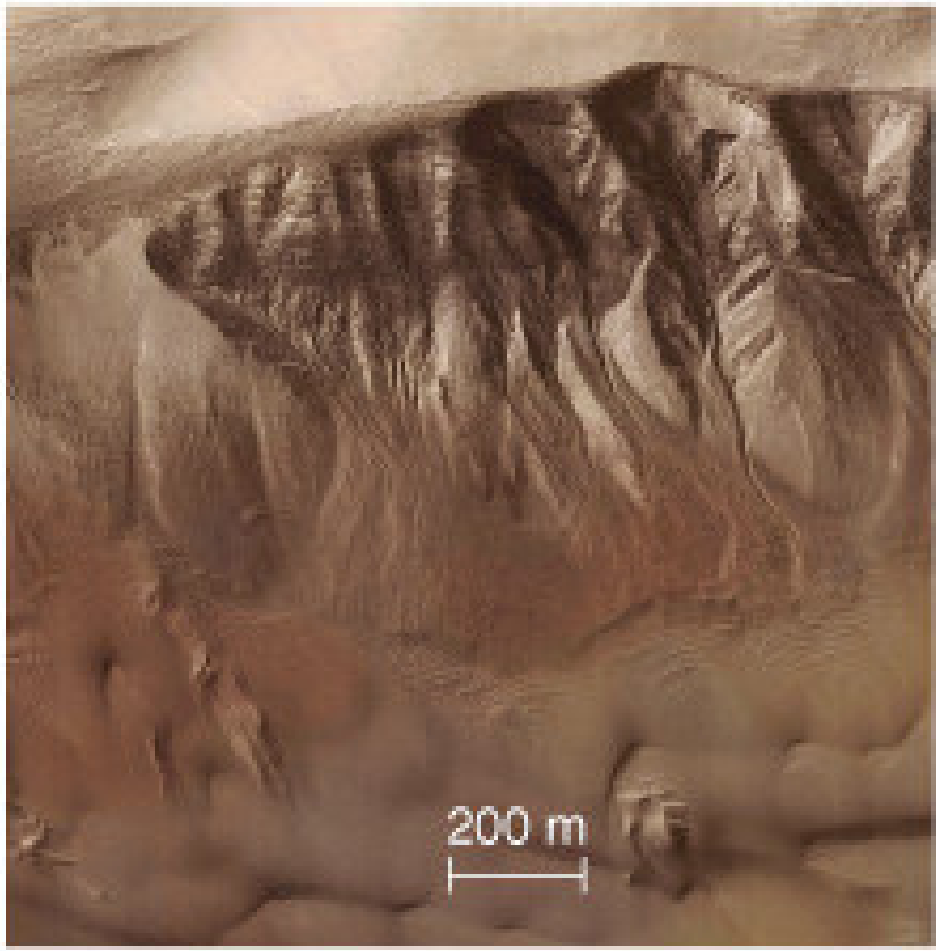
- Exploration of impact craters has revealed that Mars' deeper layers were affected by water

Hydrogen Content



- Map of hydrogen content (blue) shows that low-lying areas contain more water ice

Crater Walls

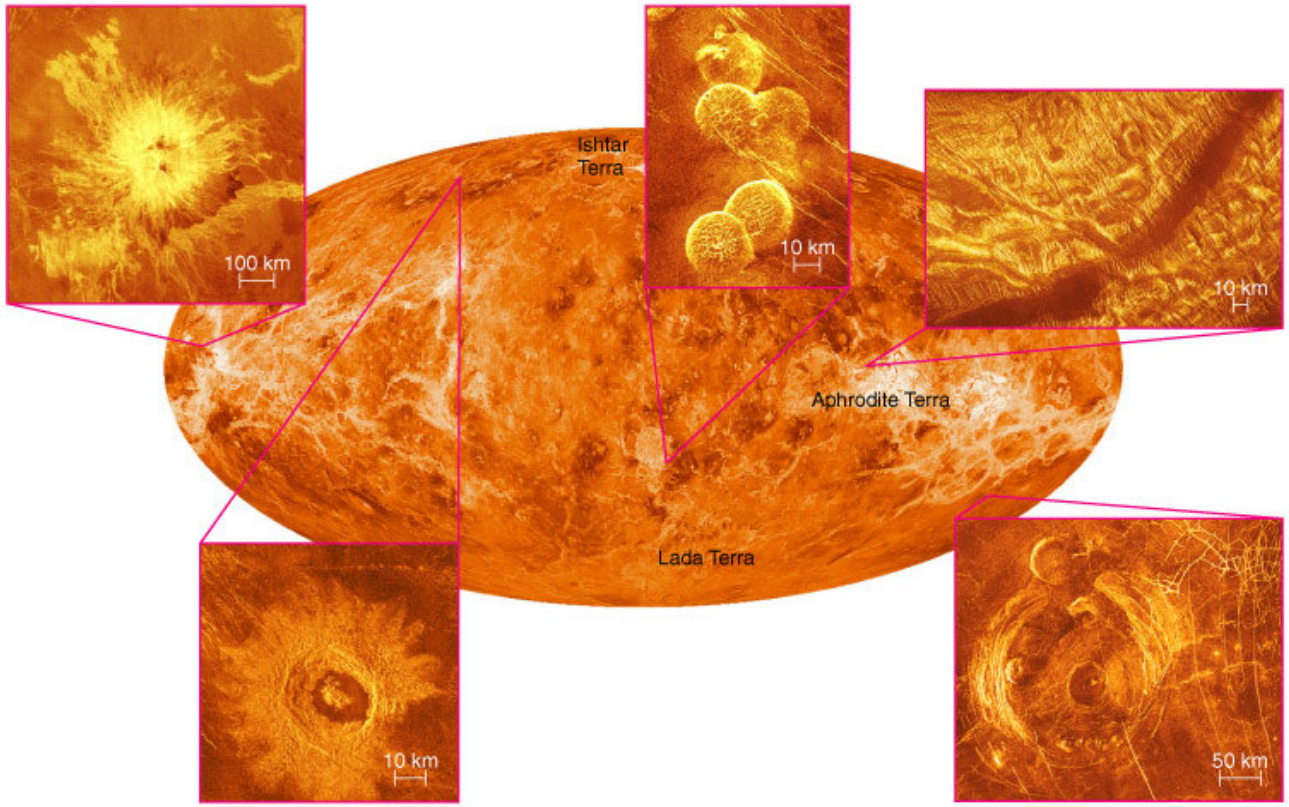


- Gullies on crater walls suggest occasional liquid water flows have happened less than a million years ago

9.5 Geology of Venus

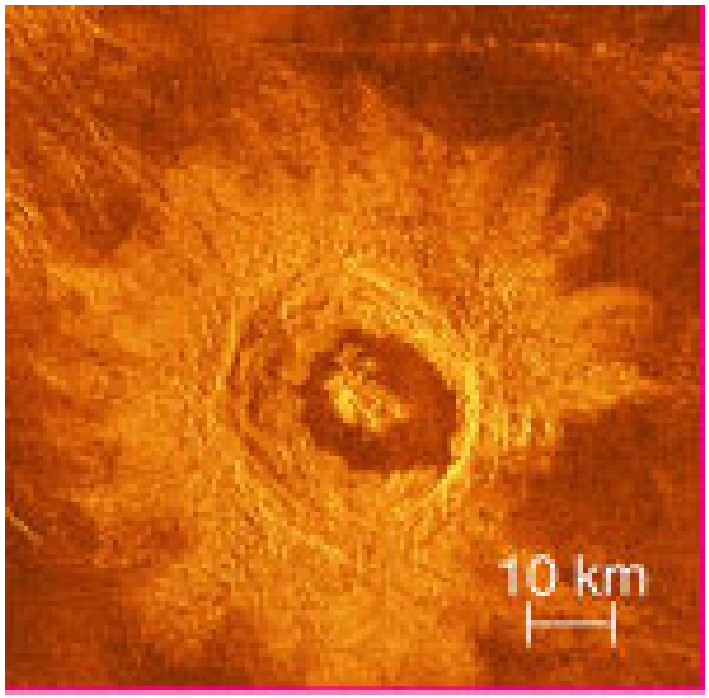
- Our goals for learning
- What are the major geological features of Venus?
- Does Venus have plate tectonics?

Radar Mapping



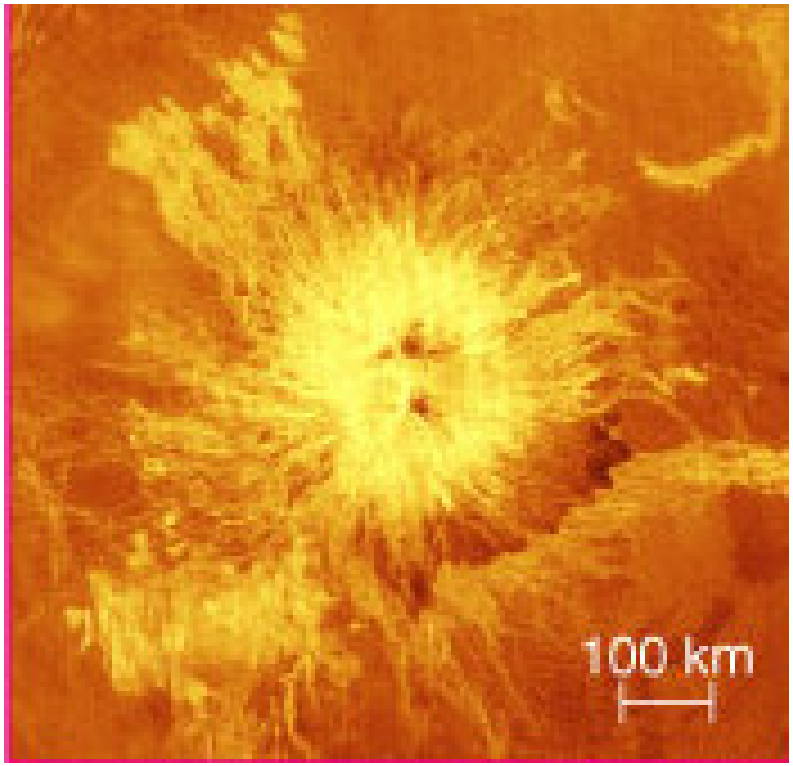
- Thick atmosphere forces us to explore Venus' surface through radar mapping

Cratering on Venus



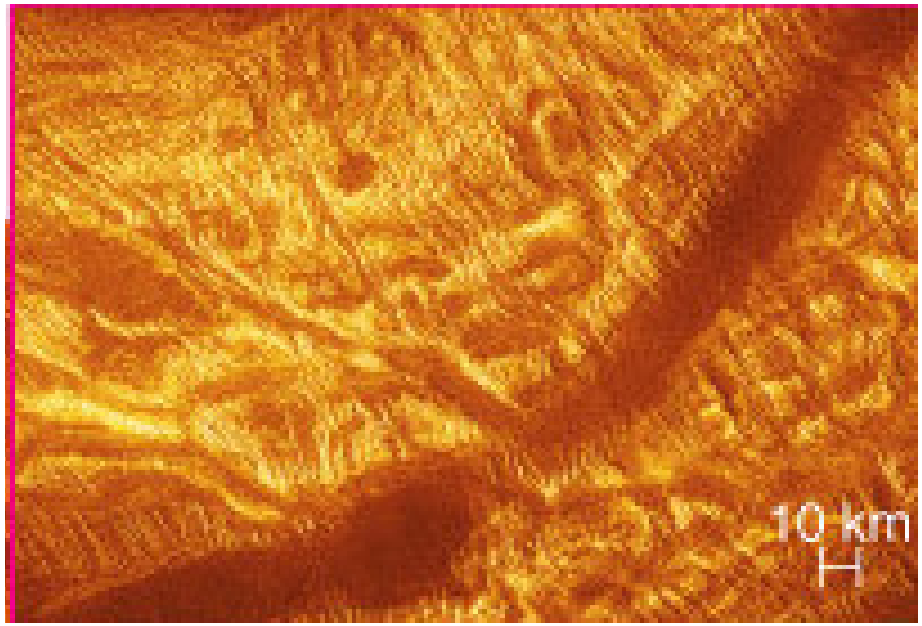
- Impact craters, but fewer than Moon, Mercury, Mars

Volcanoes on Venus



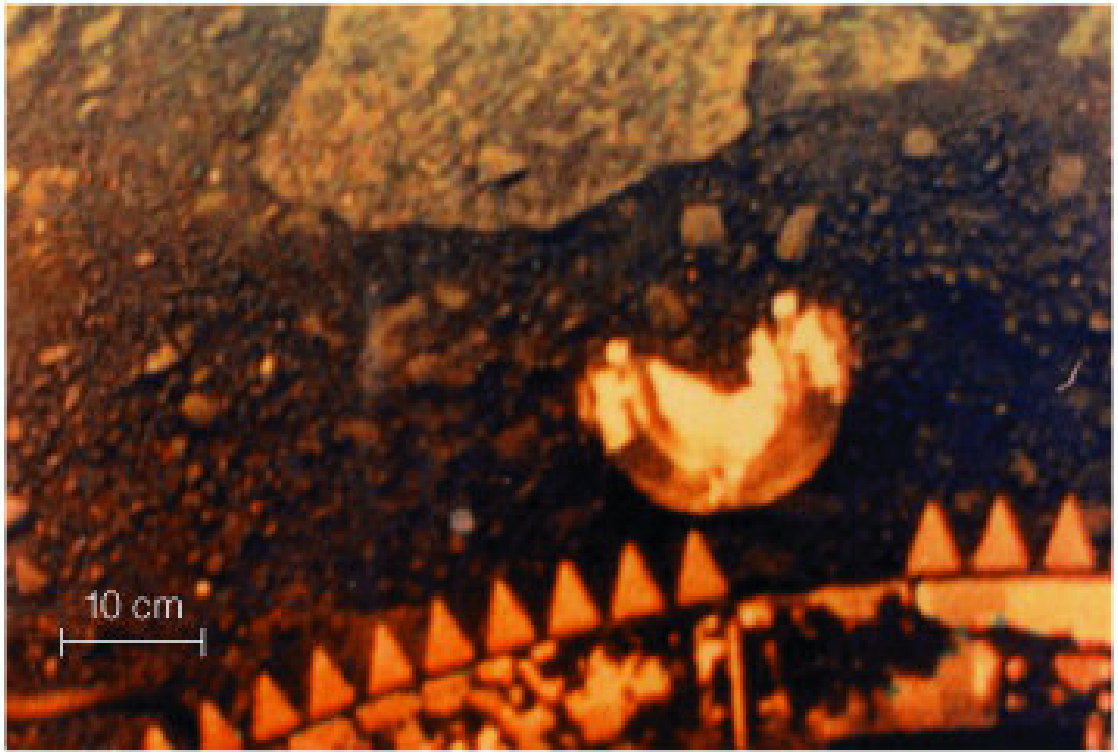
- Many volcanoes, including both shield volcanoes and stratovolcanoes

Tectonics on Venus



- Fractured and contorted surface indicates tectonic stresses

Erosion on Venus



- Photos of rocks taken by lander show little erosion

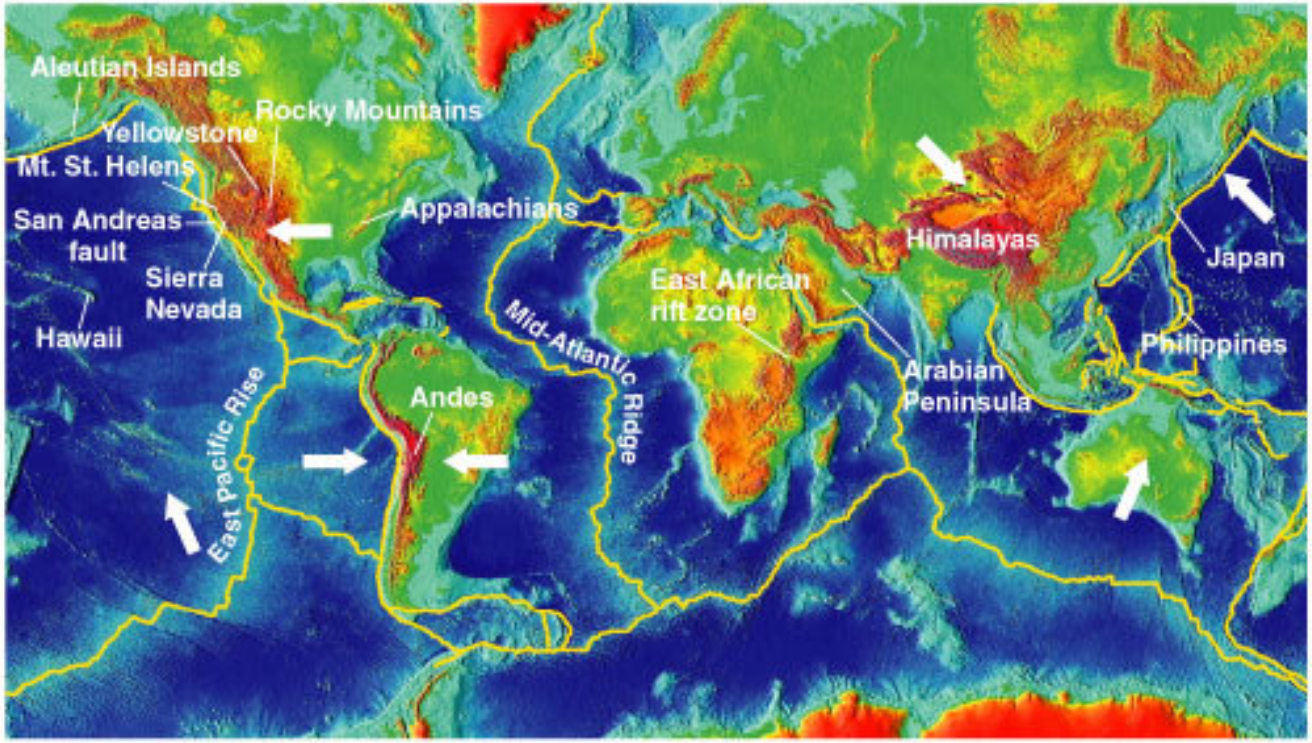
Does Venus have plate tectonics?

- Most of Earth's major geological features can be attributed to plate tectonics, which gradually remakes Earth's surface
- Venus does not appear to have plate tectonics, but entire surface seems to have been "repaved" 750 million years ago

9.6 The Unique Geology of Earth

- Our goals for learning
- How do we know Earth's surface is in motion?
- How is Earth's surface shaped by plate tectonics?
- Was Earth's geology destined from birth?

Continental Motion

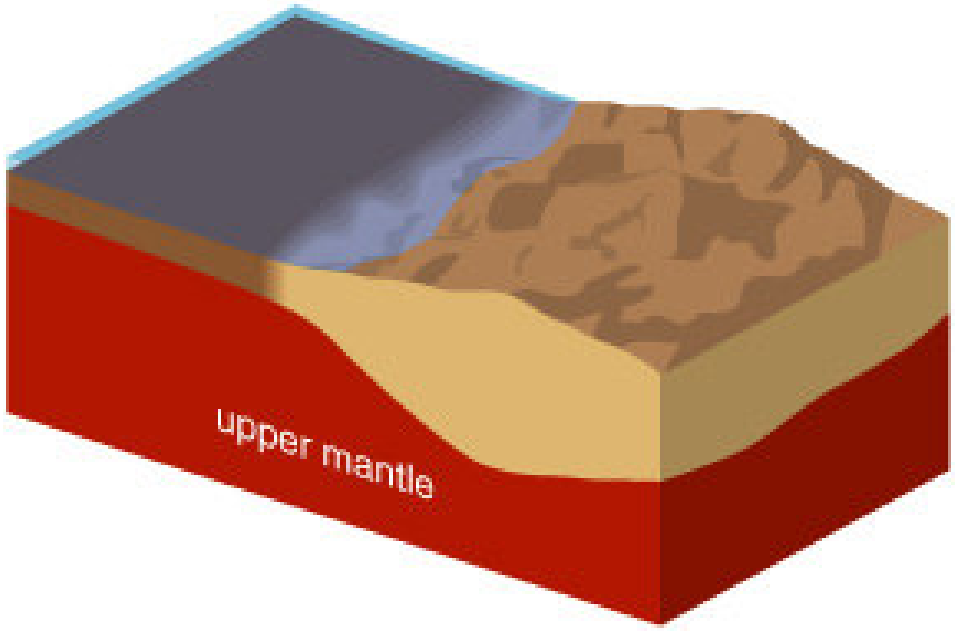


- Motion of continents can be measured with GPS

Continental Motion

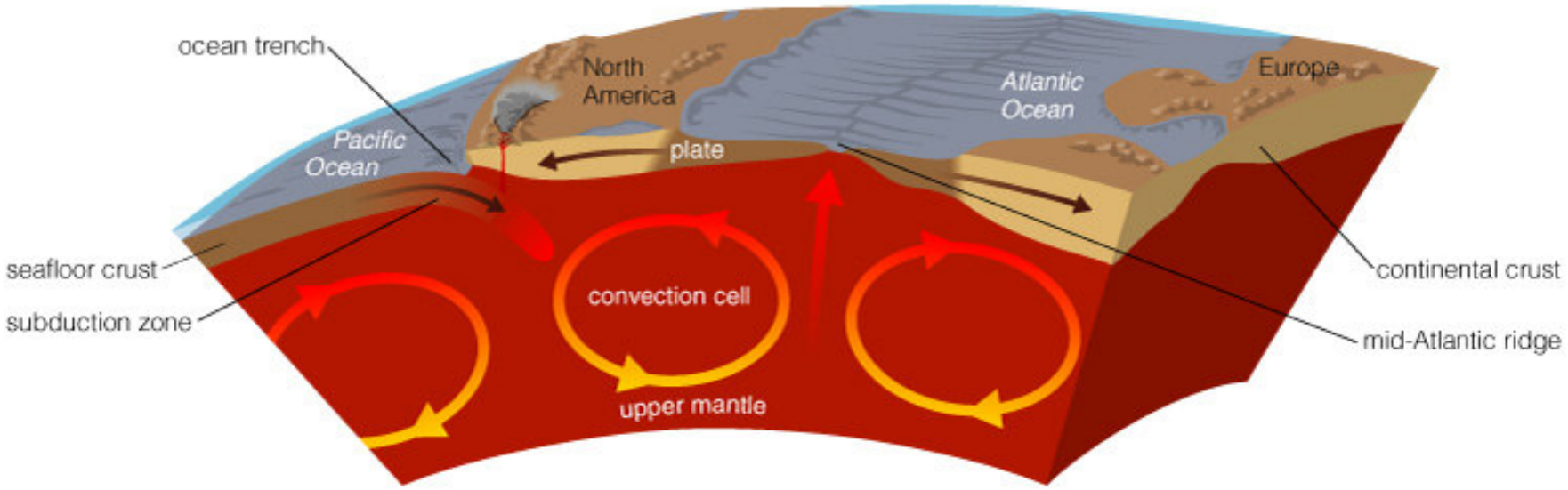
- Idea of continental drift was inspired by puzzle-like fit of continents
- Mantle material erupts where seafloor spreads

Seafloor Crust



- Thin seafloor crust differs from thick continental crust
- Dating of seafloor shows it is usually quite young

Seafloor Recycling



- Seafloor is recycled through a process known as subduction

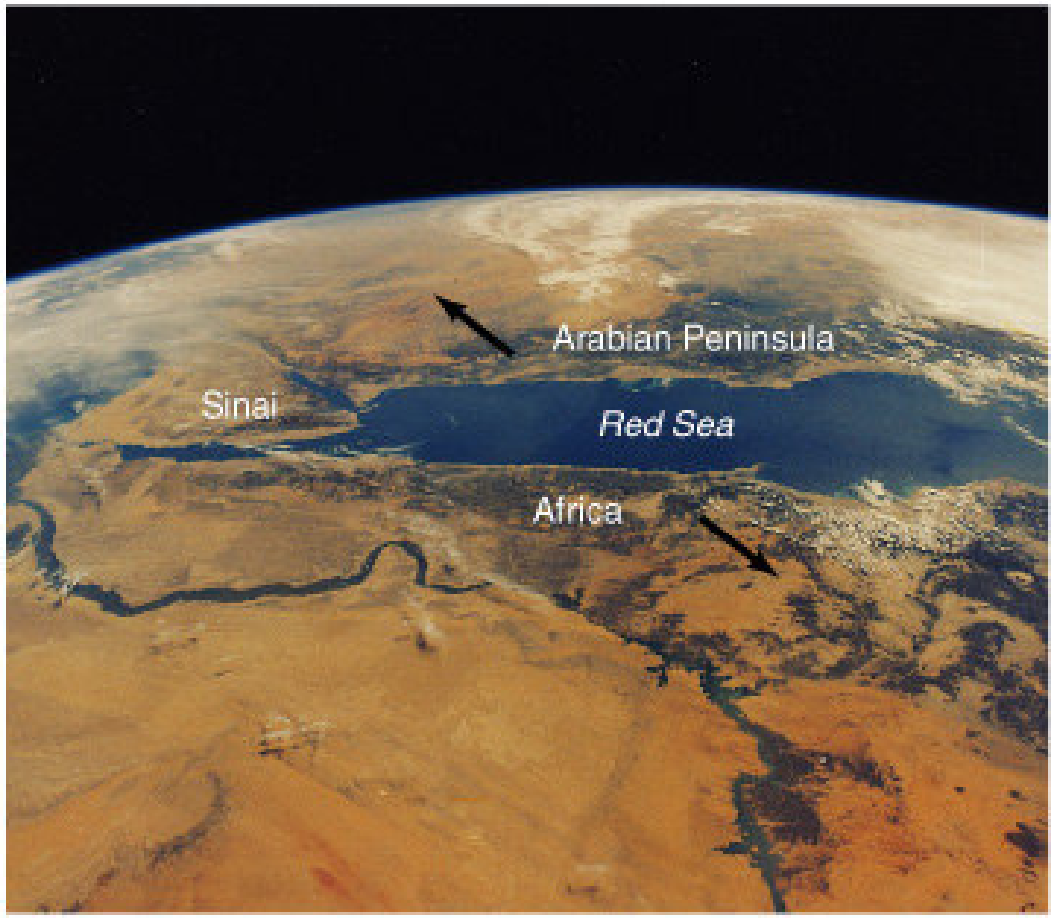
Surface Features

- Major geological features of North America record history of plate tectonics

Surface Features

- Himalayas are forming from a collision between plates

Surface Features

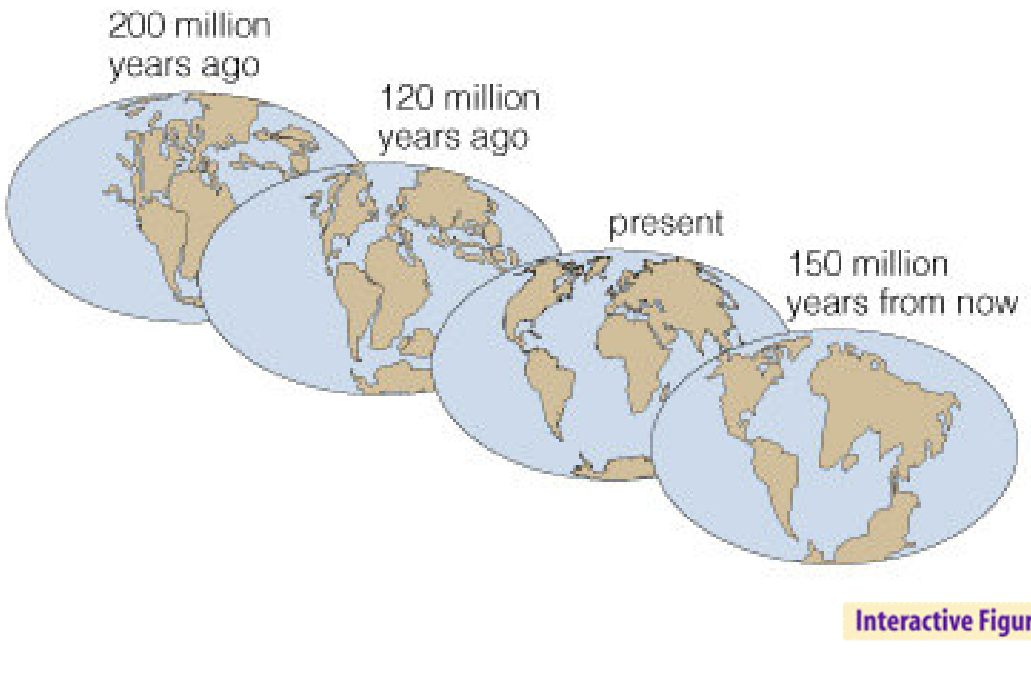


- Red Sea is forming where plates are pulling apart

Rifts, Faults, Earthquakes

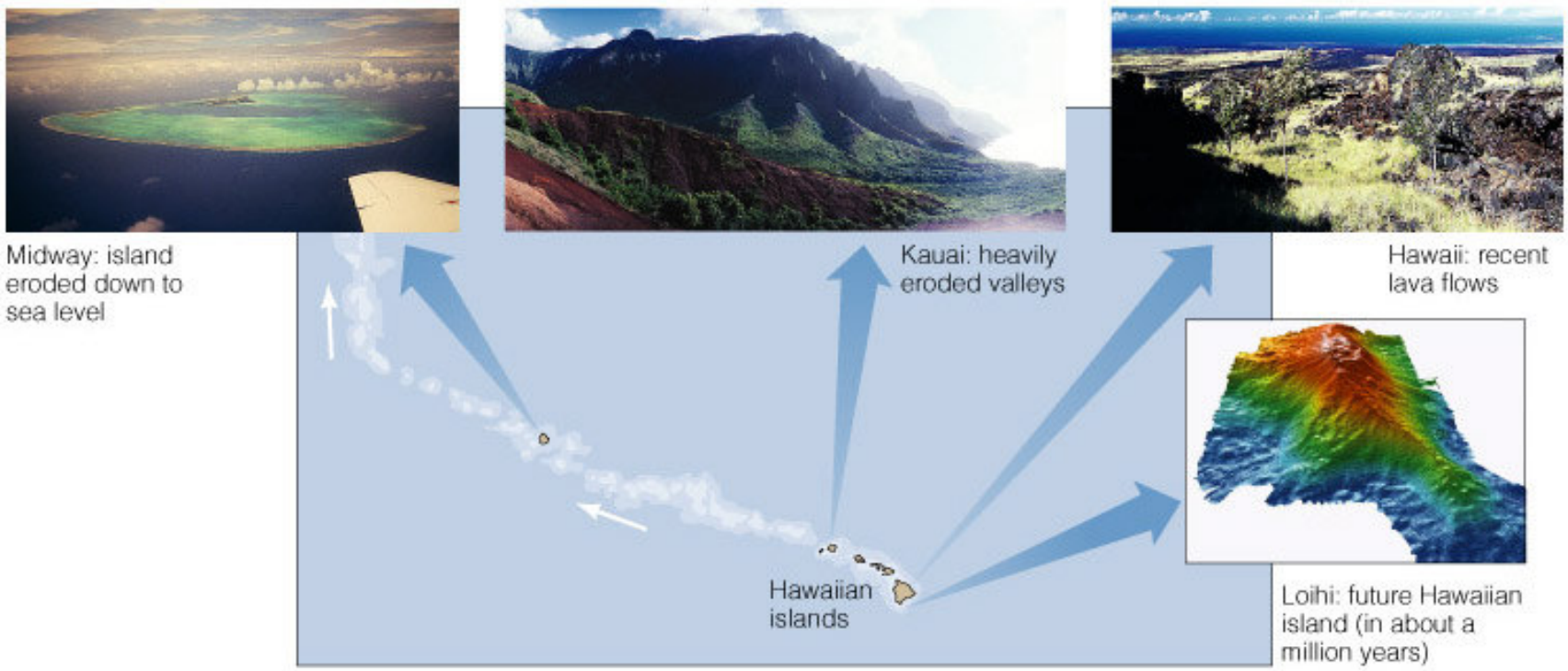
- San Andreas fault in California is a plate boundary
- Motion of plates causes earthquakes

Plate Motions



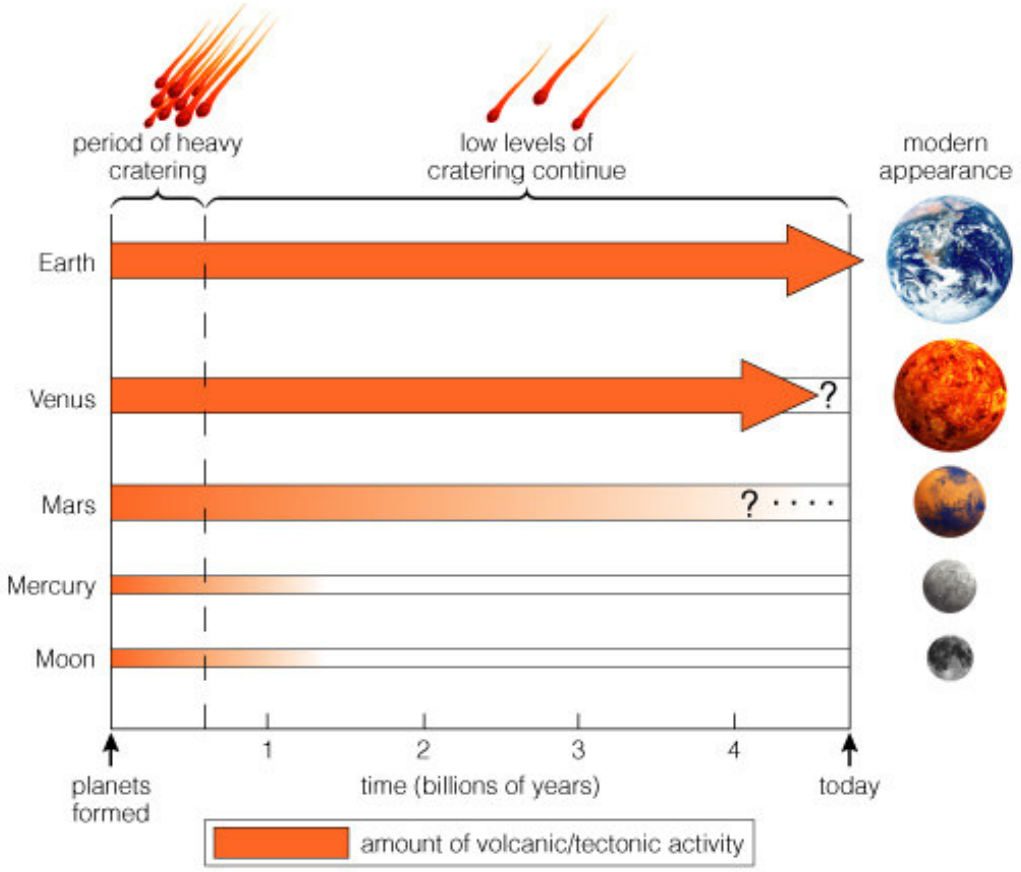
- Measurements of plate motions tell us past and future layout of continents

Hot Spots



- Hawaiian islands have formed where plate is moving over volcanic hot spot

Earth's Destiny



- Many of Earth's features determined by size, rotation, and distance from Sun
- Reason for plate tectonics not yet clear

Which two bodies show evidence of water?

- Mercury and Venus
- Mercury and Earth
- Mercury and Earth's Moon
- Earth and Venus
- Earth and Mars

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- Mercury and Earth
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- **Earth and Mars**

Which two bodies show evidence of a substantial atmosphere?

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- Mercury and Earth
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- **Earth and Venus**
- Earth and Mars

How do we learn about the Earth's core, mantle, and crust?

- Deep drilling
- Seismic waves
- We know earth's density from its size and applying Kepler's 3rd law on the moon
- All of the above
- #2 and #3

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What is the source of the Earth's magnetic field?

- Magnetic rocks
- Magnetized iron in the Earth's crust
- Magnetized iron in the Earth's core
- Molten metal circulating inside the Earth, moving electrons like in a wire

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Why are smaller terrestrial bodies such as Mercury or the Moon "geologically dead"?

- They don't have volcanoes
- They cooled off faster than the Earth did
- They don't have erosion
- They were hit by fewer meteorites
- They are made of different materials than the Earth

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The lunar crater *Tycho* is about 80 km (50 miles) across. It was probably made by:

- The eruption of the large volcano in its center
- An impactor nearly 80 km across
- An impactor about 8 km across
- Plate tectonics

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Why do the *lunar highlands* have many more craters than the *lunar maria*?

- They are on the side of the moon away from earth so they were hit by more impacts
- Lava flooded the maria, hiding many craters
- The less cratered surfaces are younger than those with more craters
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- All of the above
- **#2 and #3**

Suppose Venus rotated as fast as Earth. How would this change its relative levels of volcanism, tectonics, and erosion?

1. All would remain the same - independent of rotation.
2. Higher levels of all three.
3. Lower levels of all three.
4. The same levels of volcanism and tectonics, and a higher level of erosion.
5. Higher levels of volcanism and tectonics, and the same level of erosion.

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Should we land on Mars and search for life?

- Yes, if we found evidence of life it would have important scientific implications
- Yes, if we found evidence of life it would have major scientific, philosophical, and religious implications
- No, it's too expensive
- No, at best we're likely to find fossils, and they aren't interesting
- Of course there is or was life on Mars. We don't have to actually go there to find out.

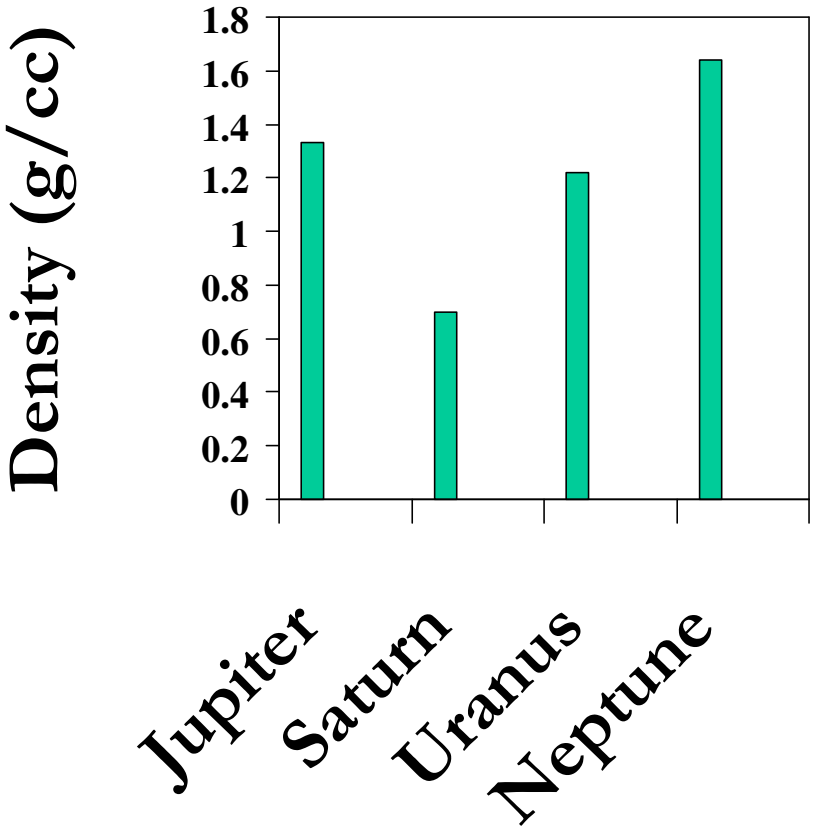
11.1 A Different Kind of Planet

- 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?

Jovian Planet Composition

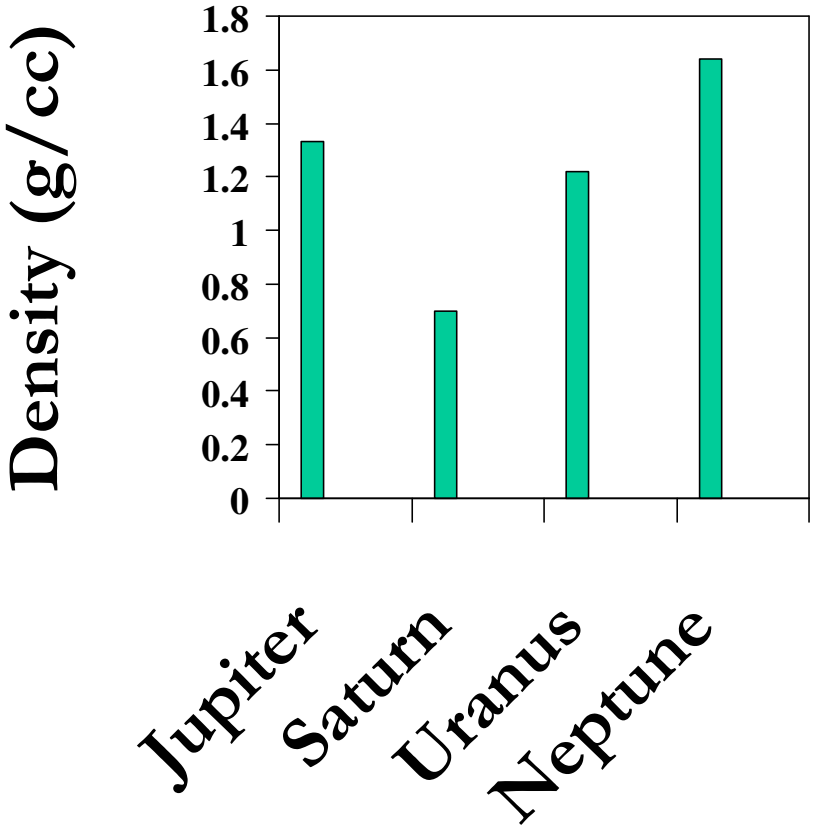
- Jupiter and Saturn
  - Mostly H and He gas
- Uranus and Neptune
  - Mostly hydrogen compounds: water (H_2O), methane (CH_4), ammonia (NH_3)
  - Some H, He, and rock

Density Differences



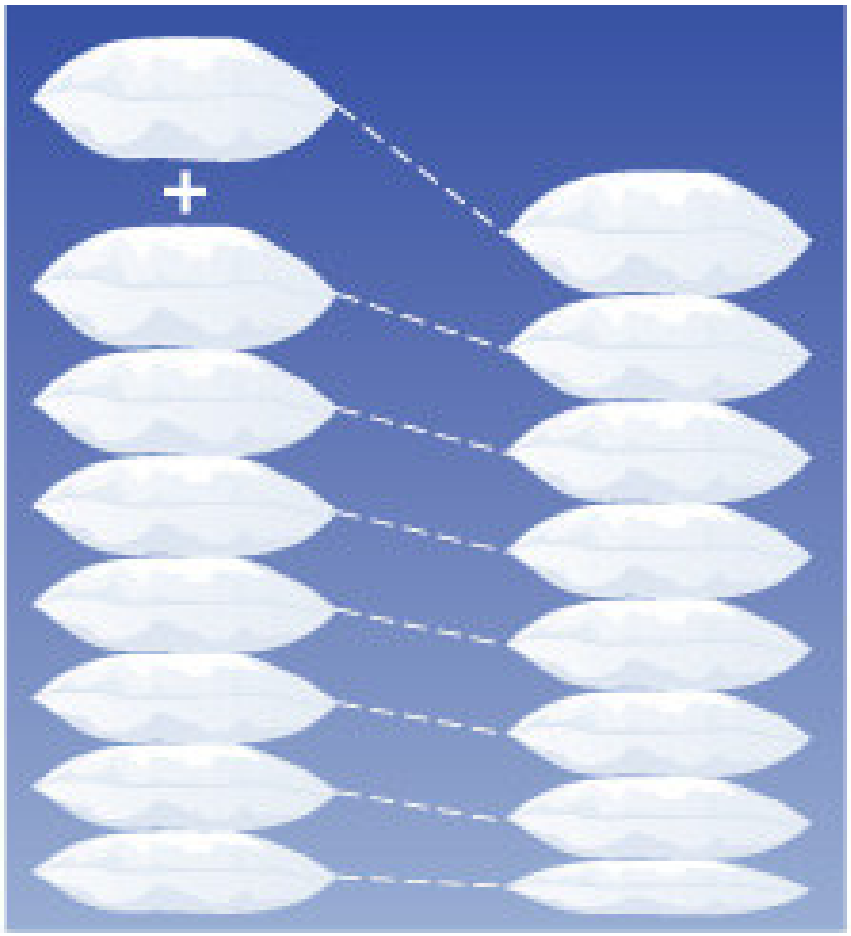
- Uranus and Neptune are denser than Saturn because they have less H/He, proportionately

Density Differences



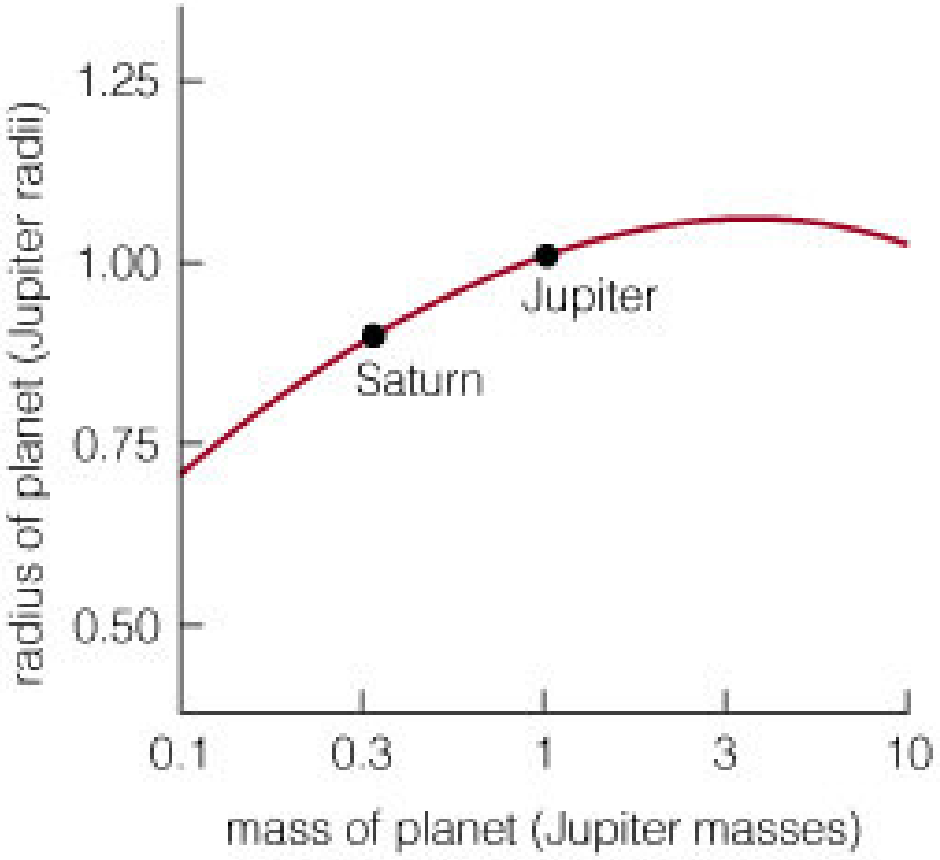
- But that explanation doesn't work for Jupiter….

Sizes of Jovian Planets



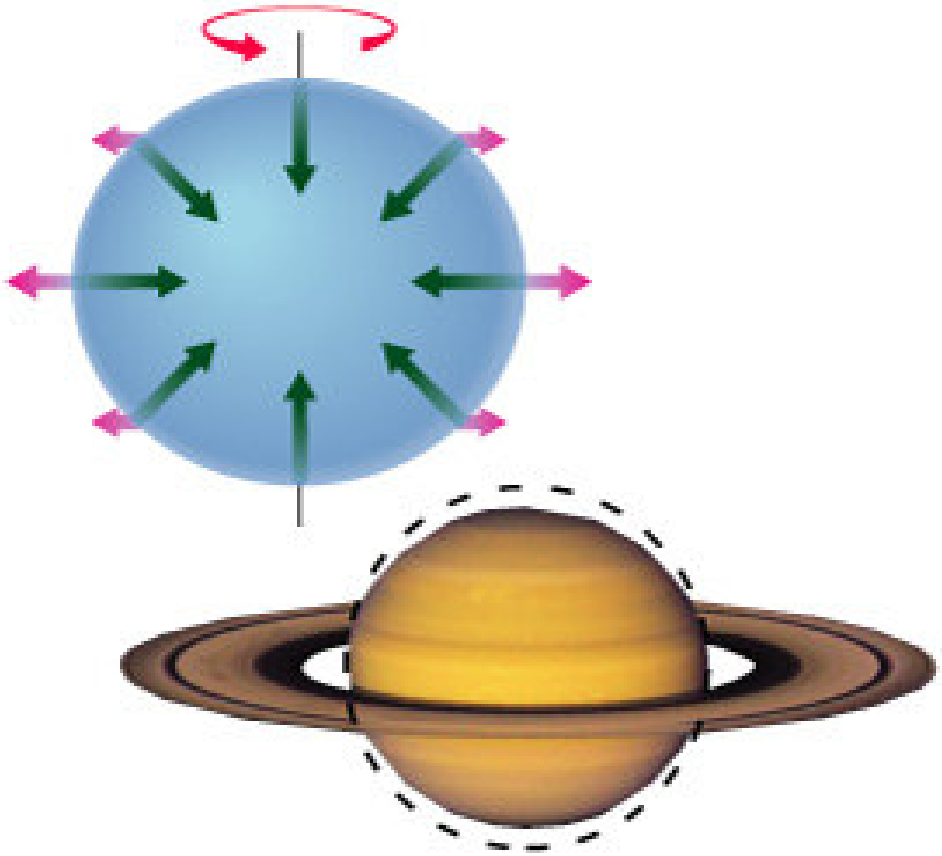
- Adding mass to a jovian planet compresses the underlying gas layers

Sizes of Jovian Planets



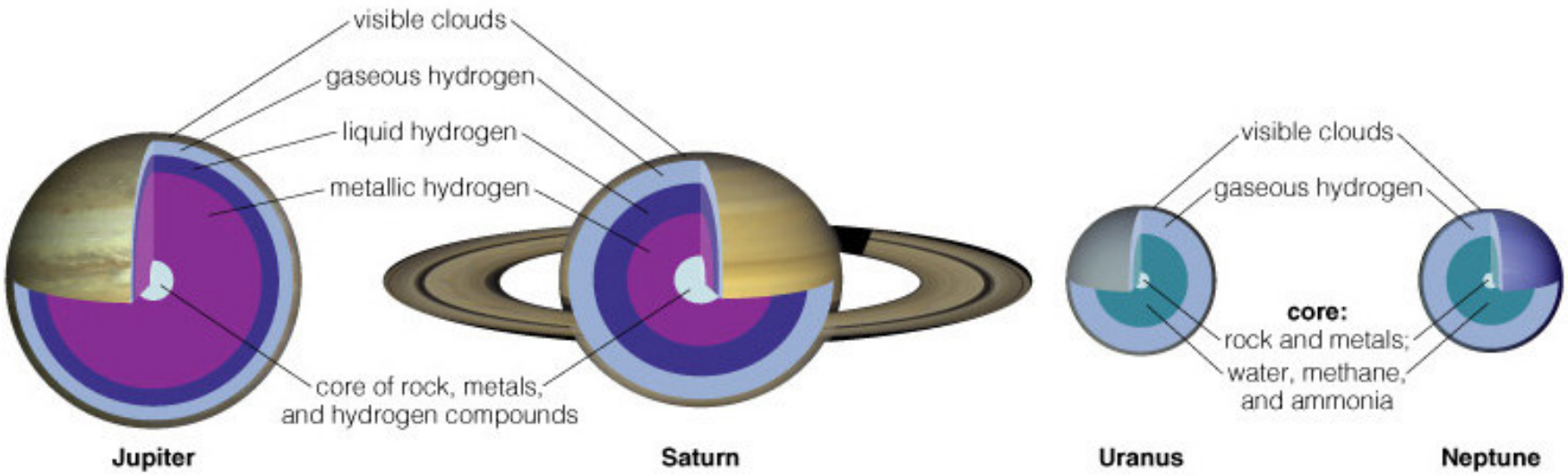
- Greater compression is why Jupiter is not much larger than Saturn even though it is three times more massive
- Jovian planets with even more mass can be smaller than Jupiter

Rotation and Shape



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

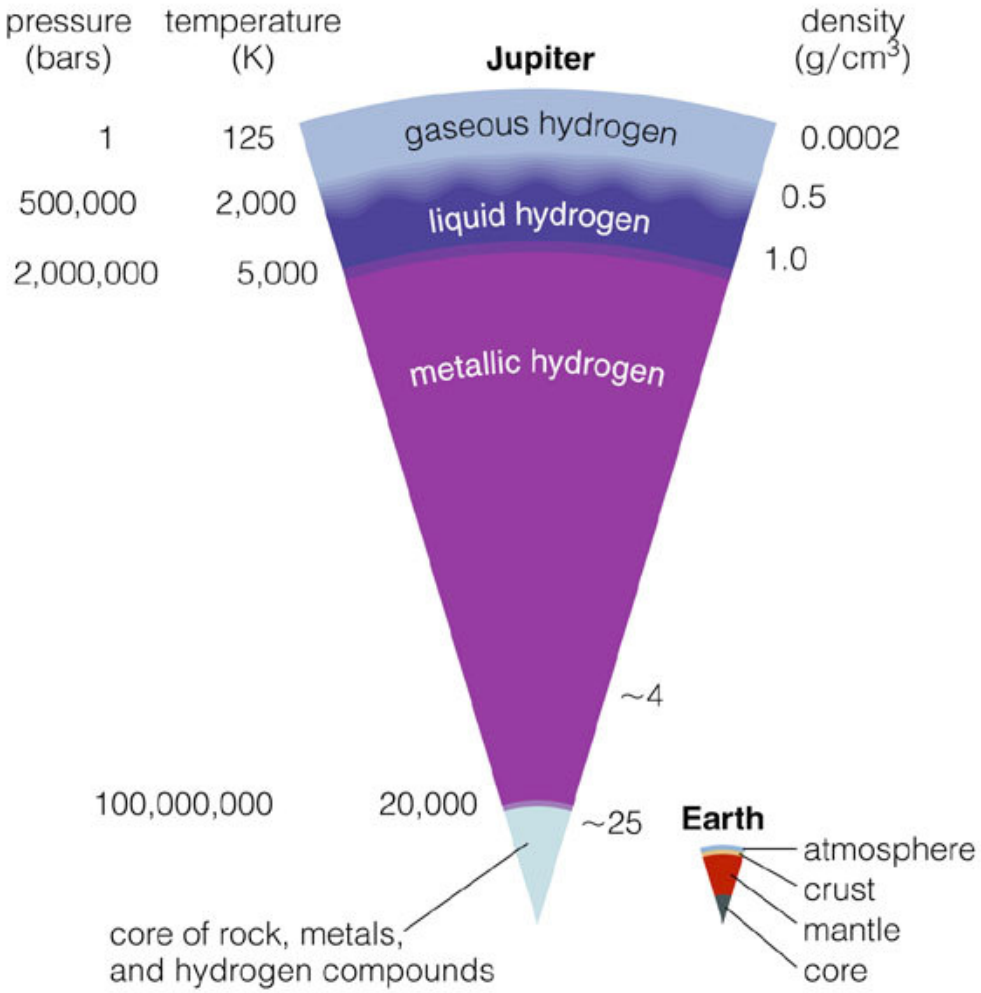
What are jovian planets like on the inside?



Interiors of Jovian Planets

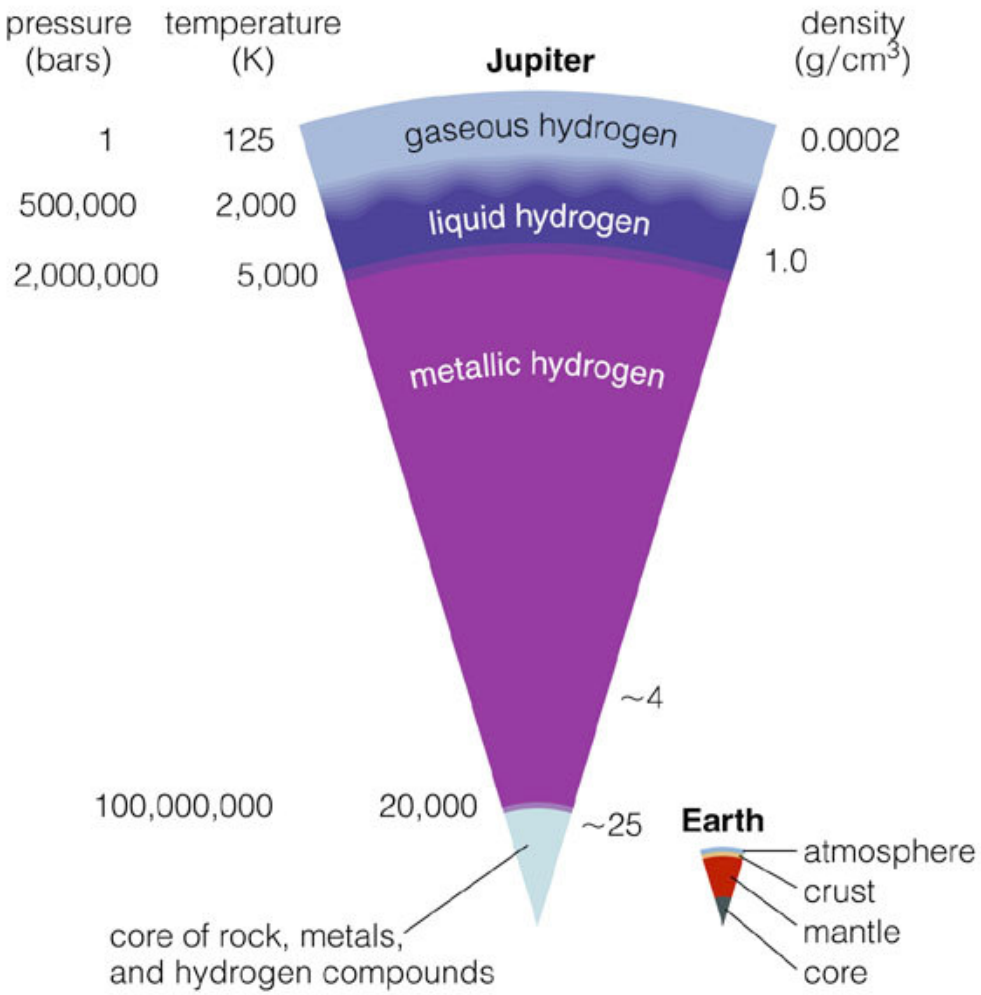
- No solid surface.
- Layers under high pressure and temperatures.
- Cores (~10 Earth masses) made of hydrogen compounds, metals & rock
- The layers are different for the different planets. WHY?

Inside Jupiter



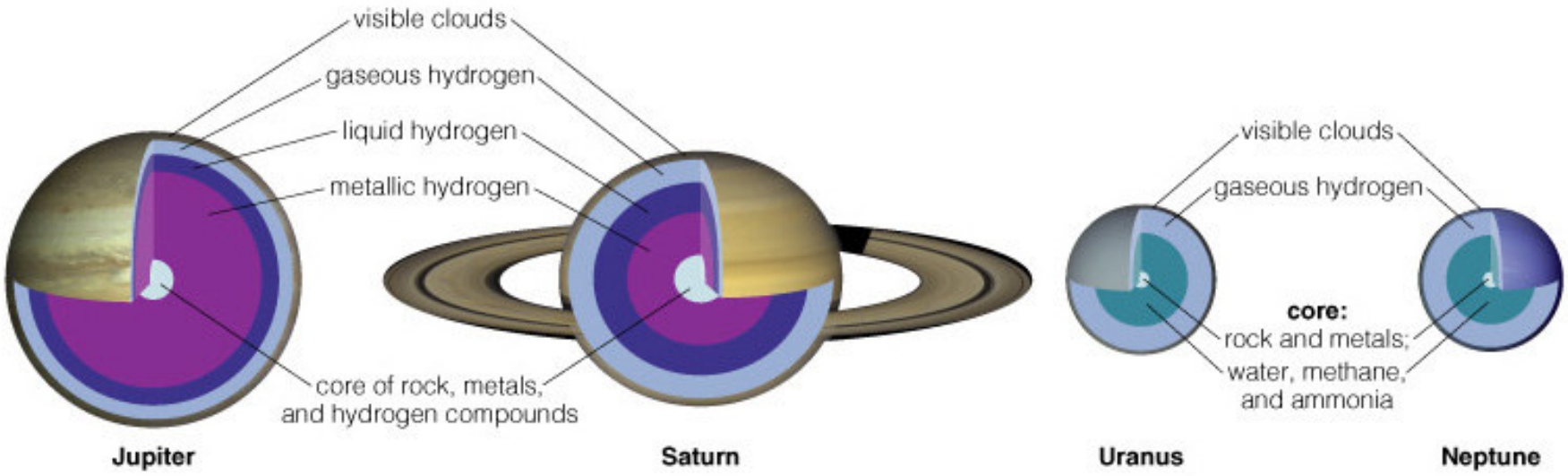
- High pressures inside Jupiter cause phase of hydrogen to change with depth
- Hydrogen acts like a metal at great depths because its electrons move freely

Inside Jupiter



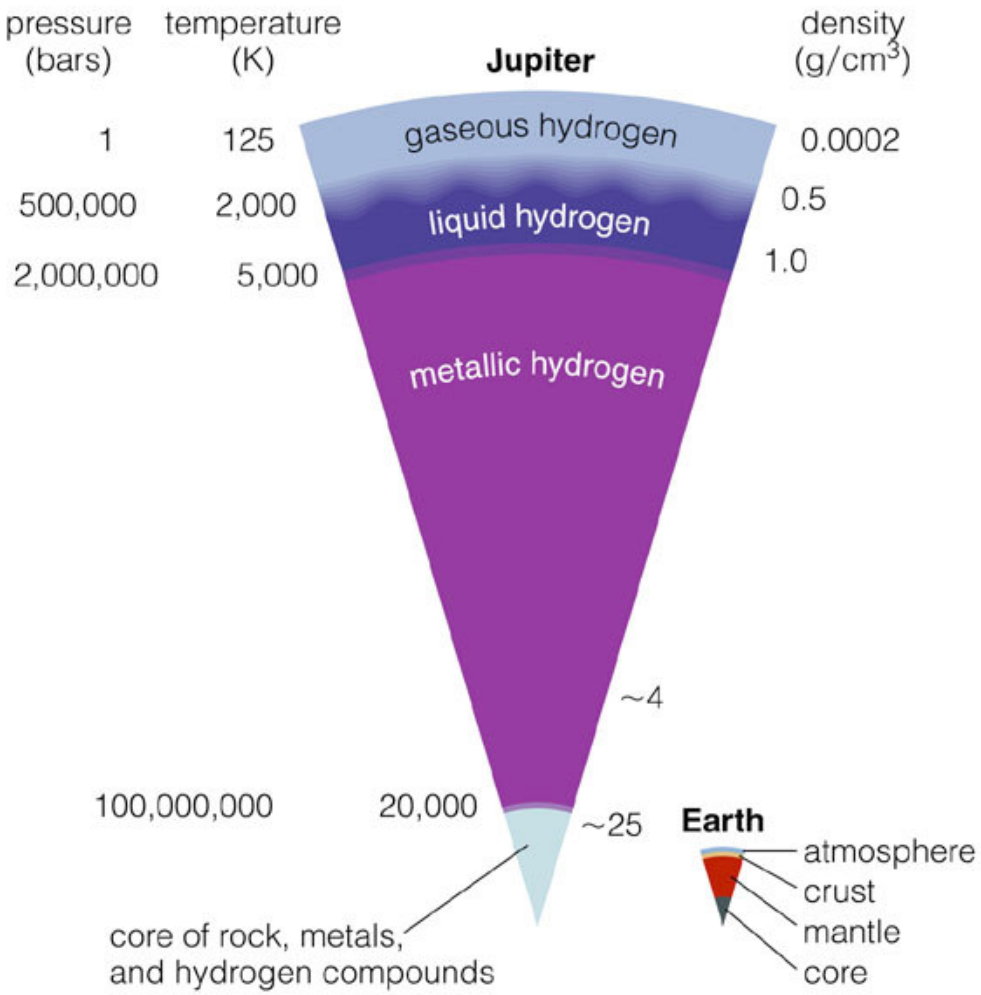
- Core is thought to be made of rock, metals, and hydrogen compounds
- Core is about same size as Earth but 10 times as massive

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

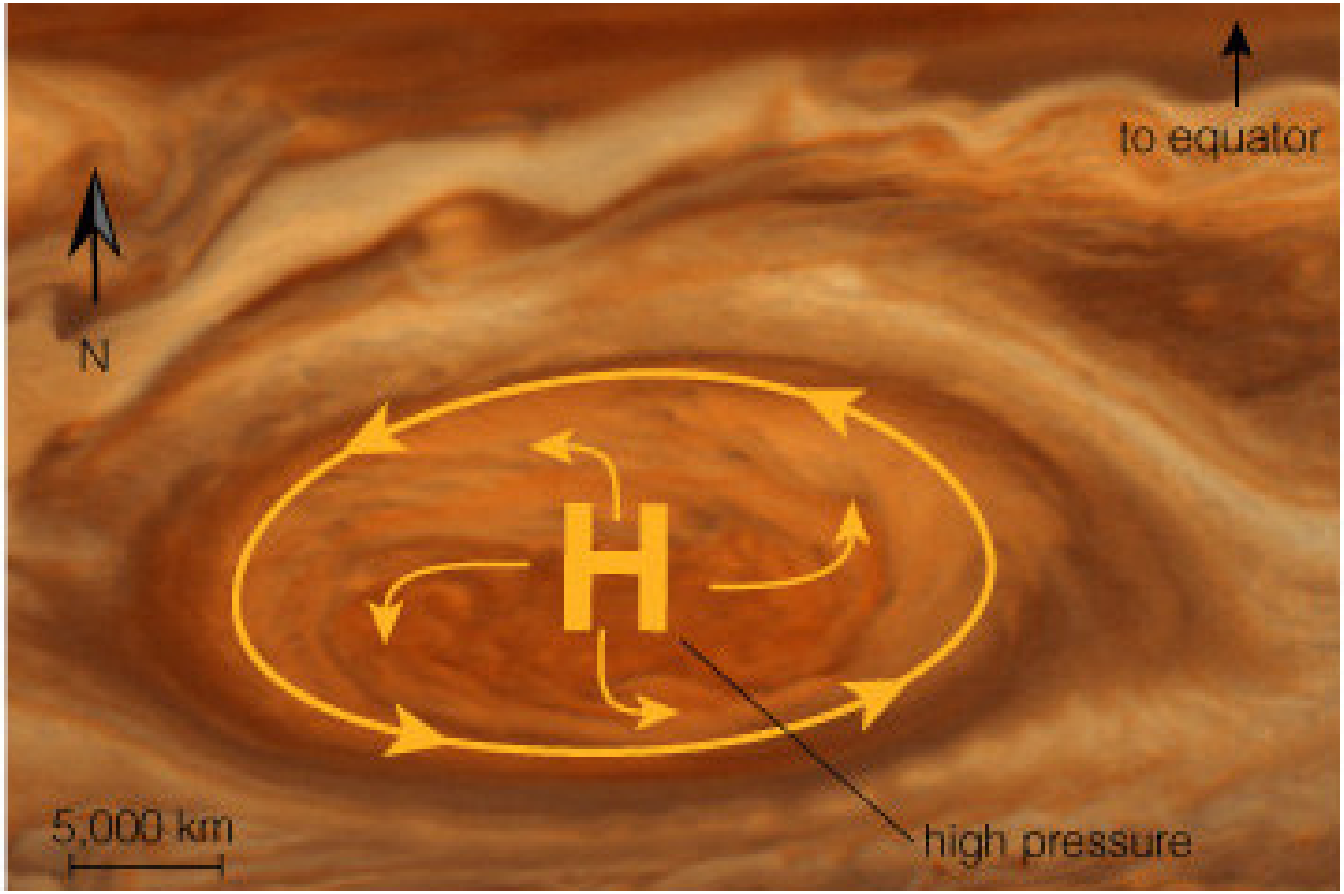


- Jupiter radiates twice as much energy as it receives from Sun
- Energy probably comes from slow contraction of interior (releasing potential energy)

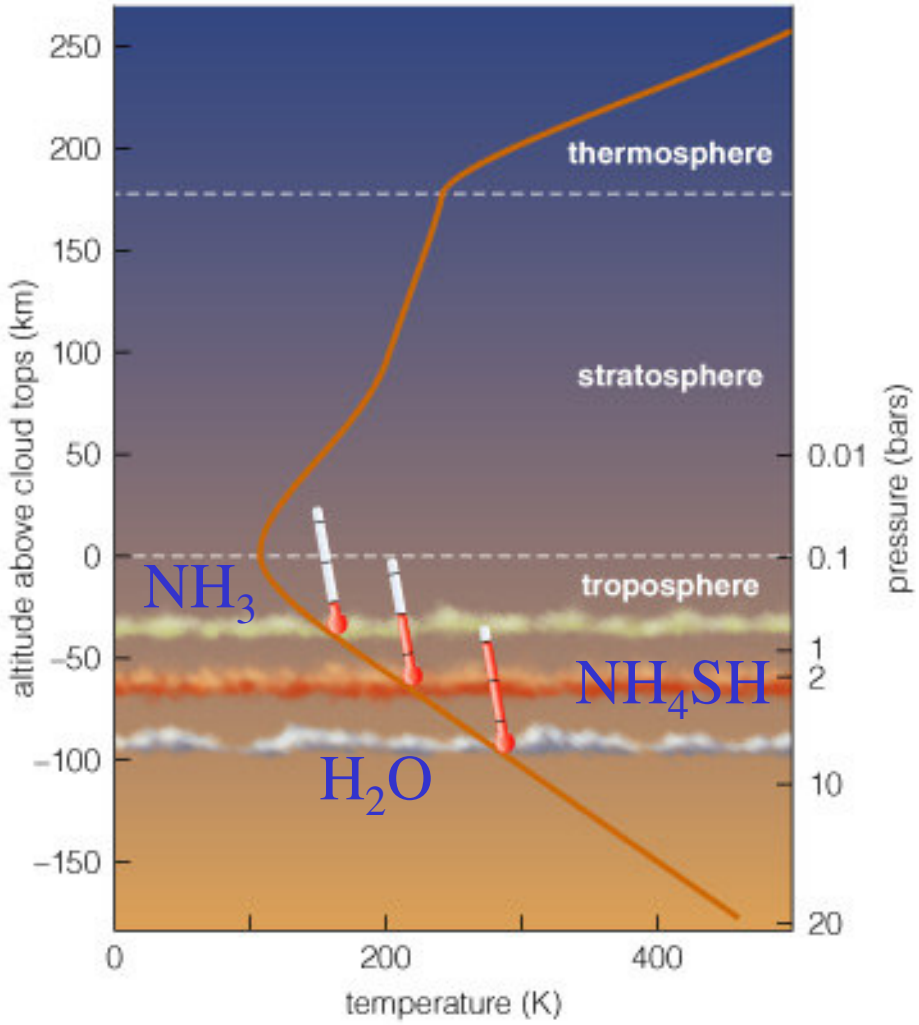
Internal Heat of Other Planets

- Saturn also radiates twice as much energy it receives from 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?

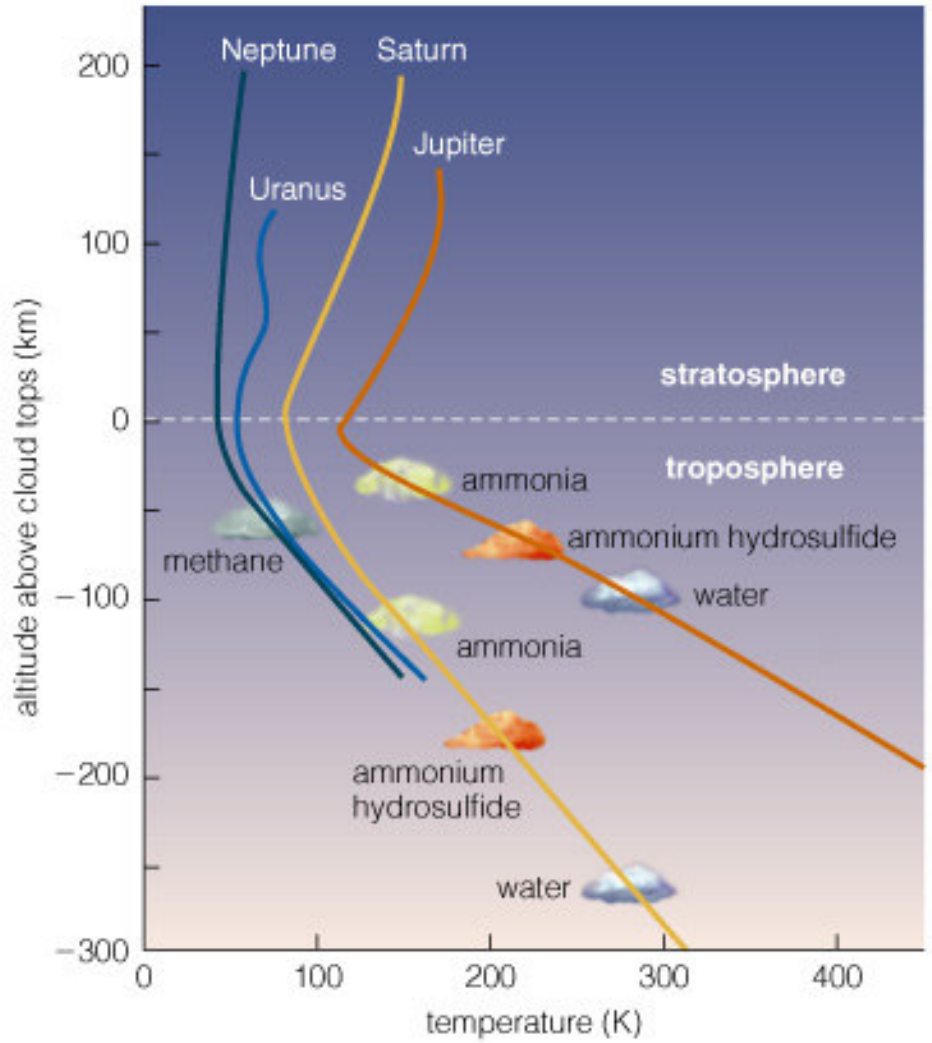


Jupiter's Atmosphere

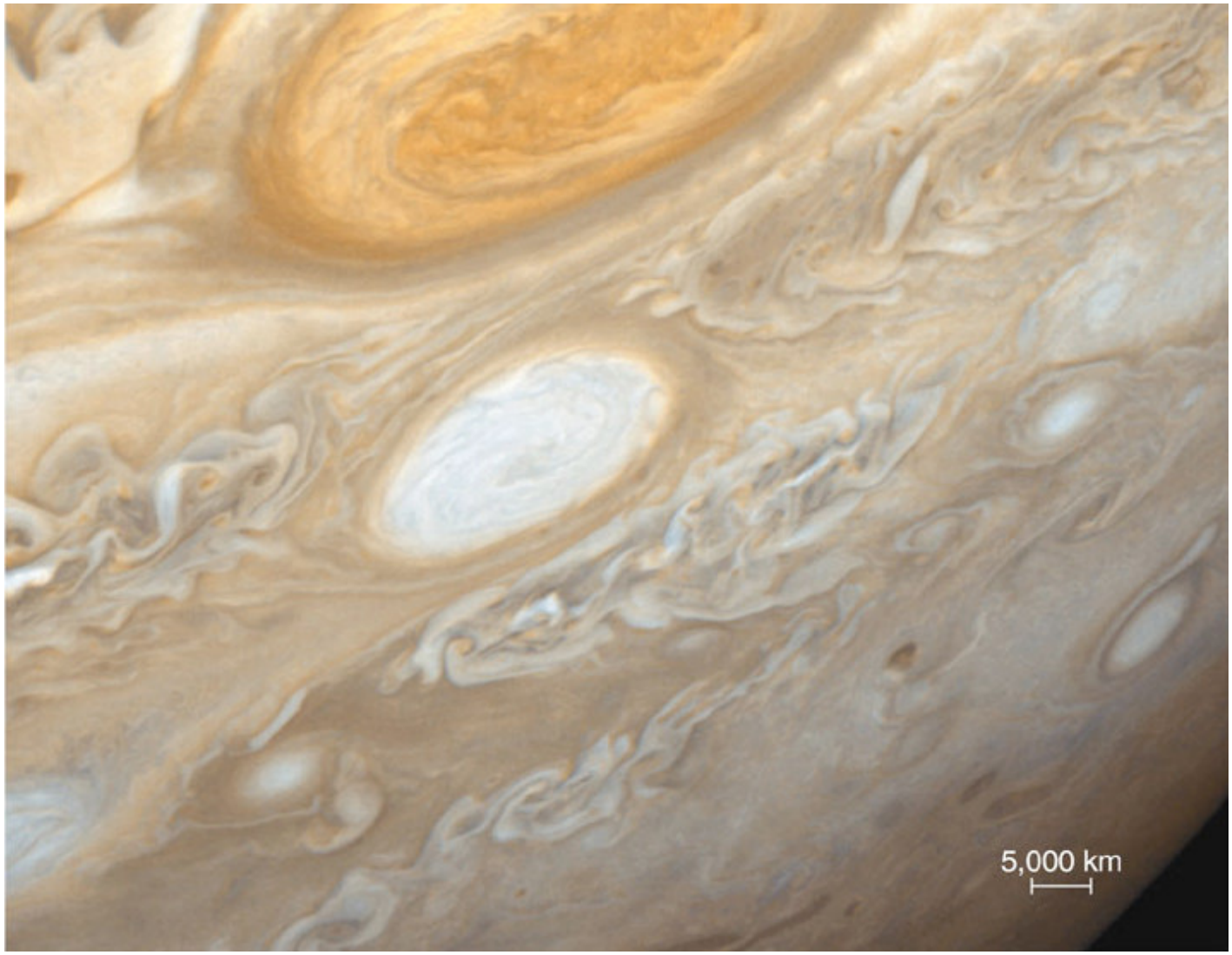


- Hydrogen compounds in Jupiter form clouds
- Different cloud layers correspond to freezing points of different hydrogen compounds

Jovian Planet Atmospheres

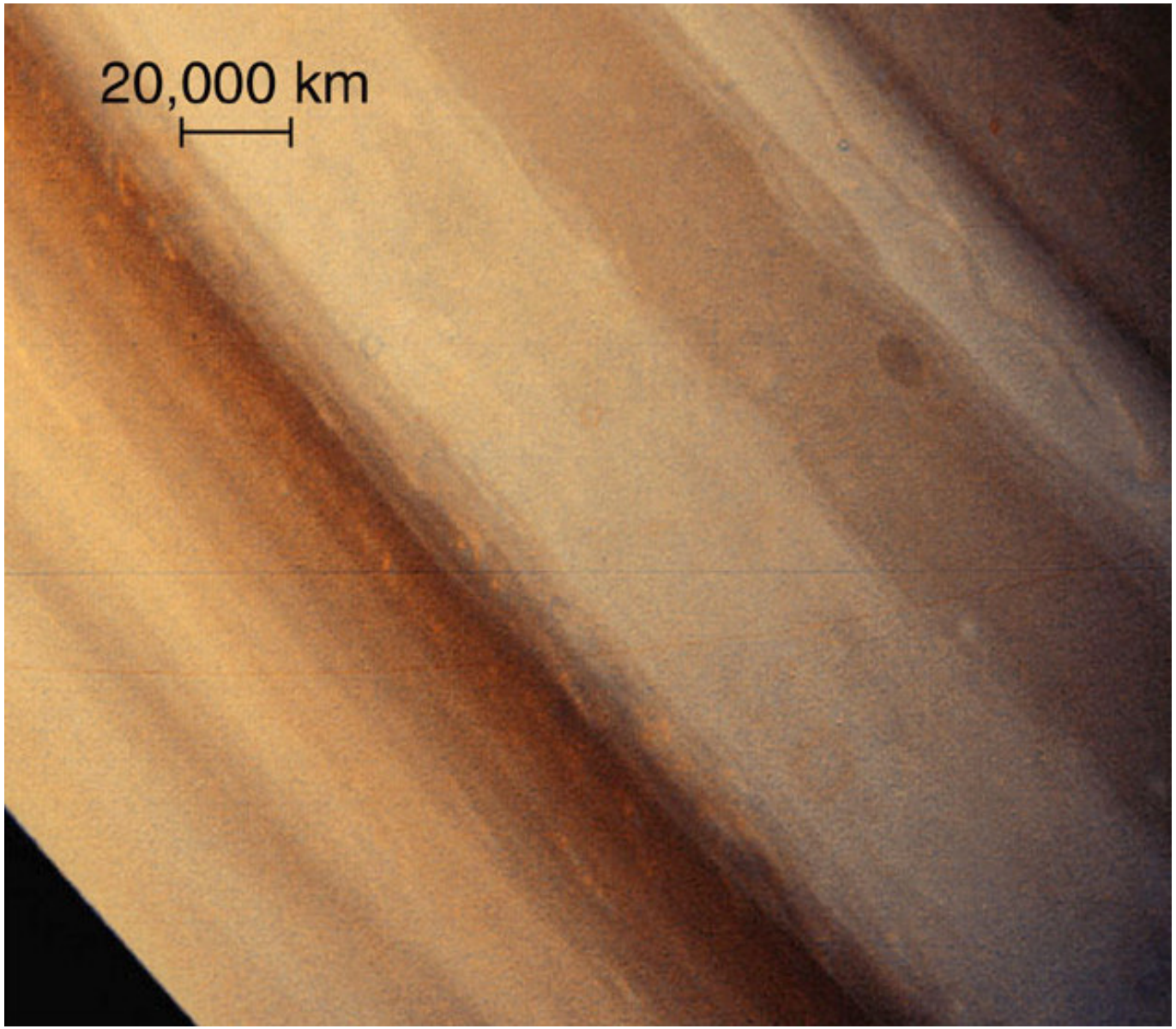


- Other jovian planets have cloud layers similar to Jupiter's
- Different compounds make clouds of different colors



Jupiter's colors

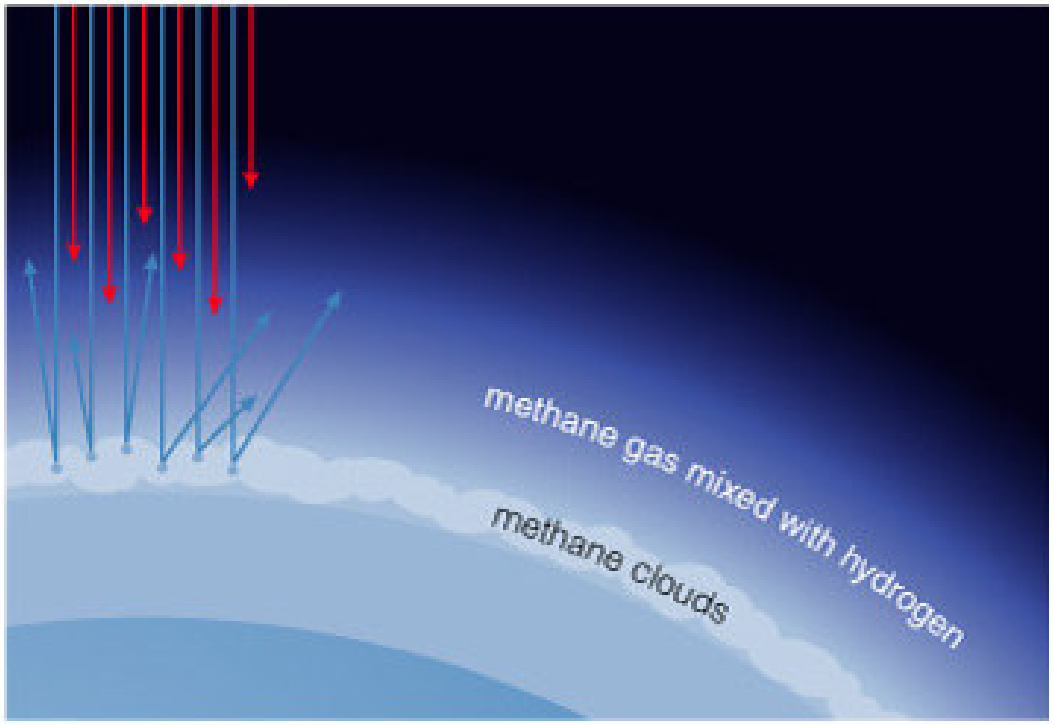
- Ammonium sulfide clouds (NH_4SH) reflect red/brown.
- Ammonia, the highest, coldest layer, reflects white.



Saturn's colors

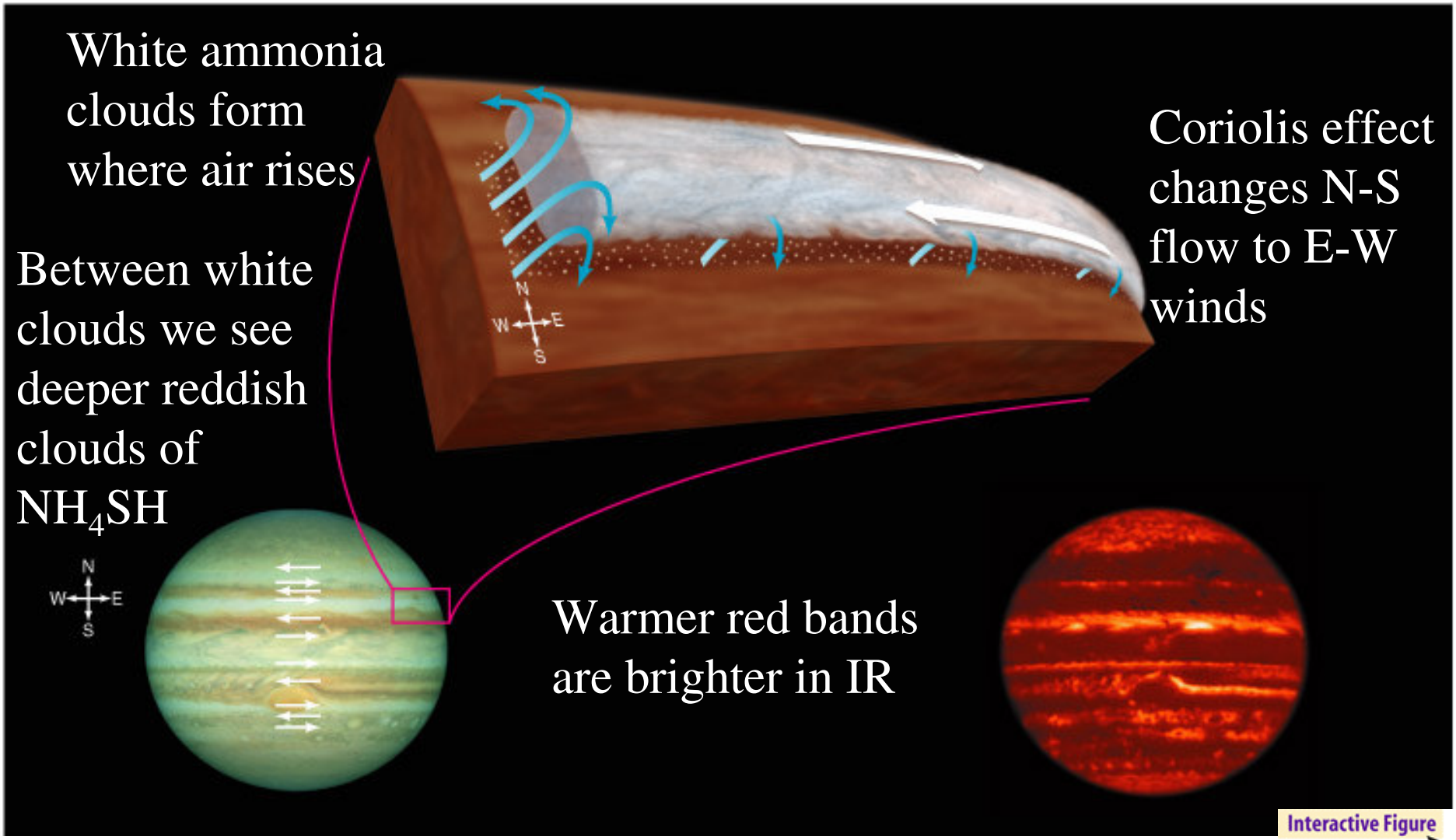
- Saturn's layers are similar, but deeper in and farther from the Sun --- more subdued.

Methane on Uranus and Neptune

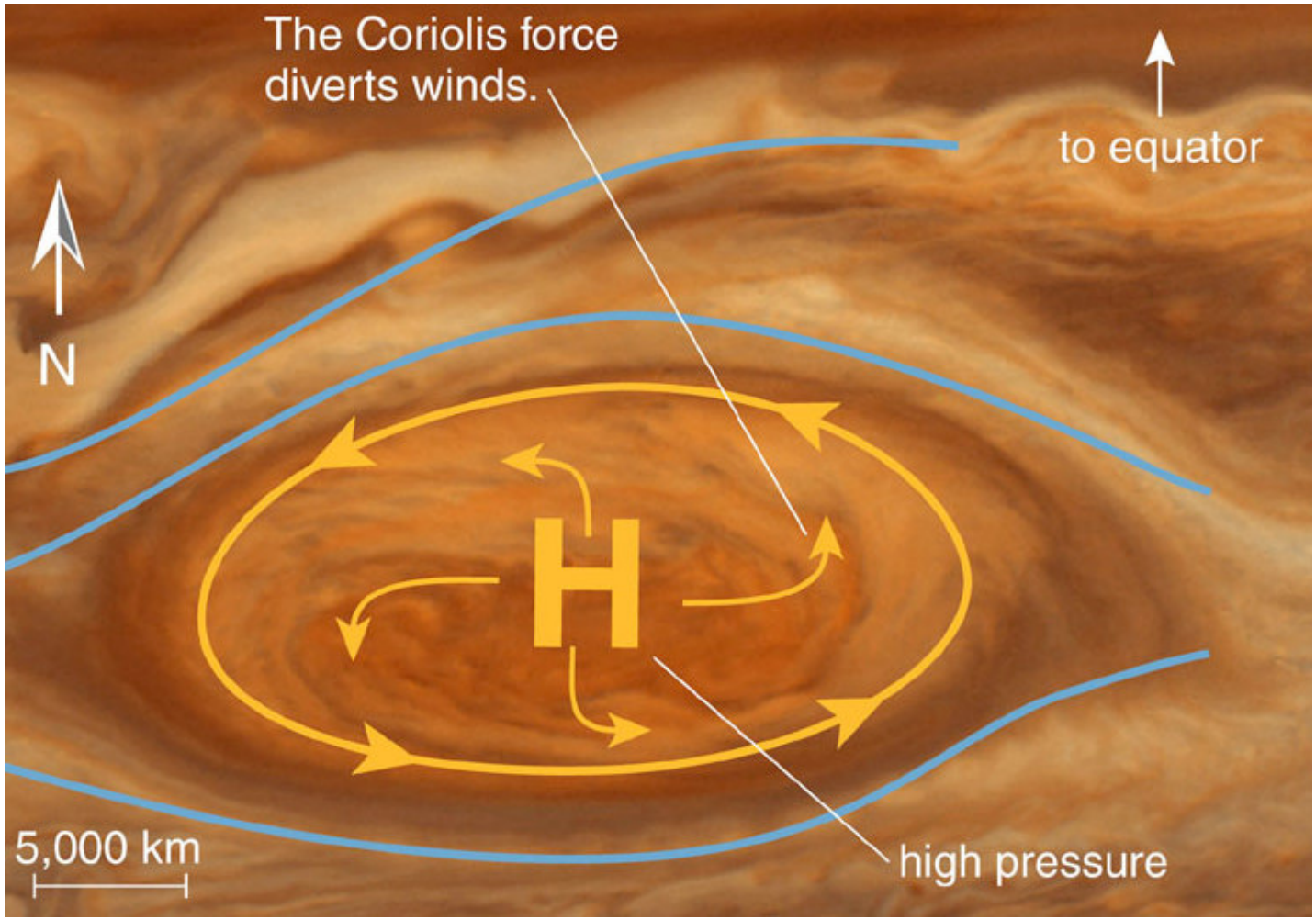


- Methane gas of Neptune and Uranus absorb red light but transmit blue light
- Blue light reflects off methane clouds, making those planes look blue

Jupiter's Bands

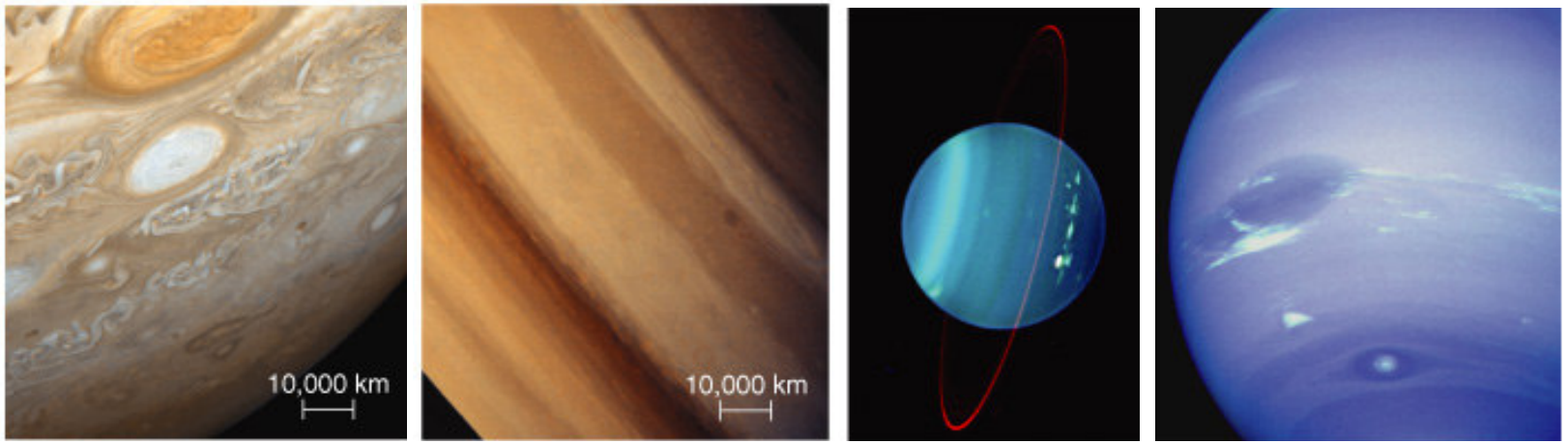


Jupiter's Great Red Spot



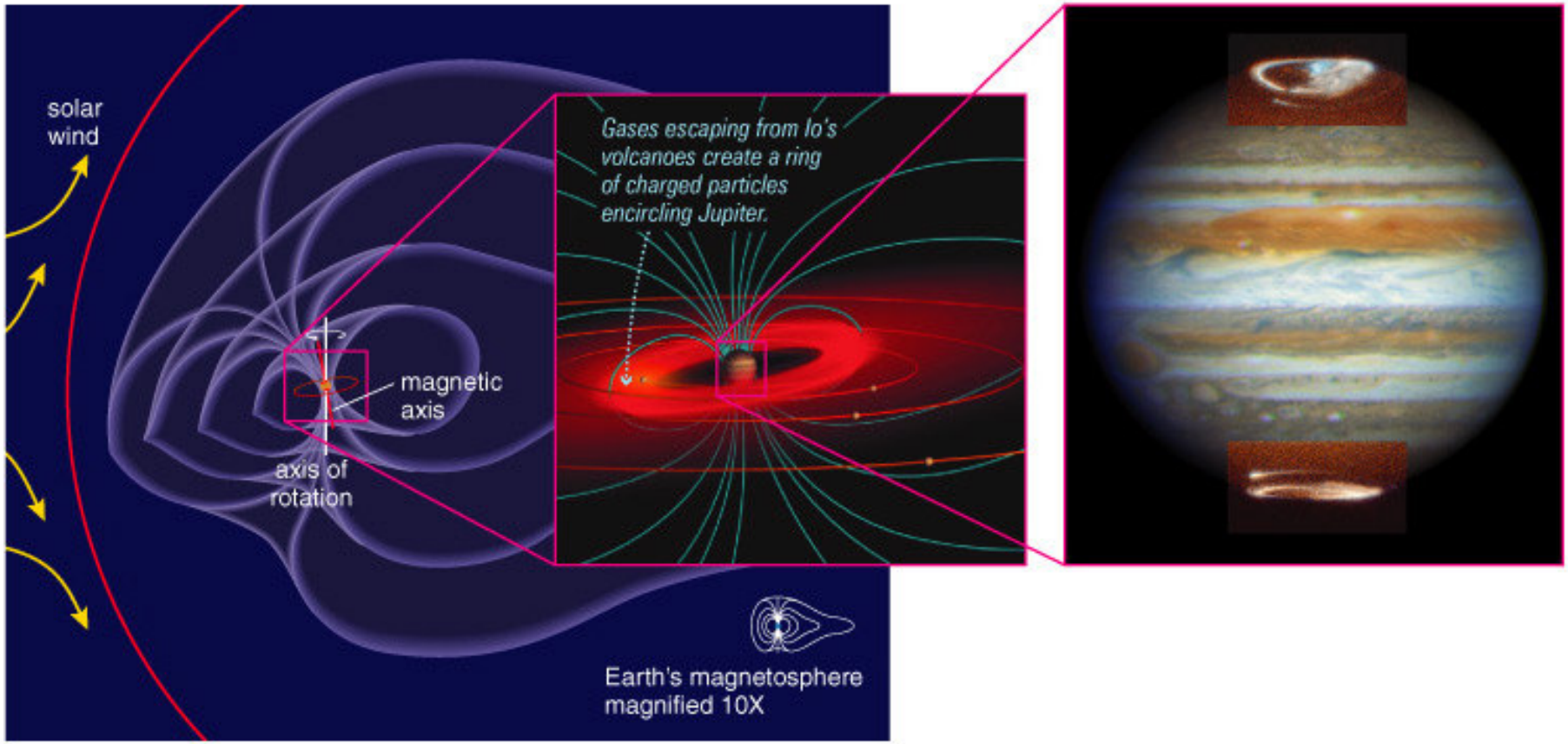
- A storm twice as wide as Earth
- Has existed for at least 3 centuries

Weather on Jovian Planets

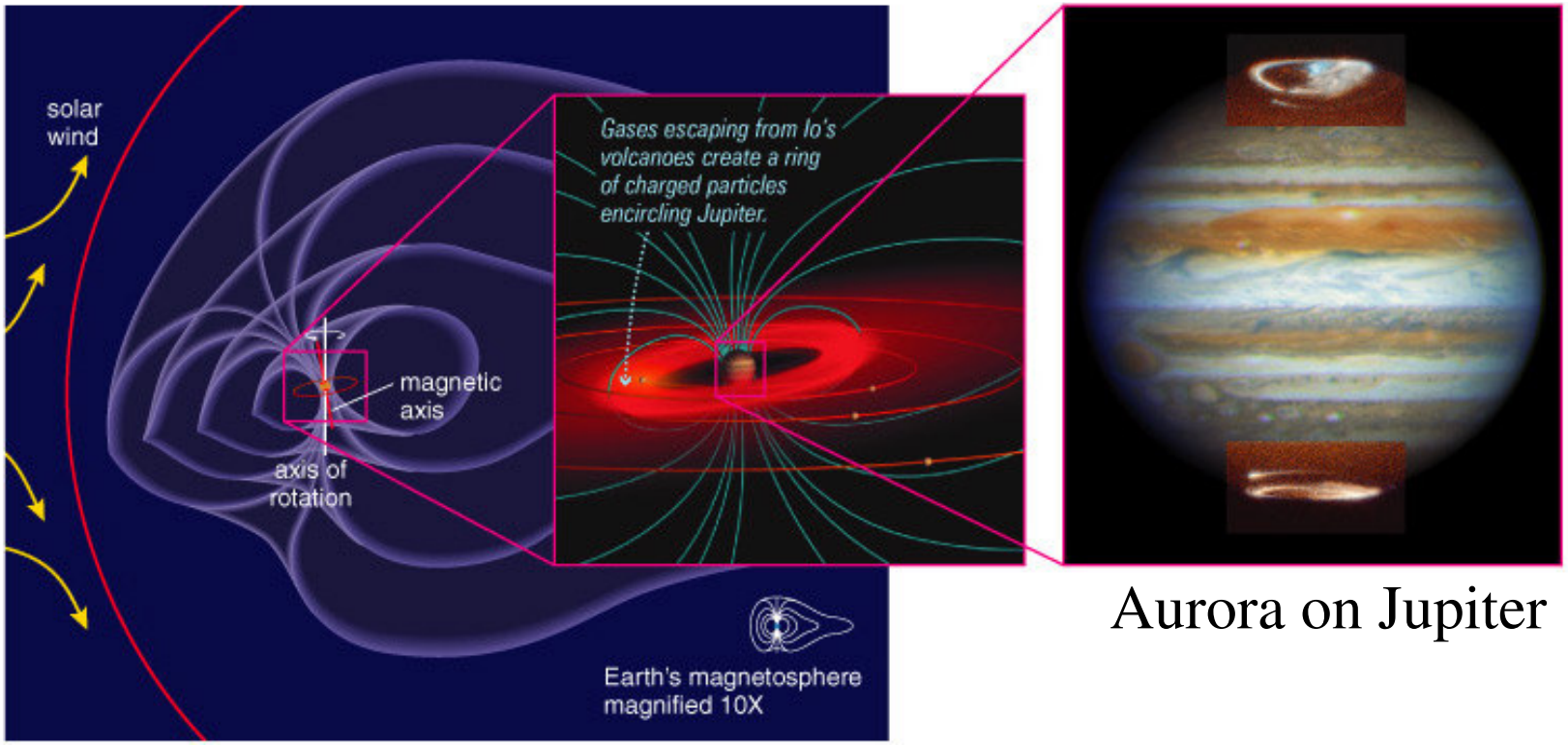


- All the jovian planets have strong winds and storms

Do jovian planets have magnetospheres like Earth's?



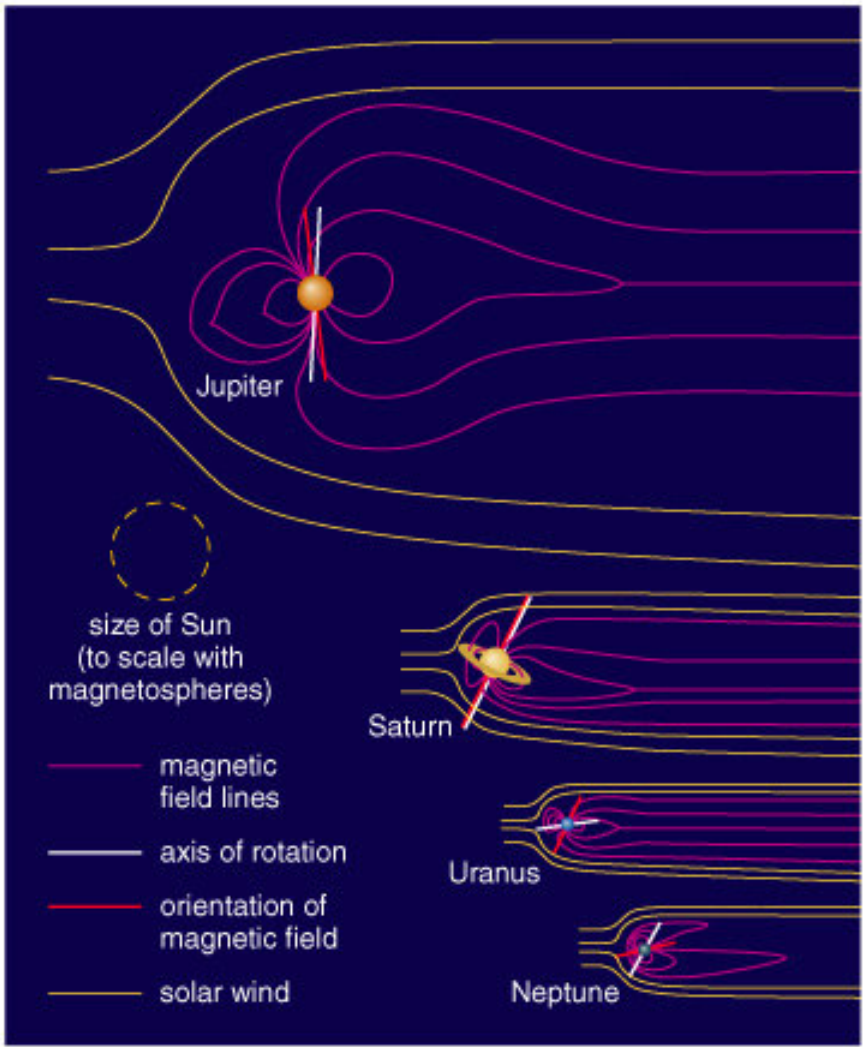
Jupiter's Magnetosphere



Aurora on Jupiter

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

Other Magnetospheres



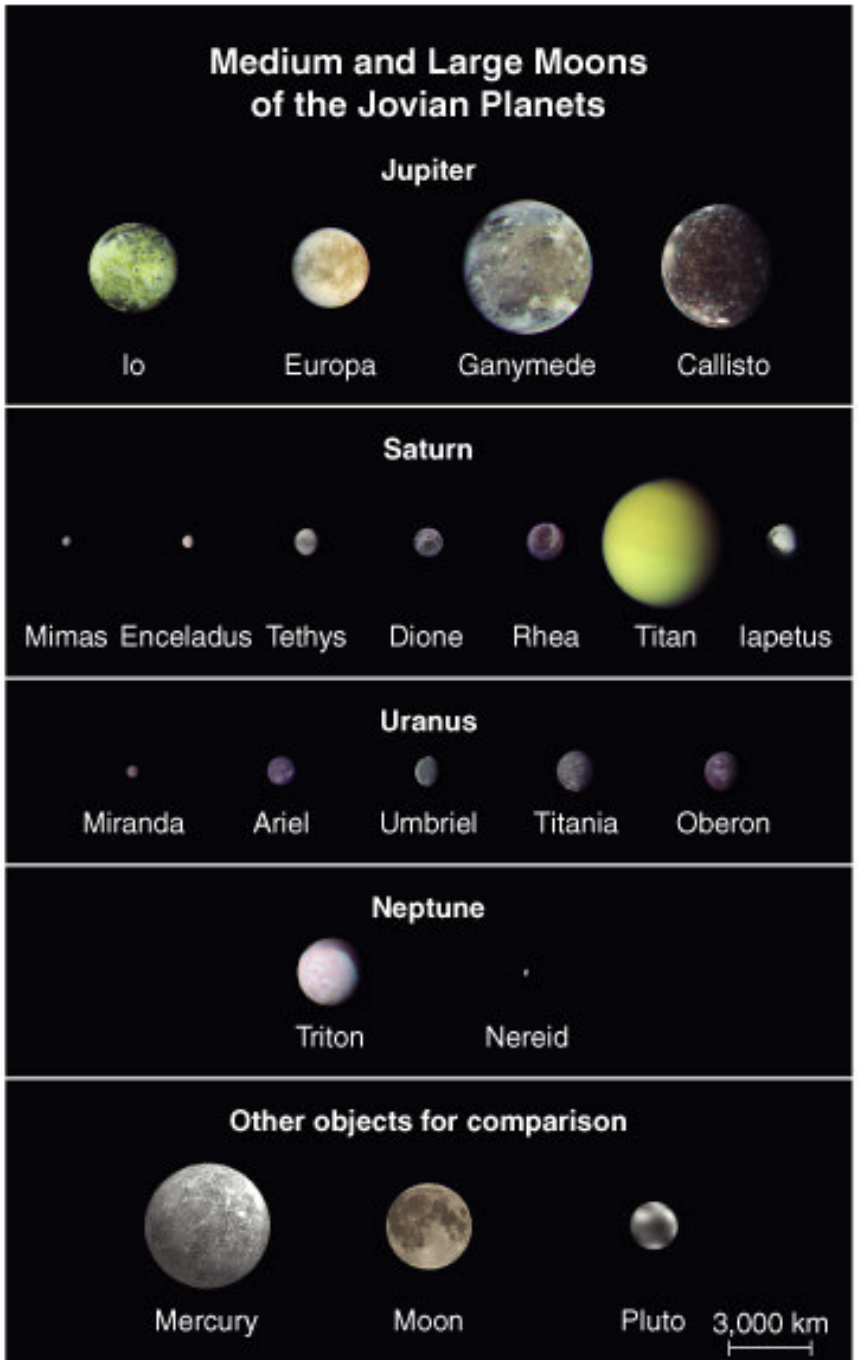
- All the jovian planets have substantial magnetospheres, but Jupiter's is largest by far

11.2 A Wealth of Worlds: Satellites of Ice and Rock

- Our goals for learning
- What kinds of moons orbit jovian planets?
- Why are Jupiter's Galilean moons so geologically active?
- What is special about Titan and other major moons of the solar system?
- Why are small icy moons more geologically active than small rocky planets?

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



Medium & 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.

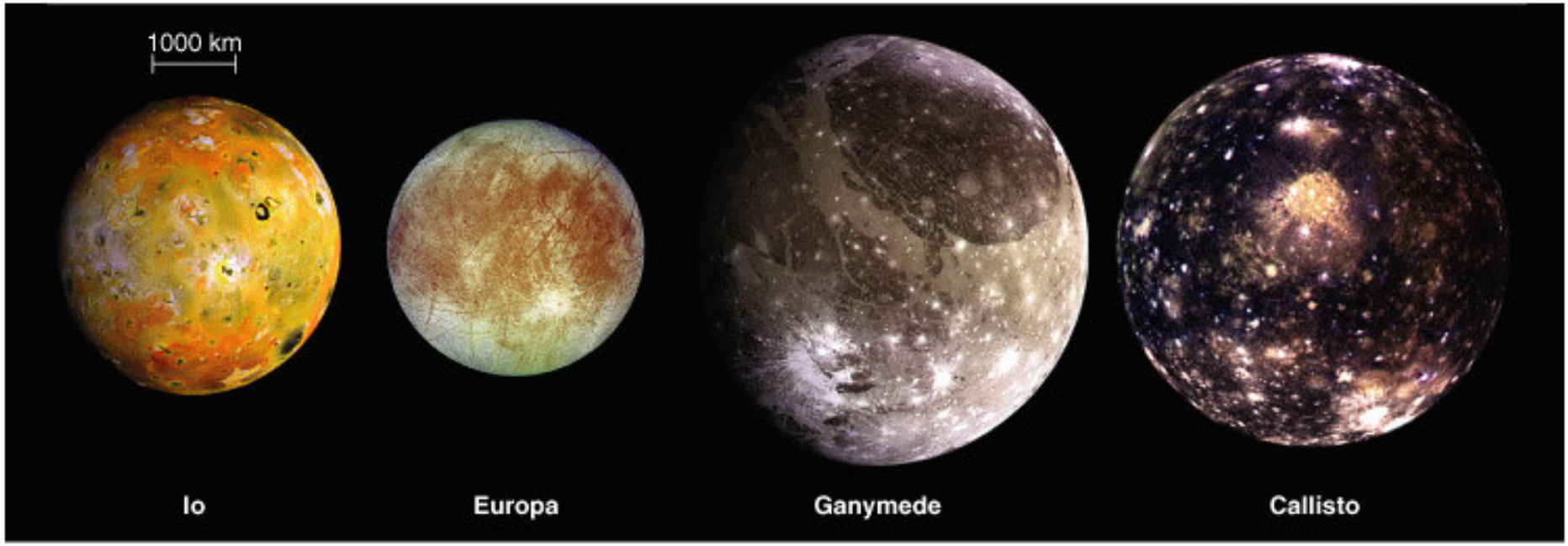
Small Moons

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

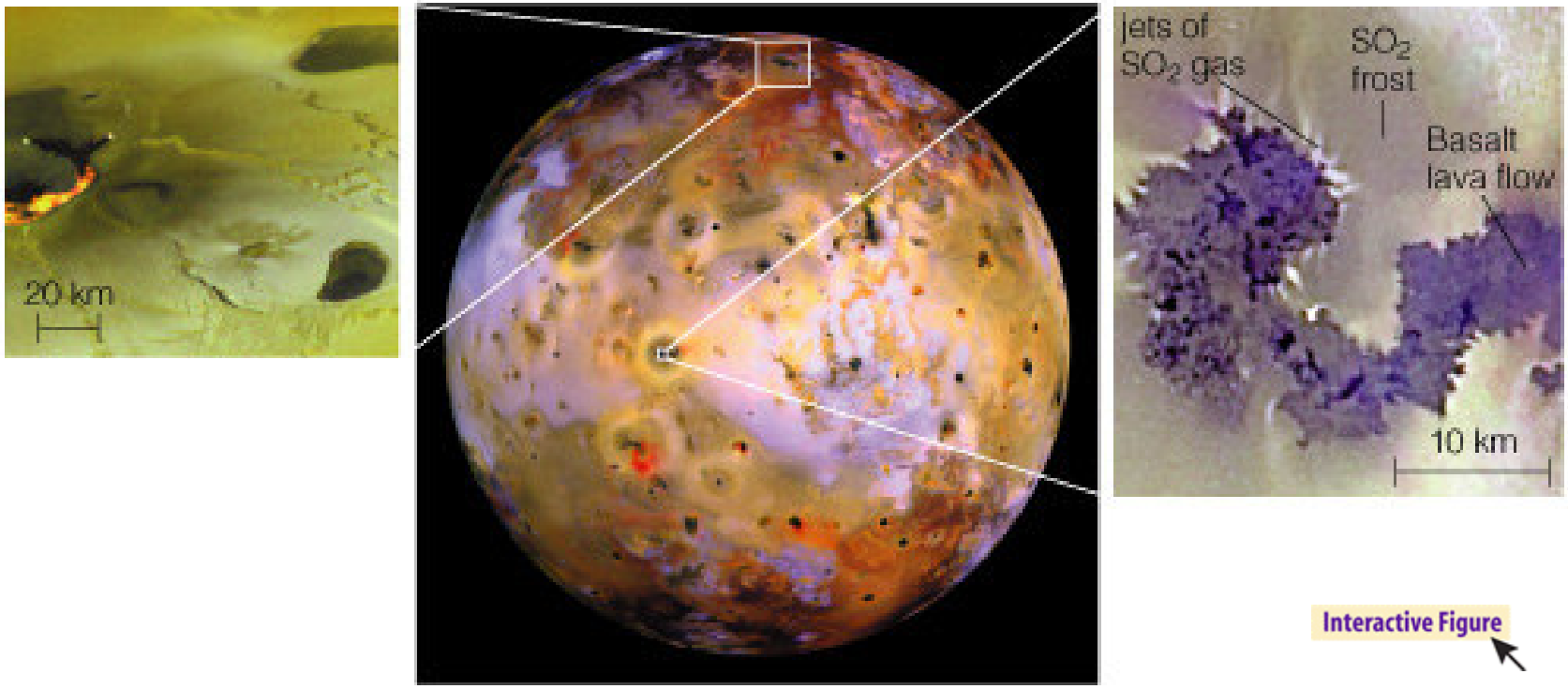
Small Moons

- Captured asteroids or comets, so orbits do not follow usual patterns.

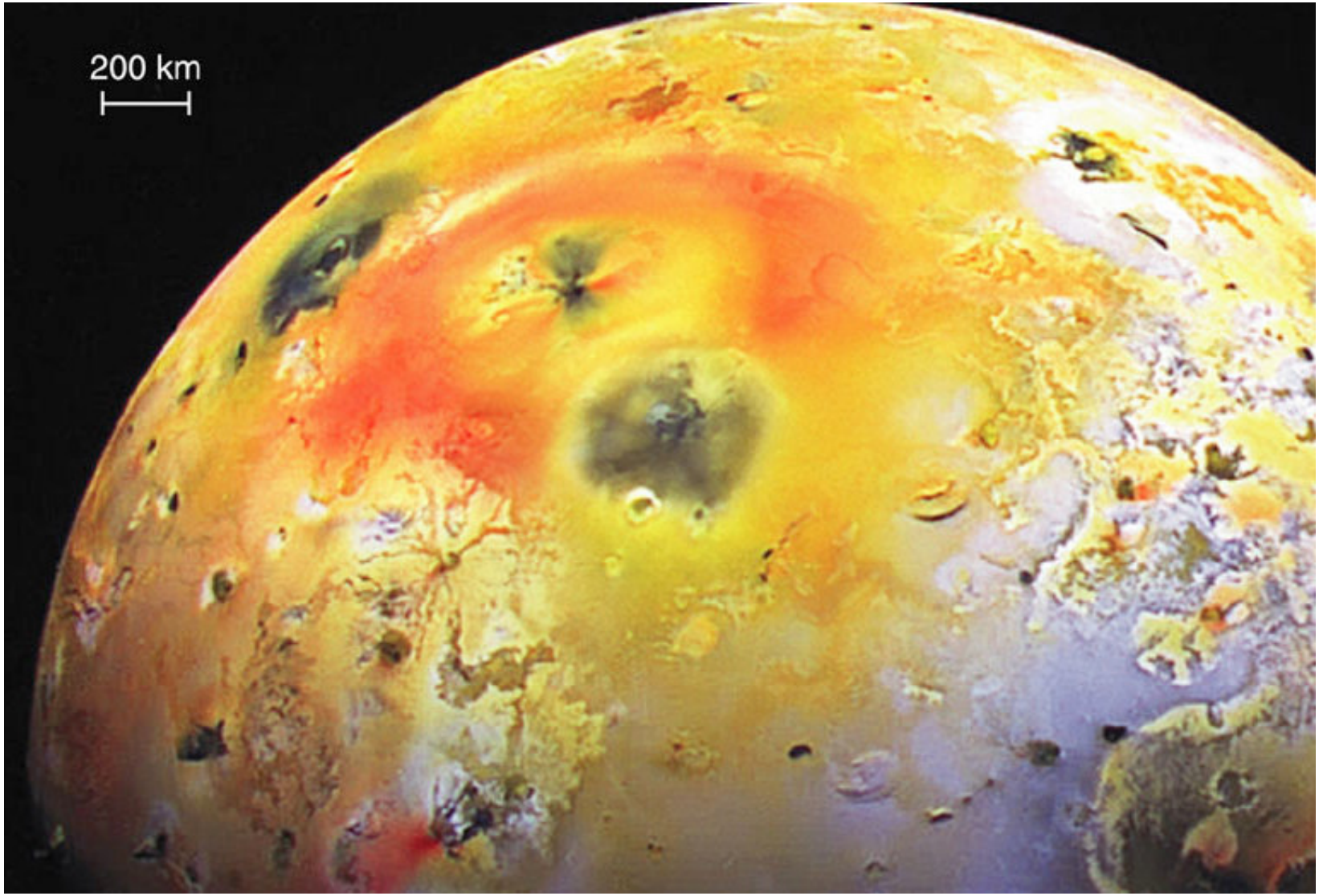
Why are Jupiter's Galilean moons so geologically active?



Io's Volcanic Activity

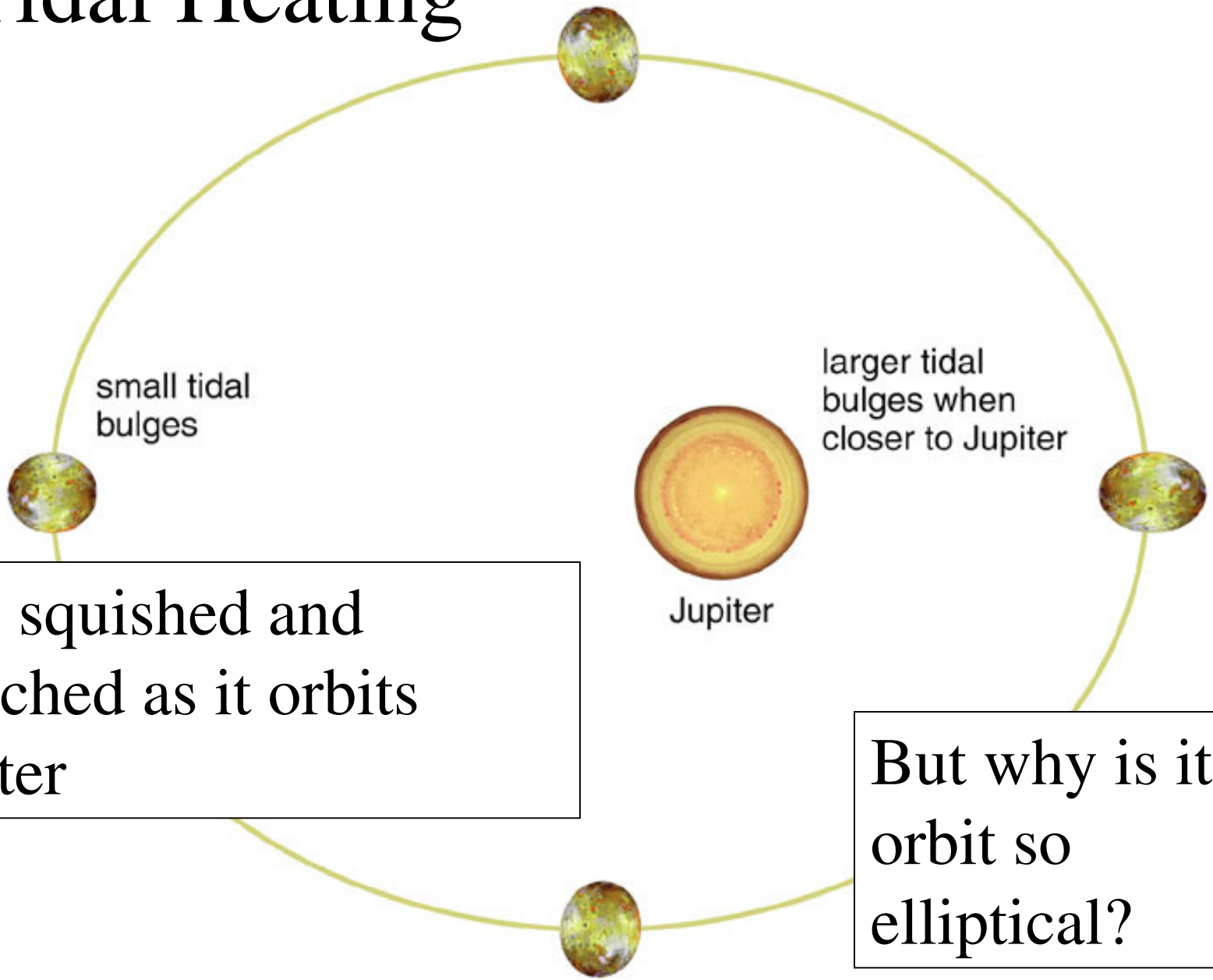


- Io is the most volcanically active body in the solar system, but why?



- Volcanic eruptions continue to change Io's surface

Tidal Heating

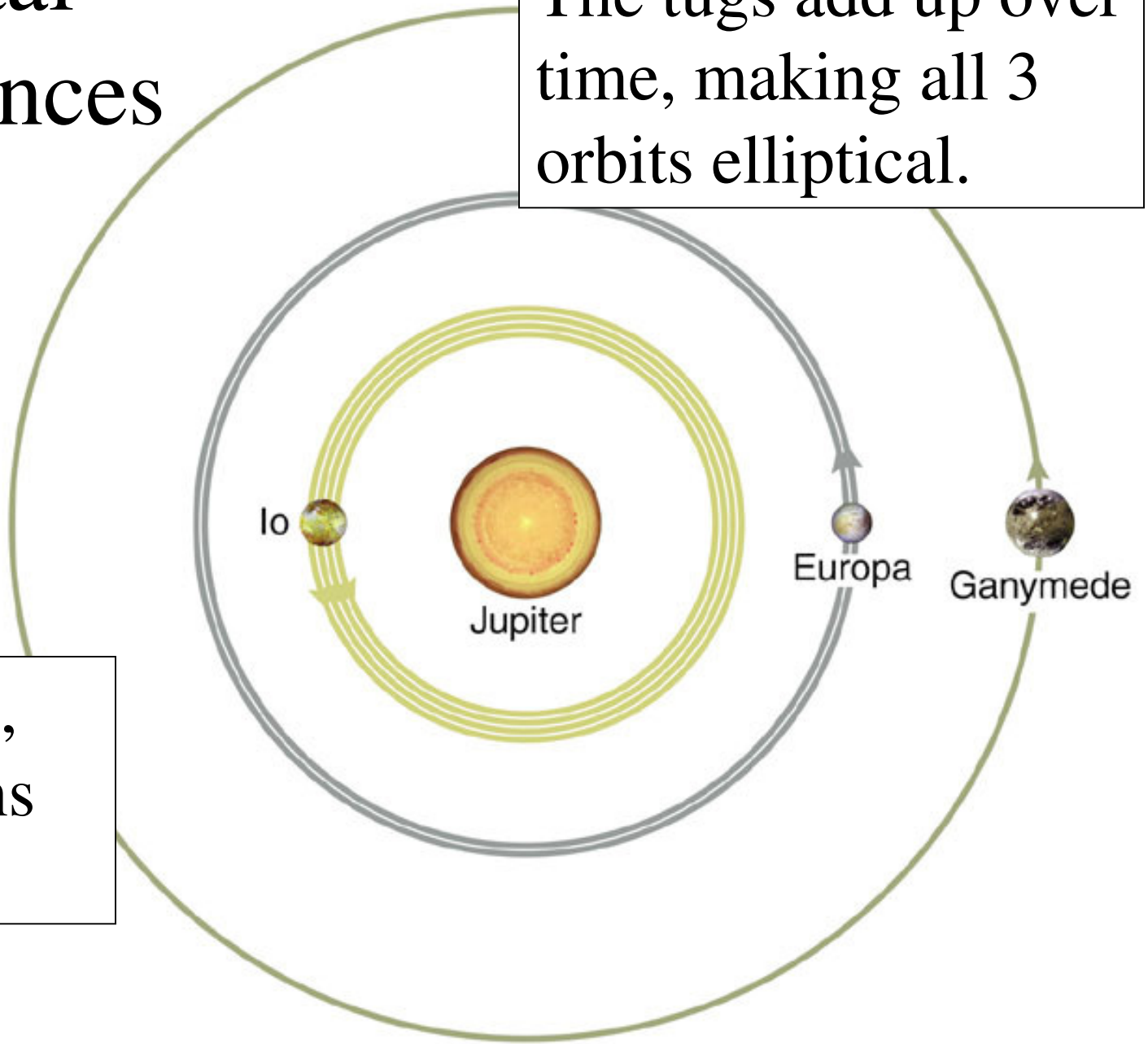


Io is squished and stretched as it orbits Jupiter

But why is its orbit so elliptical?

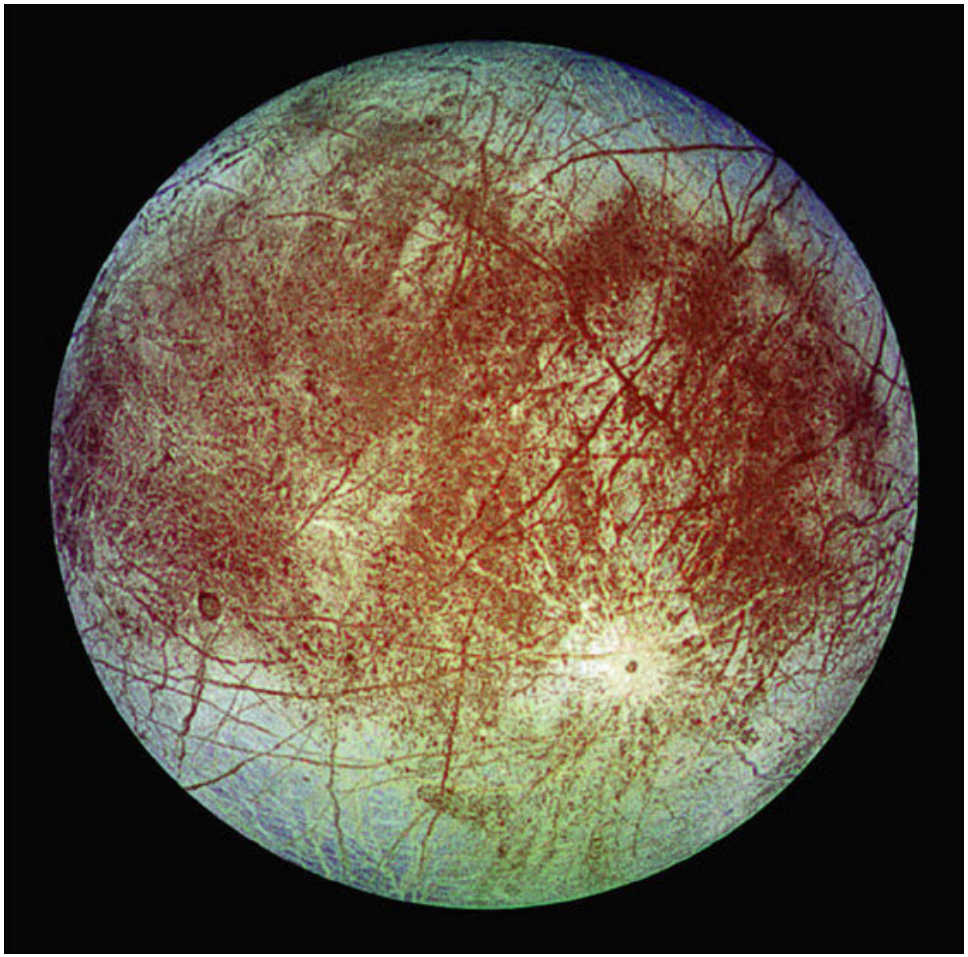
Orbital Resonances

The tugs add up over time, making all 3 orbits elliptical.

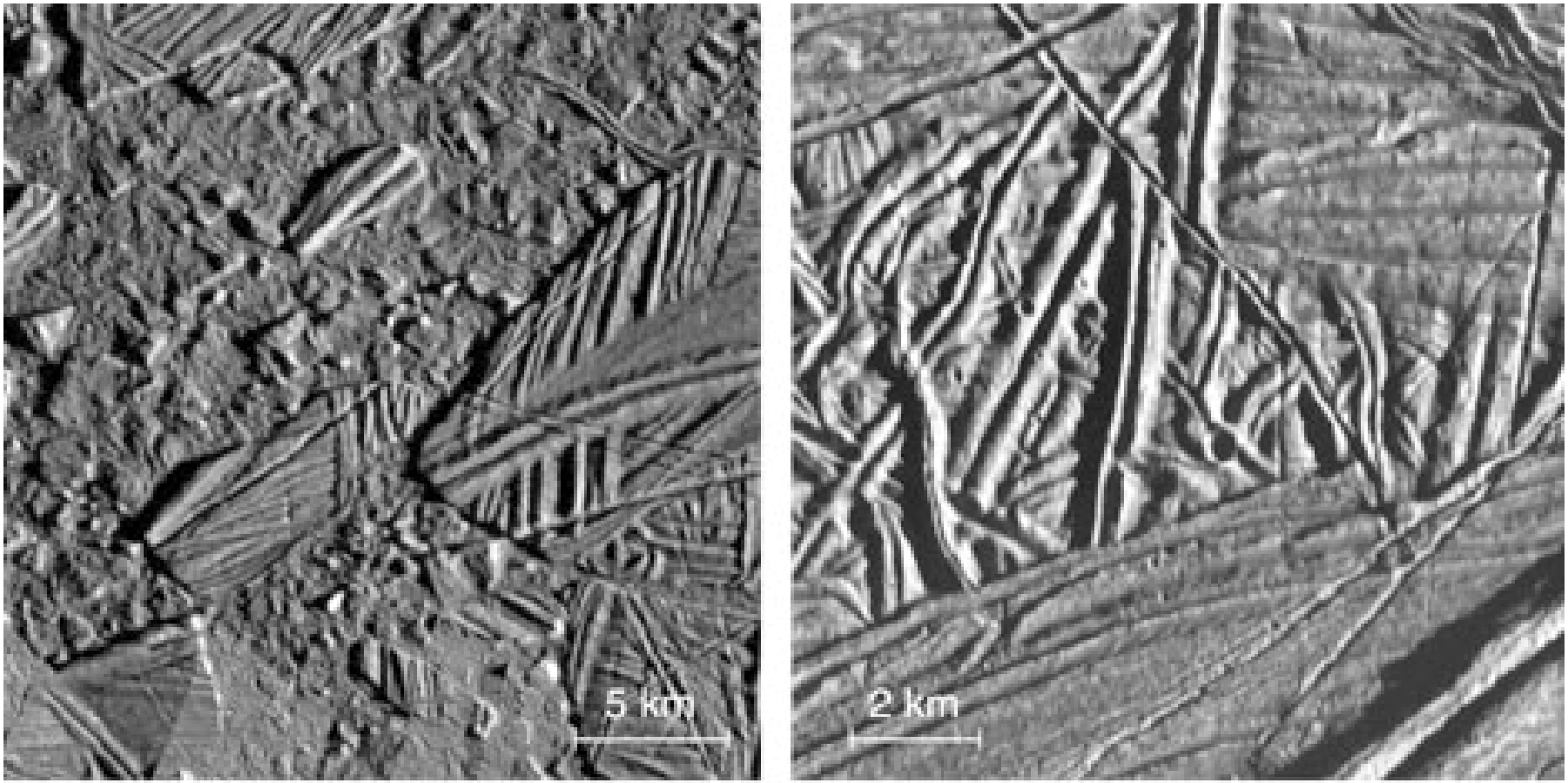


Every 7 days, these 3 moons line up.

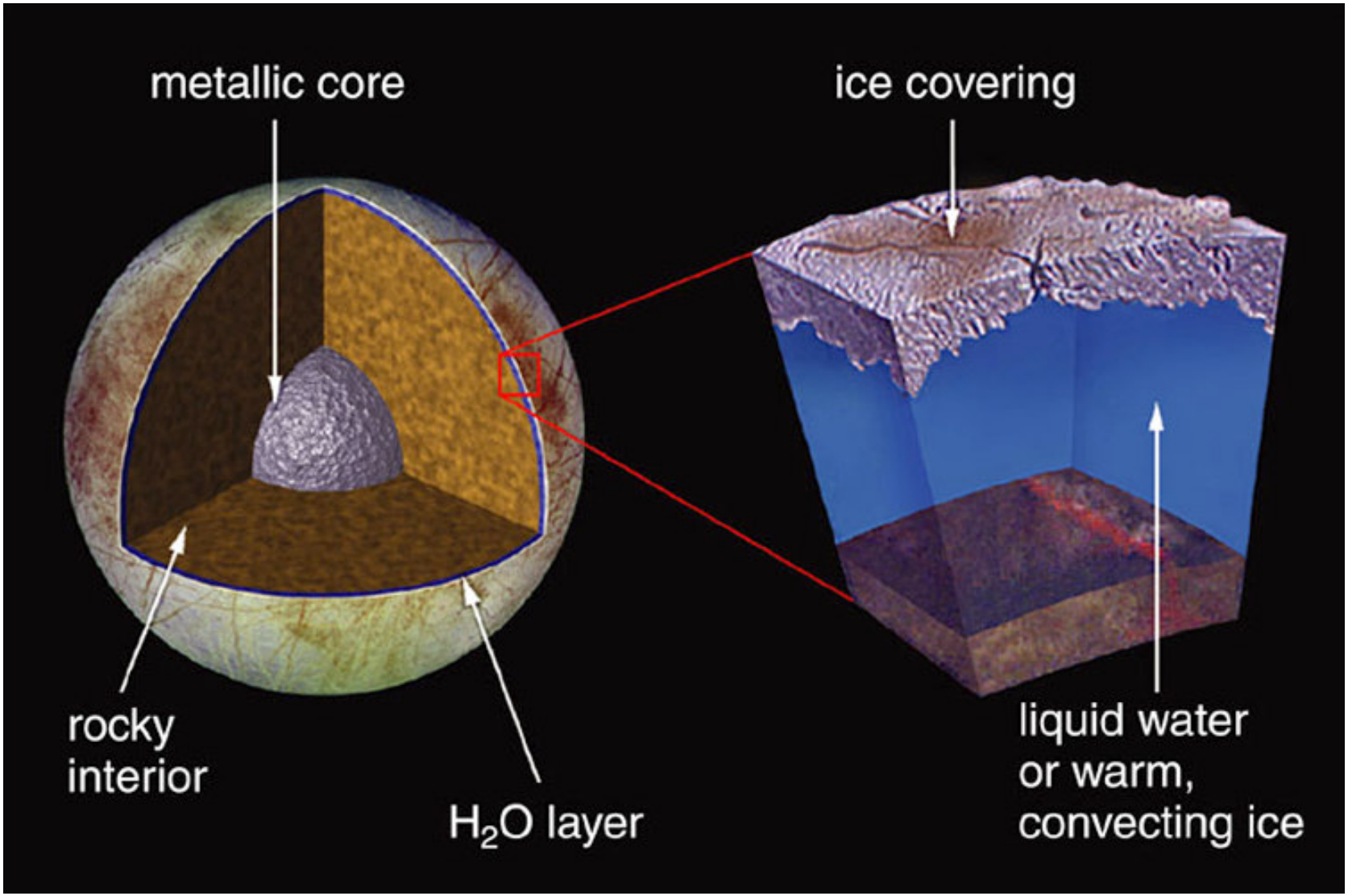
Europa's Ocean: Waterworld?



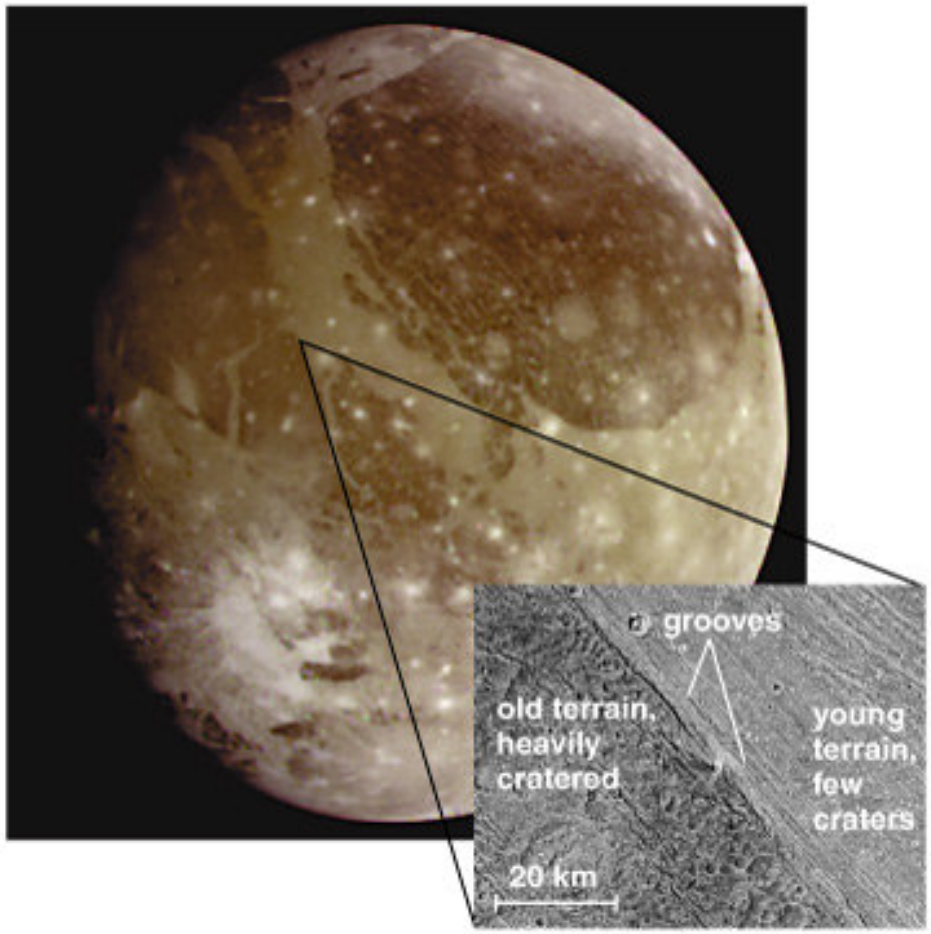
Tidal stresses crack Europa's surface ice.



Europa's interior also warmed by tidal heating

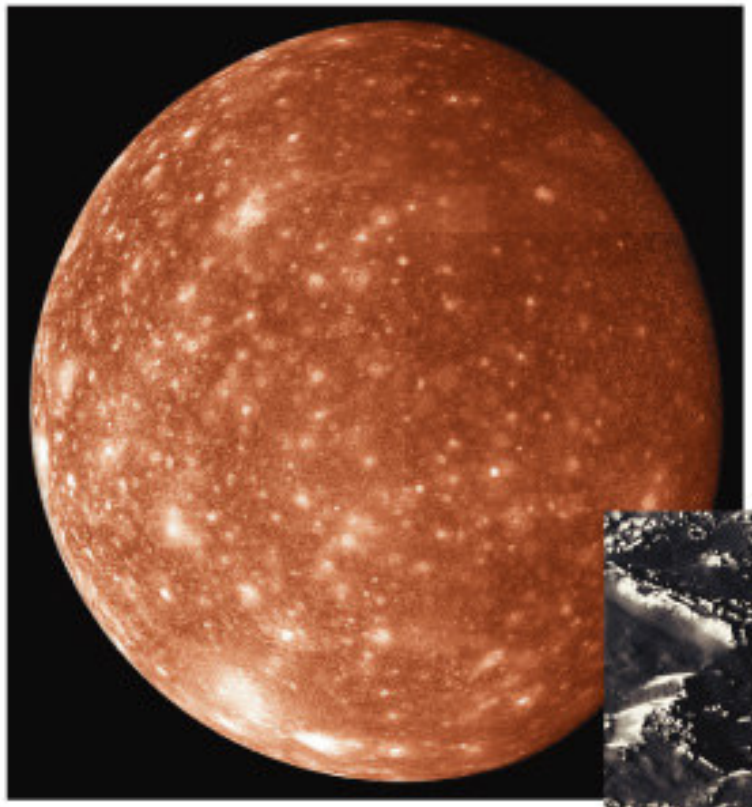


Ganymede

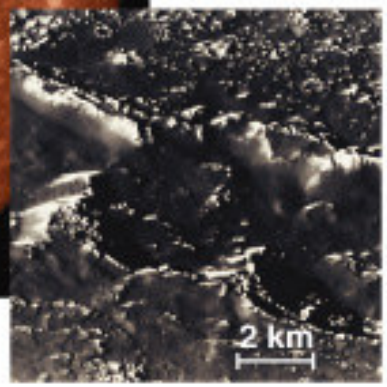


- Largest moon in the solar system
- Clear evidence of geological activity
- Tidal heating plus heat from radio-active decay?

Callisto



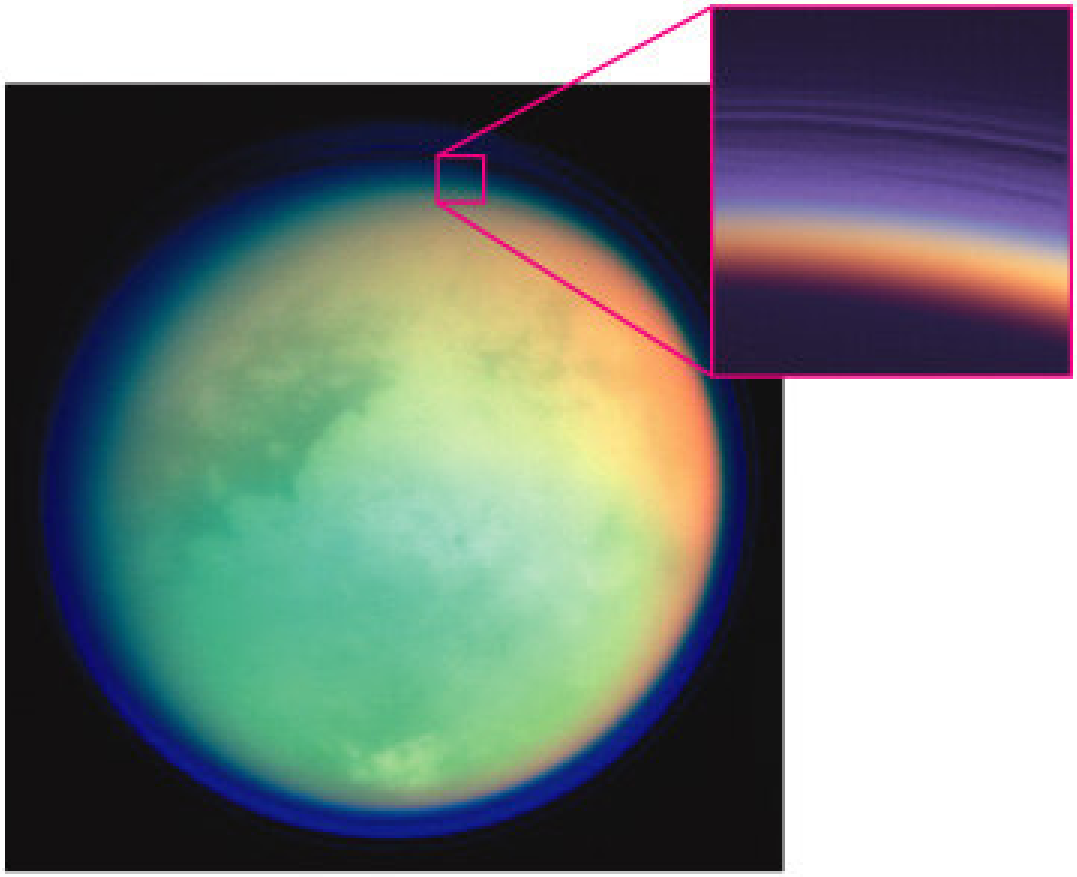
Callisto is heavily cratered, indicating an old surface that nonetheless may hide a deeply buried ocean.



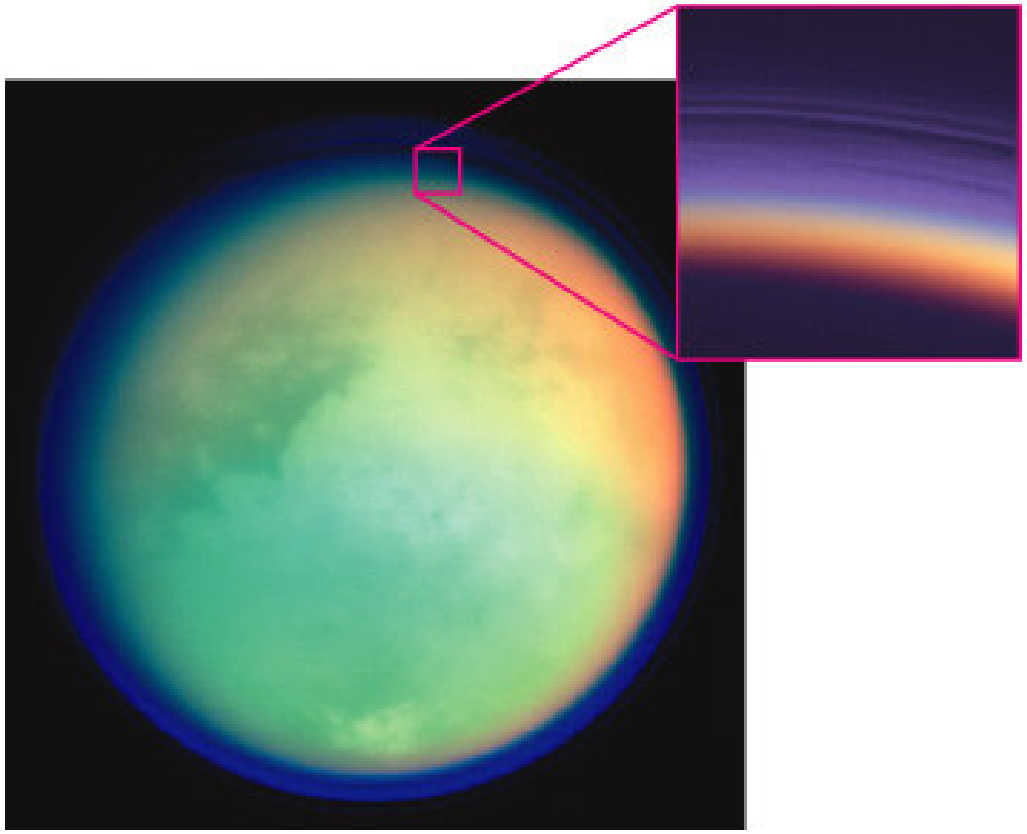
Close-up photo shows a dark powder overlaying the low areas of the surface.

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

What is special about Titan and other major moons of the outer solar system?

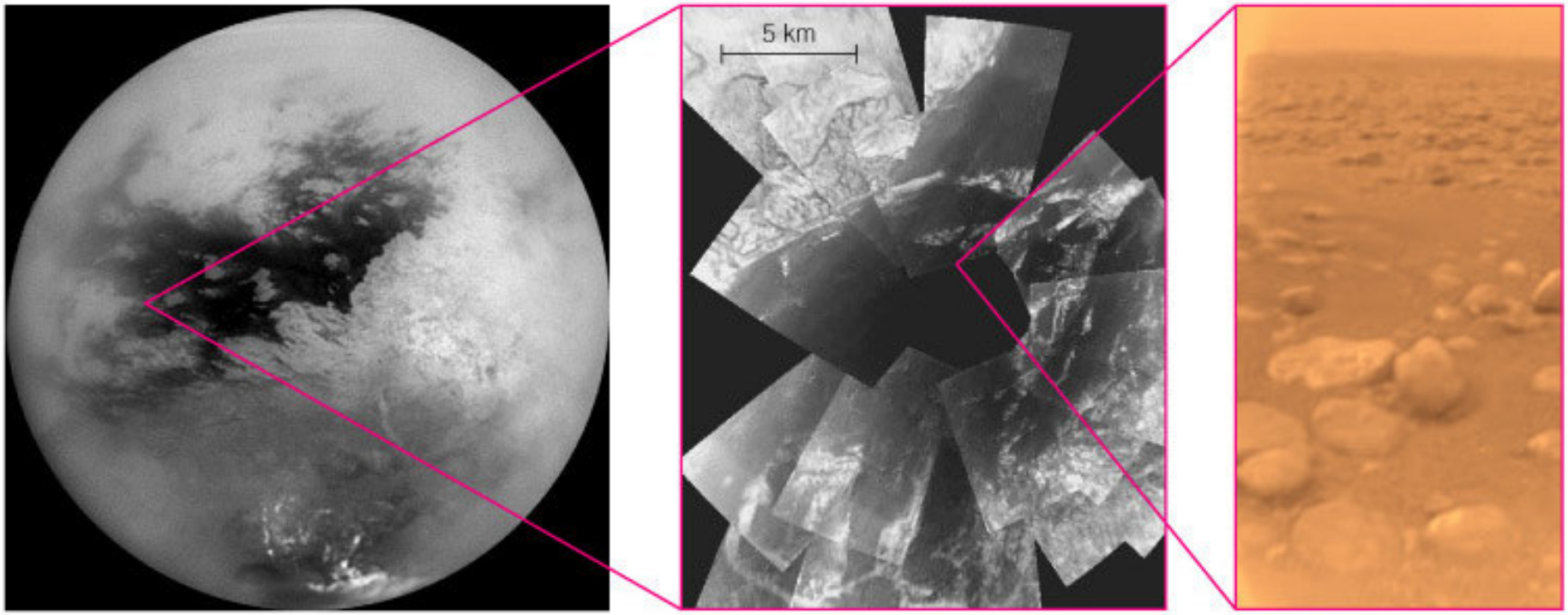


Titan's Atmosphere



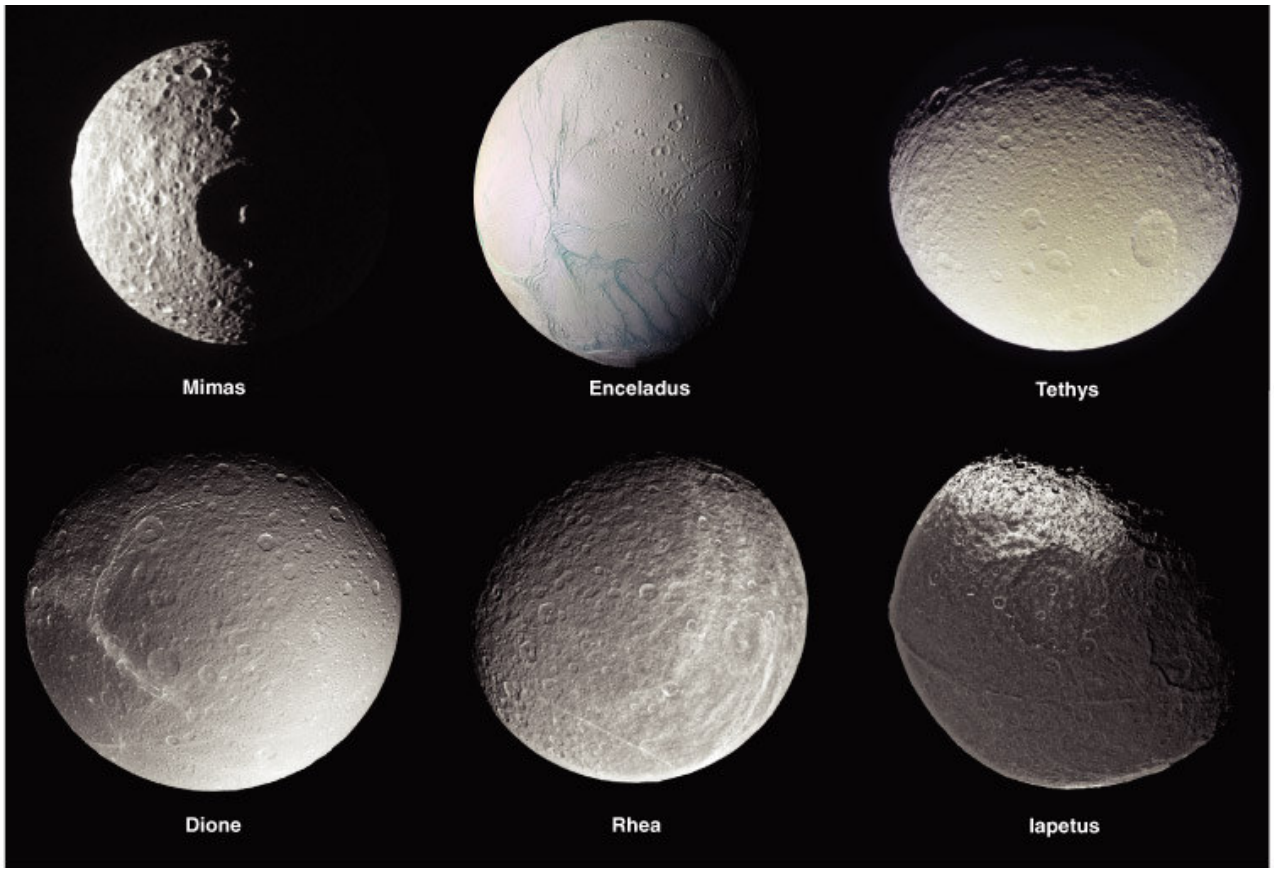
- Titan is the only moon in the solar system to have a thick atmosphere
- It consists mostly of nitrogen with some argon, methane, and ethane

Titan's Surface



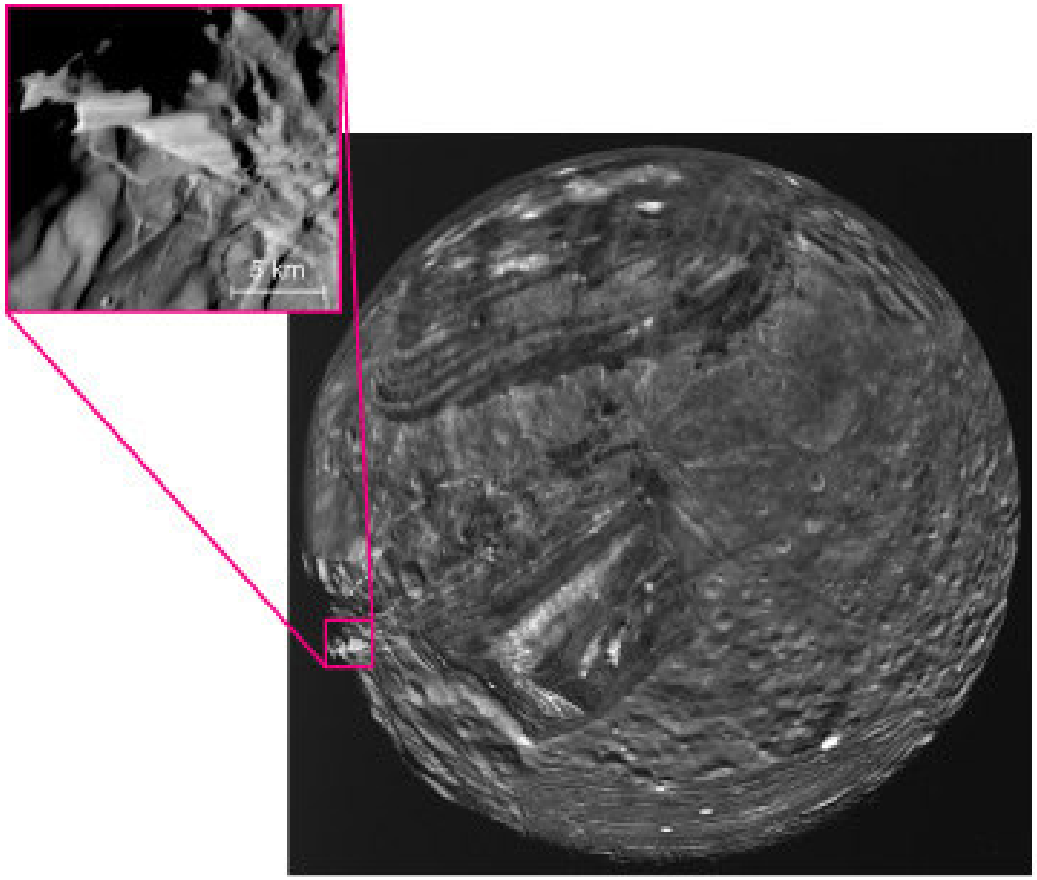
- *Huygens* probe provided first look at Titan's surface in early 2005
- Liquid methane, "rocks" made of ice

Medium Moons of Saturn



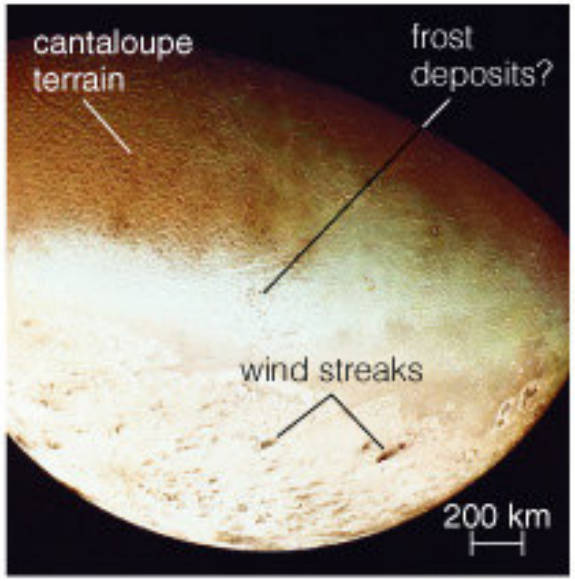
- Almost all show evidence of past volcanism and/or tectonics

Medium Moons of Uranus

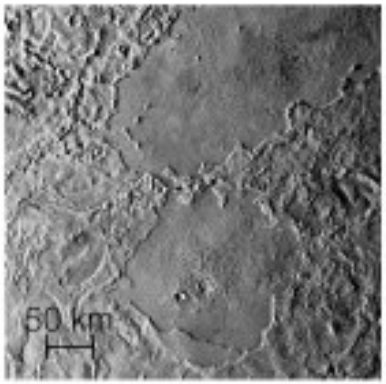


- Varying amounts of geological activity
- Moon Miranda has large tectonic features and few craters (episode of tidal heating in past?)

Neptune's Moon Triton



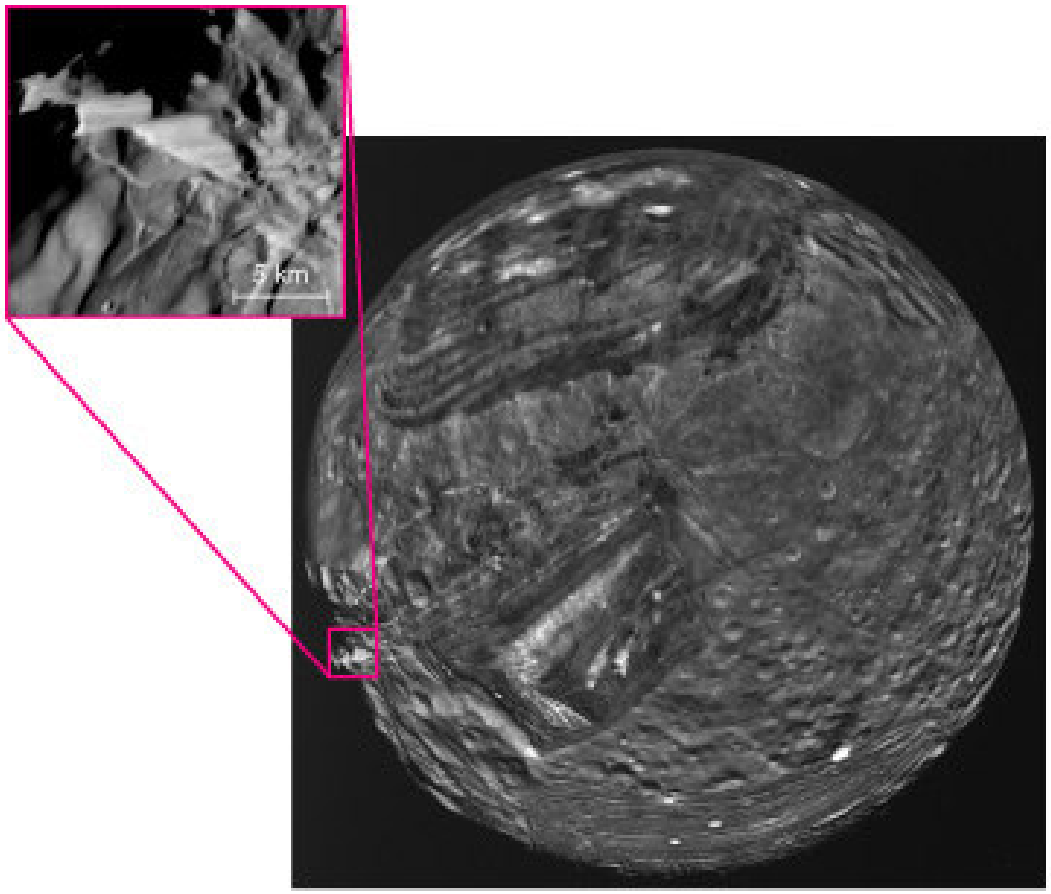
Triton's southern hemisphere as seen by *Voyager 2*.



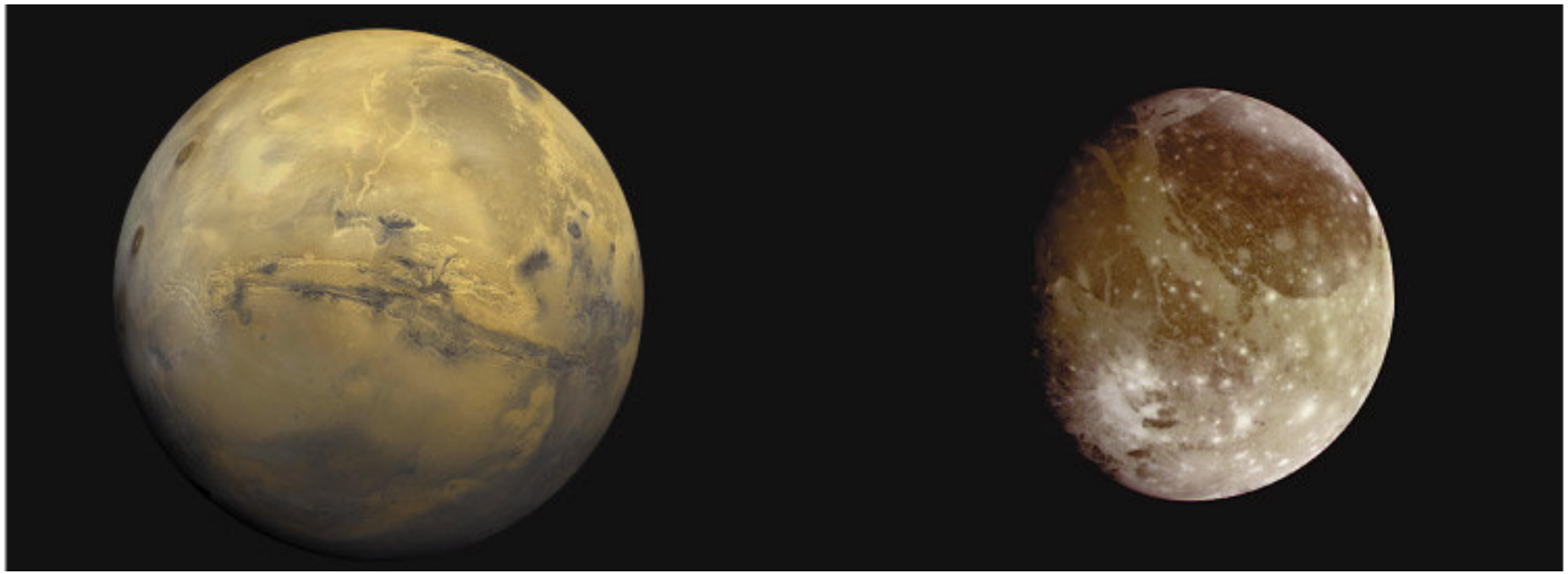
This close-up shows lava-filled impact basins similar to the lunar maria, but the lava was water or slush rather than molten rock.

- Similar to Pluto, but larger
- Evidence for past geological activity

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



Rocky Planets vs. 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 jovian planets?
  - Moons of many sizes
  - Level of geological activity depends on size
- Why are Jupiter's Galilean moons so geologically active?
  - Tidal heating drives activity, leading to Io's volcanoes and ice geology on other moons

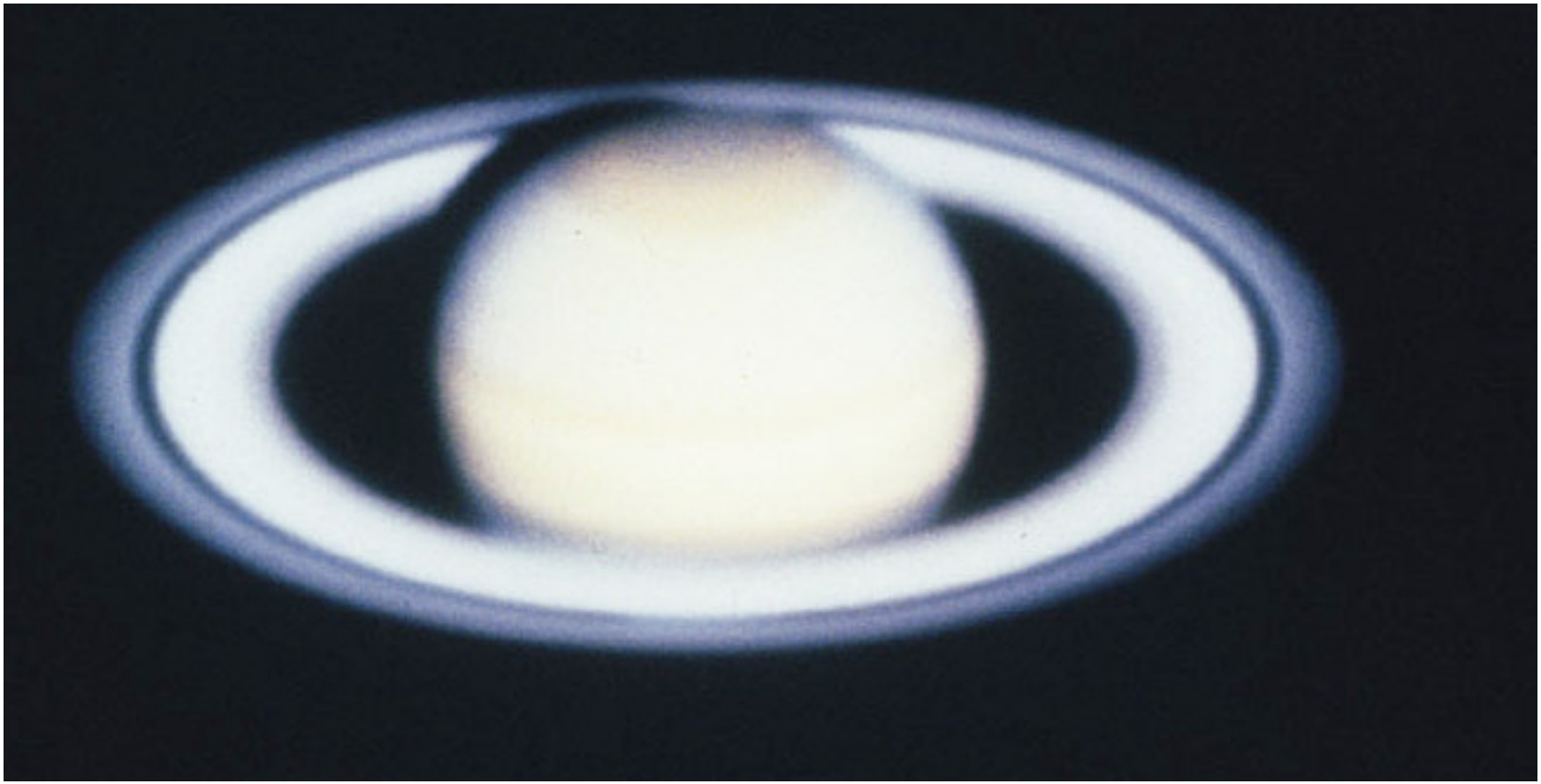
What have we learned?

- What is special about Titan and other major moons of the solar system?
  - 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?

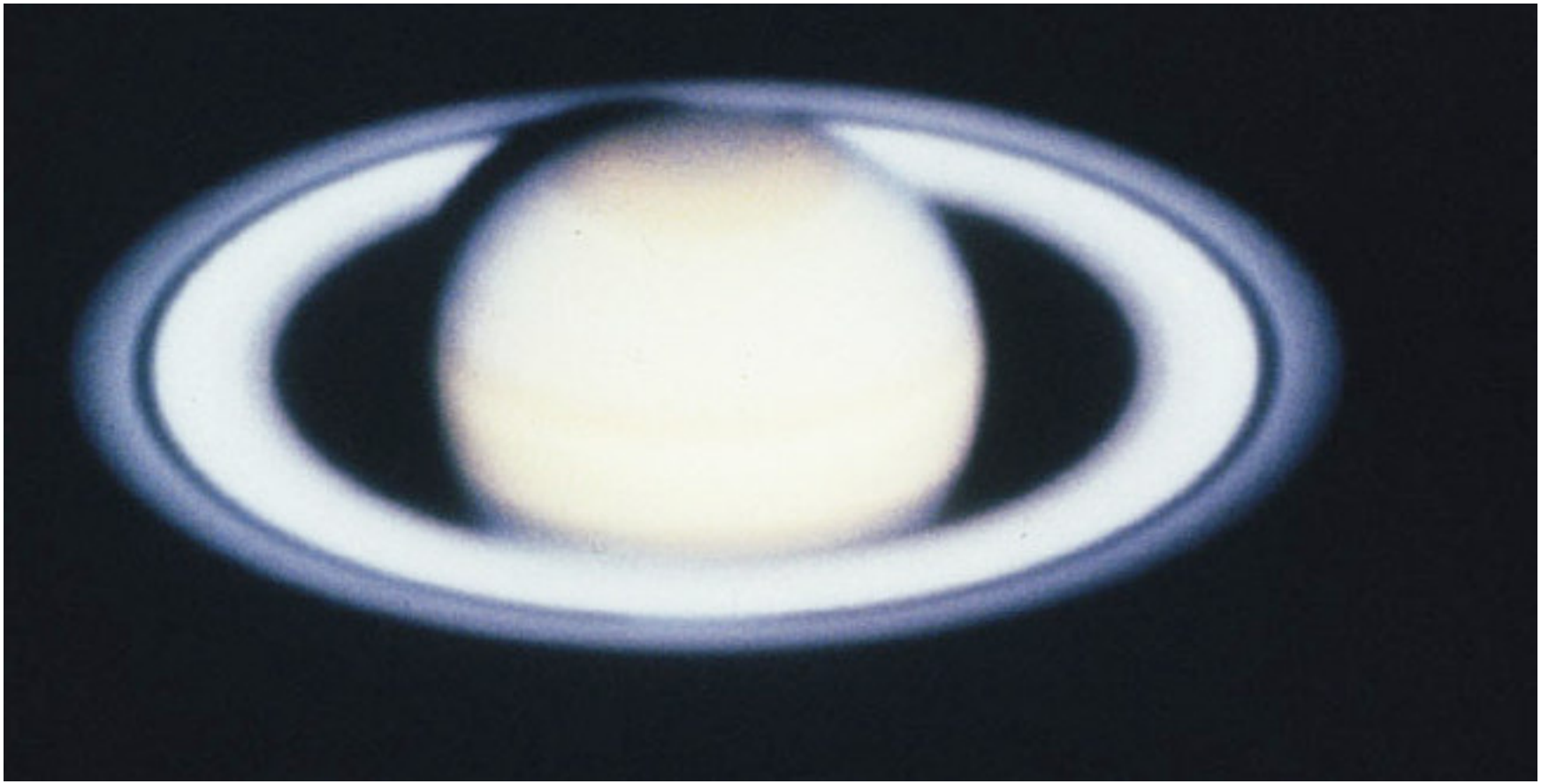
What are Saturn's rings like?



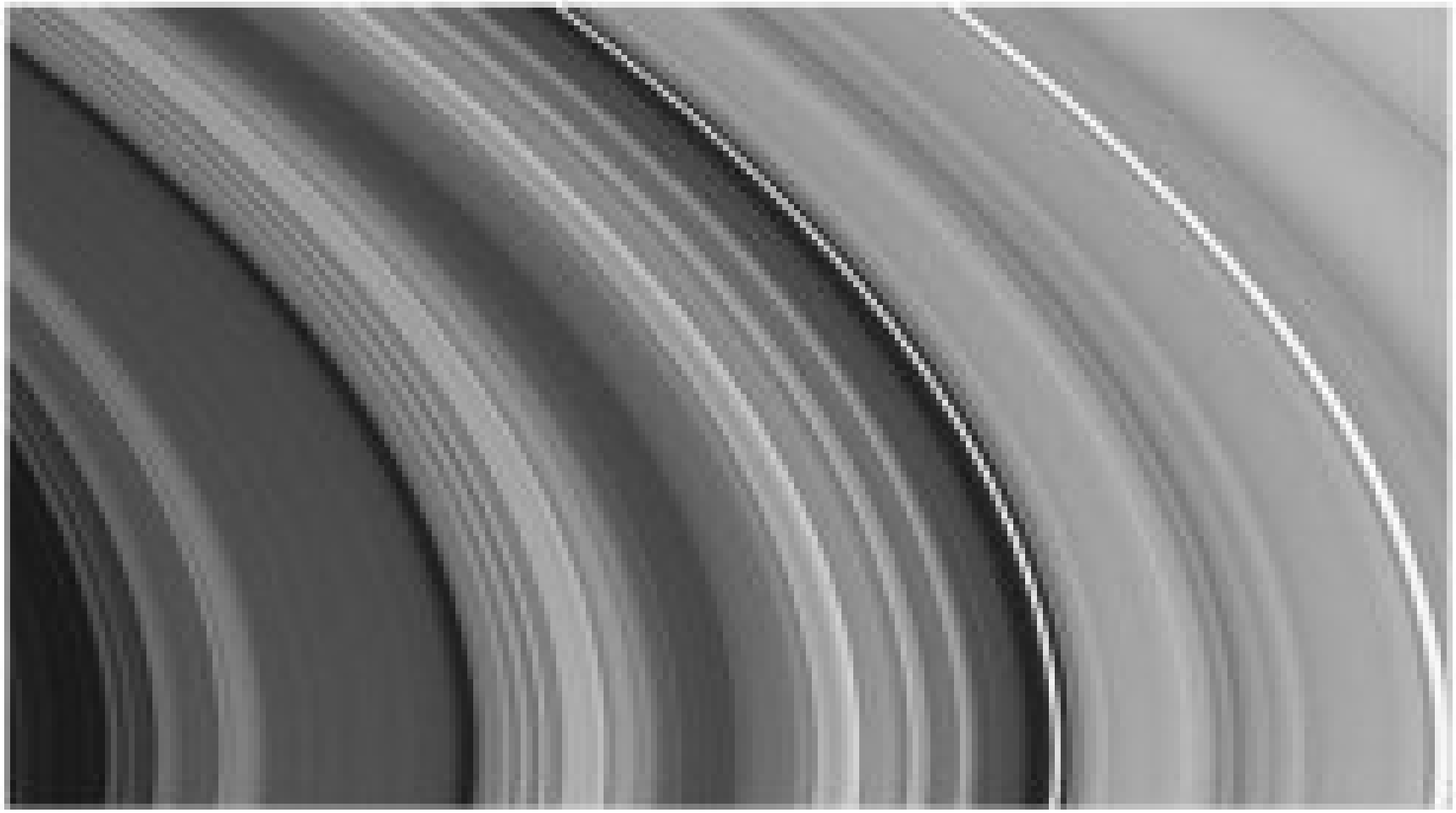
What are Saturn's rings like?

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

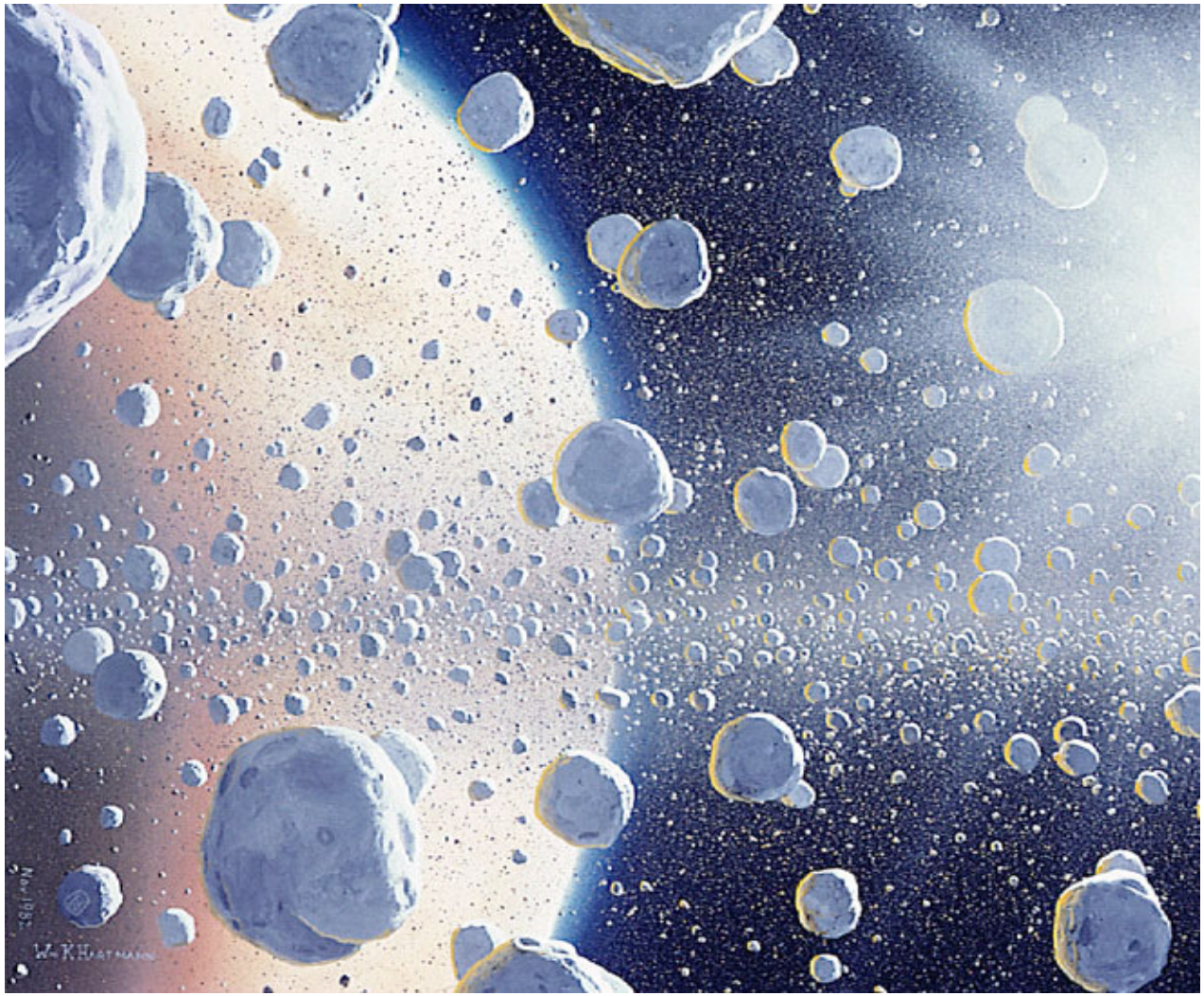
Earth-based view



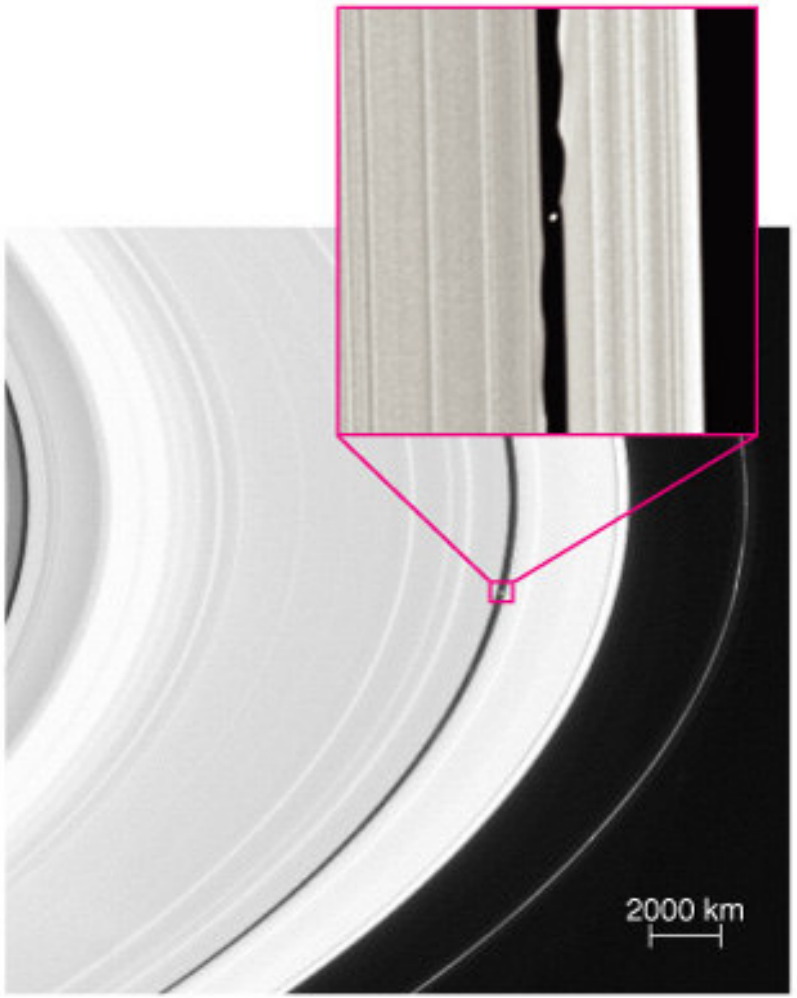
Spacecraft view of ring gaps



Artist's conception of close-up

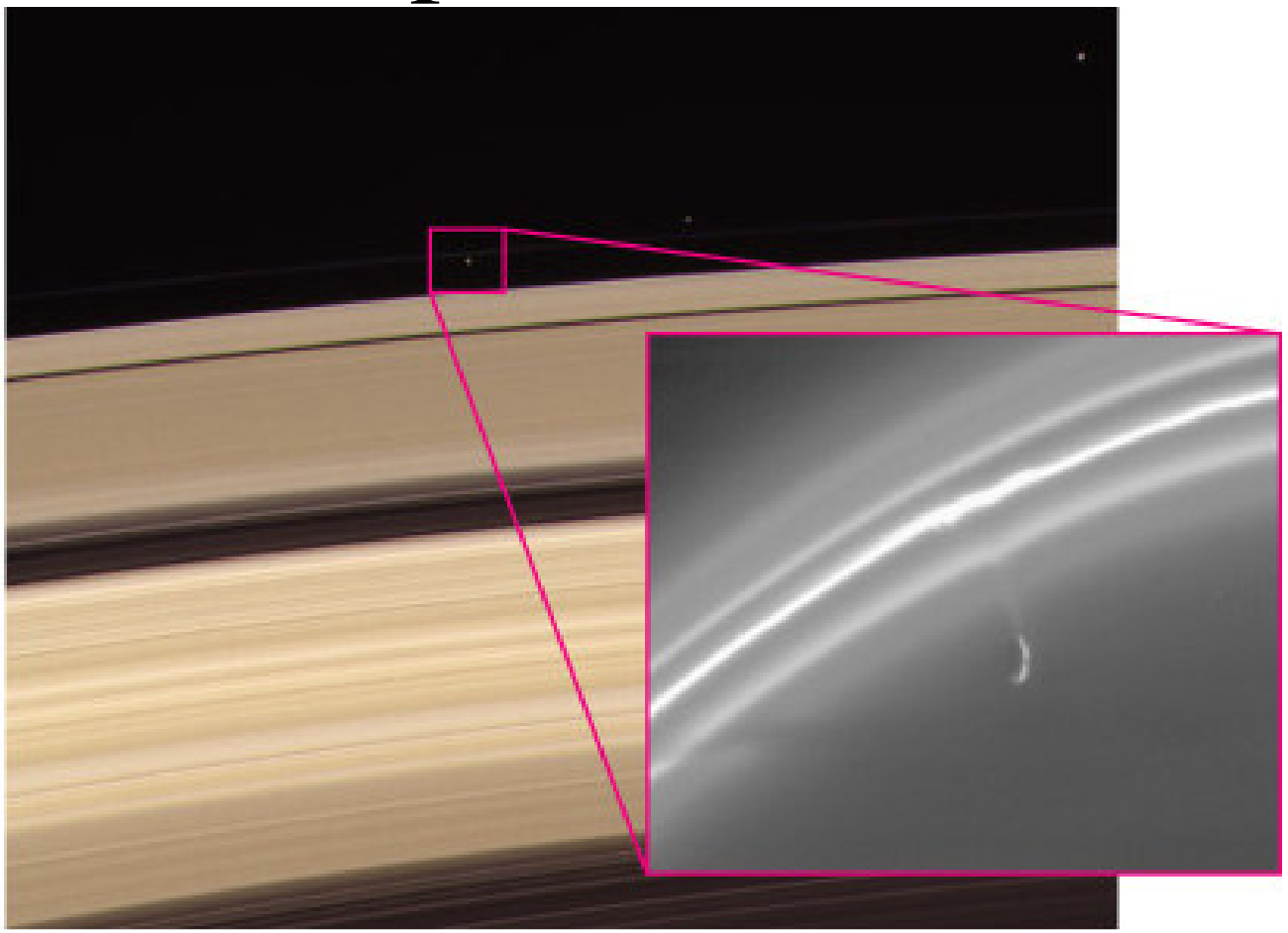


Gap Moons



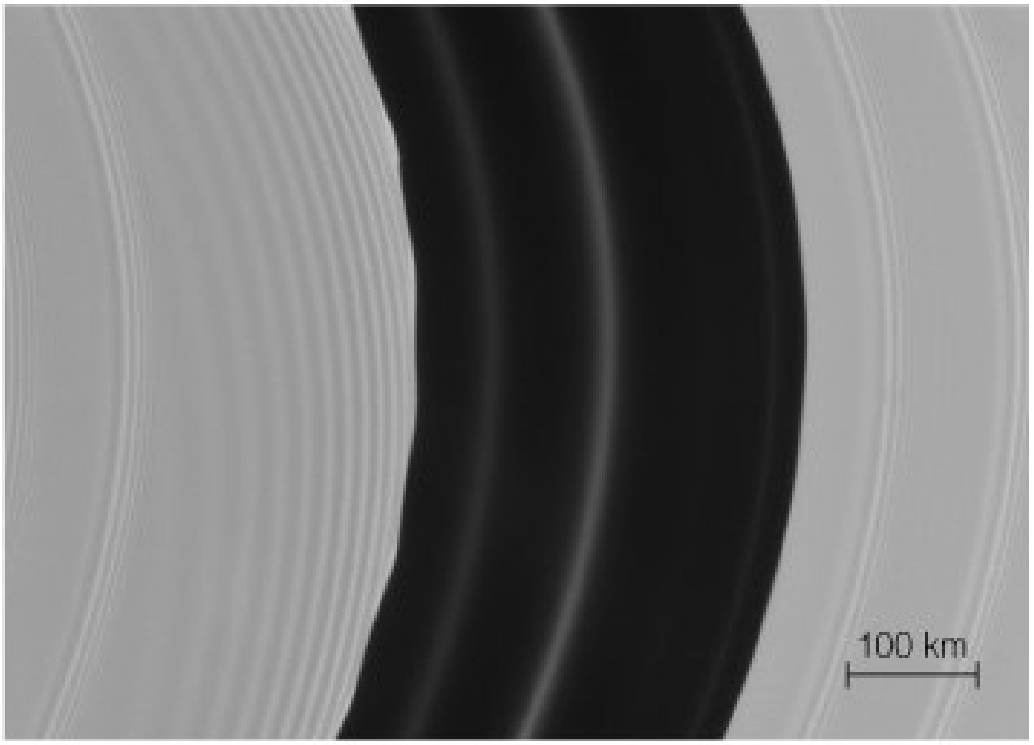
- Some small moons create gaps within rings

Shepherd Moons



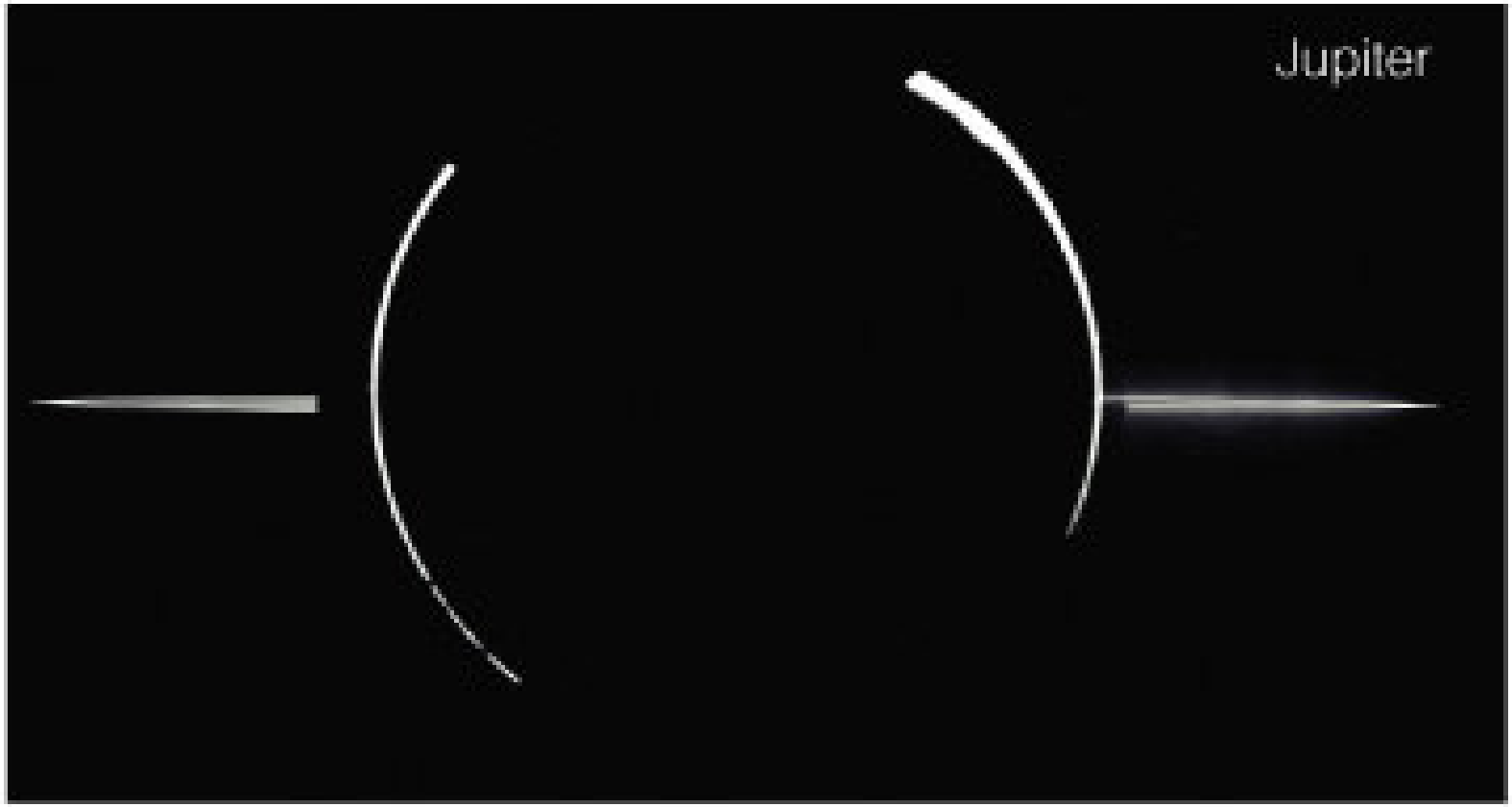
- Pair of small moons can force particles into a narrow ring

Resonance Gaps

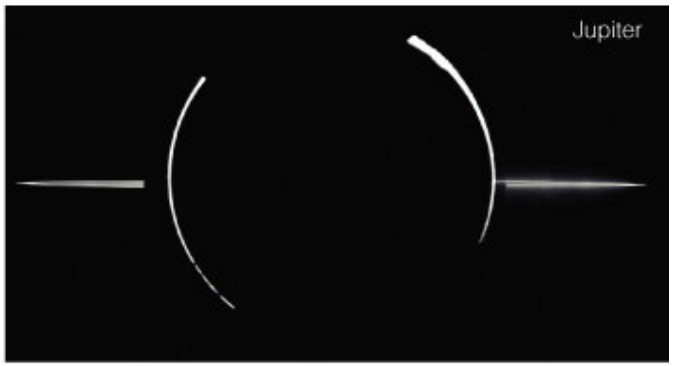


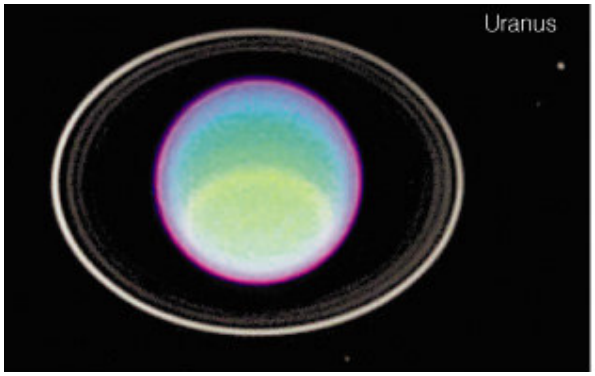
- Orbital resonance with a larger moon can also produce a gap

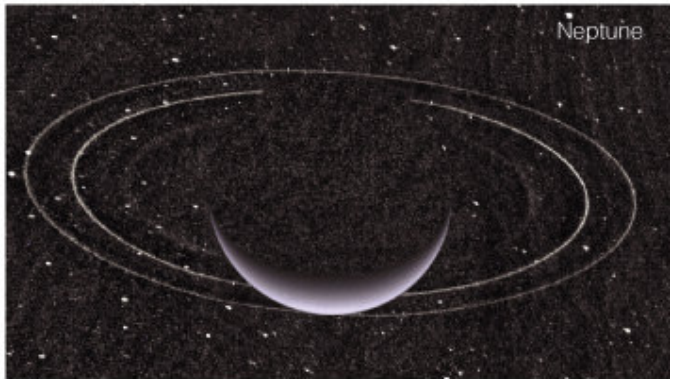
How do other jovian ring systems compare to Saturn's?



Jovian Ring Systems

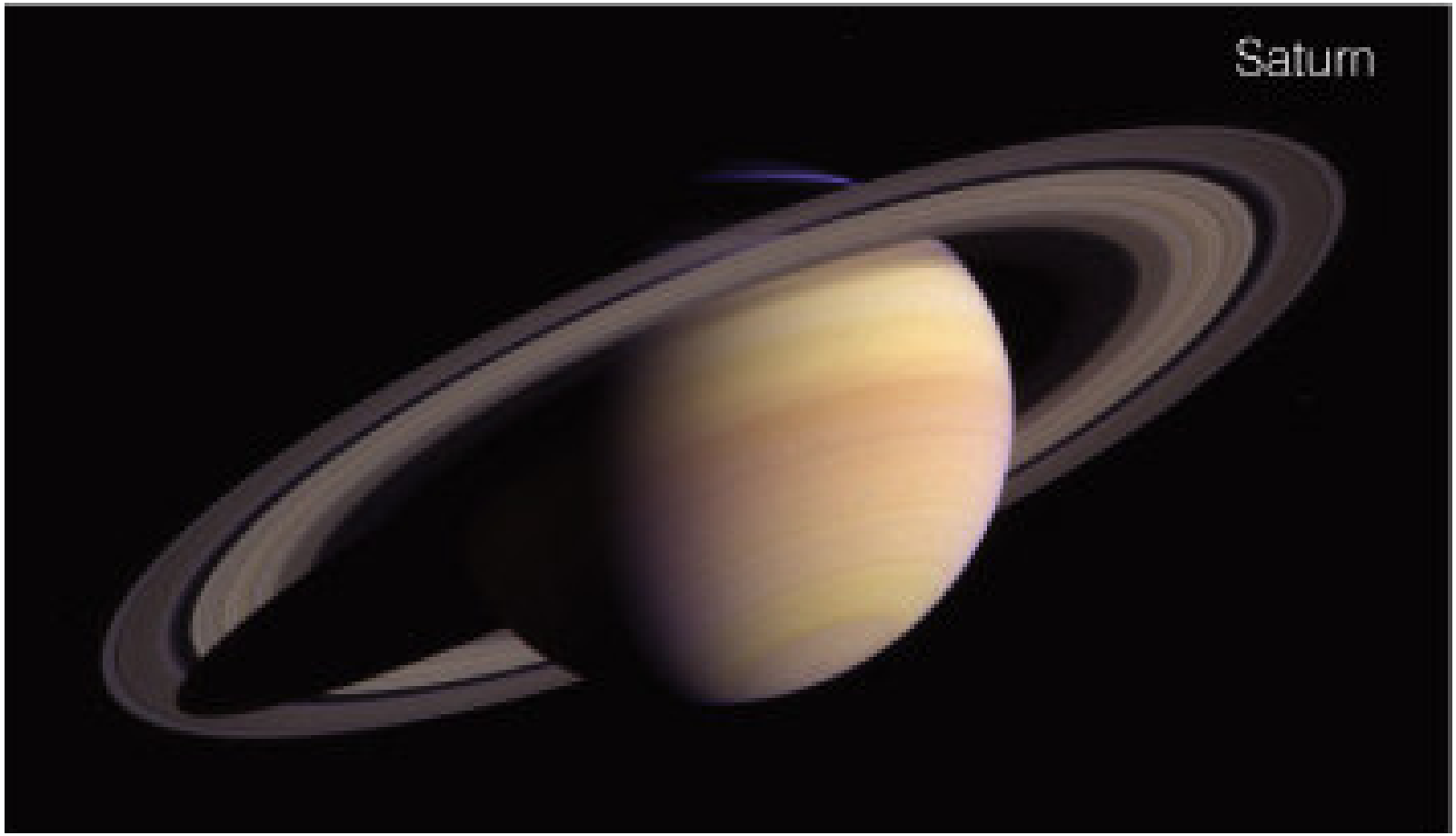






- All four jovian planets have ring systems
- Others have smaller, darker ring particles than Saturn

Why do the jovian planets have rings?



Why do the jovian planets have rings?

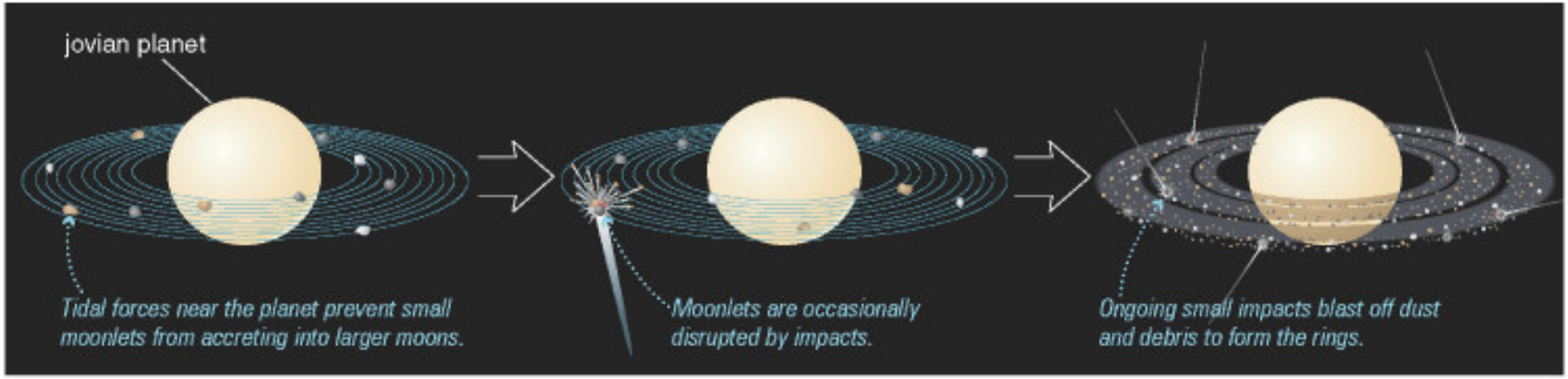
- They formed from dust created in impacts on moons orbiting those planets

How do we know that?

How do we know?

- Rings aren't leftover from planet formation because the particles are too small to have survived this long.
- There must be a continuous replacement of tiny particles.
- The most likely source is impacts with the 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?
  - Made up of countless individual ice particles
  - Extremely thin with many gaps
- How do other jovian ring systems compare to Saturn's?
  - Much fainter ring systems with smaller, darker, less numerous particles
- Why do the jovian planets have rings?
  - Ring particles are probably debris from moons