Unit 8

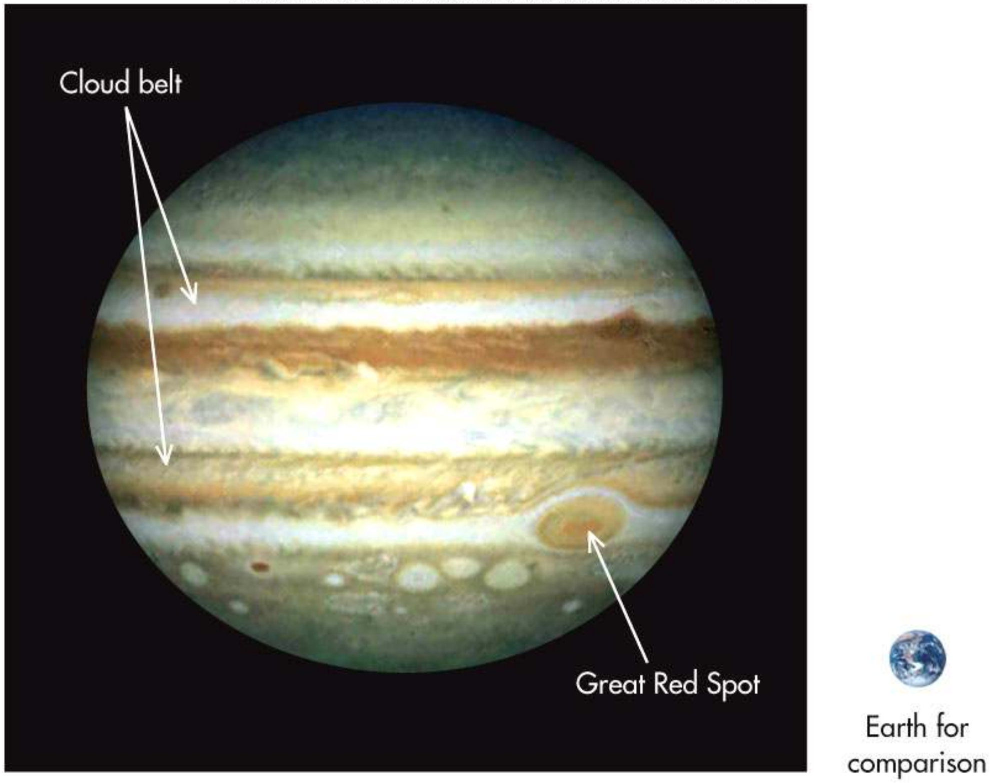
The Outer Planets

The Outer Worlds…

- Beyond the orbit of Mars, the low temperatures of the solar nebula allowed condensing bodies there to capture hydrogen and hydrogen-rich gases
- This, together with the vast amount of material in the outer Solar System, lead to the creation of the four large Jovian planets – Jupiter, Saturn, Uranus, and Neptune
- Composed mainly of gaseous and liquid hydrogen and its compounds, these planets lack solid surfaces and *may* have cores of molten rock
- The moons of the outer planets form families of miniature solar systems, although individually each moon presents a unique combination of size, structure, and appearance

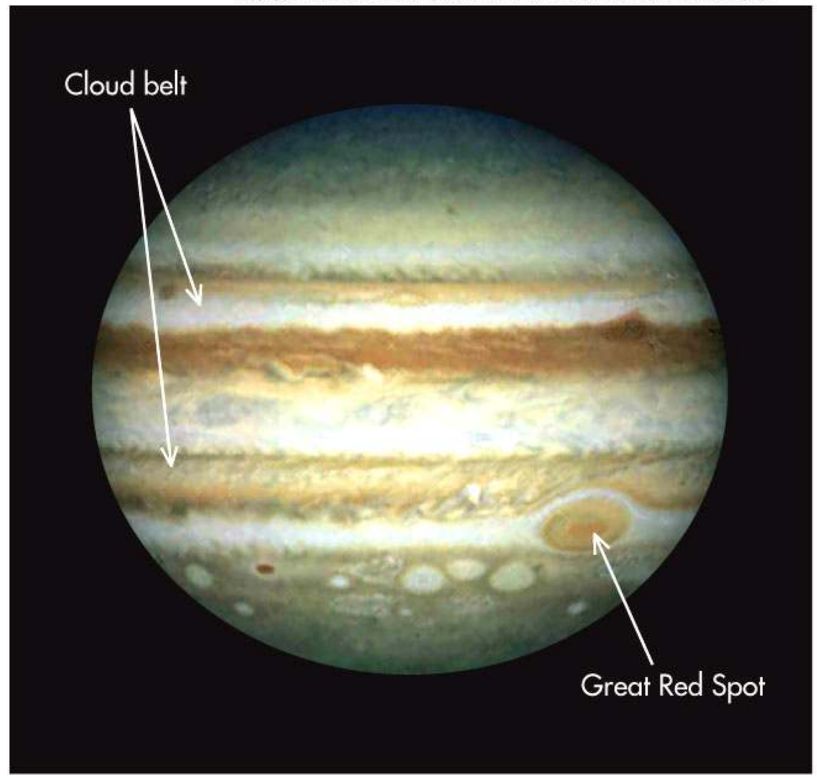
Jupiter

- Jupiter is the largest planet both in diameter and mass: more than 10× Earth's diameter and 300× the mass!
- Dense, richly colored parallel cloud bands cloak the planet
- Atmosphere is mainly H, He, CH_4, NH_3, and H_2O

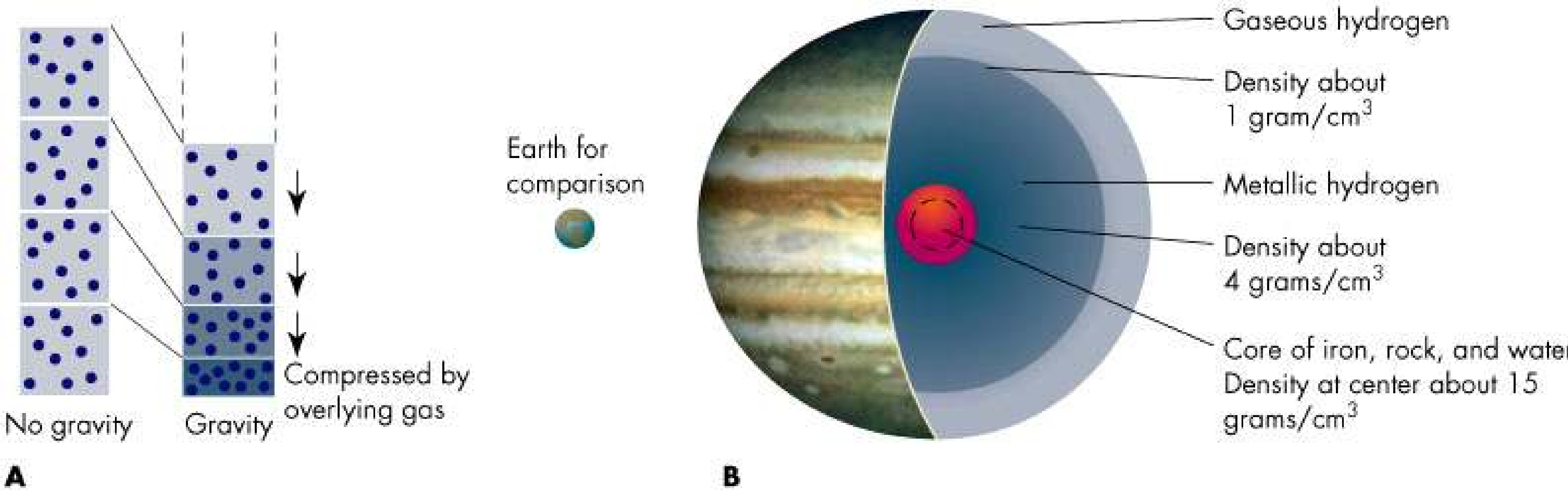


Jupiter

- Clouds appear to be particles of water, ice, and ammonia compounds
- Bright colors of clouds may come from complex organic molecules or compounds of sulfur or phosphorous
- Jupiter rotates once about every 10 hours with this fast rotation leading to a significant equatorial bulge



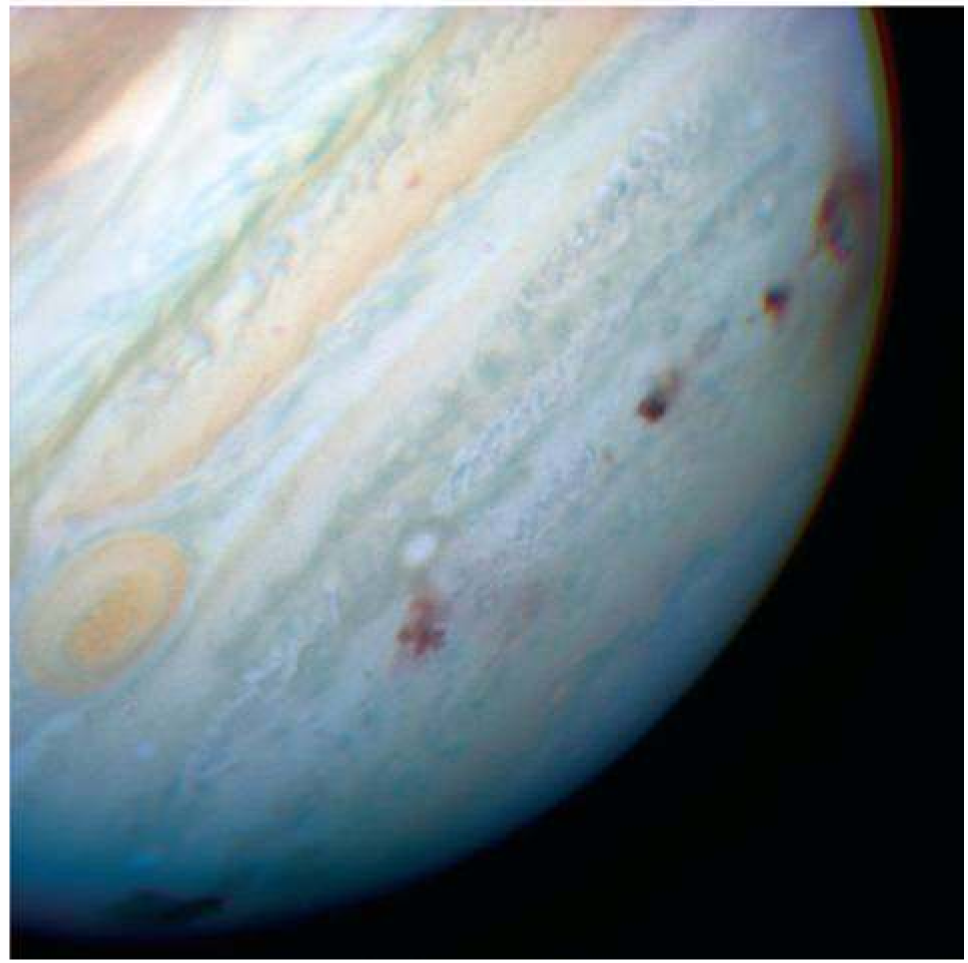
Jupiter’s Interior



- Jupiter’s average density is 1.3 g/cm^3 – indicates an interior composed of very light elements
- Interior becomes increasingly dense with depth, gas turning to liquid hydrogen about 10,000 km down
- Deeper still, liquid hydrogen compresses into liquid metallic hydrogen, a material scientists only recently created in tiny high-pressure chambers
- An iron rocky core, a few times bigger than the Earth, probably resides at the center

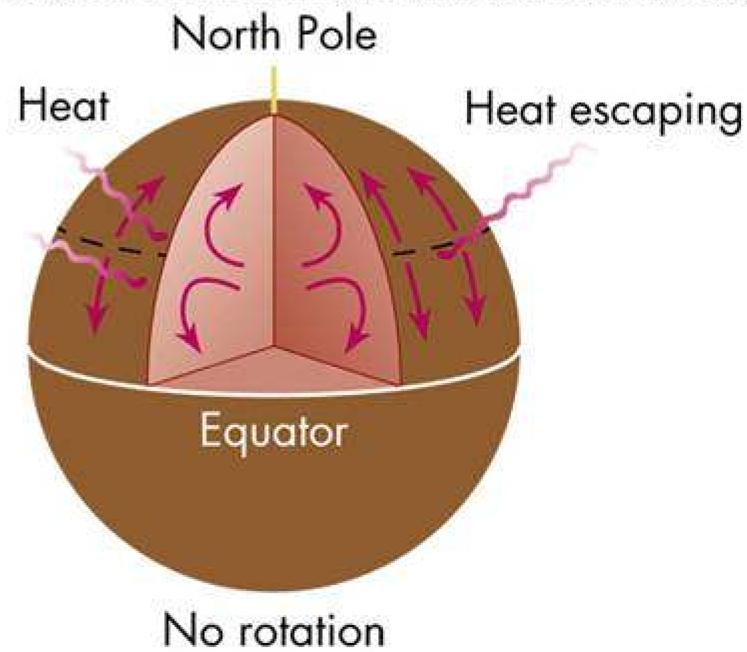
Jupiter's Interior

- Jupiter, with a core temperature of about 30,000 K, emits more energy than it receives
  - Possibly due to heat left over from its creation
  - Planet may still be shrinking in size converting gravitational energy into heat



Jupiter's Atmosphere

- General convection pattern:
  - Heat within Jupiter carries gas to the top of the atmosphere
  - High altitude gas radiates into space, cools and sinks



Hot material rises to top of atmosphere and spreads toward pole and equator.

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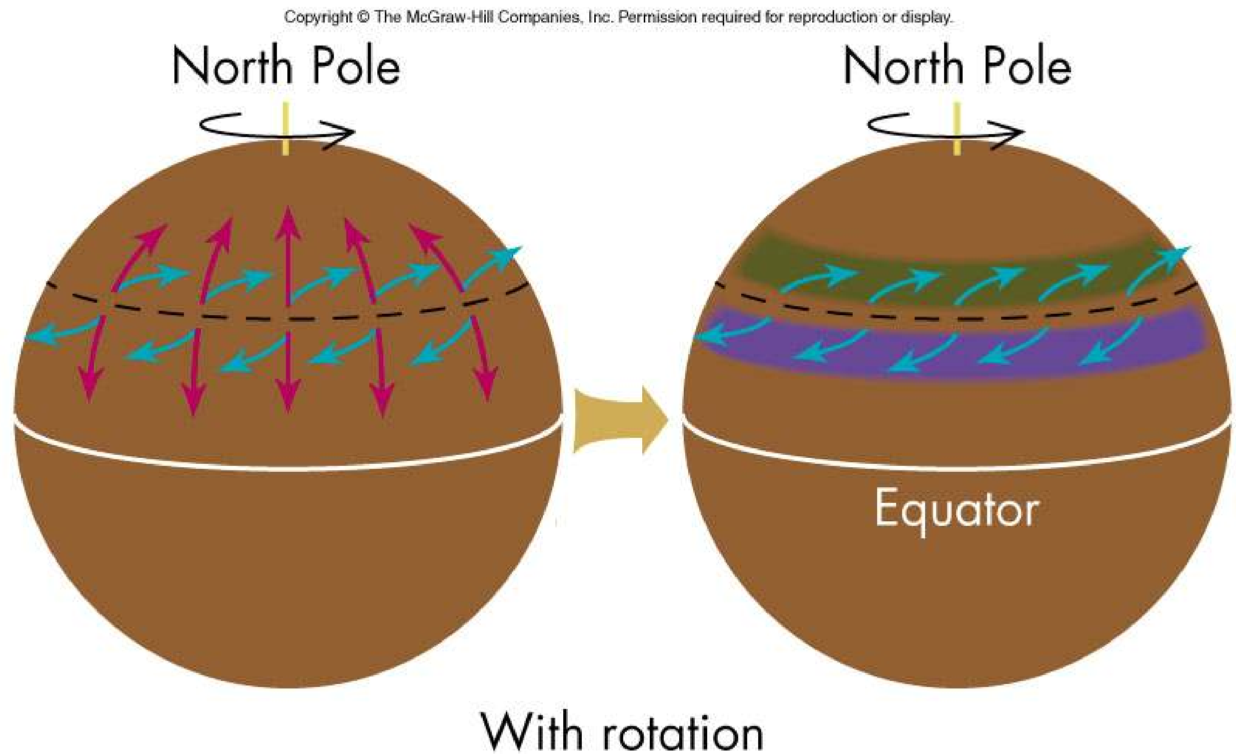
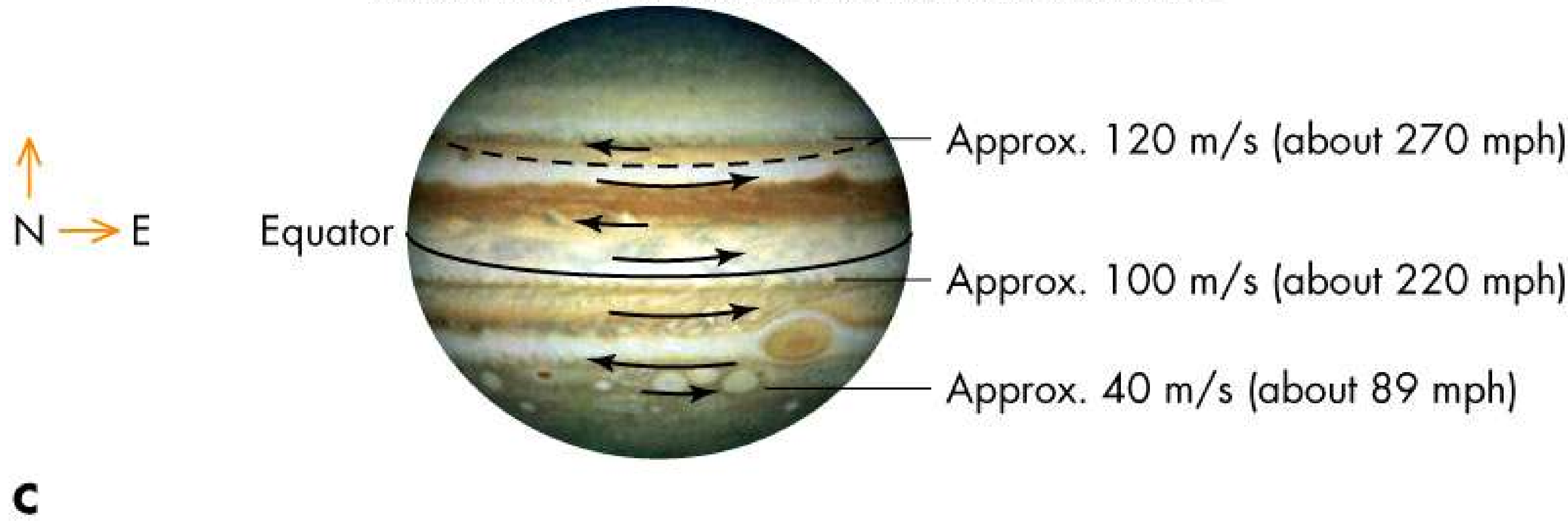
Jupiter’s Atmosphere



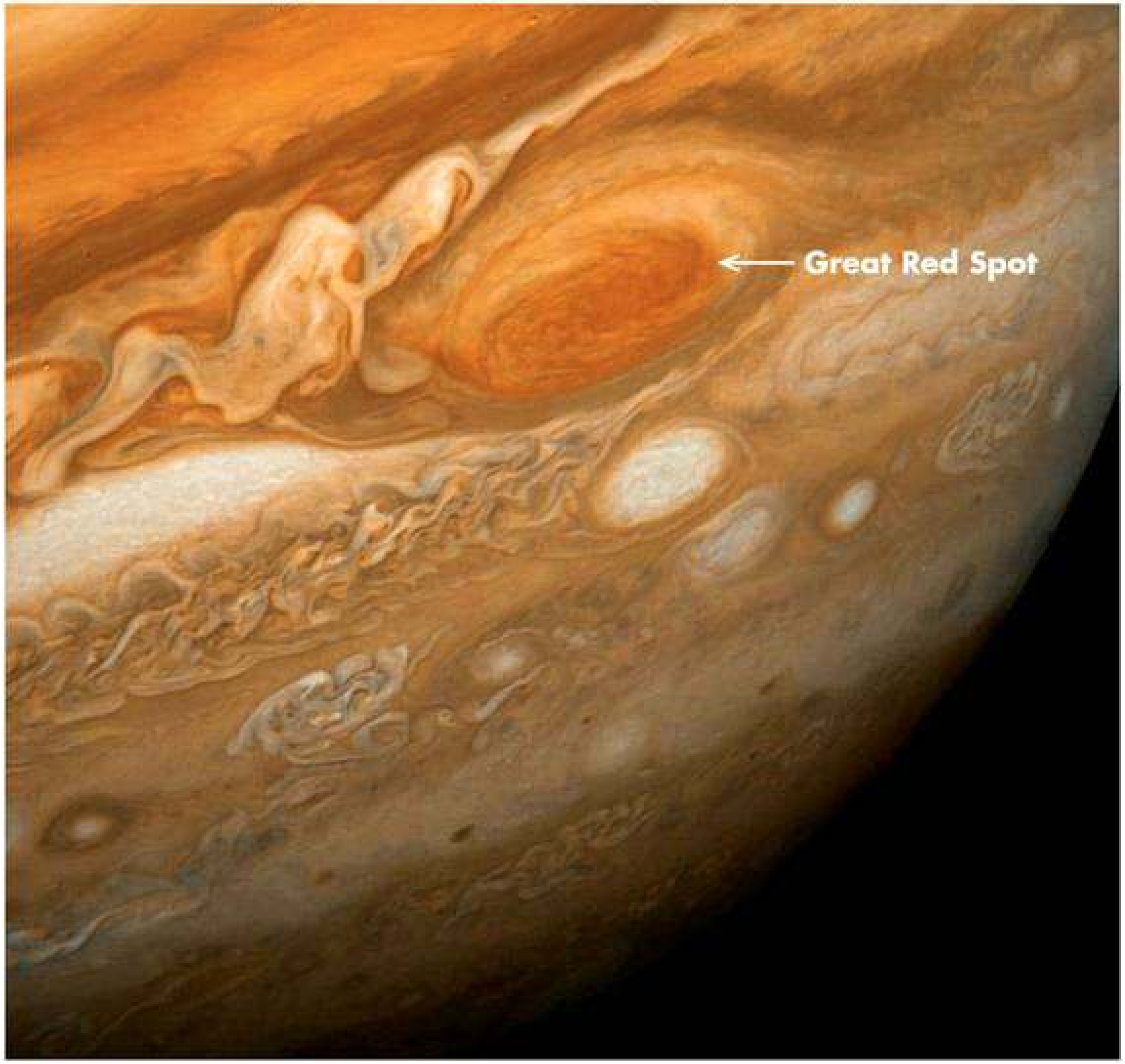
- Coriolis effect turns rising and sinking gases into powerful jet streams (about 300 km/hr) that are seen as cloud belts

Jupiter's Atmosphere



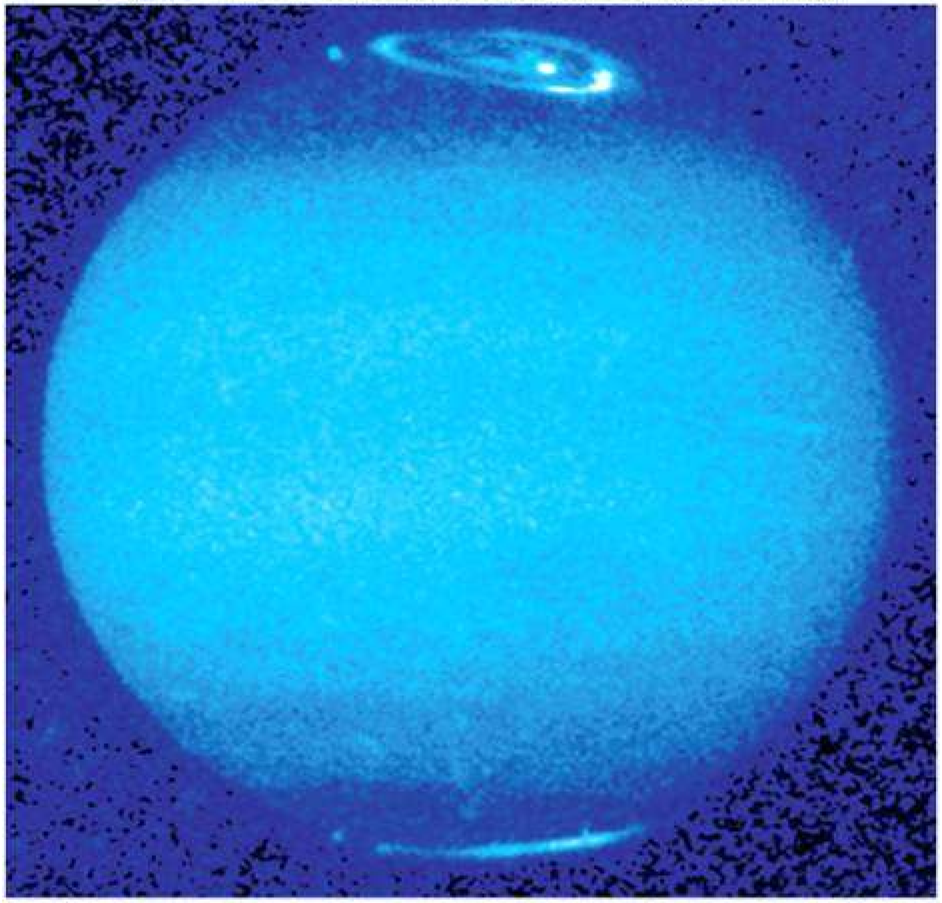
- Adjacent belts, with different relative speeds, create vortices of various colors, the largest being the Great Red Spot, which has persisted for over 300 years

The Great Red Spot



Jupiter’s Magnetic Field

- Convection in the deep metallic liquid hydrogen layer coupled with Jupiter’s rapid rotation creates a powerful magnetic field
  - 20,000× stronger than the Earth’s field, it is the largest planetary magnetic field
  - Jupiter’s auroral activity and intense radio emissions are indicative of its magnetic field



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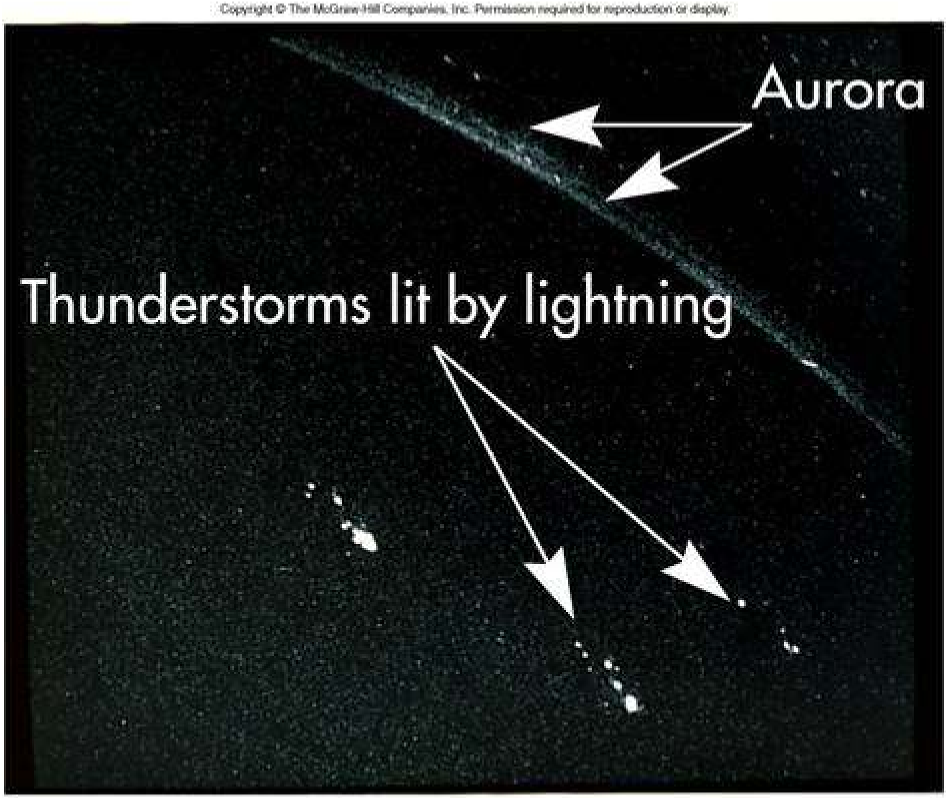
Jupiter’s Magnetic Field



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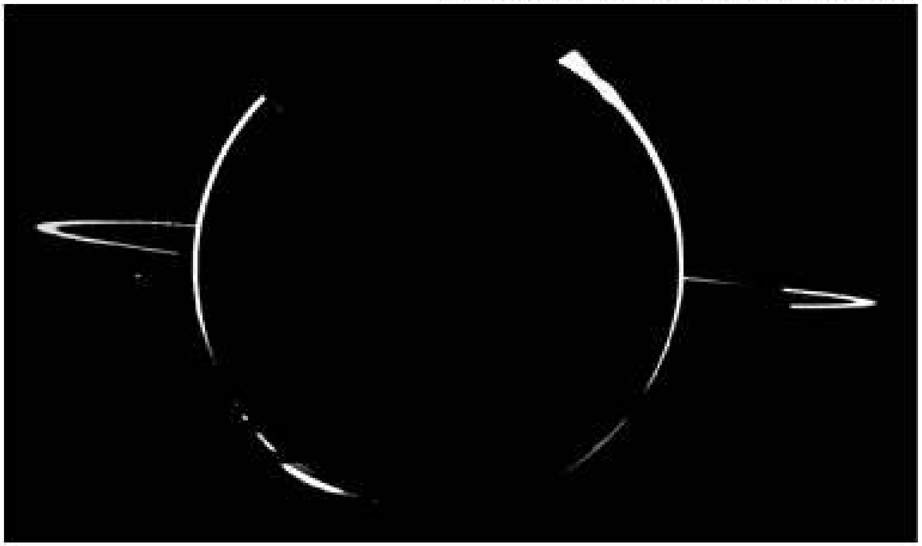
- Magnetic field also traps charged particles far above the planet in regions resembling the Earth’s Van Allen radiation belts
- Lightning in clouds has been observed

Jupiter's Ring



Jupiter

Jupiter has a thin ring made of tiny particles of rock dust and held in orbit by Jupiter's gravity

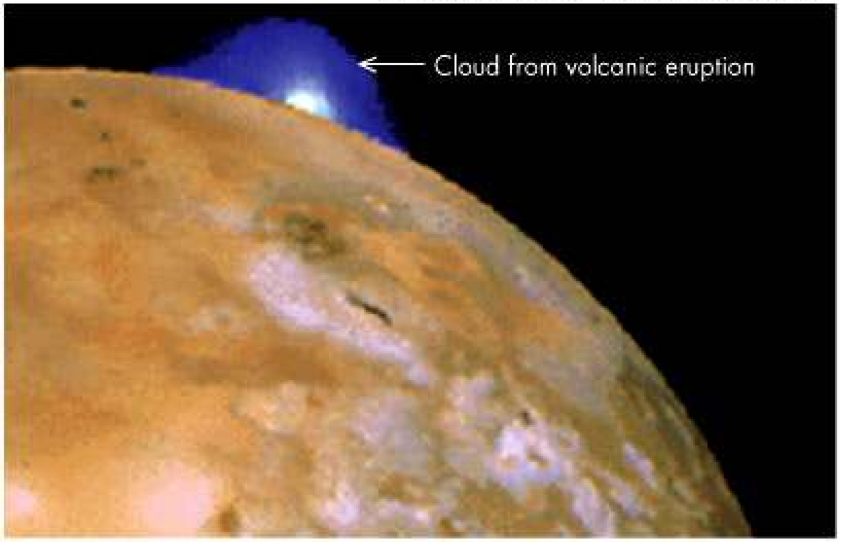
- Solar radiation and collisions with charged particles trapped in Jupiter's magnetic field exert a friction on the ring dust that will eventually cause the dust to drift into the atmosphere
- To maintain the ring, new dust must be provided – possibly from collision fragments ejected from the Jovian moons

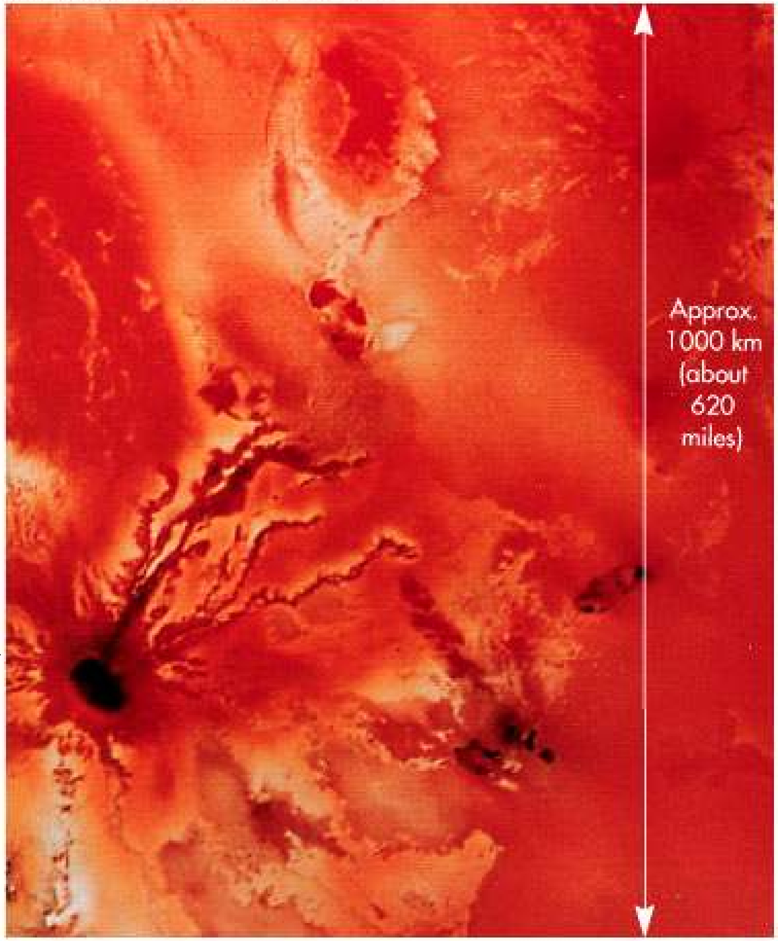
http://spacerip.com/jupiter-the-largest/

The Moons of Jupiter

- Jupiter currently has 63 natural satellites or moons
- Number changes frequently as more are discovered
- Four innermost moons are called the Galilean Moons (Io, Callisto, Ganymede, Europa)
- Except for Europa, all are larger than the Moon
- Ganymede is the largest Moon in the Solar System, and has an intrinsic magnetic field!
- Formed in a process similar to the formation of the Solar System – the density of these satellites decreases with distance from Jupiter

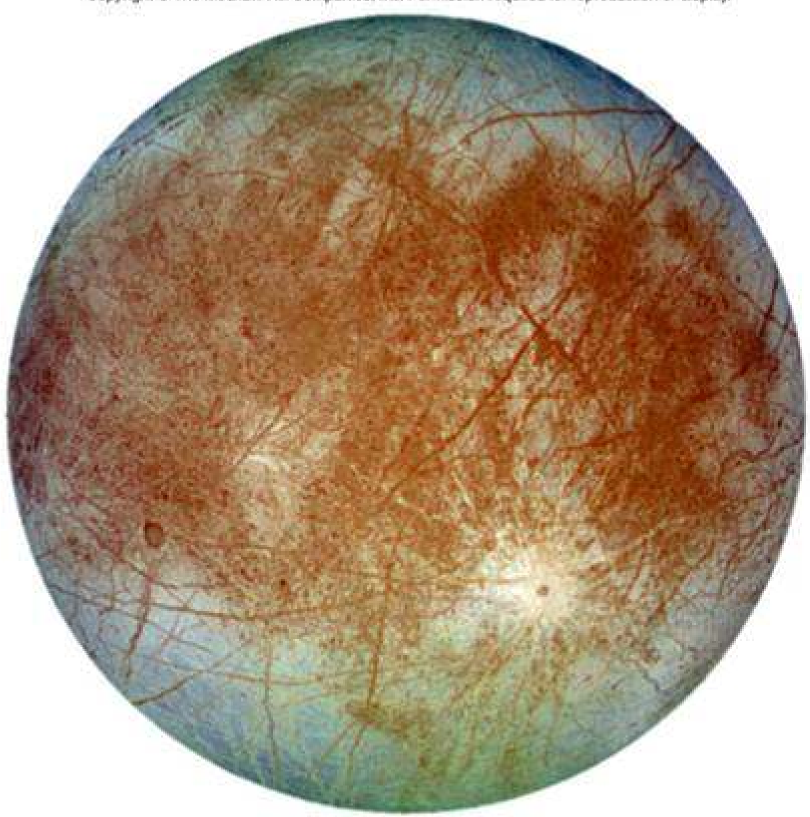
Io





- Gravitational tidal forces induced from Jupiter and Europa keeps Io's interior hot
- Volcanic plumes and lava flows are the result
- Very volcanically active!

Europa



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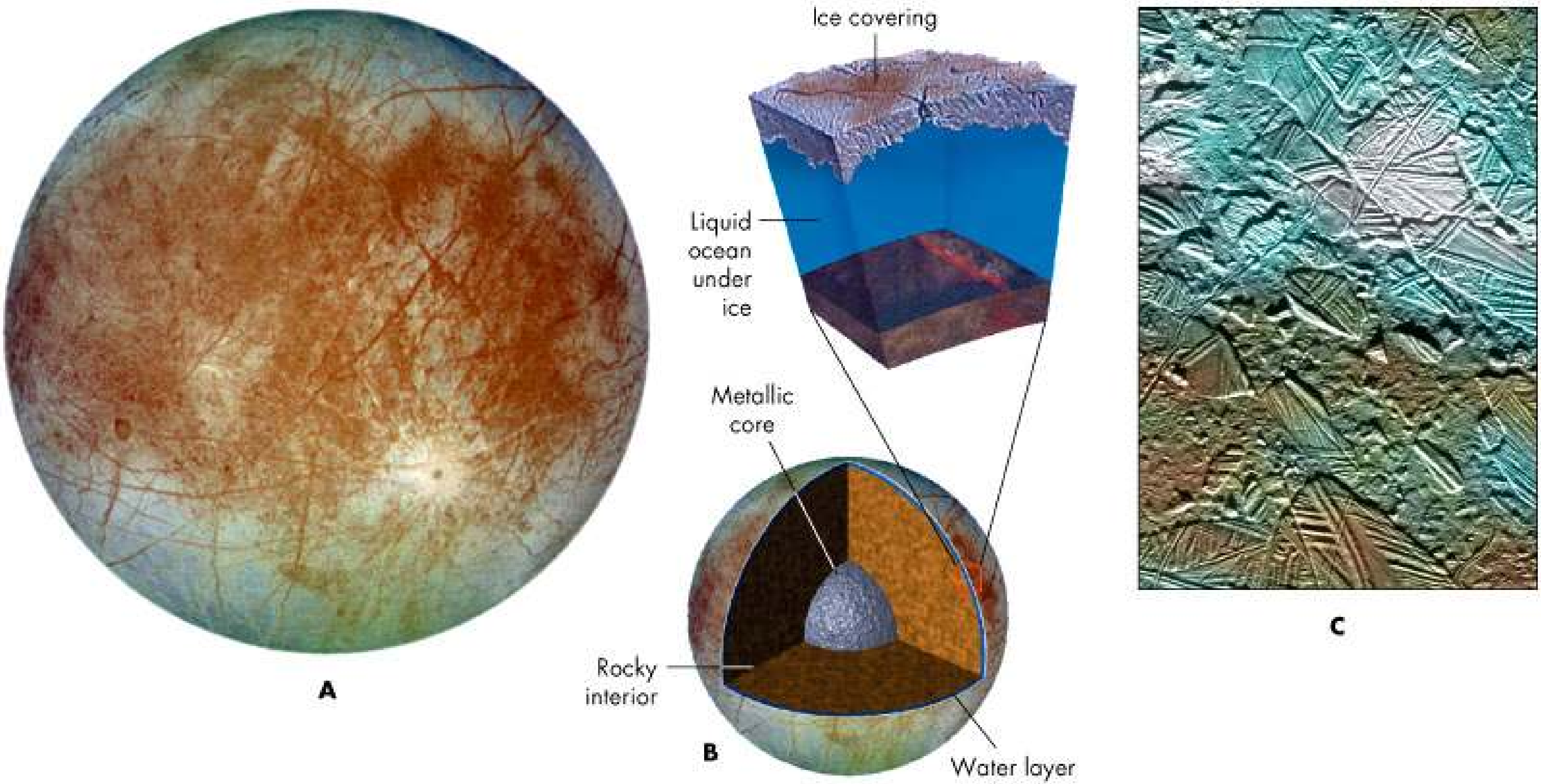
- Very few craters indicate interior heating by Jupiter and some radioactive decay
- Surface looks like a cracked egg indicating a “flow” similar to glaciers on Earth
- Heating may be enough to keep a layer of water melted below the crust

Liquid Water Ocean on Europa?



http://youtu.be/sPCpNlVJBr8

Europa NASA Ice-Penetrating Ocean Mission 2037 Animation

Ganymede and Callisto

- Look like Moon with grayish brown color and covered with craters
- However, their surfaces are mostly ice – whitish craters a very good indication of this
- Callisto may have subsurface liquid water
- Ganymede is less cratered than Callisto indicating maria-type formations although tectonic movement cannot be ruled out

Other Observations

- Galilean average densities indicate their interiors to be composed mainly of rocky material
- Differentiation may have allowed iron to sink to core

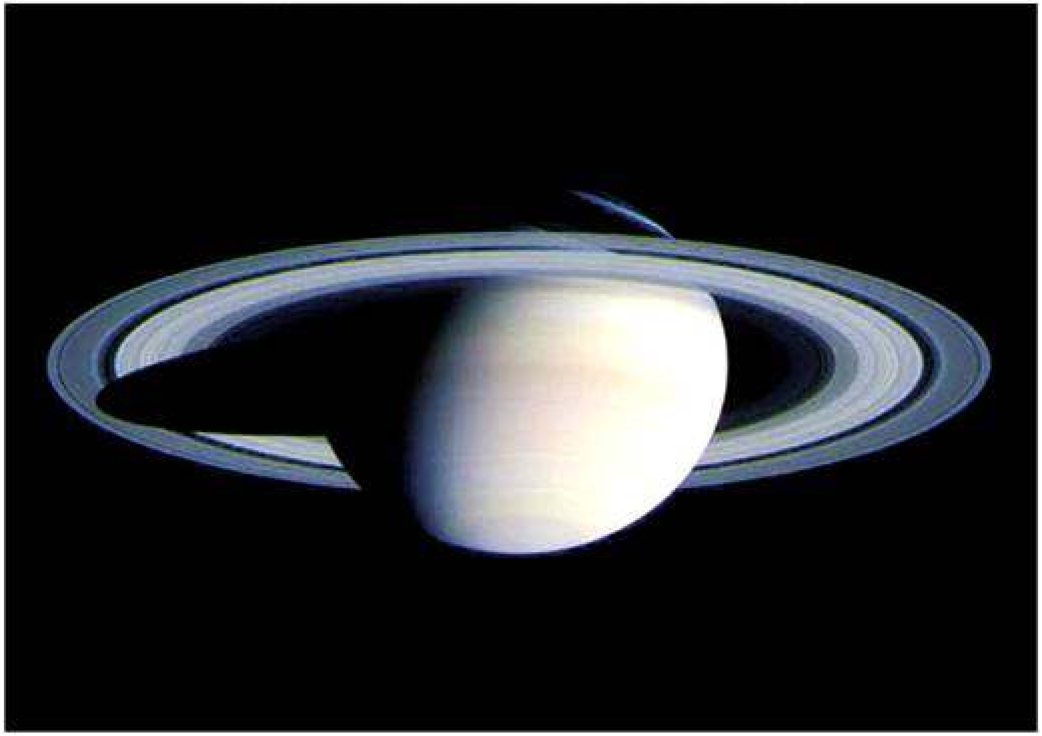
http://youtu.be/w7m-RadV5VI

Jupiter - Galilean moons

- Rest of Jupiter's moons are much smaller than the Galilean satellites and they are cratered
- Outermost moons have orbits that have high inclinations suggesting that they are captured asteroids

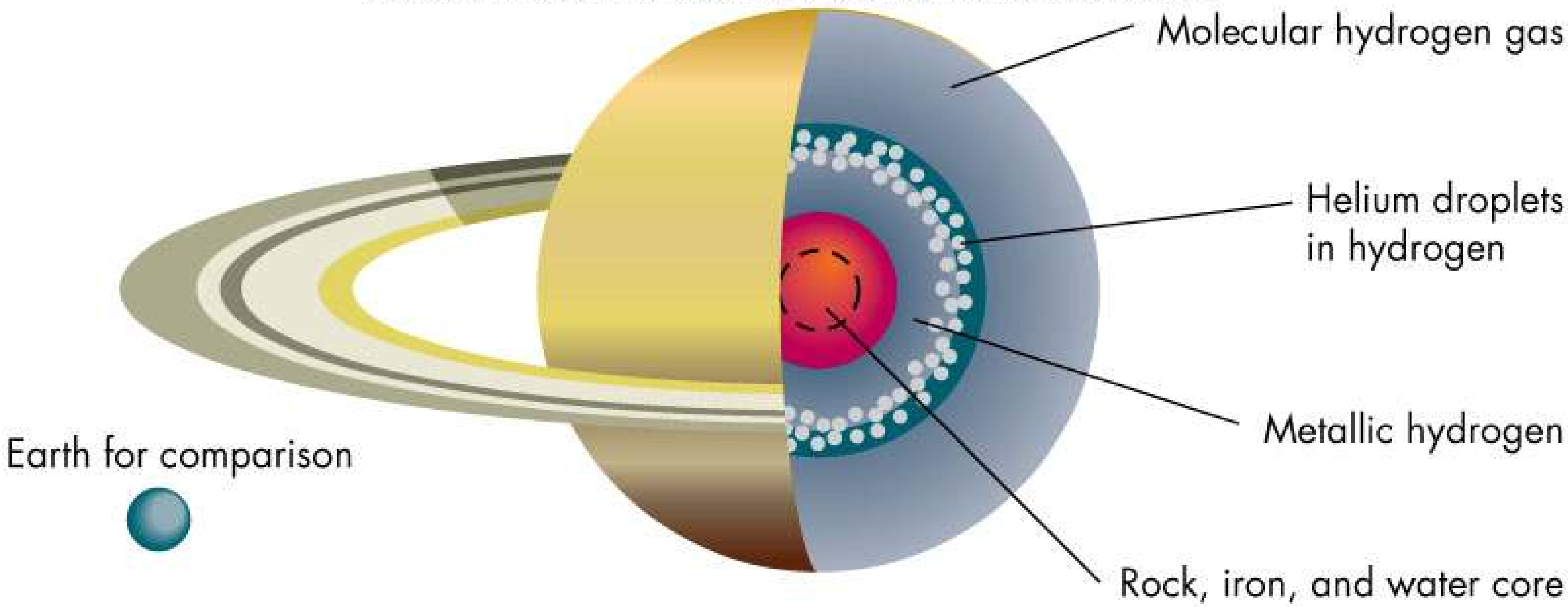
Saturn

- Saturn is the second largest planet, 10× Earth's diameter and 95 × Earth's mass
- Its average density of 0.7 g/cm^3 is less than than of water
- Low density, like Jupiter, suggests a composition mostly of hydrogen and its compounds



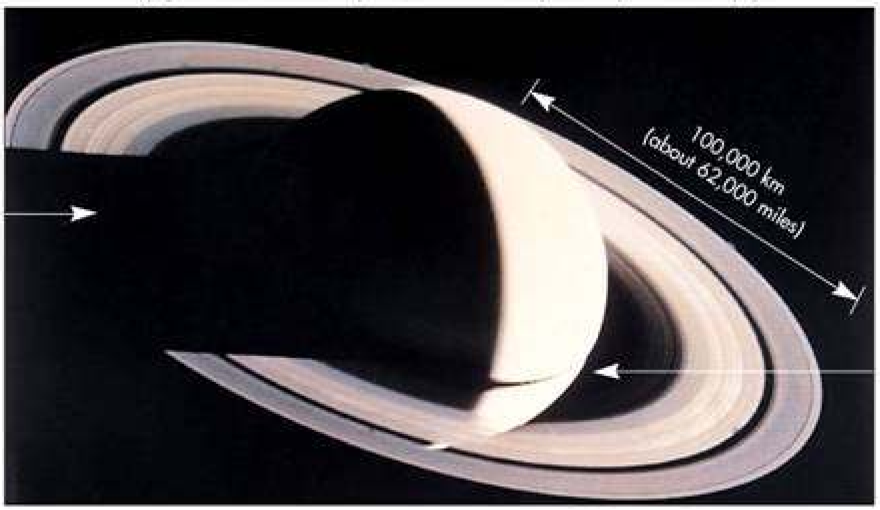
Saturn looks different from Jupiter – temperature is low enough for ammonia gas to freeze into cloud particles that veil its atmosphere's deeper layers

Interior of Saturn



- Saturn radiates more energy than it receives, but unlike Jupiter, this energy probably comes from the conversion of gravitational energy from falling helium droplets as they condense in Saturn's interior

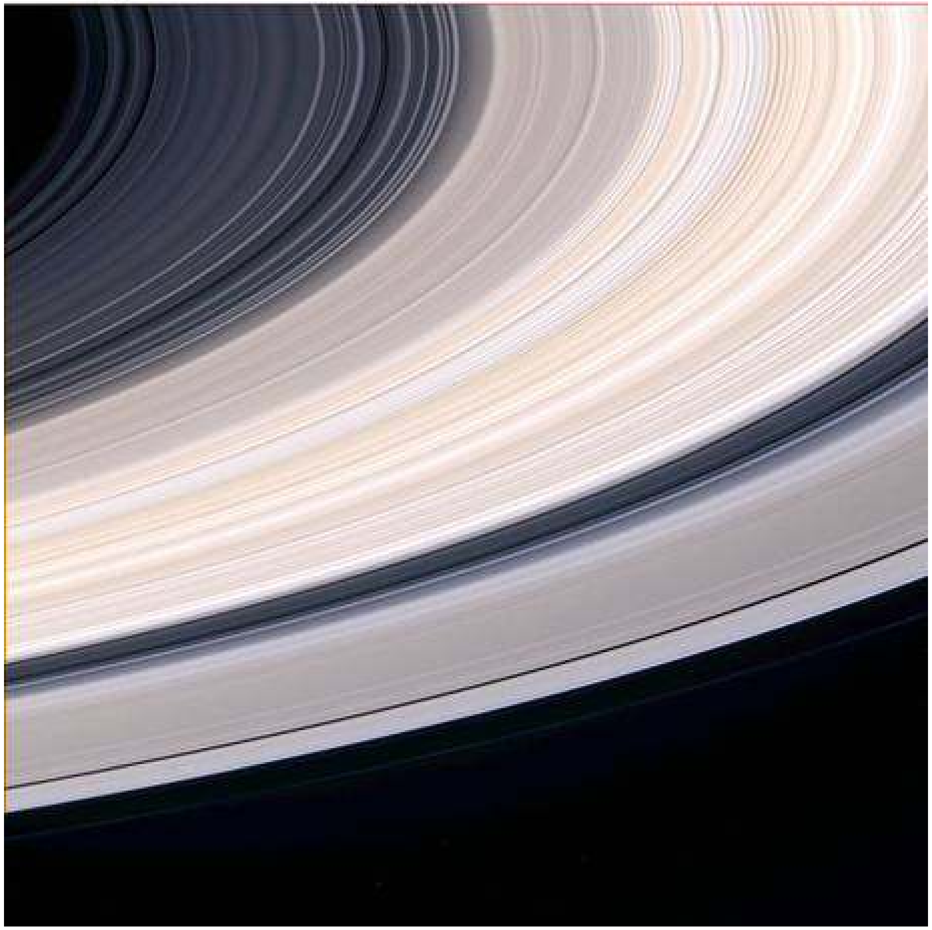
The Rings of Saturn



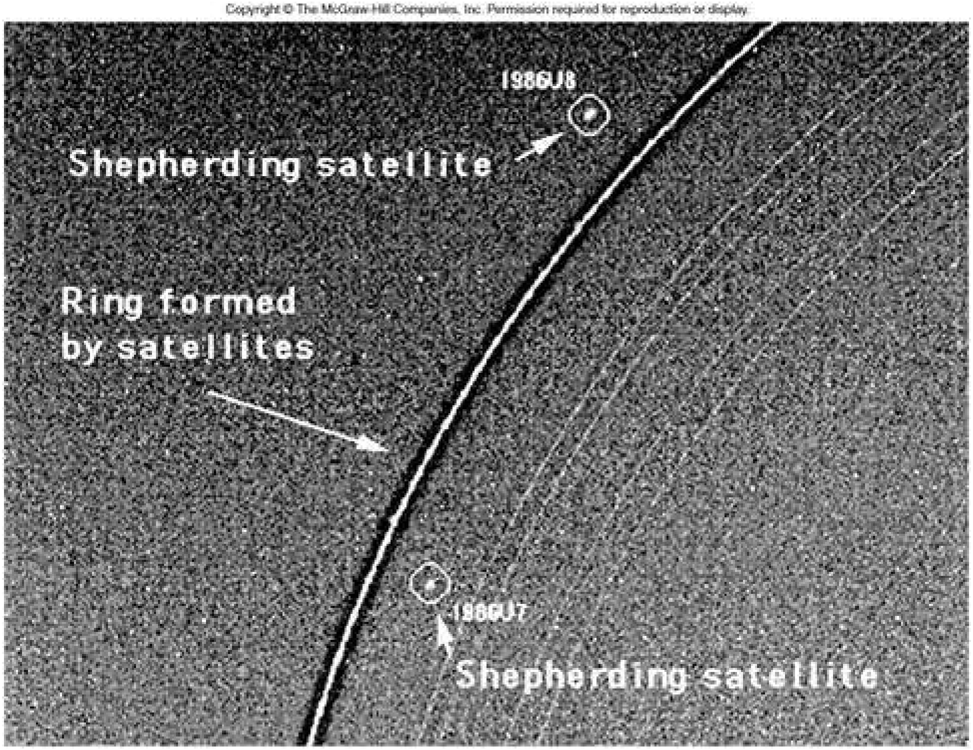
- Rings are wide but thin
  - Main band extends from about 30,000 km above its atmosphere to about twice Saturn's radius (136,000 km)
  - Faint rings can be seen closer to Saturn as well as farther away
  - Thickness of rings: a few hundred meters
  - Visible A, B and C rings, from outside in

Ring Structure

- Rings not solid, but made of a swarm of individual bodies
  - Sizes range from centimeters to meters
  - Composition mainly water, ice, and carbon compounds and is not uniform across rings



Ring Structure

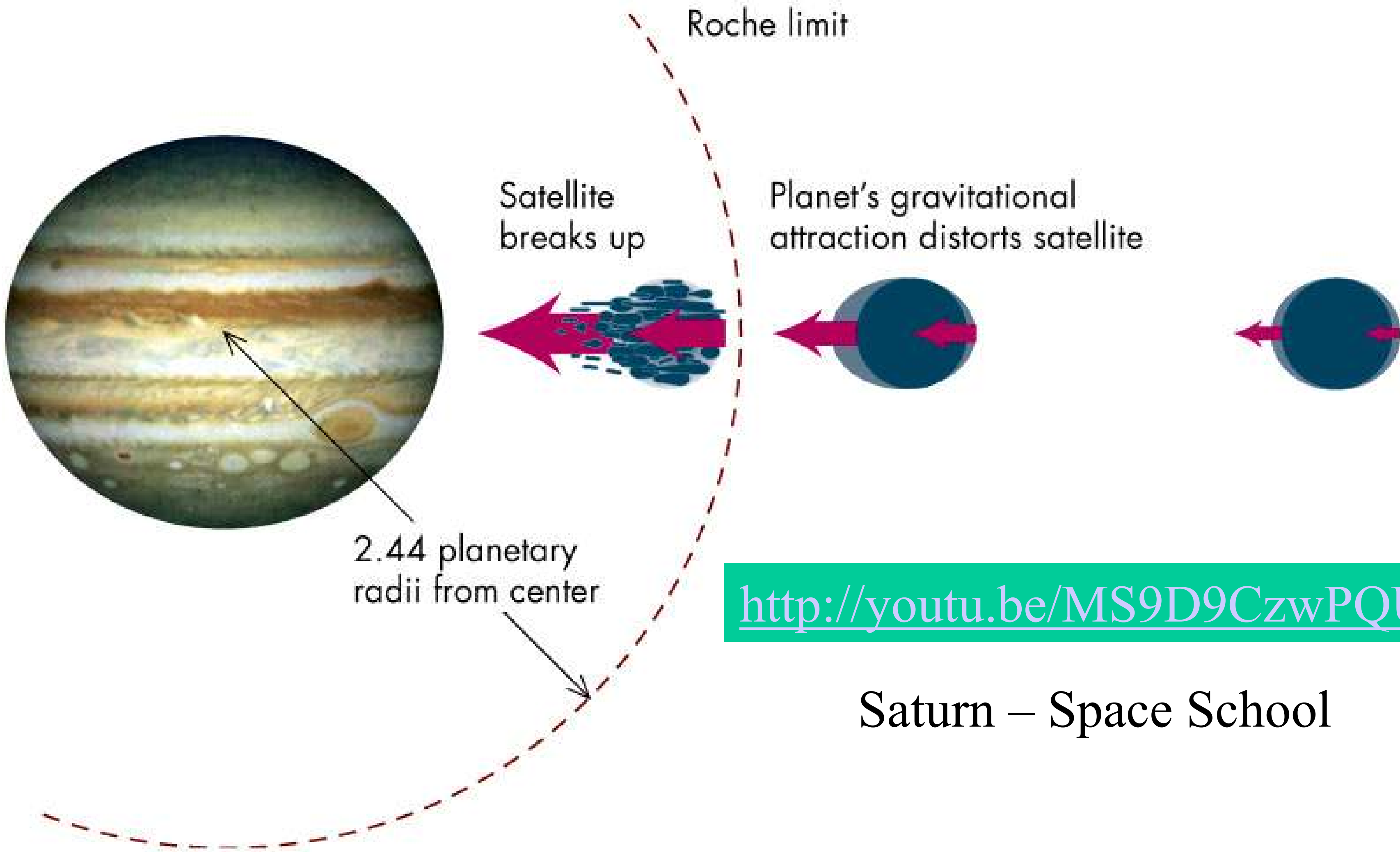


- Large gaps due to resonances with Saturn's moons located beyond the rings
- Narrow gaps due to complex interaction between ring particles and tiny moons in the rings

The Roche Limit

- Any object held together solely by gravity will break apart by tidal forces if it gets too close to the planet.
- Distance of breakup is called the ***Roche limit*** and is 2.44 planetary radii if object and planet have the same density
- All planetary rings lie near their planet's Roche limit
- Existence of side-by-side ringlets of different compositions indicates rings supplied by varied comets and asteroids
- Objects bonded together chemically will survive Roche limit

The Roche Limit



http://youtu.be/MS9D9CzwPQU

Saturn – Space School

Saturn's Moons

- Saturn has several large moons and many more smaller ones. A total of 62 moons.
- Like Jupiter, most of the moons form a mini-solar system, but unlike Jupiter, Saturn's moons are of similar densities indicating that they were not heated by Saturn as they formed
- Saturn's moons have a smaller density than those of Jupiter indicating interiors must be mostly ice
- Most moons are inundated with craters, many of which are surrounded by white markings of shattered ice
- The moons also have several surface features that have yet to be explained

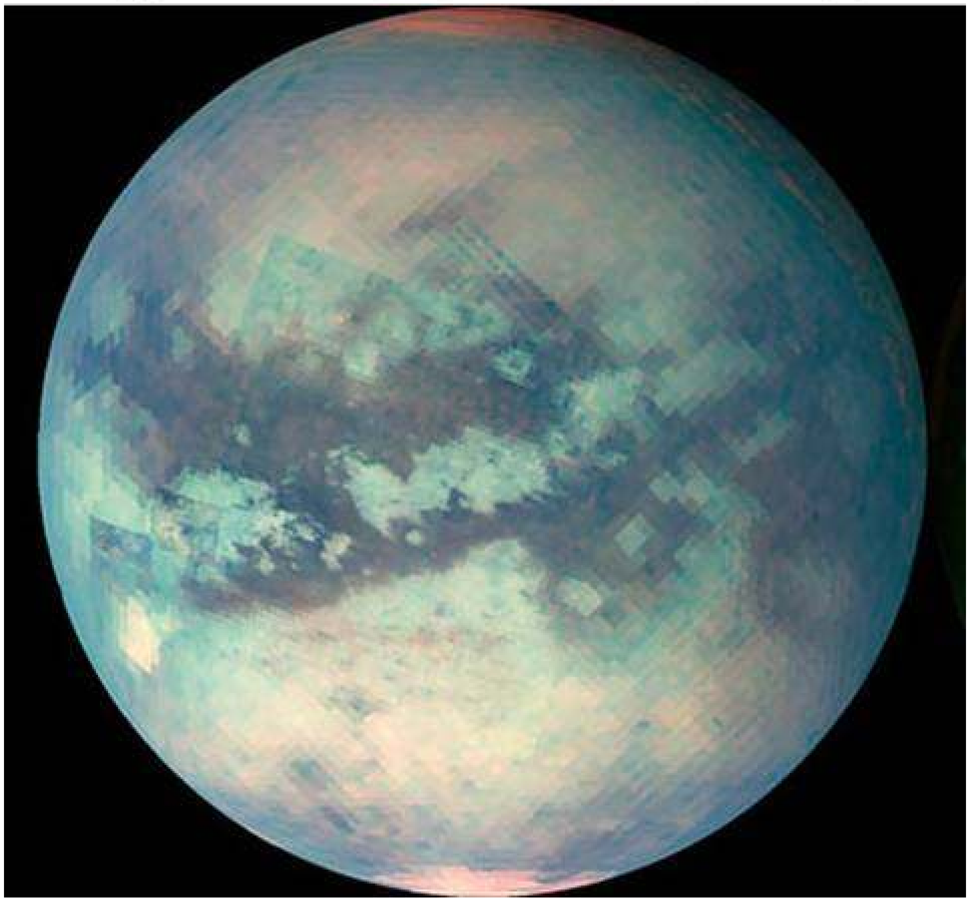
Saturn's Moons

(all): NASA/JPL/Space Science Institute

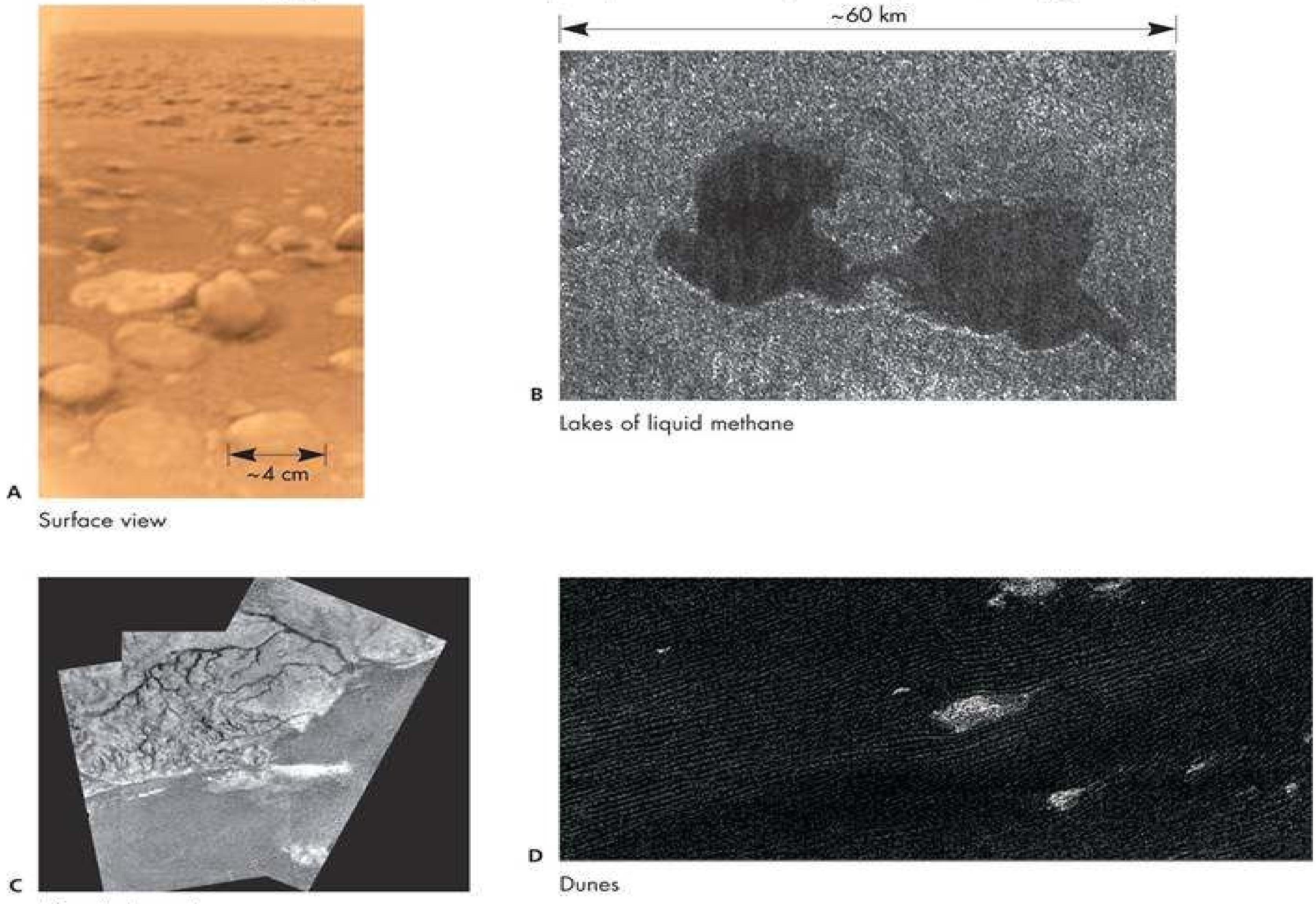
http://youtu.be/rBhAPz5pqYg **Enceladus - Saturns moon**

Titan

- Saturn's largest moon
- Larger than Mercury
- Mostly nitrogen atmosphere
- Solid surface with liquid oceans of methane
- The Huygens Probe landed on the surface



Images from Titan’s Surface

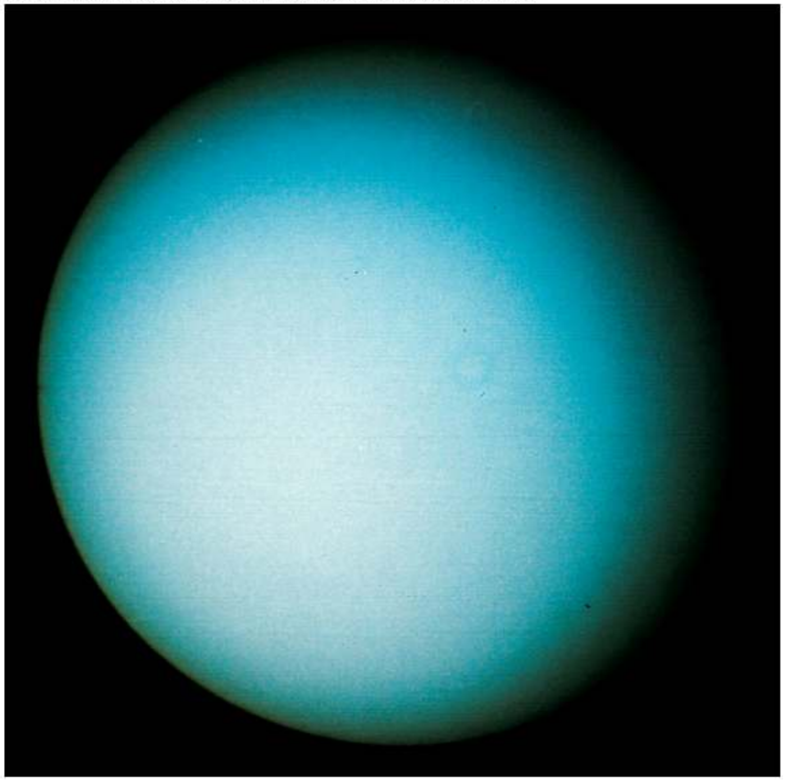


http://youtu.be/YJ0hwTzOMPE

Scientists research surface of the Titan moon - BBC

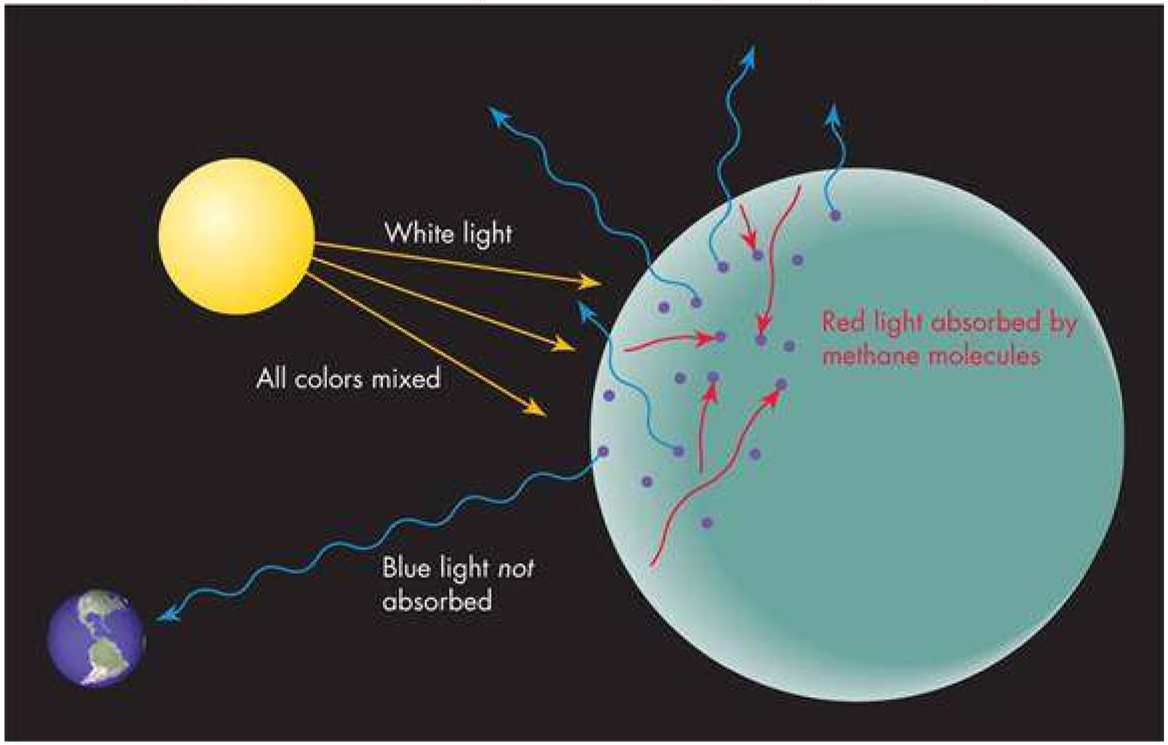
Uranus

- Uranus was not discovered until 1781 by Sir William Herschel
- While small relative to Jupiter/Saturn, Uranus is 4× larger in diameter than Earth and has 15× the mass
- At 19 AU, Uranus is difficult to study from Earth, but even close up images from Voyager reveal a rather featureless object



Earth for comparison

Atmosphere of Uranus

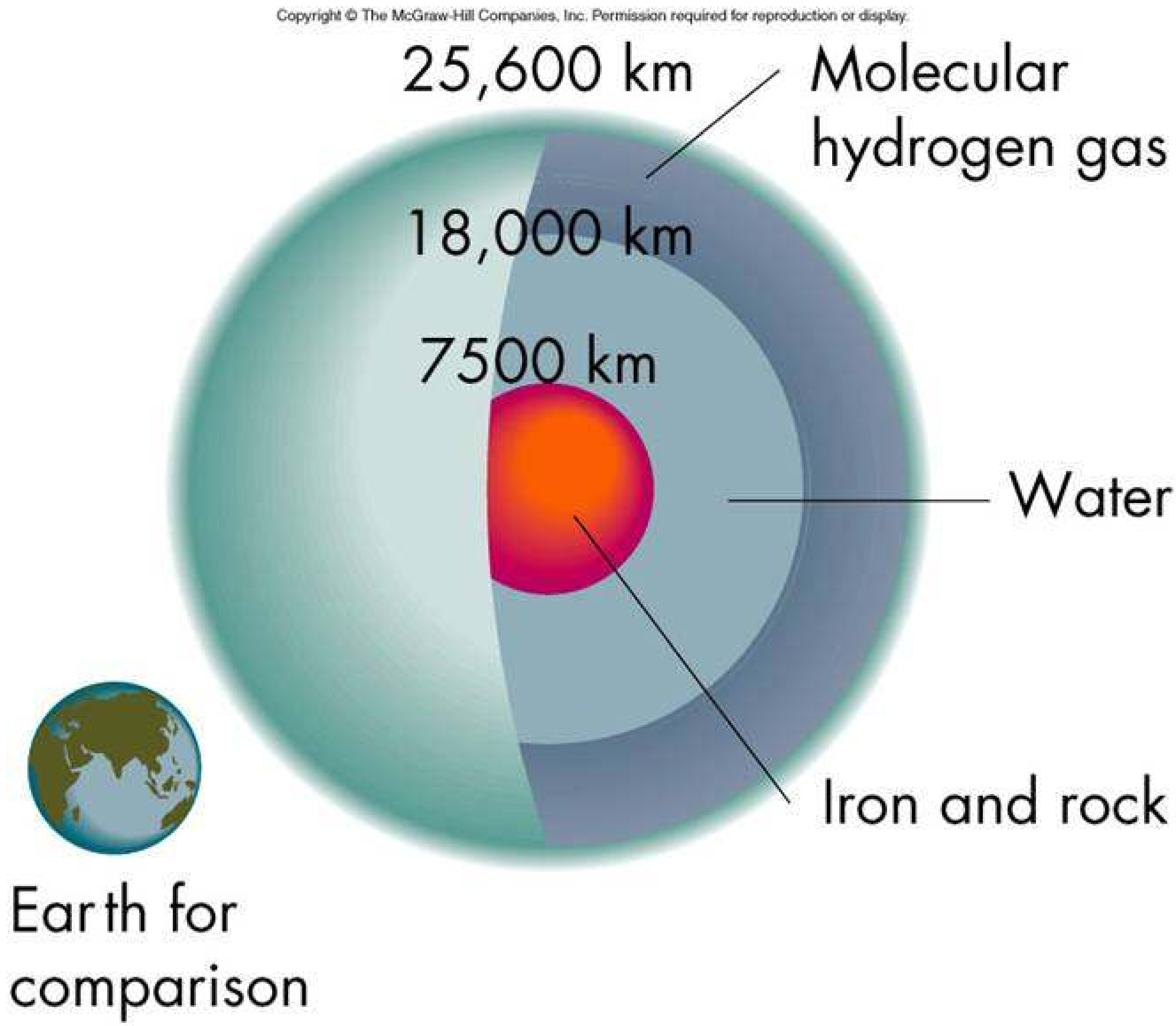


- Atmosphere is rich in hydrogen and methane
- Methane gas and ice are responsible for the blue color of Uranus's atmosphere

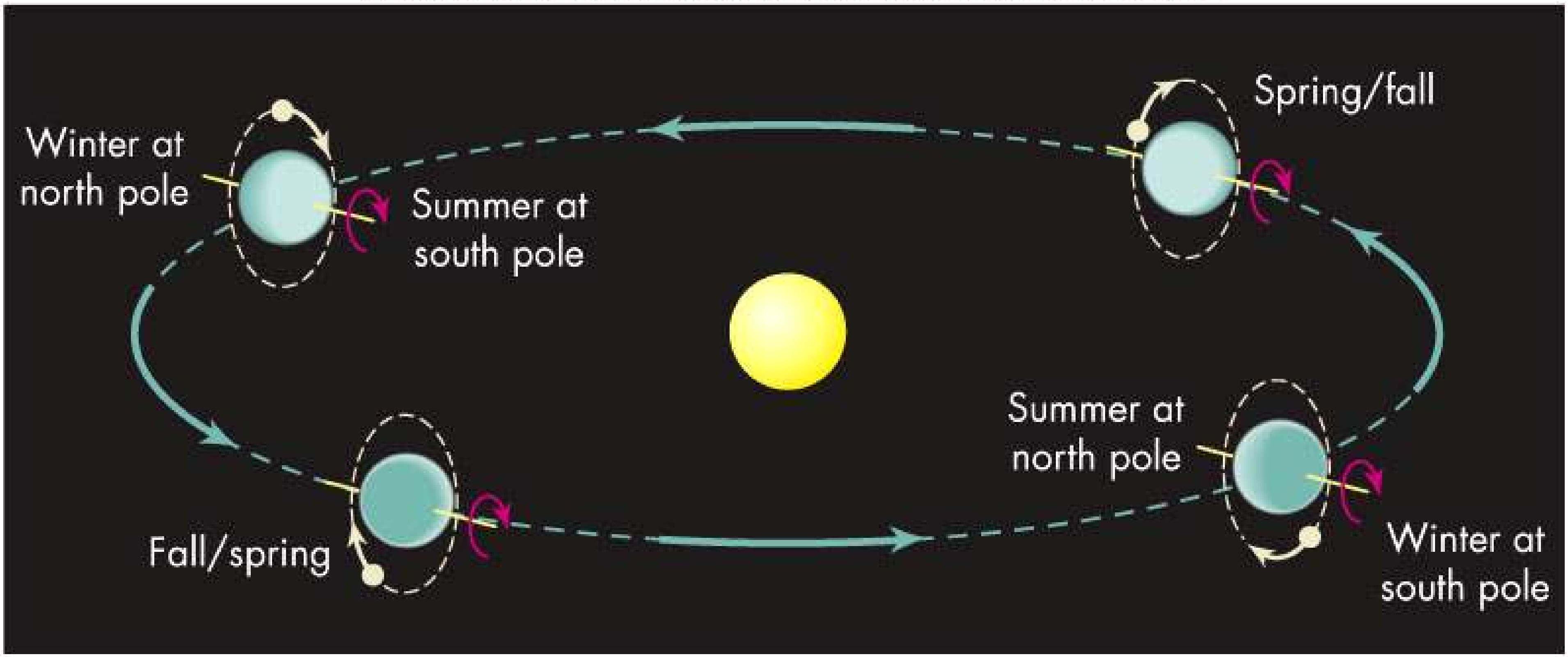
Interior of Uranus

- With a density of 1.2 g/cm^3 and smaller size, Uranus must contain proportionally fewer light elements than Jupiter/Saturn
- Density is too low for it to contain much rock or iron
- Uranus's interior probably contains water, methane, and ammonia
- Size of equatorial bulge supports the idea that the interior is mostly water and other hydrogen-rich molecules and that it may have a rock/iron core
- It is currently not known if the core formed first and attracted lighter gases that condensed on it, or the core formed by differentiation after the planet formed.

Interior of Uranus



Uranus's Odd Tilt



- Uranus's spin axis is tipped 97.7 degrees so that it nearly lies in its orbital plane
- The orbits of Uranus's moons are similarly tilted
- Uranus may have been struck during its formation and splashed out material to form the moons, or gravitational forces may have tipped it

Rings of Uranus

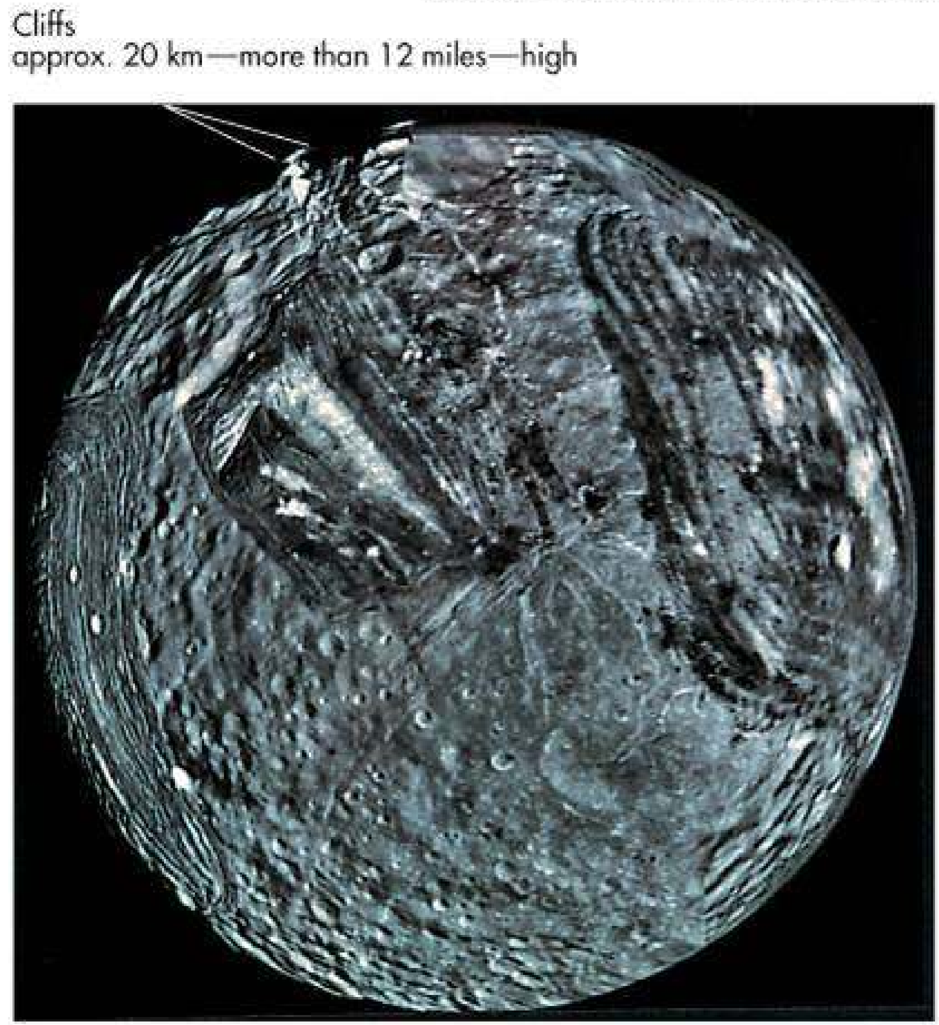
- Uranus is encircled by a set of narrow rings composed of meter-sized objects
- These objects are very dark, implying they are rich in carbon particles or organic-like materials
- The extremely narrow rings may be held in place by ***shepherding satellites***

http://youtu.be/scvVpjRT-4M

The Planet Uranus (AggManUK)

Moons of Uranus

- Uranus has 5 large moons and several small ones that form a regular system (total of 27 moons).
- Moons probably composed of ice and rock and many show heavy cratering
- Miranda is very unique in that it appears to have been torn apart and reassembled

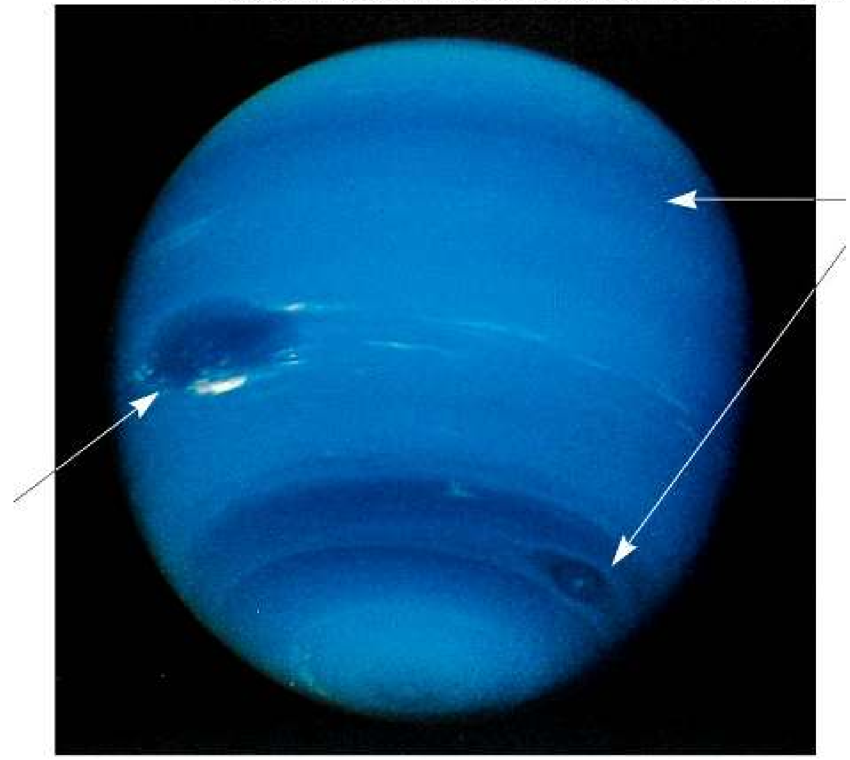


Uranus Moons

http://youtu.be/jtKKVpONlgs

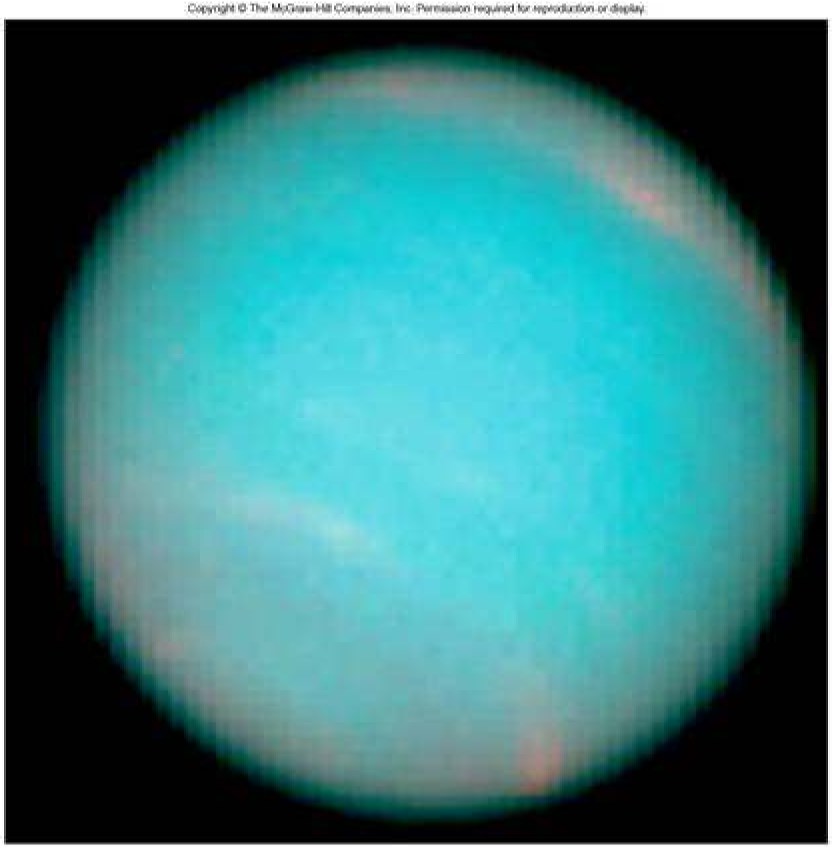
Neptune

- Neptune is similar in size to Uranus
- Deep blue world with cloud bands and vortex structures – the Great “Dark” Spot being, at one time, the most prominent feature
- Neptune was discovered from predictions made by John C. Adams and Urbain Leverrie, who calculated its orbit based on disturbances in Uranus’s orbit



Earth for comparison

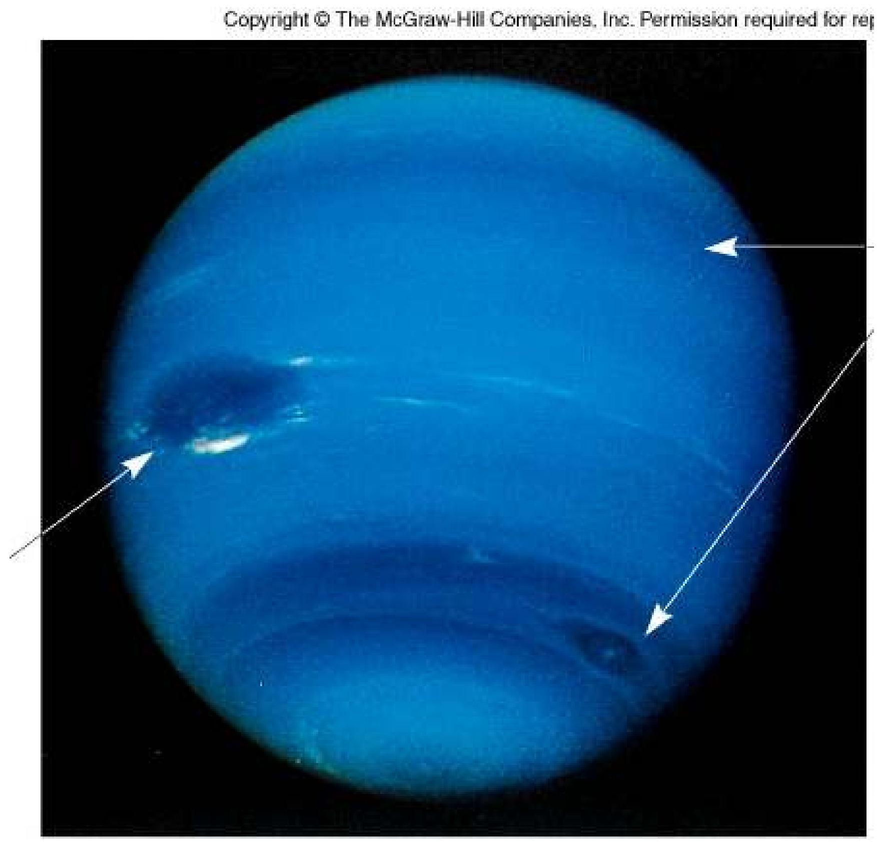
Interior of Neptune



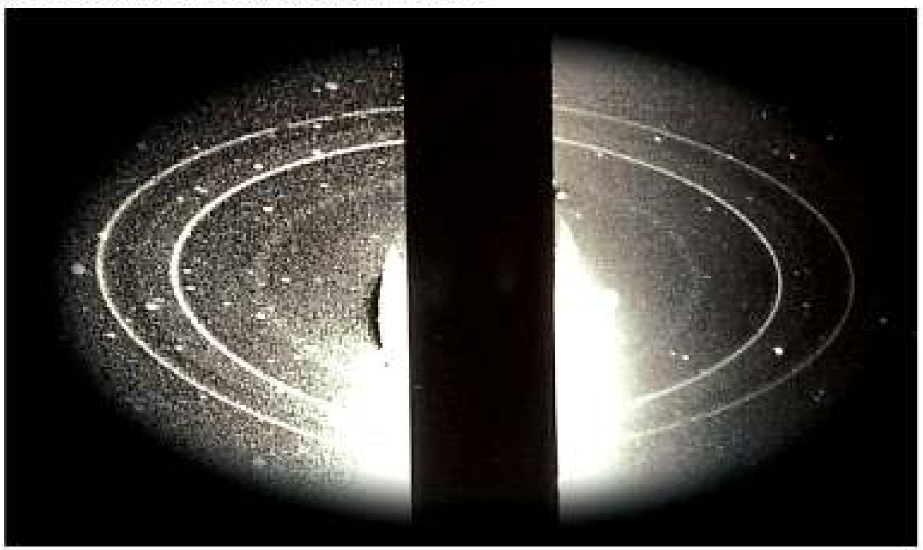
- Neptune's interior is probably similar to Uranus's – mostly ordinary water surrounded by a thin atmosphere rich in hydrogen and its compounds and probably has a rock/iron core

Neptune's Atmosphere

- Neptune's blue, like Uranus, comes from methane in its atmosphere
- Unlike Uranus, Neptune has cloud belts
  - Like Jupiter/Saturn, Neptune radiates more energy than it gains from the Sun
  - The deep interior heat source drives convective currents which then lead, via the Coriolis effect, to the visible atmospheric belts



Rings of Neptune



Neptune

http://youtu.be/76xz74X4ivw

The Planet Neptune (AggManUK)

- Neptune, like the other giant planets, has rings
- They are probably debris from satellites or comets that have broken up
- They contain more dust than the Saturn/Uranus rings
- The rings are not distributed uniformly around the ring indicating they are relatively new

Triton

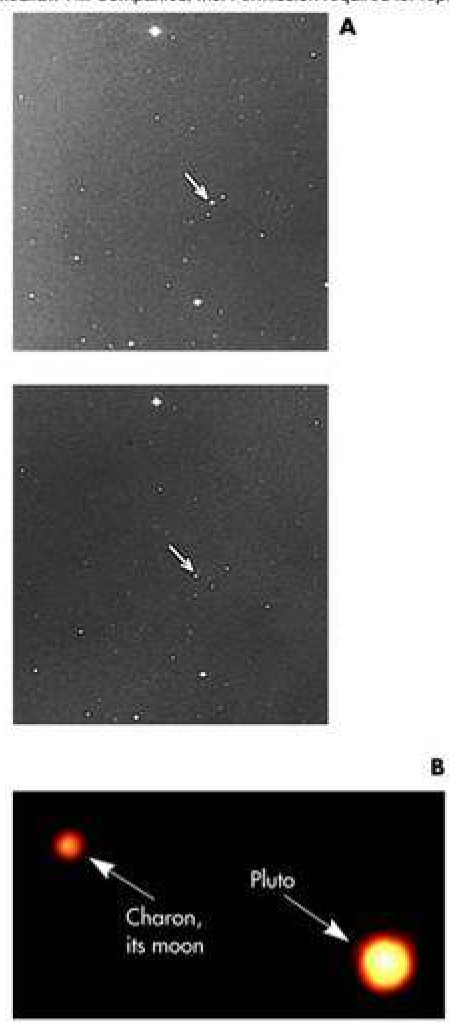
- Triton's orbit is "backwards" and is highly tilted with respect to Neptune's equator – Triton is perhaps a captured planetesimal from the Kuiper belt
- Triton is large enough and far enough from the planet to retain an atmosphere
- Triton has some craters with dark steaks extending from them – at least one of which originates from a geyser caught in eruption by the passing *Voyager II*
- The material in the geyser is thought to be a mixture of nitrogen, ice, and carbon compounds heated beneath the surface by sunlight until it expands and bursts to the surface

Triton

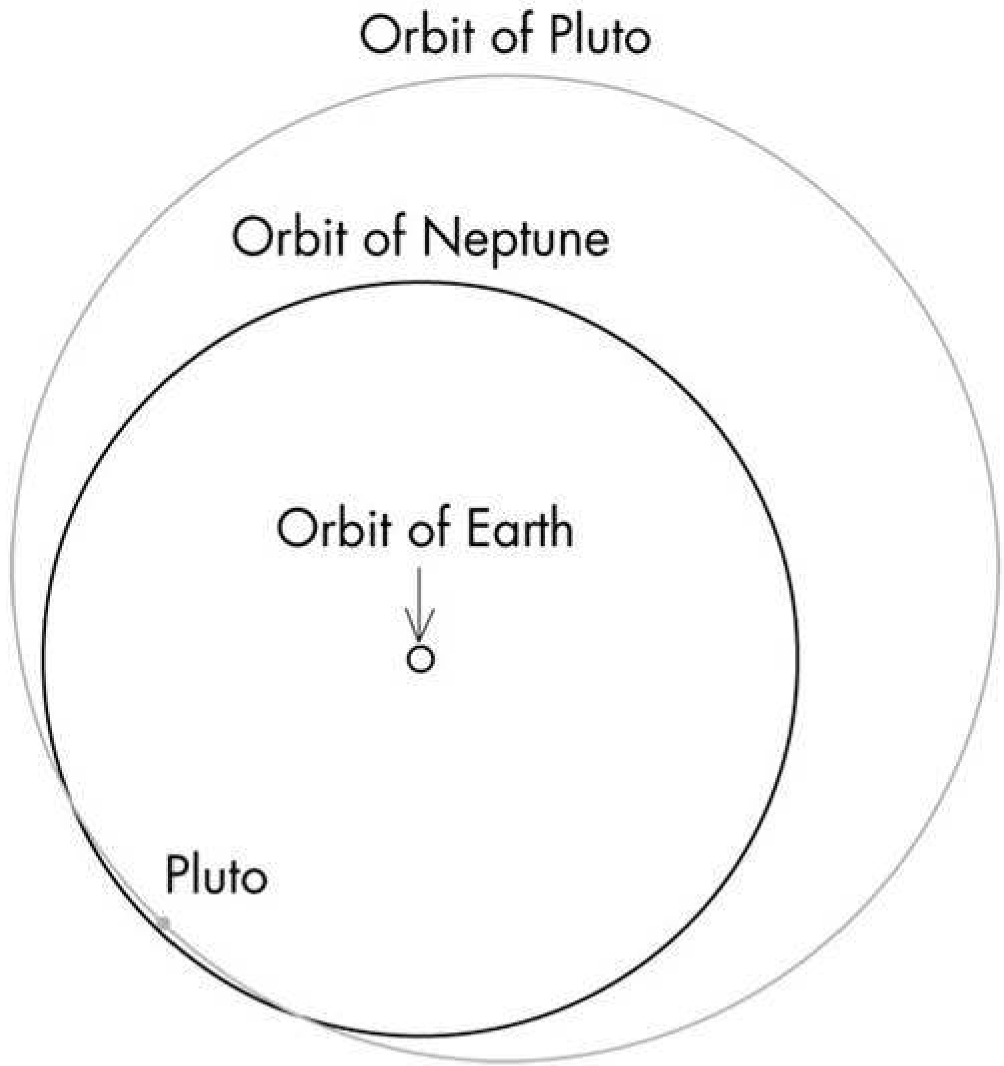
http://youtu.be/wriUZ8J0Ofw **Neptune's moon Triton (AggManUK)**

Pluto (not a planet)

- Discovered by Clyde Tombaugh in 1930 by scanning millions of star images over the course of a year
- Pluto's large distance and very small size make it difficult to study, even in the largest telescopes
- In 1978, James Christy discovered Charon, Pluto's moon
- In 2006, Pluto was classified as a Dwarf Planet due to its small size and unusual orbit.



Orbit of Pluto



Pluto and Charon

- The orbiting combination of Pluto and Charon allows an accurate measurement of their masses – Pluto is the least massive planet
- Charon's steeply tilted orbit implies that Pluto is highly tilted as well
  - Charon takes 6.4 days to orbit Pluto once
  - Pluto rotates with the same period of 6.4 days

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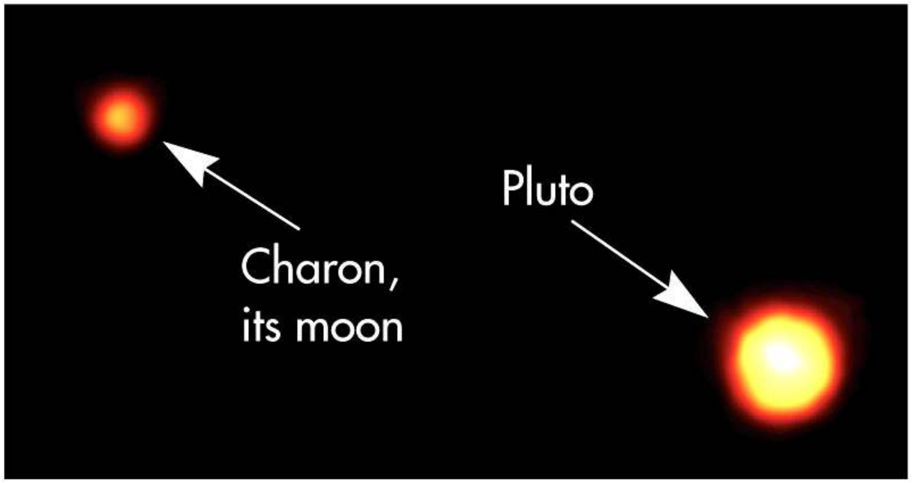
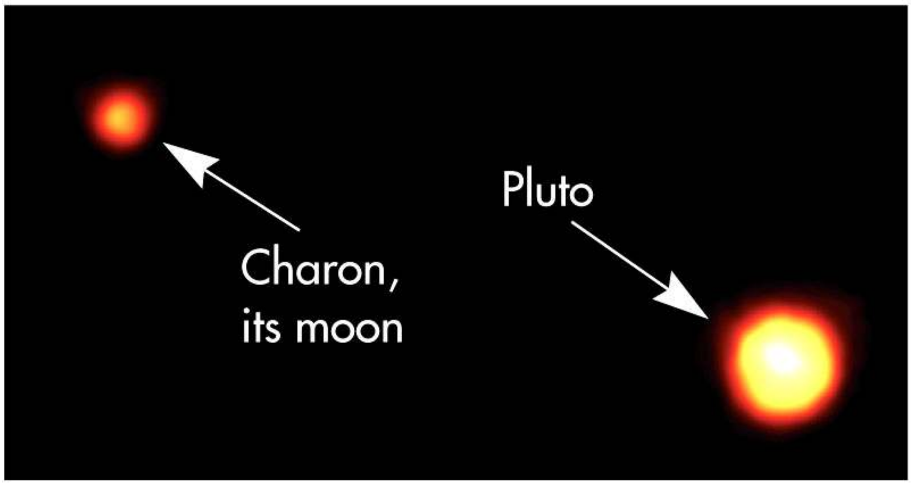


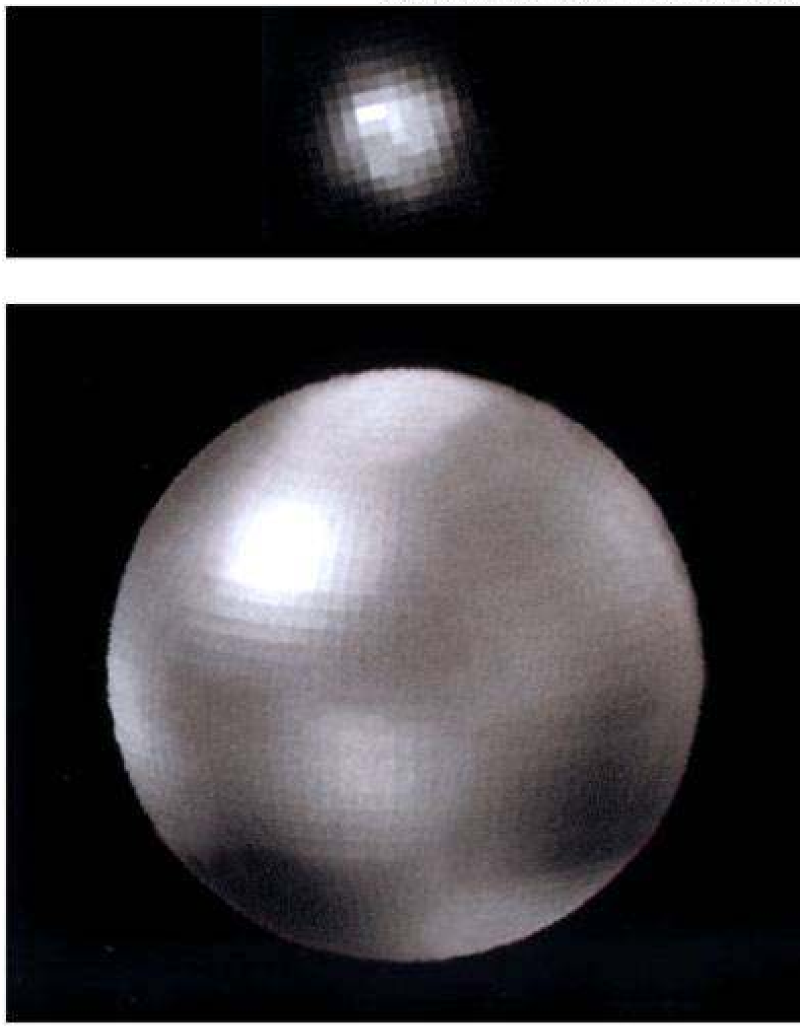
Pluto and Charon

- The recent eclipses of Pluto with Charon have allowed the radii of both objects to be determined
  - Pluto is 1/5 the diameter of Earth
  - Charon is relatively large being about 1/2 Pluto’s diameter
- From these masses and diameters, Pluto’s density is 2.1 g/cm^3, suggesting an object of water, ice, and rock

B



Mystery Planet!



- Very little is known of Pluto's surface, but computer analysis of eclipse images suggests a bright south pole, perhaps a frozen methane cap
- Pluto also has a tenuous atmosphere of N_2, CO, and traces of CH_4

The Dwarf Planets

(Triton, Orcus, Sedna, Haumea, Quasar, Makemake, Eris): NASA Jet Propulsion Laboratory (NASA-JPL); (Pluto, Charon): Images courtesy of Marc W. Buie/Lowell Observatory; (Earth): © Stocktrek/Getty Images RF; (Moon): © Digital Vision RF/Punchstock.