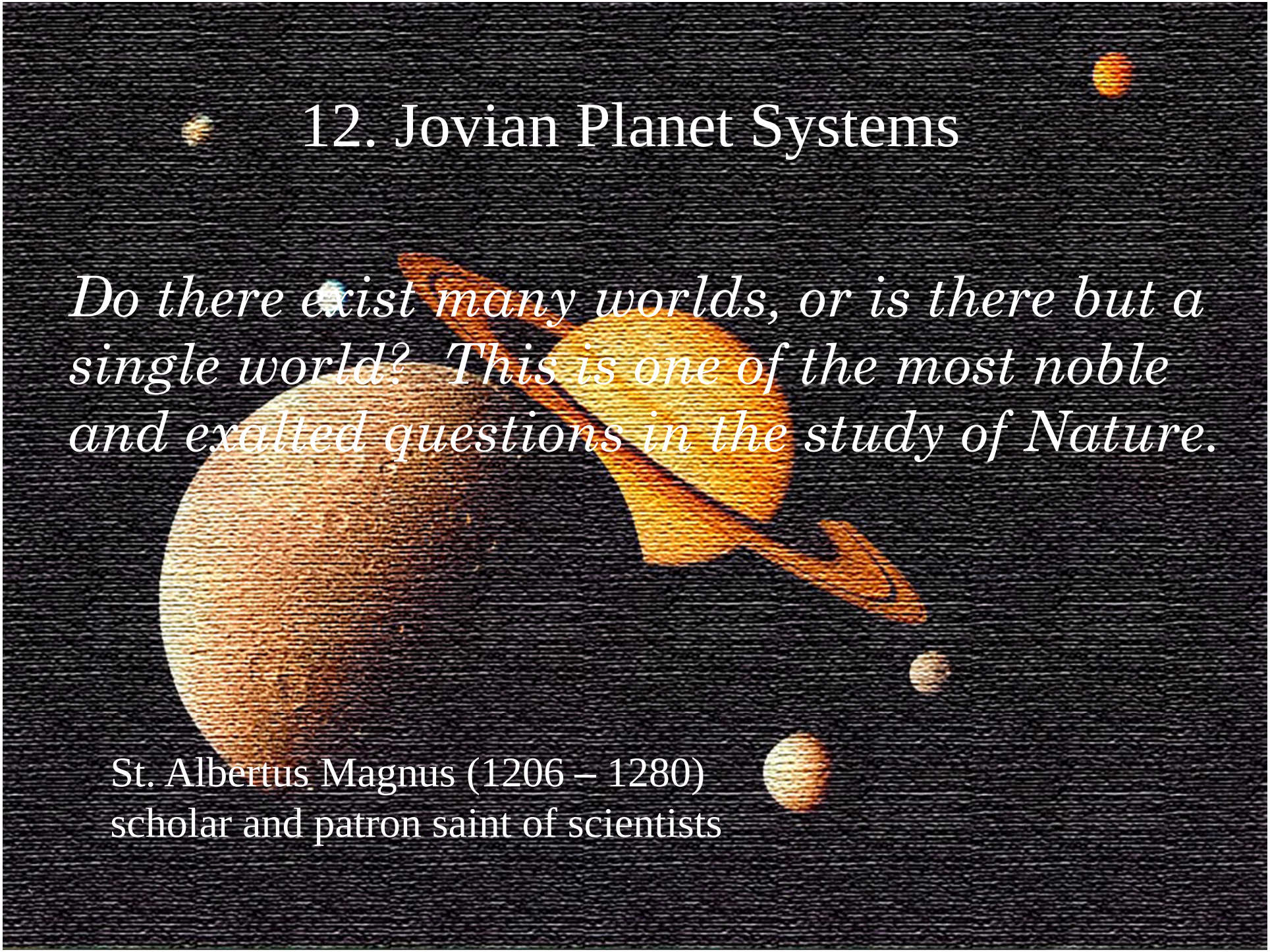
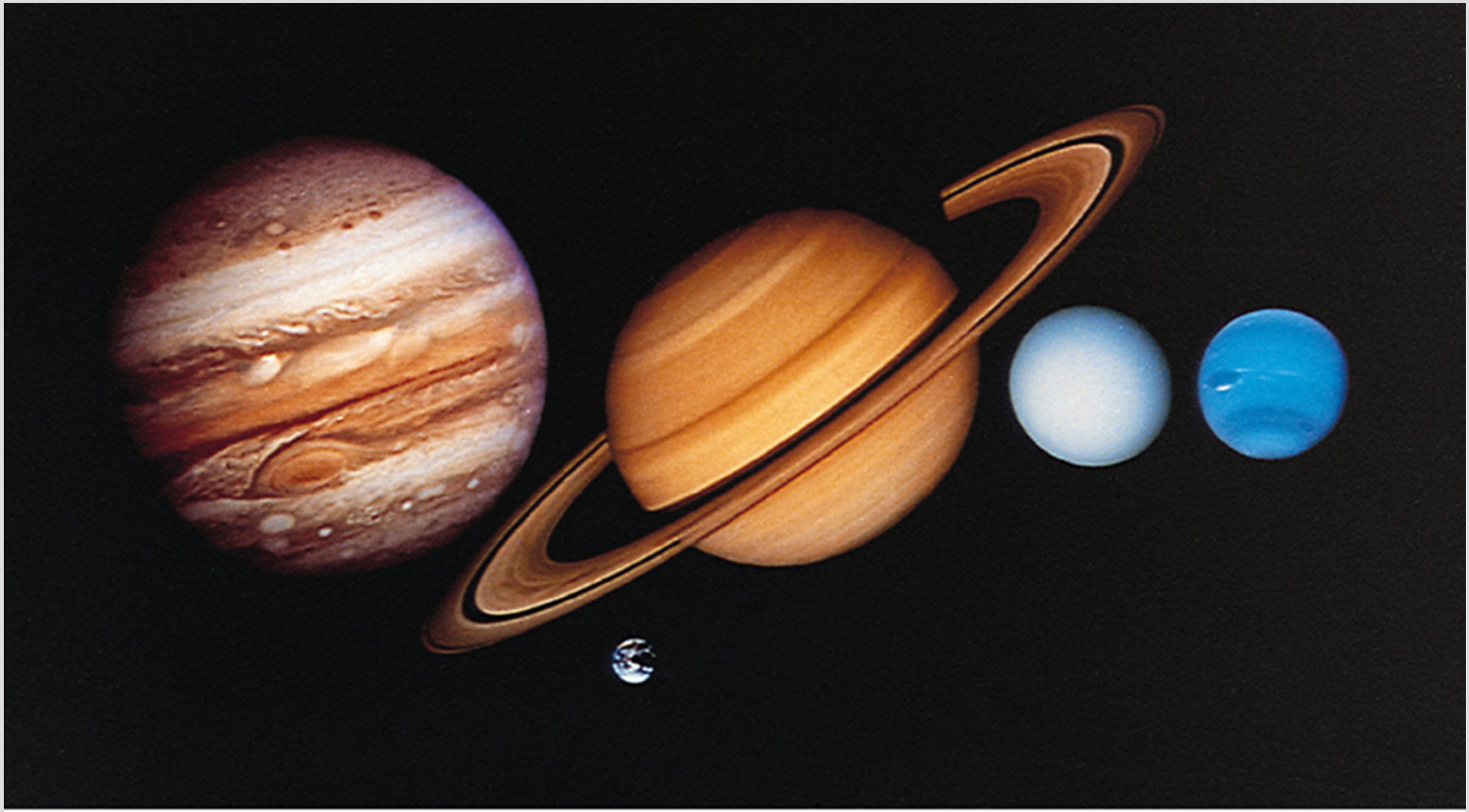
12. Jovian Planet Systems



Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature.

St. Albertus Magnus (1206 – 1280)
scholar and patron saint of scientists



- Pioneer 10 & 11 flybys early 1970s
- Voyager 1 & 2 flybys late 70s early 80s
- Galileo (Jupiter) 1995
- Cassini (Saturn) 2004

Jovian Planet Properties

Table 12.1. Comparison of Bulk Properties of the Jovian Planets

Planet		Average Distance from Sun (AU)	Mass (Earth masses)	Equatorial Radius (Earth radii)	Average Density (g/cm^3) (Earth = 5.52 g/cm^3)	Bulk Composition
Jupiter		5.20	318	11.2	1.33	Mostly H, He
Saturn		9.54	95	9.46	0.71	Mostly H, He
Uranus		19.2	14	3.98	1.24	Hydrogen compounds and rock, H and He
Neptune		30.1	17	3.81	1.67	Hydrogen compounds and rock, H and He

Jovian Planet Properties

- Compared to the terrestrial planets, the Jovians:
  - are much larger & more massive
  - are composed mostly of Hydrogen, Helium, & Hydrogen compounds
  - have no solid surfaces
  - all atmosphere/little core – opposite of terrestrials
  - Sun-like in composition but no fusion

Jovian Rotation

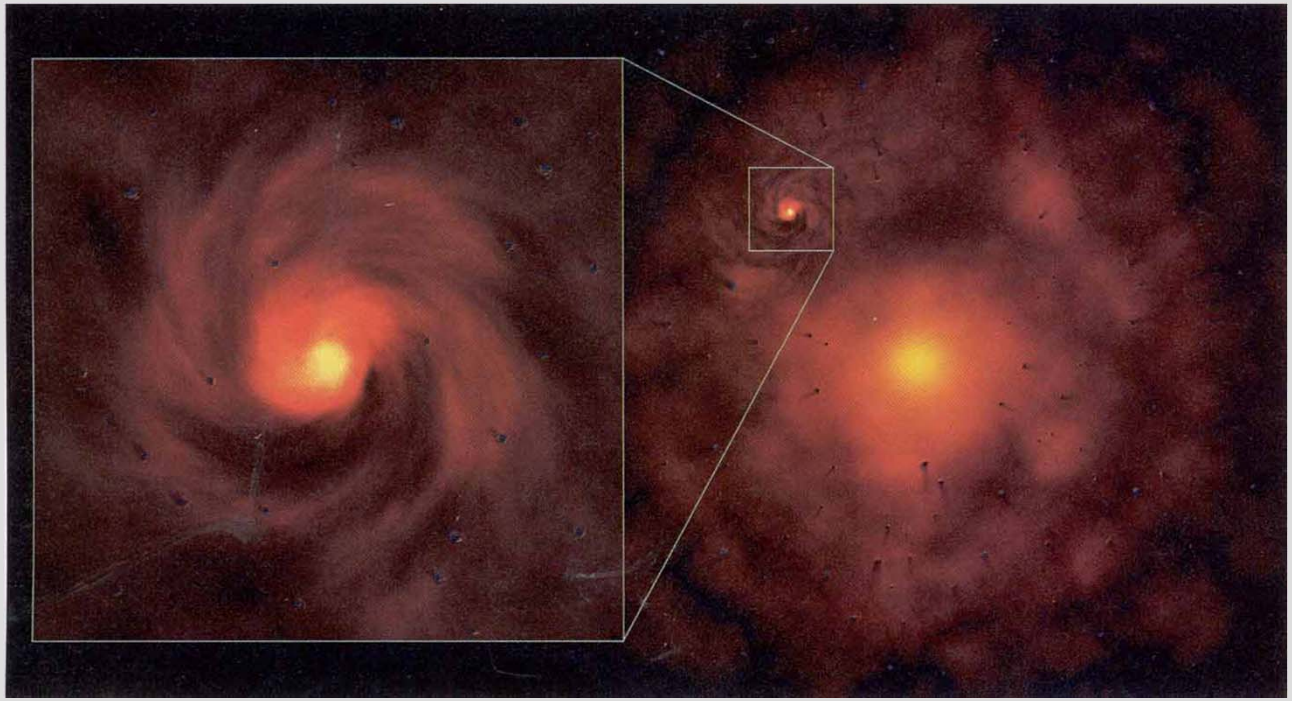
- Rotation rate inferred by measuring rotation rate of the magnetosphere
- 10 hours for Jupiter and Saturn
- 16-17 hours for Neptune and Uranus
- Even though they’re large, they rotate very quickly
- Due to the fast rotation, an equatorial bulge makes the planets slightly squashed.

Satellites and Rings

- >100 known Jovian satellites
  - Some are terrestrial like but most are probably captured asteroids
- All Jovians have rings
  - Small pieces of rock and ice orbiting in the same plane

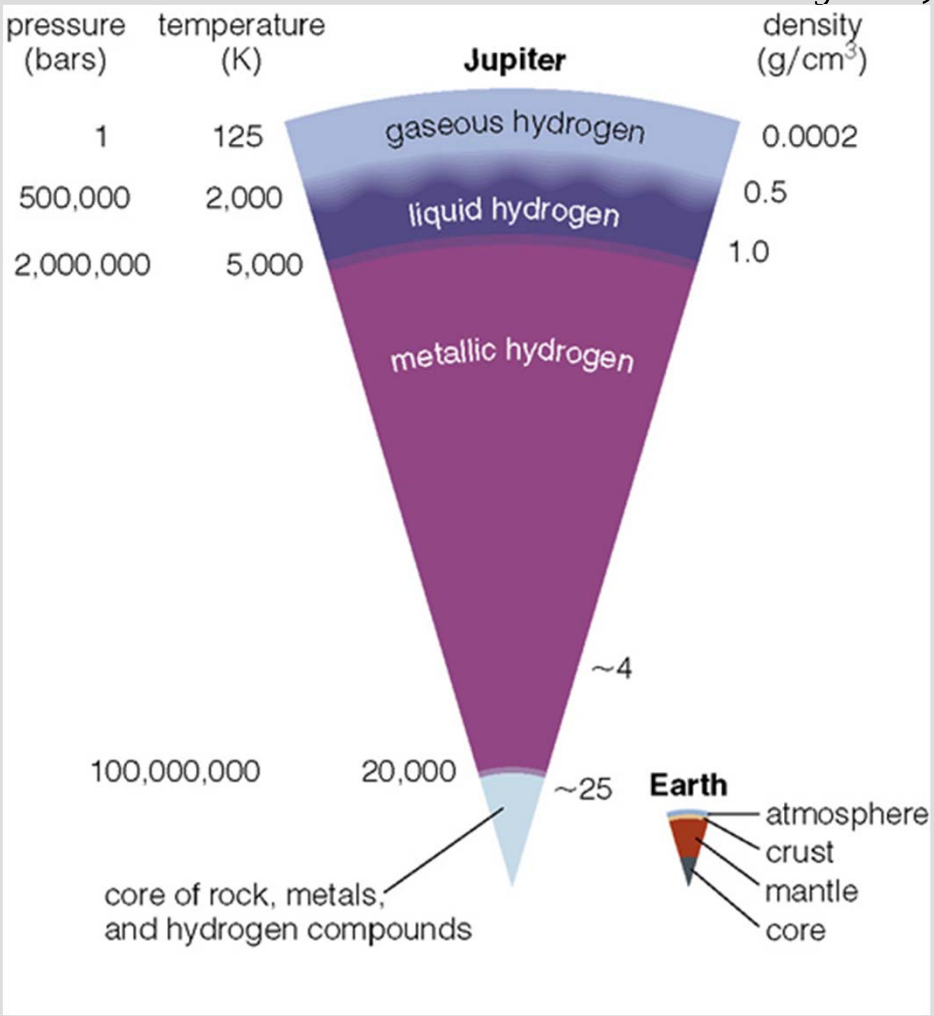
Why are the Jovian Planets so Different?

- They formed beyond the frost line to form large, icy planetesimals which were massive enough to…
- Capture H/He far from Sun to form gaseous planets.
- Each Jovian planet formed its own “miniature” solar nebula.
- Moons formed out of these disks.



Inside Jupiter

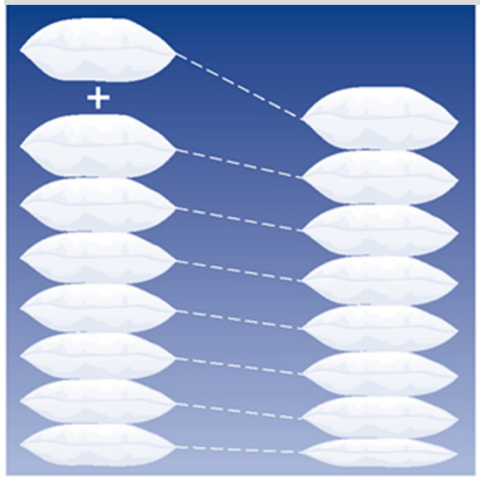
Although Jupiter has no solid surface and consists mostly of H & He, it does have distinct interior layers, defined by *phase*.

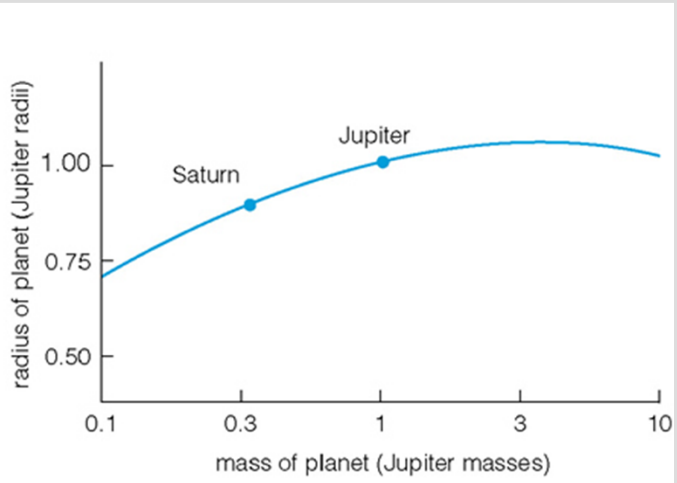


- Moving from the surface to the core:
  - temperature increases
  - pressure & density increases
- The core of Jupiter is slightly larger than Earth.
- But it is 5 times as dense!
  - thank to tremendous weight from above
- So Jupiter's core has 10 times the mass of Earth.

Inside Jupiter

- Jupiter emits almost twice as much energy as it absorbs from the Sun.
  - accretion, differentiation, radioactivity can not account for it
  - Jupiter must still be contracting
- Jupiter has 3 x more mass than Saturn, but is not much larger!
  - the added weight of H & He compresses the core to a higher density
  - just like stacking pillows

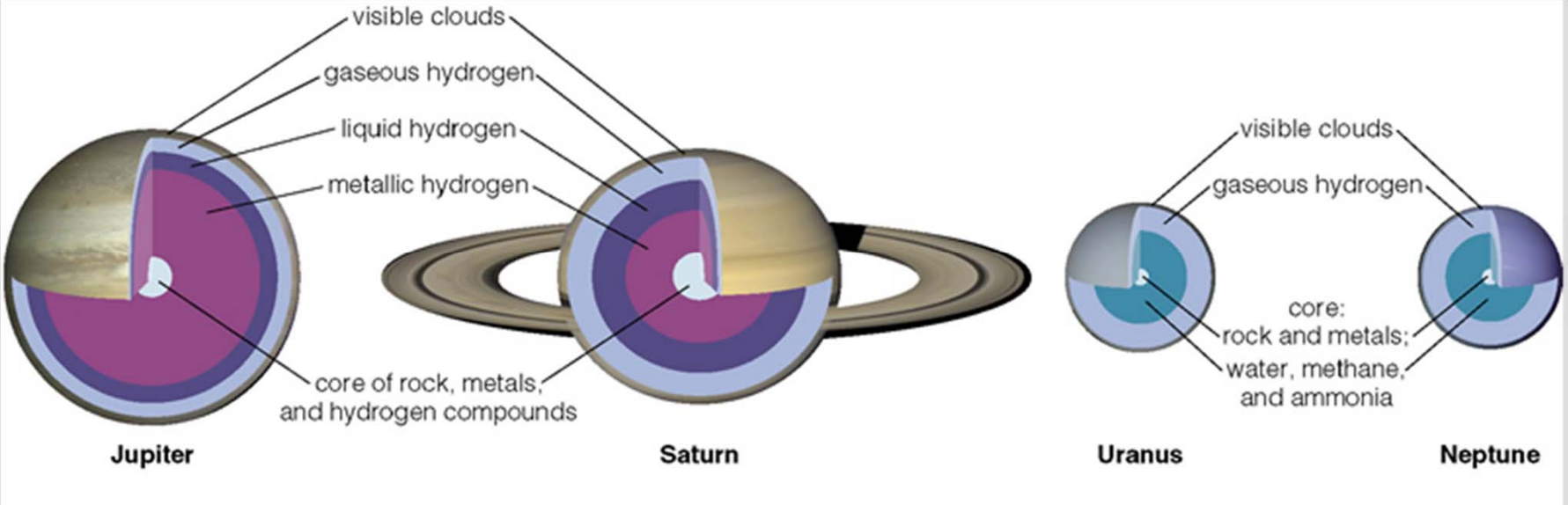




- Add even more mass, and Jupiter would get smaller.
- Jupiter is about as large as a planet can get.
- Uranus & Neptune have less mass than Saturn, yet
  - they have higher densities
  - they must be made of denser material

Inside the Jovian Planets

- All Jovian cores appear to be similar.
  - made of rock, metal, and Hydrogen compounds
  - 10 x the mass of Earth
- Uranus & Neptune captured less gas from the Solar nebula.
  - accretion of planetesimals took longer
  - not much time for gas capture before nebula was cleared out by Solar wind
- Only Jupiter and Saturn have high enough pressure for H & He to exist in liquid and metallic states.



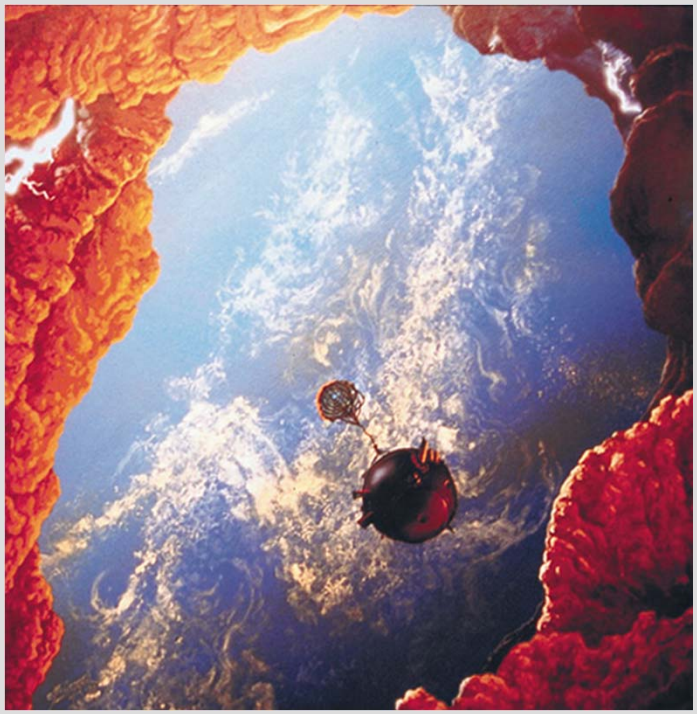
Internal Heat

- Saturn emits 2x as much as it absorbs
  - Not due to contraction but perhaps due to He rain causing ongoing differentiation
- Uranus is much smaller and shows no excess heat that needs to be accounted for
- Neptune is smaller like Uranus but still emits 2x as much as it absorbs. Unknown but probably due to contraction.

Jupiter's Atmospheric Composition

- 75% H, 24% He, rest hydrogen compounds
- CH_4, NH_3, H_2O, acetylene, ethane, propane, etc.
- Responsible for Jupiter's appearance
  - Clouds
  - Colors

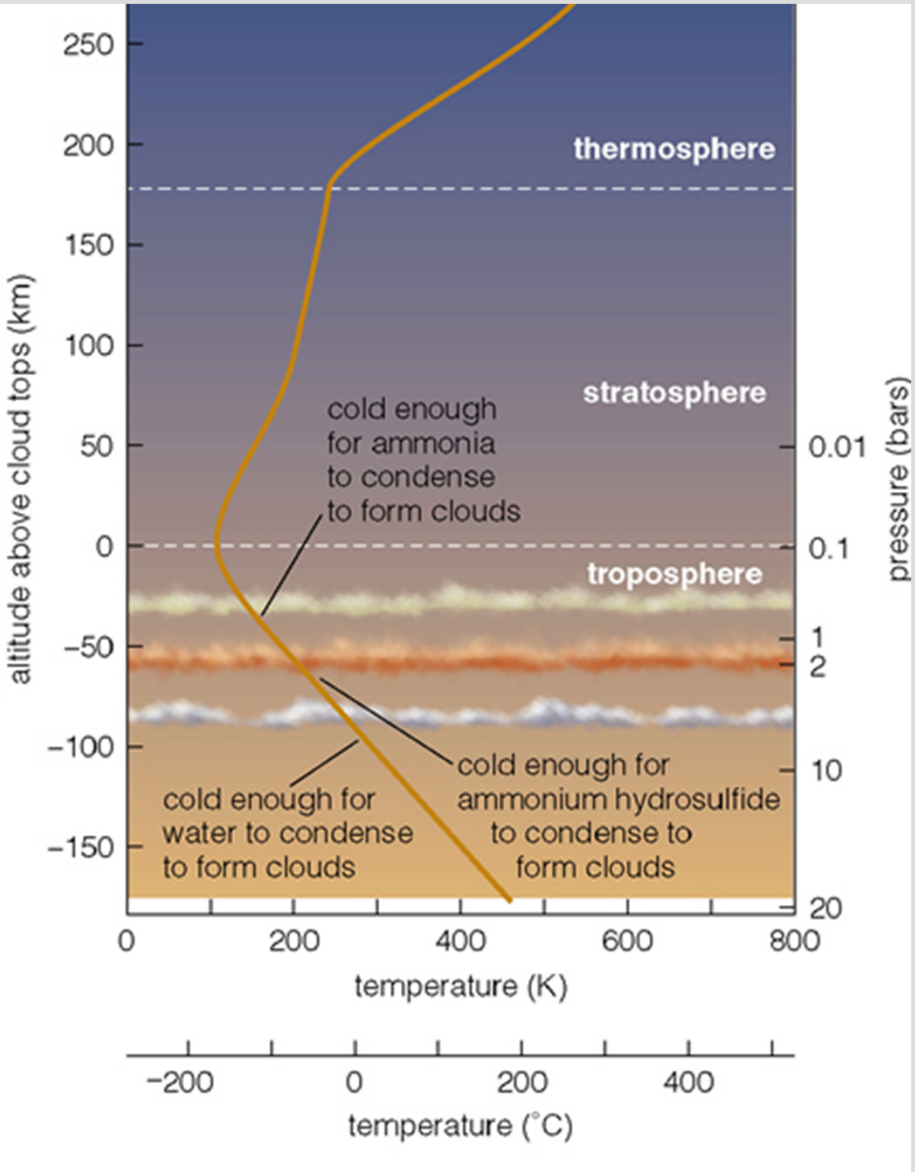
Jupiter's Atmosphere



- In 1995, the Galileo space probe plunged into the planet Jupiter
- It measured the atmospheric structure of Jupiter (T,P,comp,rad)
  - thermosphere {absorbs Solar X-rays}
  - stratosphere {absorbs Solar UV}
  - troposphere {greenhouse gases trap heat from both Jupiter and the Sun}

- These are the same structures found in Earth's atmosphere.
  - Atmospheres are governed by interactions between sunlight and gases.

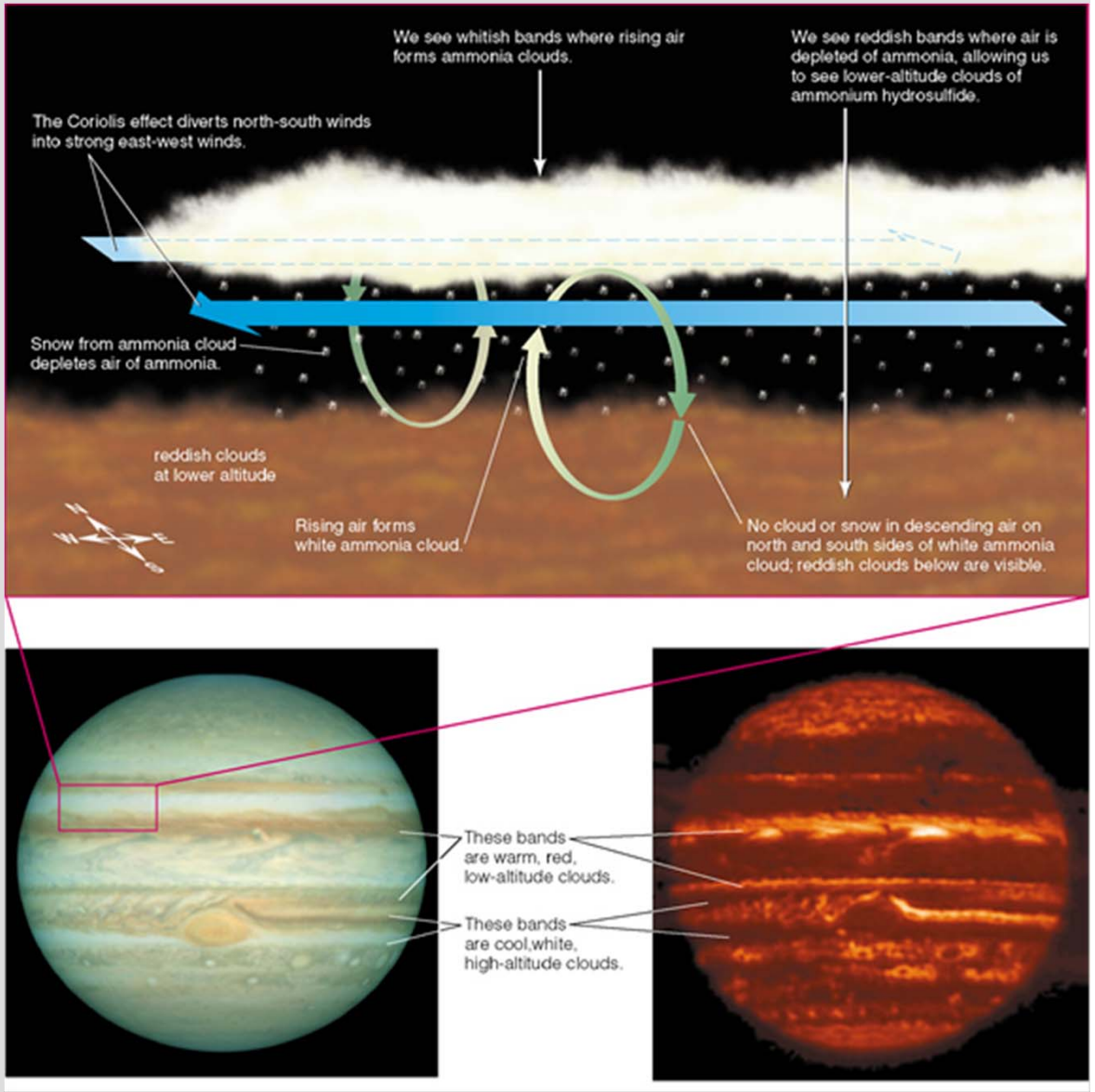
Jupiter's Cloud Layers



- Convection in the troposphere causes Jovian winds and weather.
- Warm gas rises to cooler altitudes, where it condenses to form clouds.
- Three gases condense in the Jovian atmosphere:
  - ammonia (NH_3)
  - ammonium hydrosulfide (NH_4SH)
  - water (H_2O)
- They condense at different temperatures, so their clouds form at different altitudes.

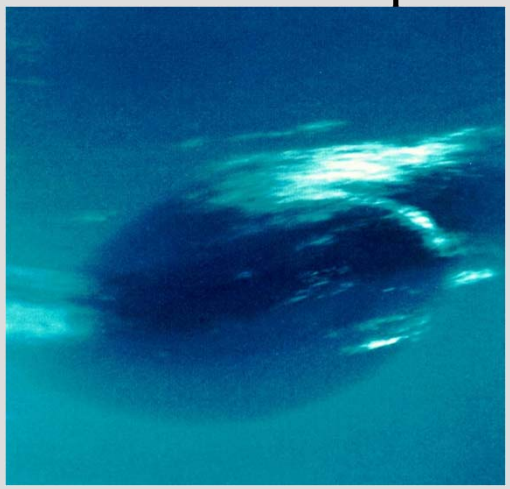
Jupiter's Cloud Layers

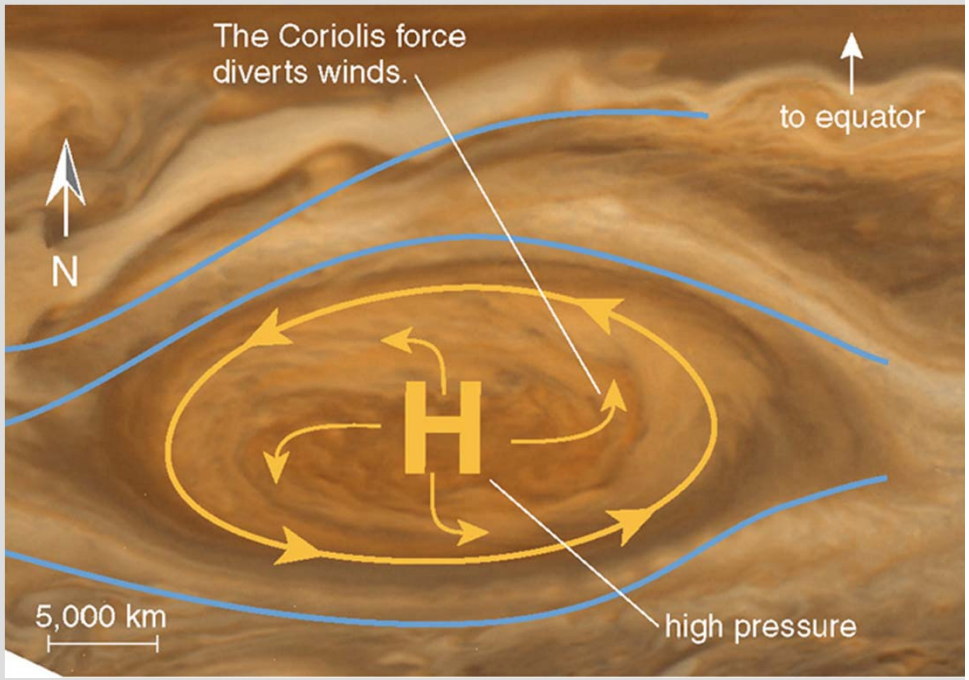
- Like Earth, Jupiter has circulation cells in its atmosphere.
- Jupiter is much larger & rotates much faster.
  - Coriolis effect is much stronger on Jupiter
  - circulation cells are split into many bands of rising and falling air
  - these are the colored "stripes" which we see
- The so-called:
  - zones (rising air)
  - belts (falling air)



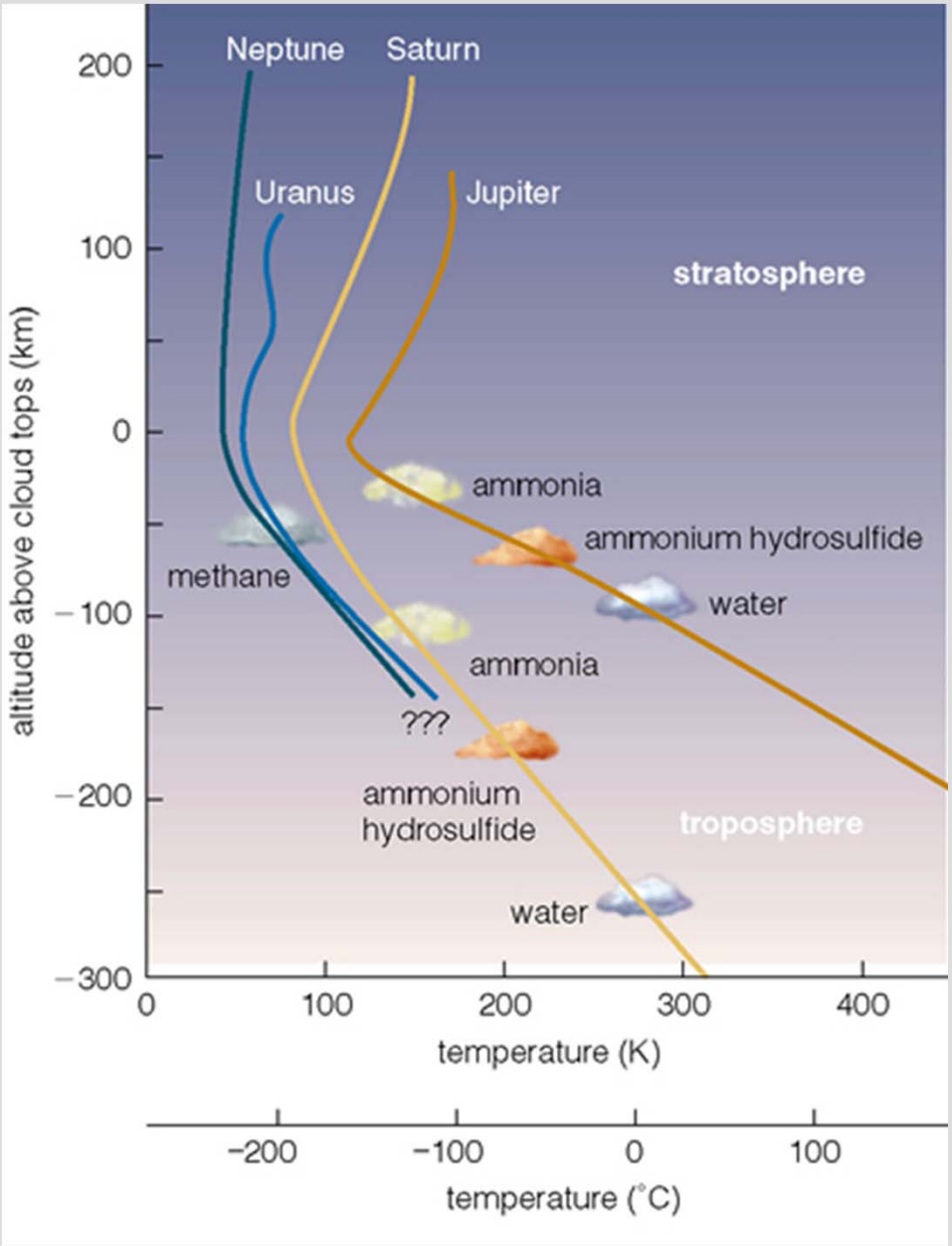
Jovian Storms

- Winds strongest near equator and between belts & zones
- We also see high pressure storms
  - analogous to hurricanes, but they rotate in the opposite direction
- Jupiter
  - the Great Red Spot
  - we are not sure why it is red
- Neptune
  - the Great Dark Spot





The Jovian Atmospheres

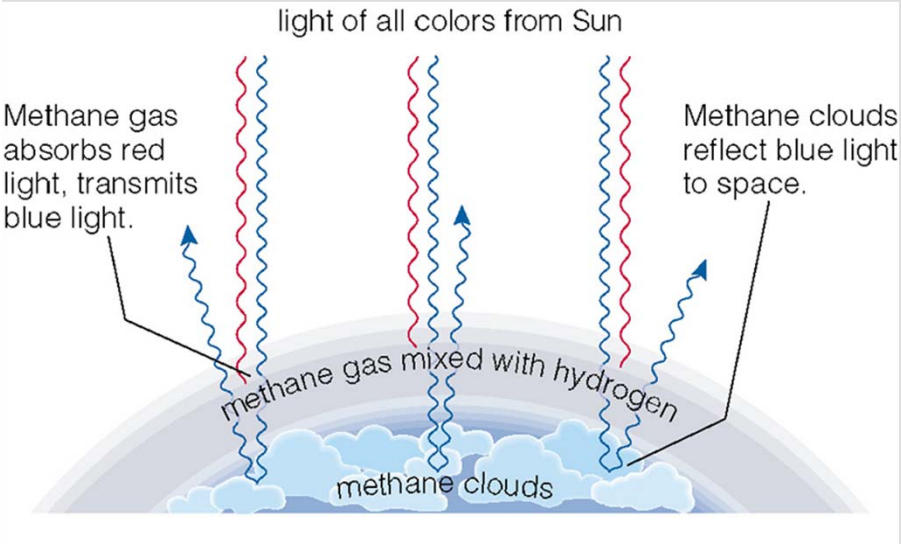


- The temperature profile of each planet determines the color of its appearance.
- Cloud layers form where a particular gas condenses.
- Saturn has the same cloud layers as Jupiter.
  - they form deeper since Saturn is colder overall
  - they are spread farther apart since Saturn has lower gravity
- Uranus & Neptune
  - cold enough to form methane clouds

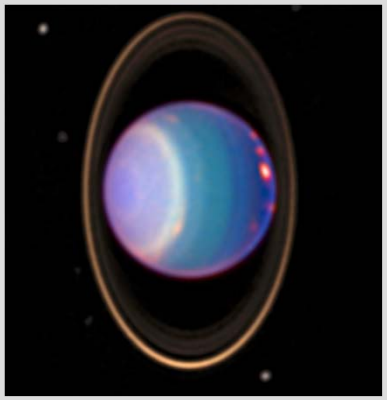
Jovian weather

- Jupiter's weather is the most active
- Saturn has stripes like Jupiter but lacks the amount of color change. Smaller storms than Jupiter but stronger winds. Might expect seasons due to axis tilt but internal heat keeps temperature uniform.
- Neptune also striped. Has large storms (Great Dark Spot). Internal heat makes uniform temp.
- Uranus is tilted ~90° => extreme seasons?
  - No clouds or stripes in 1986
  - More recent HST observations show extreme weather
    - Possibly due to southern hemisphere seeing light for the first time in decades

Why Uranus & Neptune are Blue



1986 - Visual

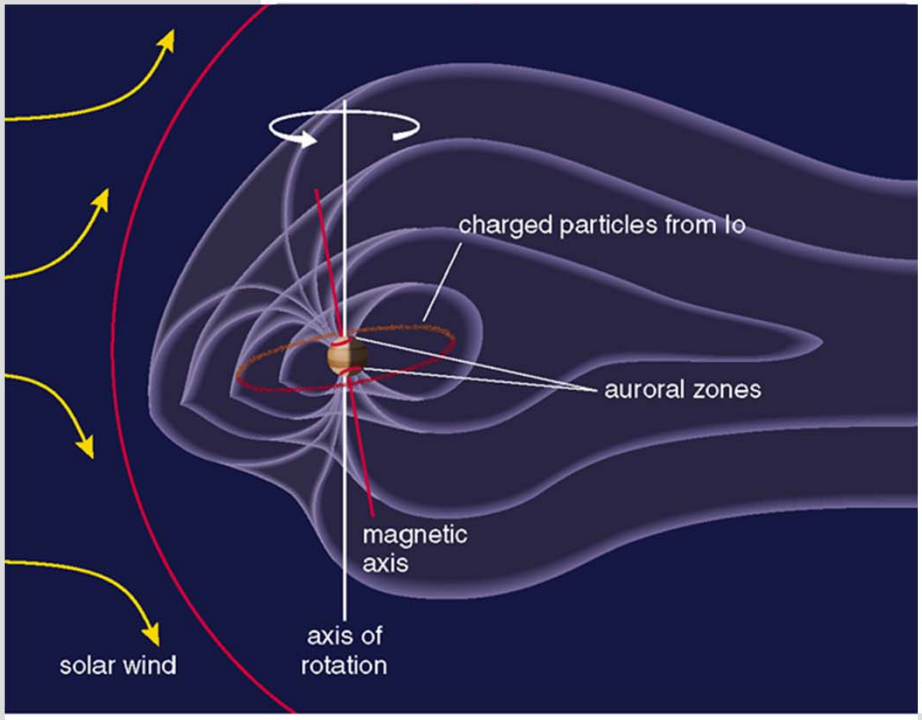


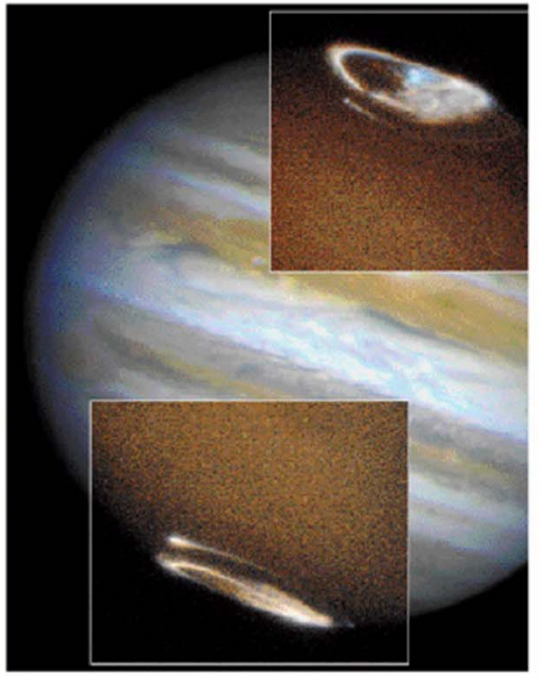
1998 - IR

- They have a higher fraction of methane gas 20x more than others.
  - Methane absorbs red sunlight.
  - Only blue light is reflected back into space by the clouds.
- Neptune bluer because light penetrates more deeply
- Uranus has more of a smoglike haze that scatters the light before it hits the methane clouds
  - This extra haze could help the long extreme seasons

Jupiter's Magnetosphere

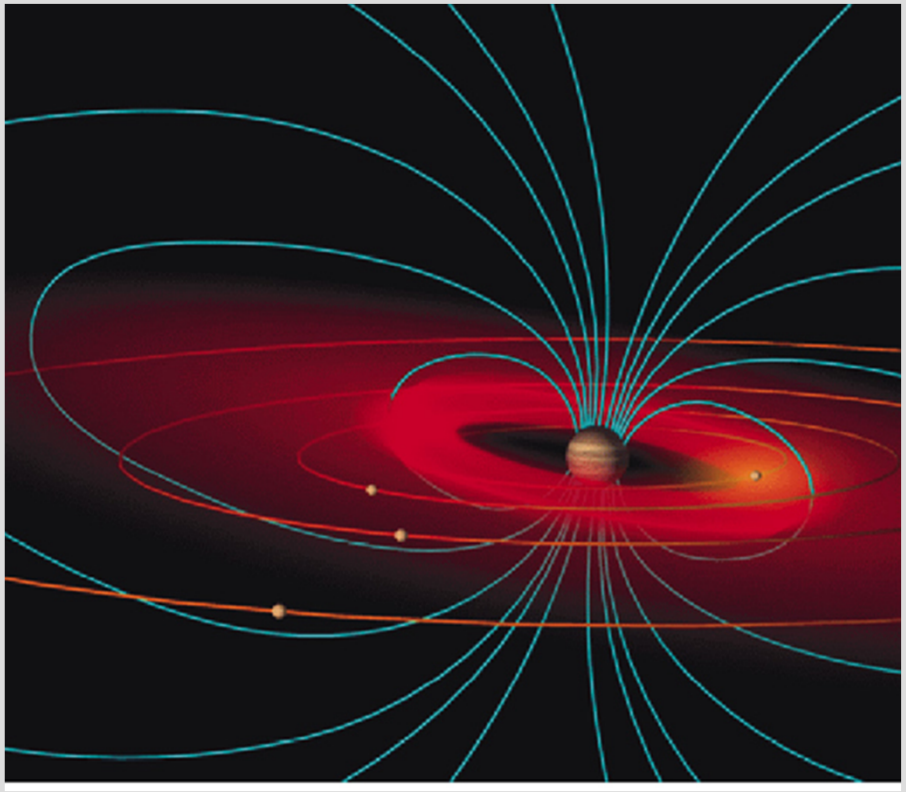
- Its general properties are very similar to Earth's, except
  - it is about 20,000 times stronger
  - it extends 3,000,000 km beyond Jupiter
    - As large as the full moon and extended to Saturn
- Charged particles from the Solar wind (& Io) cause auroras.





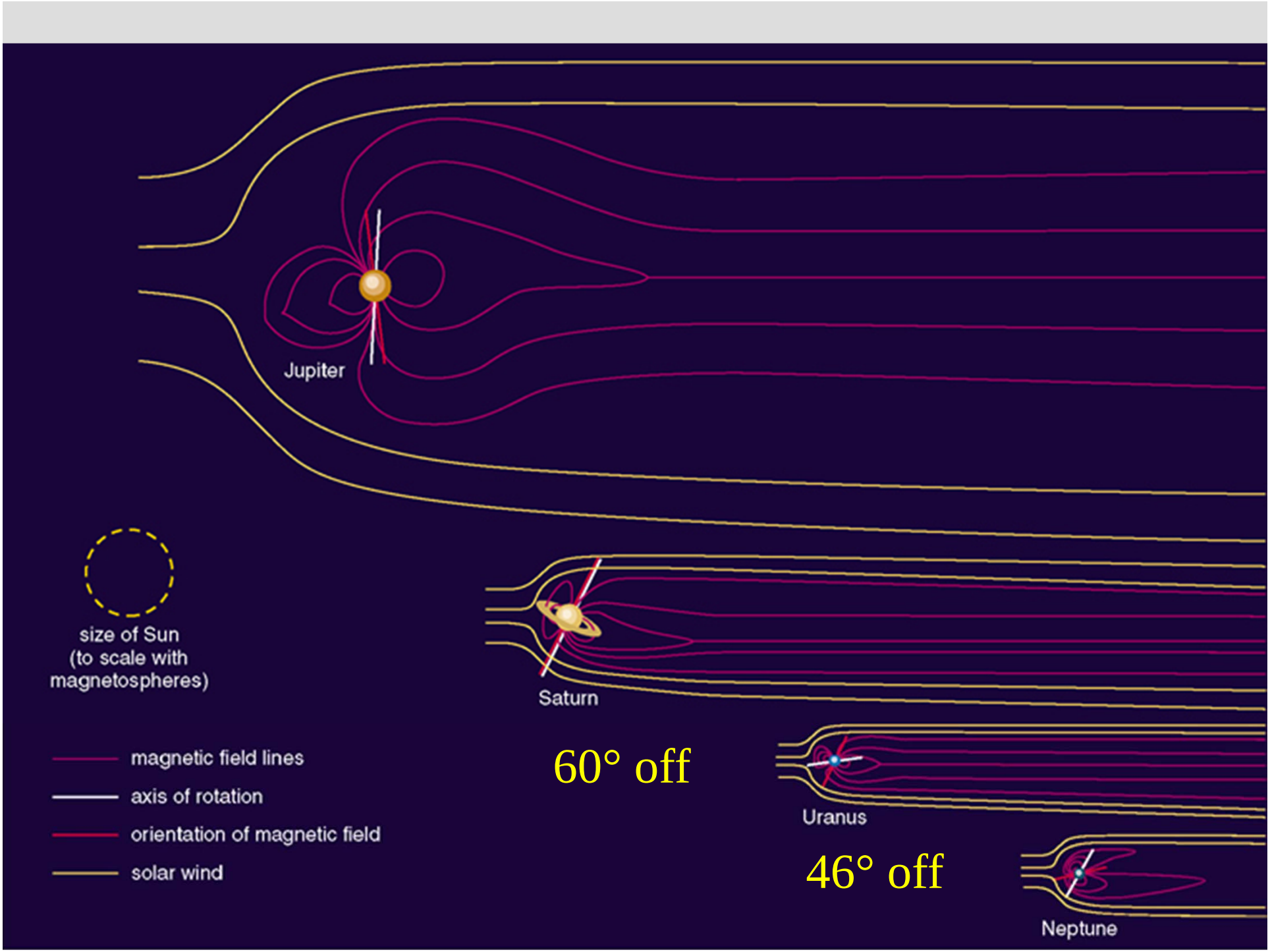
The Io Torus

- The moon Io loses volcanic gases into space.
  - gases are ions of Sulfur, Oxygen, Sodium
  - they form a donut-shaped belt of charged particles, called the **Io torus**
  - they follow Io's orbit & are a source of charged particles for the auroras
- Charged particles also alter the surfaces of other moons & form bombardment atmospheres



Jovian Magnetospheres

- Saturn, Uranus, & Neptune have smaller & weaker magnetospheres.
  - Saturn's metallic H layer is smaller
  - Uranus and Neptune's are probably due to their H compound/rock/metal fluid cores.
  - we can not explain the magnetic field tilts of Uranus & Neptune.
- Solar wind is weaker farther out, or else their magnetospheres would be even smaller. Lack of pressure allows moderate size even though they're weak.


Jupiter
size of Sun
(to scale with
magnetospheres)
Saturn
60° off
Uranus
46° off
Neptune
magnetic field lines
axis of rotation
orientation of magnetic field
solar wind

Jovian Planets have Numerous Moons

We can divide them into three groups:

- small moons
  - less than 300 km across
  - they are not spherical
  - probably captured asteroids
- medium moons
  - 300 to 1,500 km in diameter
- large moons
  - greater than 1,500 km in diameter
- both groups formed like planets out of the “mini-Solar nebulae” surrounding the Jovian planets

Jovian moons (M/L)

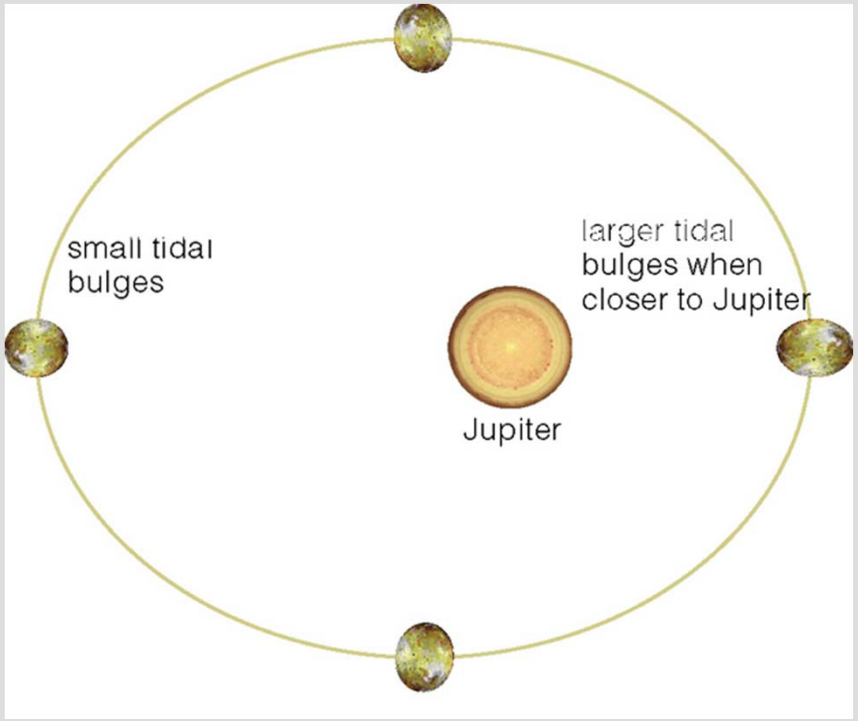
- Spherical, solid surface unique geologies
- Some atmospheres, hot interiors and magnetic fields
- 2 larger than Mercury (Ganymede & Titan)
- 4 larger than Pluto (Io, Europa, Callisto, Triton)
- Nearly all synchronous rotation

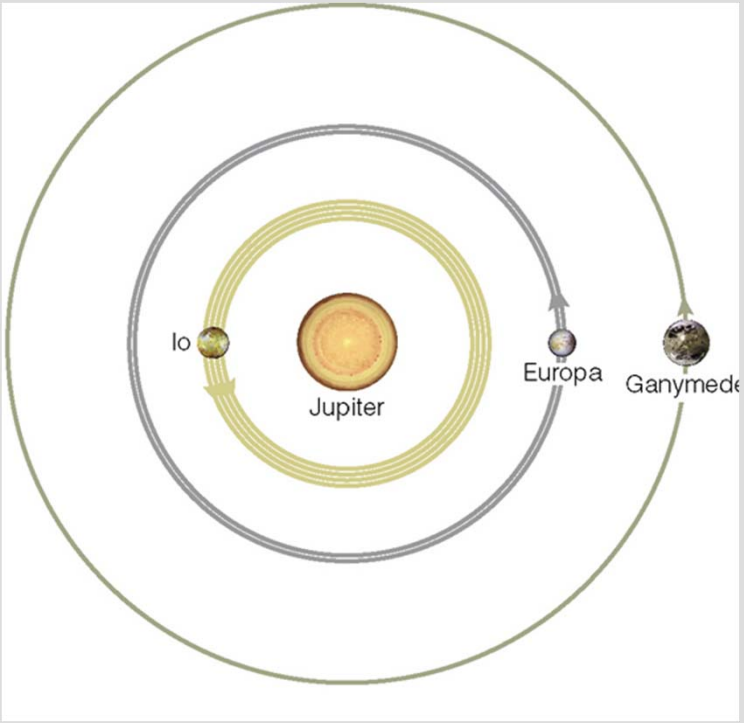
Why are these moons geologically active?

- Formation distance
  - terrestrial planets are made mostly of rock
  - Jovian moons are made mostly of ice
- Ices melt at lower temperatures than rock.
  - less heating is required to have molten cores
  - volcanism and tectonics can occur
- There is another heat source.
  - tidal heating plays a more important role
- There is very little erosion due to lack of substantial atmospheres *with the exception of Titan*.

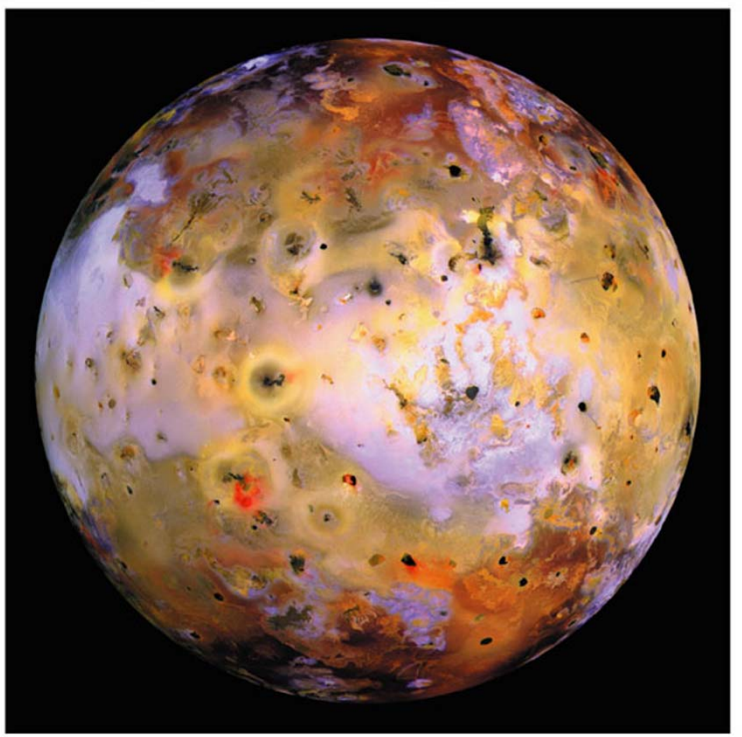
The Jovian Moons

- The moons of Jupiter become less dense as you get farther from Jupiter
  - “mini Solar System”
- Gravitational tidal heating keeps the interiors of the inner moons hot.

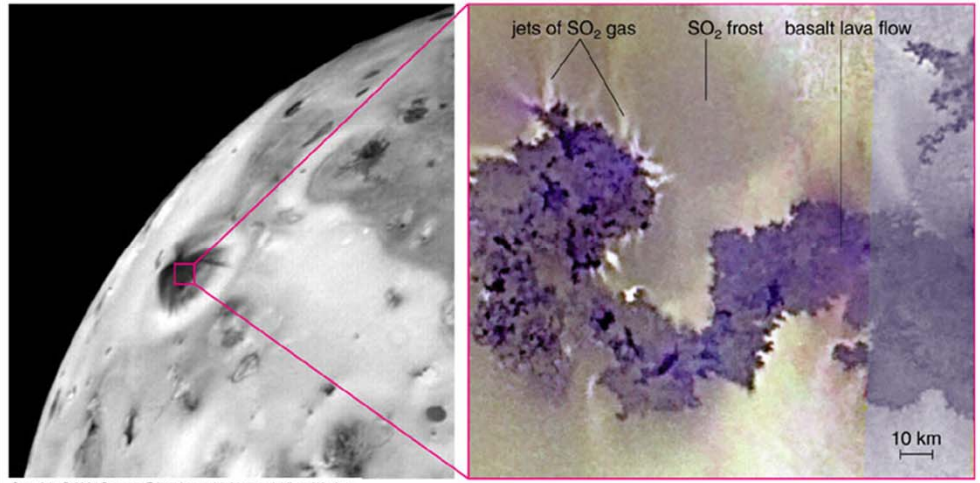


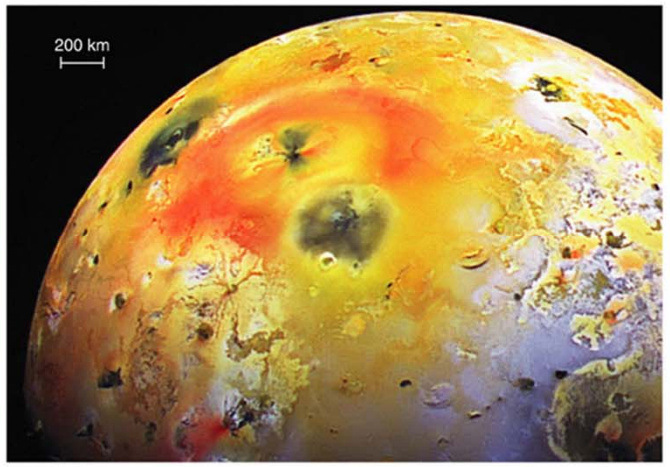


Io

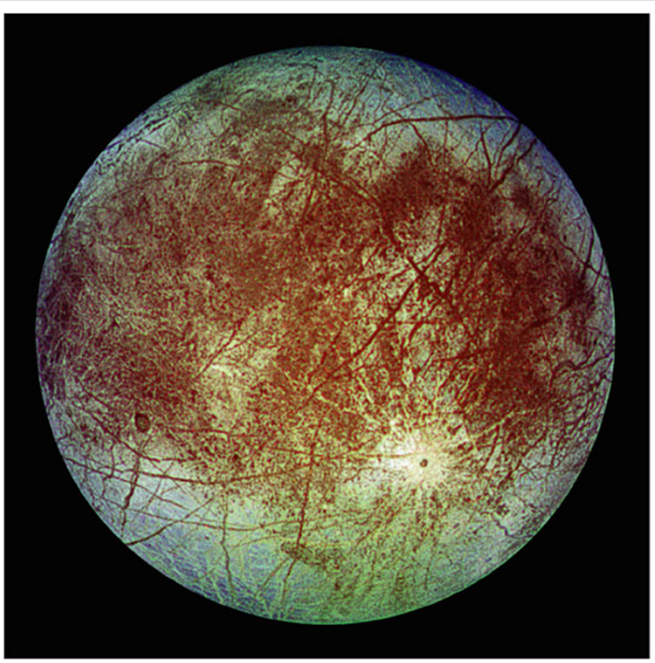


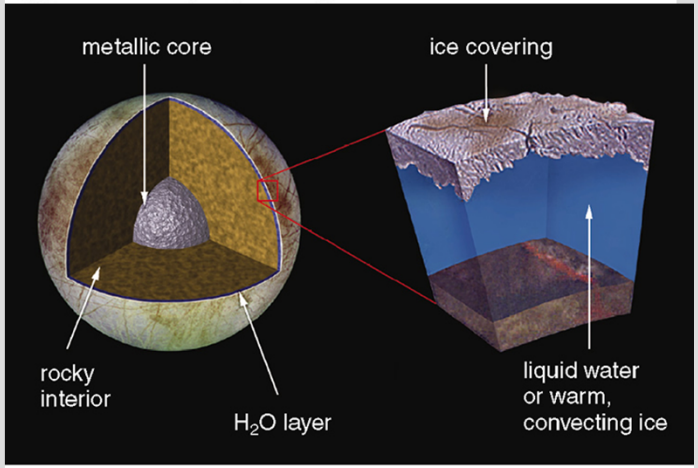
- Jupiter's tidal forces flex Io like a ball of silly putty.
  - friction generates heat
  - interior of Io is molten
- Volcanoes erupt frequently.
  - sulfur in the lava accounts for yellow color
  - surface ice vaporizes and jets away
- Evidence of tectonics & impact cratering is covered.





Europa

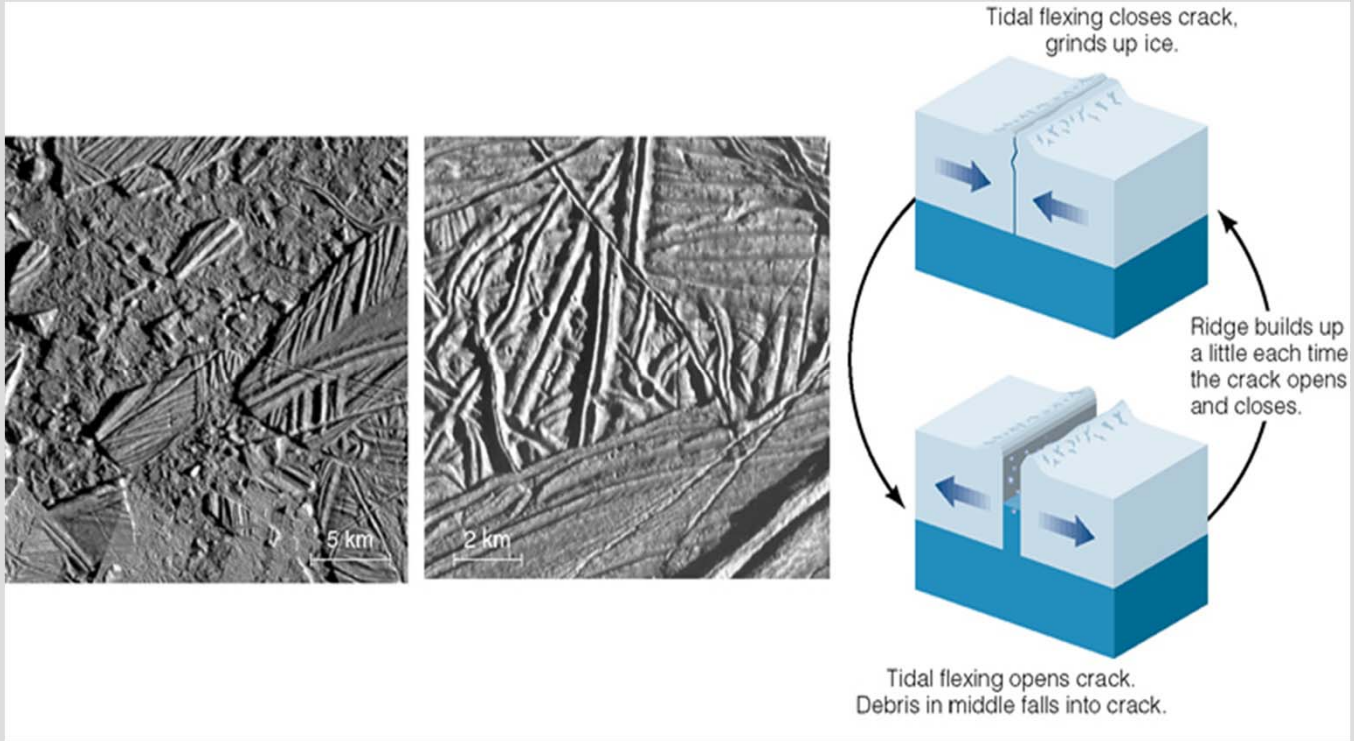




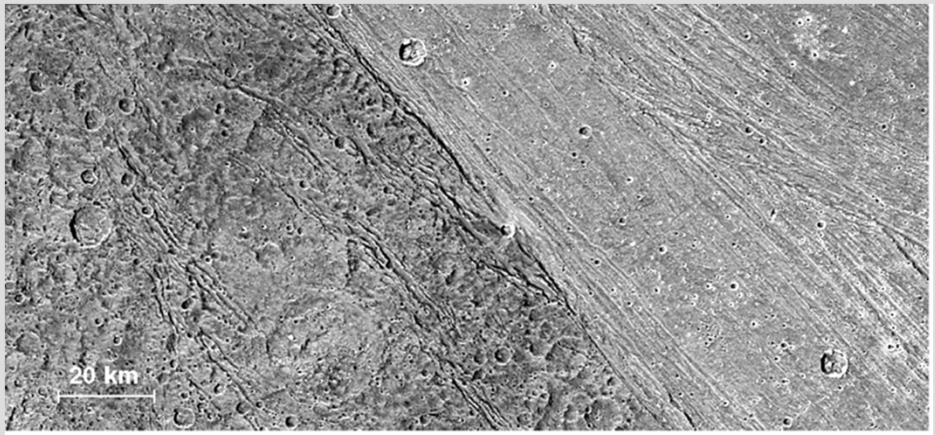
- metallic core, rocky mantle, and a crust made of H_2O ice
- Its fractured surface tells a tale of tectonics.
- These provide photographic evidence of a subsurface ocean.
- Europa has a magnetic field.
  - implies liquid salt water beneath the icy crust
- Where liquid water exists, there could be life!

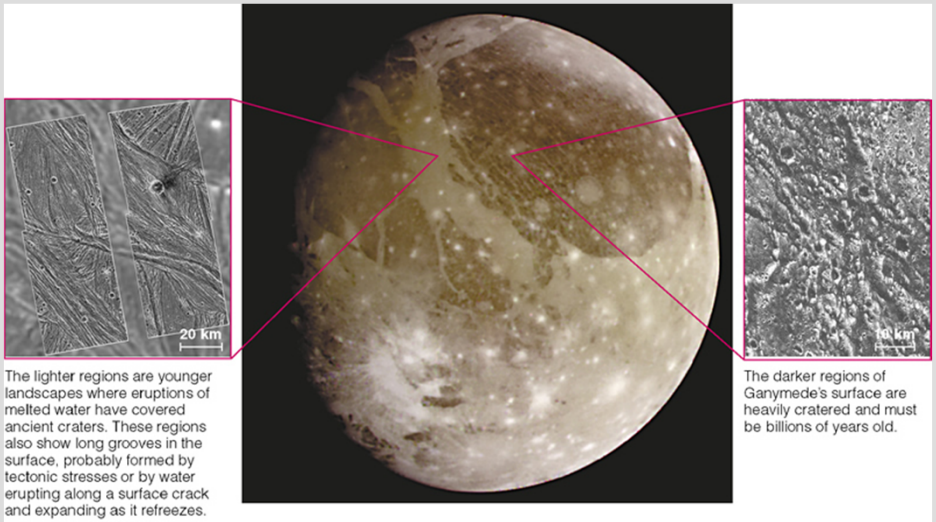
Evidence for H_2O

- Jumbled icebergs
- Double ridged cracks



Ganymede





- largest moon in the Solar System
- Its surface (ice) has 2 types of terrain:
  - Darker, heavily cratered, implies old
  - Lighter, long grooves, few craters, implies young like Europa
- It also has a magnetic field.
- Could it have subsurface ocean?
  - case not as strong as Europa's
  - tidal heating would be weaker
  - would need additional heating from radioactive decay

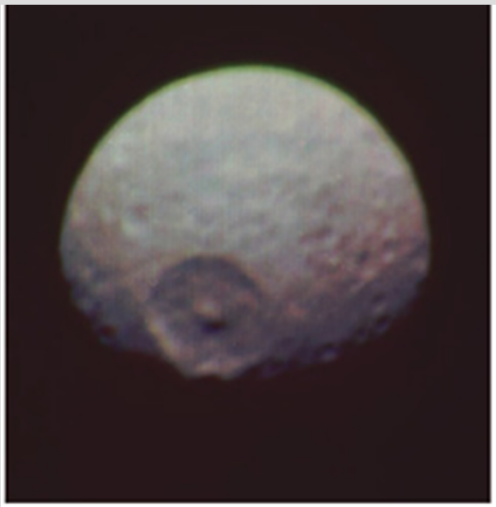
Callisto

- It has an old surface.
  - heavily cratered, dirty ice
  - cratering reveals clean, white ice
  - no evidence of tectonics
- Its interior did not differentiate.
  - rock mixed with ice
- It does not experience tidal heating.
- Yet it has a magnetic field.
- Could it have a subsurface ocean anyway?

Titan

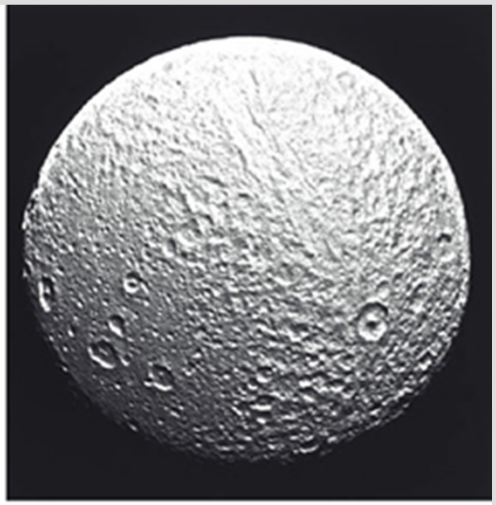
- largest of Saturn's moons
- It has a thick atmosphere.
  - Nitrogen (90%), Argon, methane, ethane
  - N comes from dissociated NH_3
  - methane, ethane are greenhouse gases: surface is warmer than it should be (93K)
  - Surface pressure = 1.5bars
- Book says no methane in atmosphere, actually there is. Measured by Cassini/Huygens
  - Found no surface oceans
  - Methane in atmosphere probably from volcanic outgassing evaporating methane ice and putting it into the atmosphere
  - Methane ice crust on a subsurface water/ammonia ocean

Saturn’s medium moons



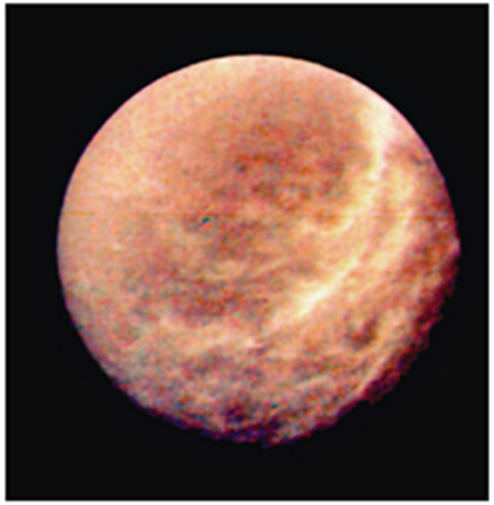
Mimas

Enceladus

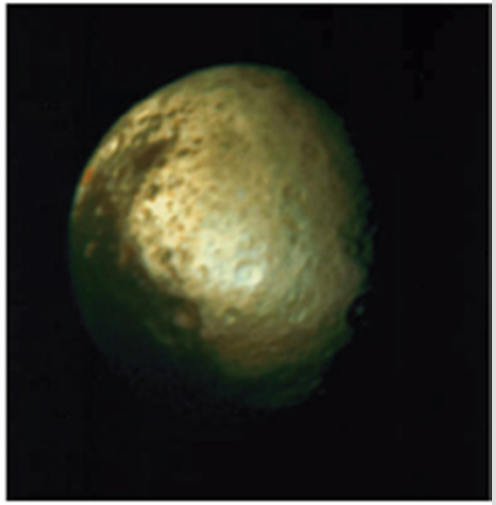


Tethys

Dione

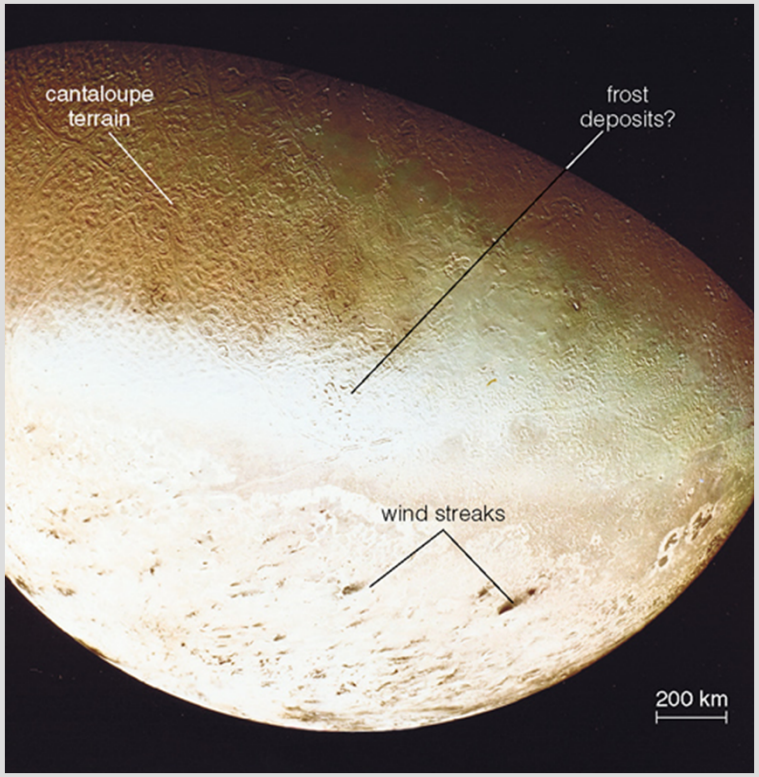


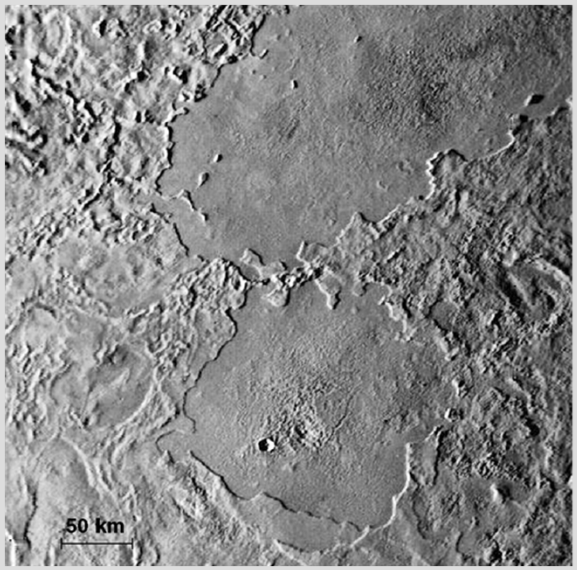
Rhea



Iapetus

Triton

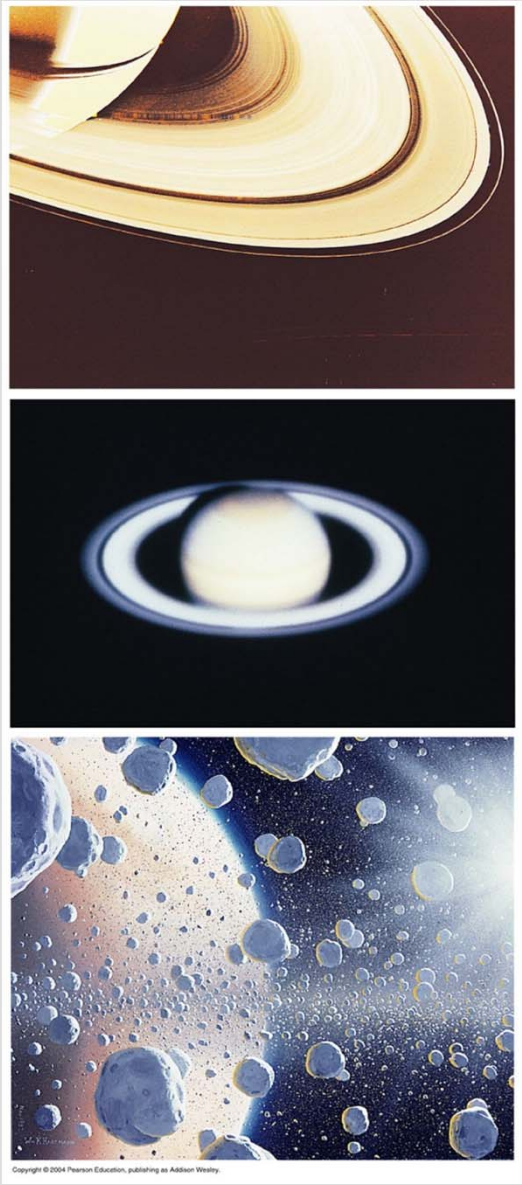




- The coldest world
- It orbits in the opposite direction of Neptune's rotation in a highly inclined orbit.
  - this implies that it was probably captured by Neptune
- It has a thin Nitrogen atmosphere, sublimed from the surface, causing wind streaks.
- “Ice geology” again probably due to tidal heating, again.

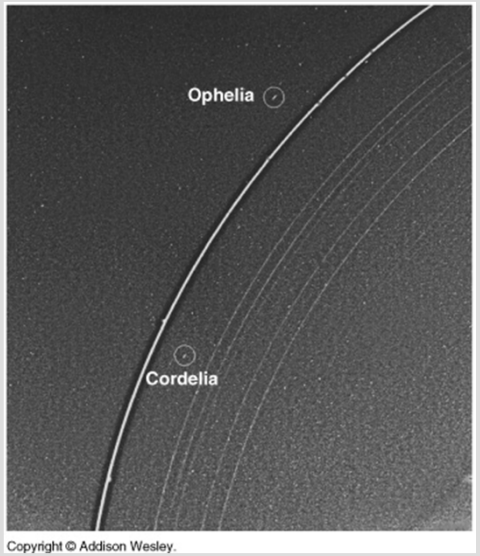
The Rings of Saturn

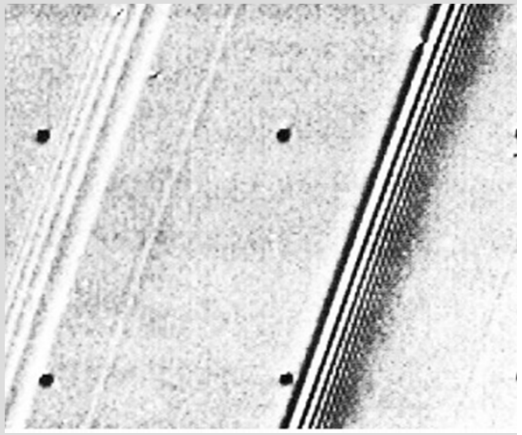
- From Earth, they look solid.
  - concentric rings separated by the *Cassini division*
- From spacecraft flybys, we see thousands of individual rings.
  - separated by narrow gaps
  - they differ in brightness & transparency
- From within the rings, we would see many individual particles
  - size ranges from boulders to dust
  - made of reflective H_2O ice (snowballs)
  - many collisions keep ring thin (tens of meters thick)

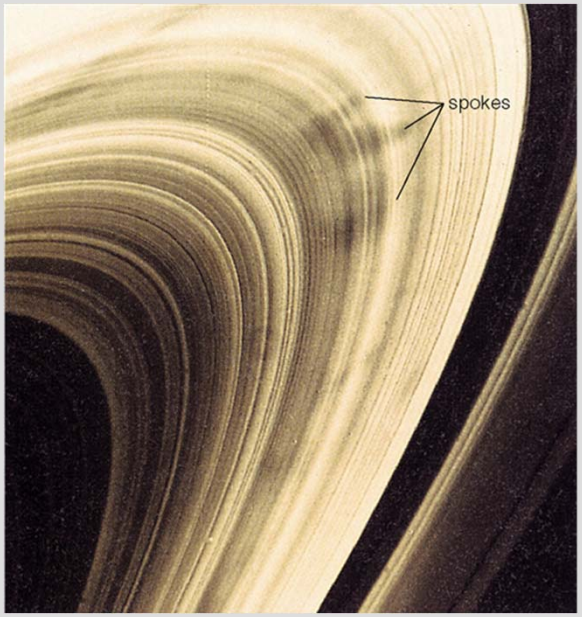


Rings, Ripples, and Spokes

- Gravitational interaction with moons inside the rings push particles into specific orbits.
  - clear gaps
- Interaction with larger, distant moons can clear gaps and form ripples. Mimas and Cassini

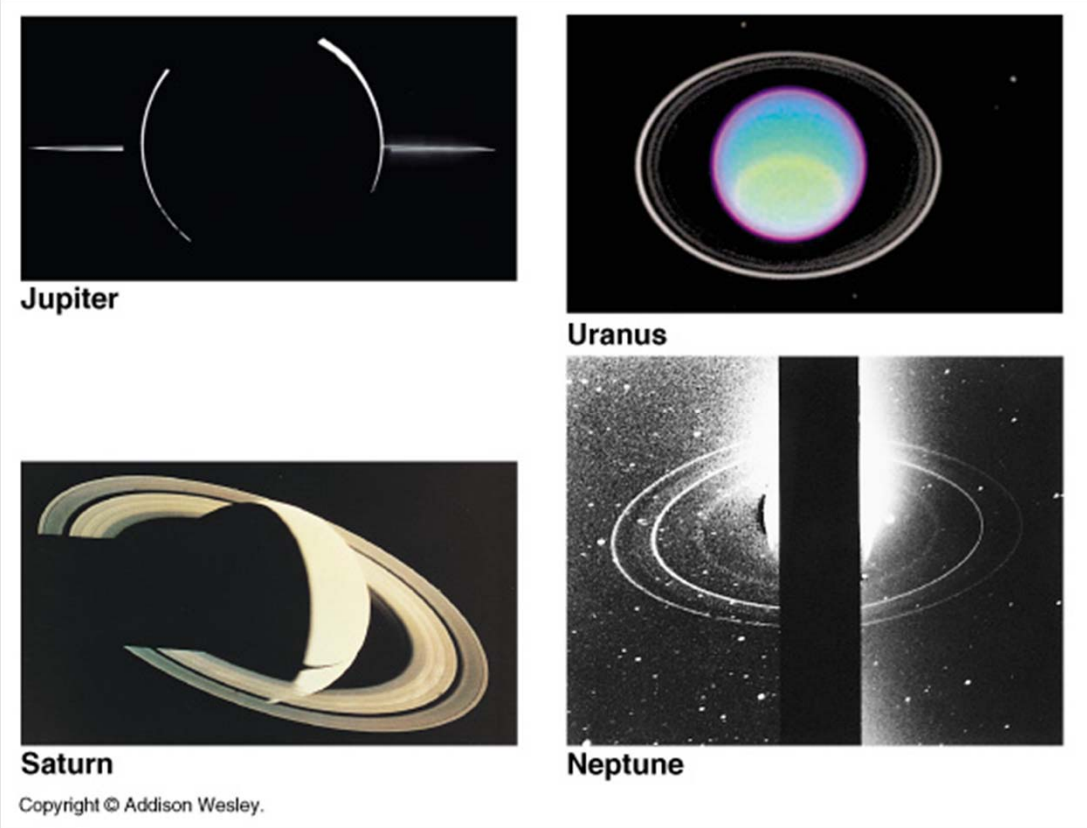






- Dark patches called **spokes** appear and disappear on short timescales.
- They are still a mystery.
- Perhaps they might be particles of dust drawn out by Saturn's magnetic field.

Comparing Jovian Ring Systems



- Lie in the equatorial plane
- Rings and gaps
- Circular orbits

- Compared to Saturn, the other ring systems:
  - have fewer particles
  - are smaller in extent
  - have darker particles
- Why this is so, we are not sure.
- Other unsolved mysteries:
  - Uranus' rings are eccentric and slightly tilted from its equatorial plane.
  - Neptune has partial rings.