The Outer Planets

Astronomy

Introduction

The Outer Planets

- The outer planets are all frozen gas and ice
- Lots of hydrogen-rich materials
  - Ex: methane (CH_4), ammonia (NH_3), and water (H_2O)
- Much larger than the terrestrials
- Much different in structure and composition
- Lack solid surfaces and have no surface features (land based)
- Lots of moons!

Jupiter

Appearance and Physical Properties

- Jupiter was the king of the gods, according to the ancient Romans
  - Mainly for its size
- Largest planet of the solar system both in radius and in mass
- Its mass is larger than all of the other planets combined
- 10x Earth's diameter and 300x Earth's mass
- Rich, colored, parallel bans cover the planet
- Spectra shows that the atmosphere is primarily:
  - Hydrogen
  - Helium
  - Hydrogen-rich gases (ammonia, methane, water)

Jupiter

Appearance and Physical Properties

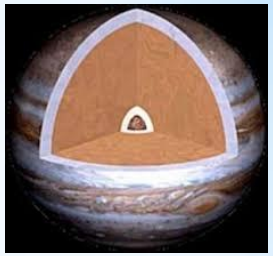
- The colors might be from complex organic molecules or compounds of sulfur or phosphorus
- Time lapse shows us that the clouds move swiftly in jet streams around the planet that are far faster than those on Earth
- It rotates every 10 hours
  - This is so fast that the equator actually bulges because of the speed and pull of the quick rotation

Jupiter

Interior

- We cannot see through Jupiter's cloud layers to its interior nor can we probe its interior with seismic detectors like the terrestrials
- Despite its incredible mass, its density is lower, on average, than Earth
- Astronomers calculate the density against the moons it tugs on gravitationally to determine a possible interior structure
  - Only about 1.3 g/cm^3 in density
  - This means it has to be made up of pretty light elements - hydrogen

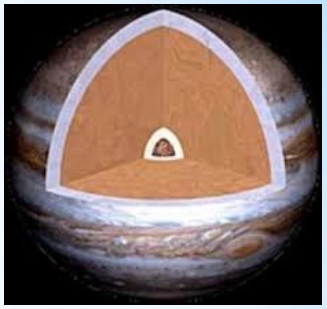
Jupiter



Interior

- The intense mass exerts a really large gravitational pull on its atmosphere and interior, holding the planet together and compressing its gas
- Near the cloud tops, the compression is only slight, so the gas density there is low
- Deep in the interior, however, the weight of thousands of kilometers of gas compresses the matter to a high density (about 3x that of iron)
  - The density increases with depth to the point of compressing the gases to liquid
  - This happens about 1/6th of the way into the planet

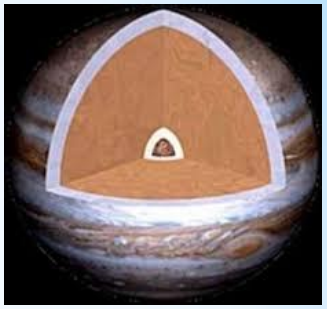
Jupiter



Interior

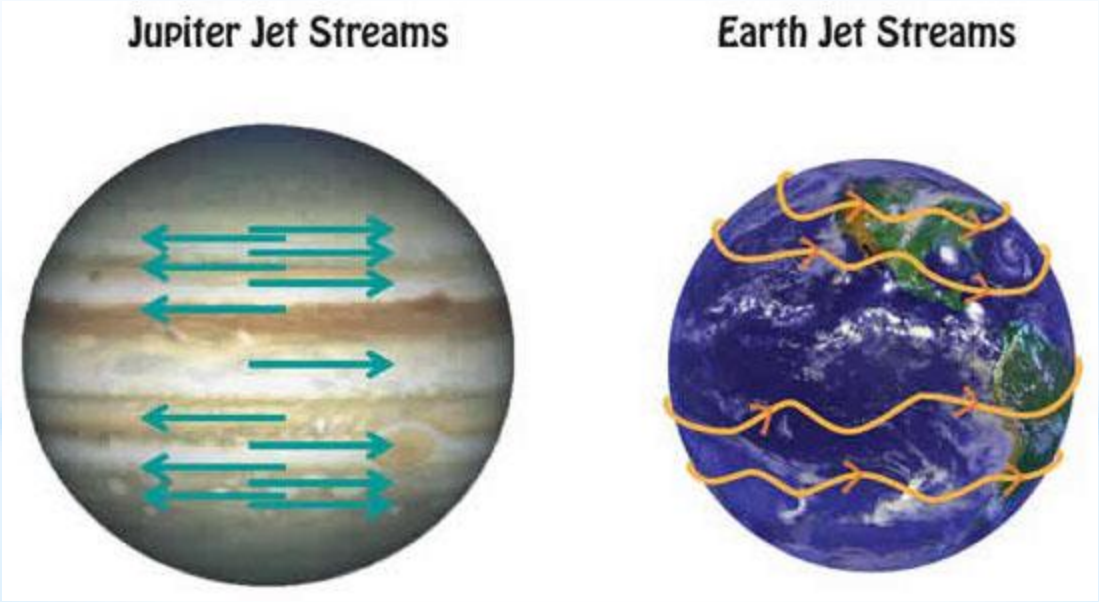
- With the density being what it is and the mass being as high as it is, the core has to contain silicates (rock) and iron
- This core is looking like it could be 18x Earth's mass alone
- The interior is extremely HOT (30,000˚K or 29,727˚C!)
  - That's 5x hotter than Earth's!
- That really hot core slowly releases infrared radiation which is being recorded by probes
- There is more heat coming from the inside of the planet than being received by the Sun
  - Astronomers believe this is left over heat from the planet's formation process

Jupiter



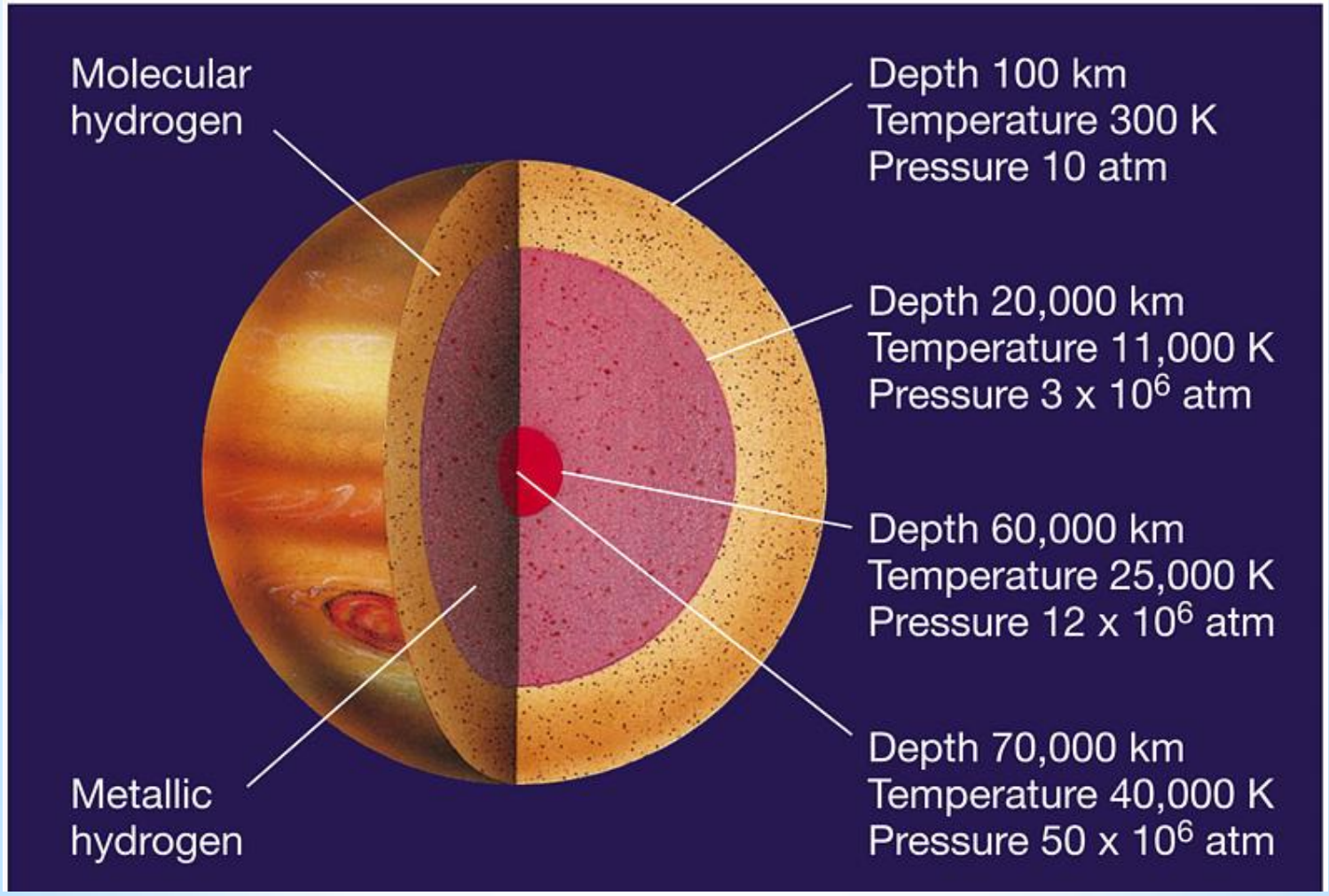
Interior

- With all of the heat getting released, it actually creates convection currents similar to the ones on Earth that move parallel to the equator due to the rotation on its axis



Jupiter

Interior



Jupiter

Atmosphere

- Currents from the heat released by the core make it all the way to the surface and on up through the atmosphere creating a Coriolis effect just like Earth
  - Rotation drives movements to run parallel with the planet
- These create *jet streams* on Jupiter just like Earth has
  - Astronomers see these winds as the cloud belts that move up to 300 km/hr (200 mph)
  - Winds that move towards the equator are deflected to the west and winds moving towards the poles are deflected to the east
- Gases get spun into huge, whirling atmospheric vortices

Jupiter

Atmosphere

- These spinning vortices of gas are brightly colored
- The *Great Red Spot* is a gas spiral that is bright red and larger than Earth
  - It has changed location and shape since it was discovered in the 17th century
- These convection currents go all the way to the inside of the planet and create the strongest magnetic field of any planet in the solar system
  - 20,000x more powerful than Earth's
  - This ends up causing Jupiter to release really strong radio waves which astronomers can detect
- Storms: lightning – due to the rise and cooling of the gases and the friction between the particles

Jupiter

Jupiter's Rings

- Until 1977, the only planet believed to have rings was Saturn
  - Thin ones were found around Uranus, so astronomers wondered if there were others out there with rings… Jupiter happened to be one of them
- *Voyager I* spacecraft flew by Jupiter in 1979 and picked up on them
- Very thin, but present
- Made up of dust and ice that got caught in Jupiter's gravity pull
- These particles end up getting pulled into Jupiter and other dust particles replace them

Jupiter

Jupiter's Moons

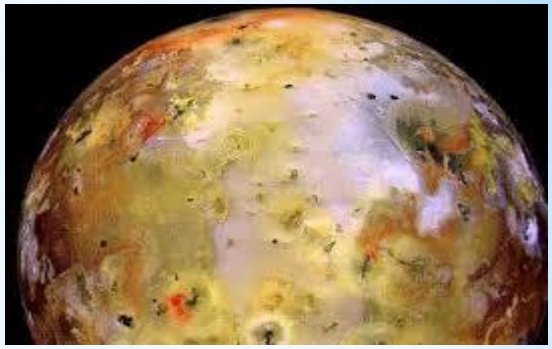
- Galileo originally found four moons
  - They're called the "Galilean satellites"
  - Io, Europa, Ganymede, and Callisto
- The *Voyager I* spacecraft helped identify a total of 67 moons around Jupiter
  - Many are way too small to see from Earth, so it was a tough count
- All four of the Galilean satellites are very large and bigger than Earth's moon except for Europa
- Ganymede has a diameter larger than Mercury, making it the largest moon in the solar system
- These moons orbit in a plane and may have developed in a similar way to how the solar system did

Jupiter

Jupiter's Moons

- The heat from Jupiter would have affected how these moons developed, by sublimating ice and evaporating it
  - This would have affected their density and composition
- The densest satellites are the ones closest to Jupiter and then it decreases as you move away from the planet
  - Io: 3.53 g/cm^3
  - Europa: 2.99 g/cm^3
  - Ganymede: 1.94 g/cm^3
  - Callisto: 1.85 g/cm^3

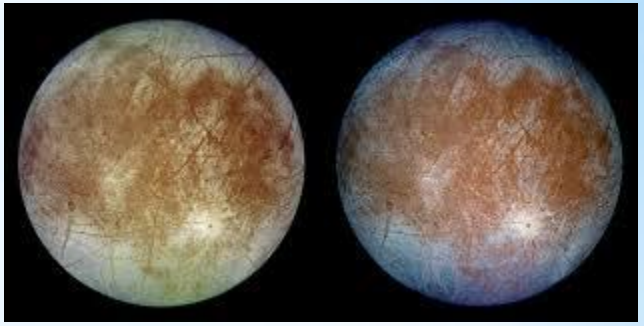
Jupiter



Jupiter's Moons

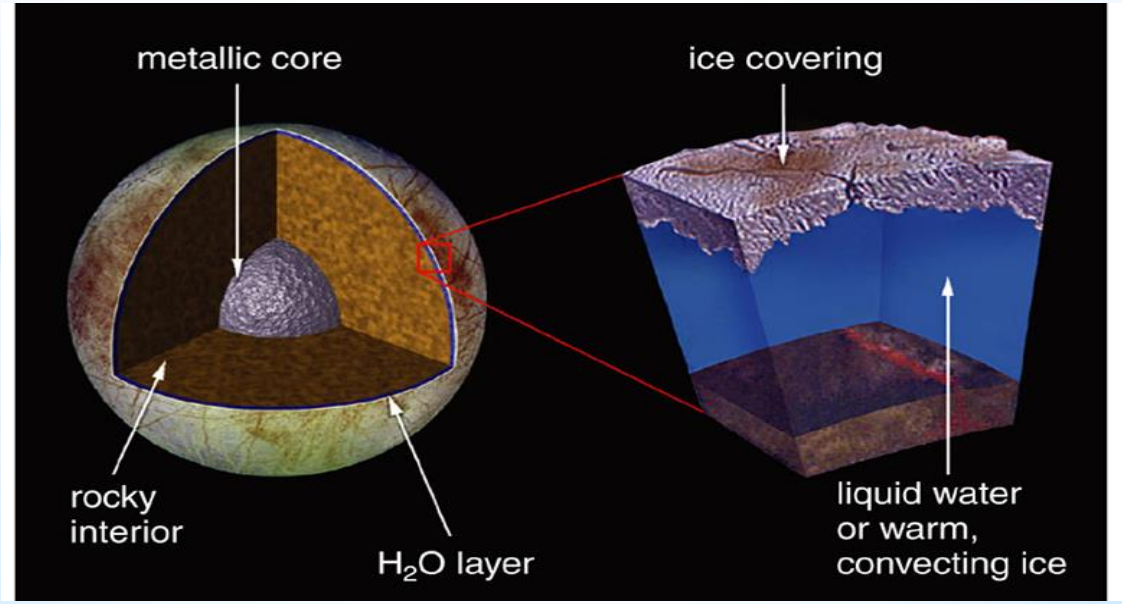
- Io was named after Jupiter's maiden with who he fell in love with, but changed into a young cow so that his wife, Hera, wouldn't suspect his infidelity
- Io gets locked into orbit around Jupiter in the same way that Earth's moon is locked
- Io also gets pulled on by Europa which isn't far behind causing it to change shape by twisting and pulling between the two
- This causes internal friction and creates active volcanoes on Io

Jupiter



Jupiter's Moons

- Europa was named for another one of Jupiter's maidens that he ventured on a long journey (what is now Europe) with
- Looks like a cracked egg with the scar lines on it
- Shows signs of having an ocean underneath its frozen cap



Jupiter

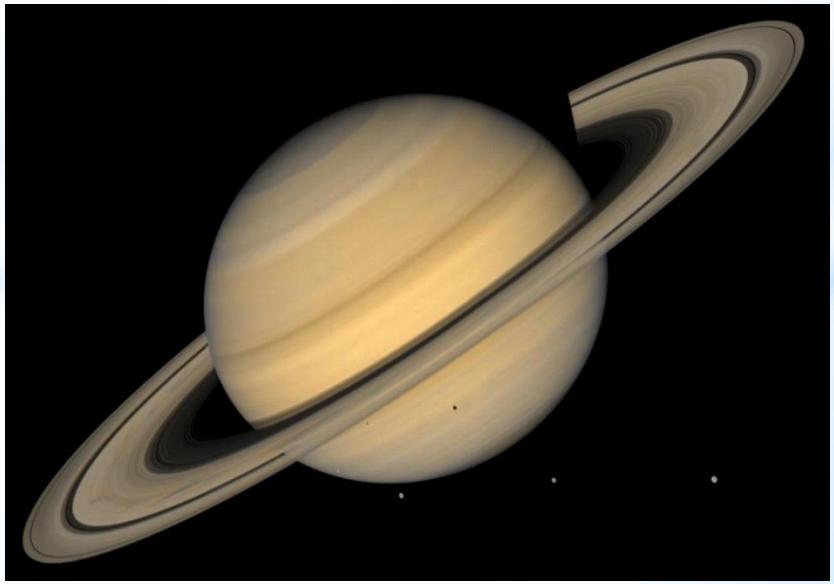
Jupiter's Moons

- Ganymede and Callisto both resemble Earth's moon in appearance
- Grayish brown and covered with craters
- The surface is probably mostly ice with it being so cold

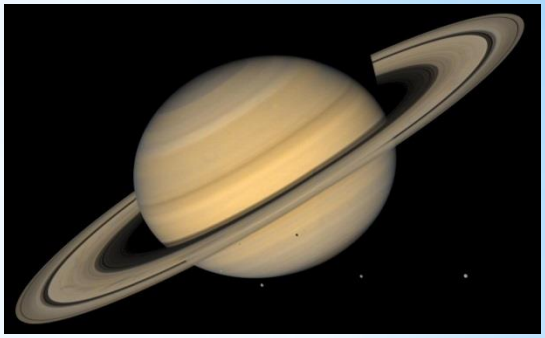
Saturn

Introduction

- 2nd largest planet
- 10 (ish) AUs from the Sun
- Surrounded by rings
- Named after the ancient Roman god of the harvest



Saturn



Appearance and Physical Properties

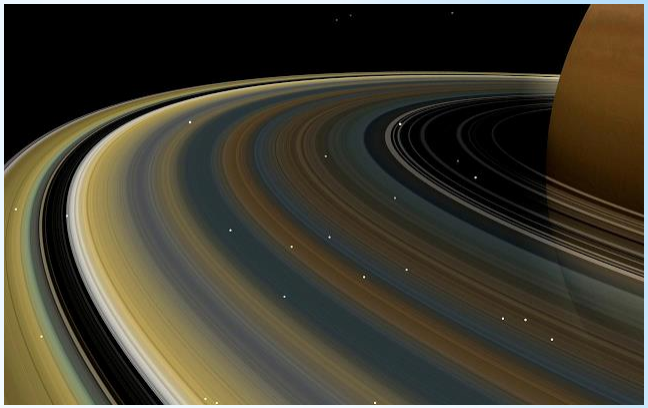
- Its diameter is about 10x what Earth's is, too
- Its mass is about 95x Earth's
- Very low density: .69 g/cm^3
- Composed mostly of hydrogen and hydrogen-rich compounds
  - Thanks to spectra
- Seems to be very similar to Jupiter in size and composition both externally and internally

Saturn

Appearance and Physical Properties

- Saturn also radiates more energy than it gains from the Sun, so it would have an internal heat source just like Jupiter
  - It may be from deep under Saturn's clouds where helium droplets condense in its atmosphere and as the droplets fall towards the core they release gravitational energy that heats the planet's interior
- Saturn's greater distance from the Sun and its lower temperature could be a good reason why it looks so different in appearance compared to Jupiter
- Saturn's atmosphere is cold enough for ammonia gas to freeze into cloud particles that hide its atmosphere's deep layers

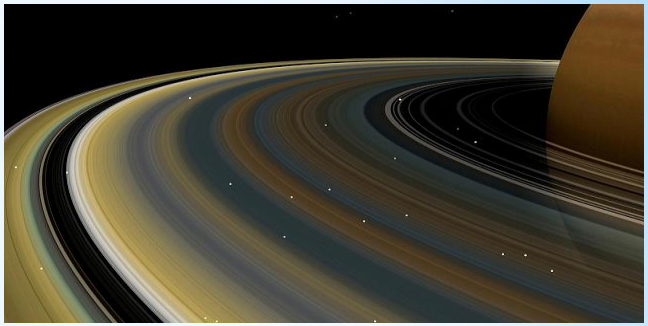
Saturn



Saturn's Rings

- The first rings were seen by Galileo
- Through his telescope they looked like handles and astronomers thought that's what they were until 1659 when a Dutch scientist saw that they were rings and detached away from the planet
  - *Christiaan Huygens*
- The rings are wide but very thin
  - Thin enough to be able to see stars through them
- Bands extend about 30,000 km above the top of Saturn's atmosphere to about 136,000 km (84,000 mi) out

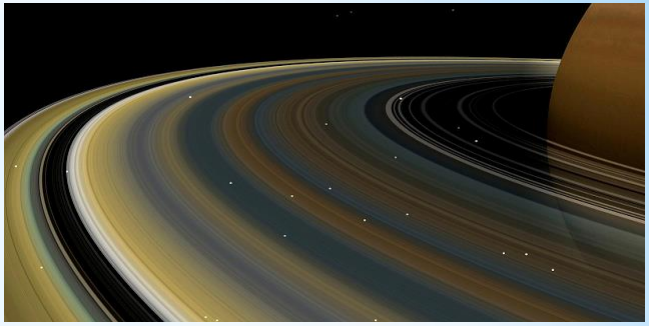
Saturn



Saturn's Rings

- The inner and outer parts orbit at different velocities
- The rings are a swarm of particles
- These particles are only a few cm to a few m in diameter
- They're too small to see with telescopes, but they reflect radar and that's how astronomers can tell what they are
  - Radio signals from the *Voyager I* were also used to help verify their sizes
- The spectra of the ring particles gave their compositions which was primarily water-ice, but with the rings being different colors, that means their compositions vary a little bit

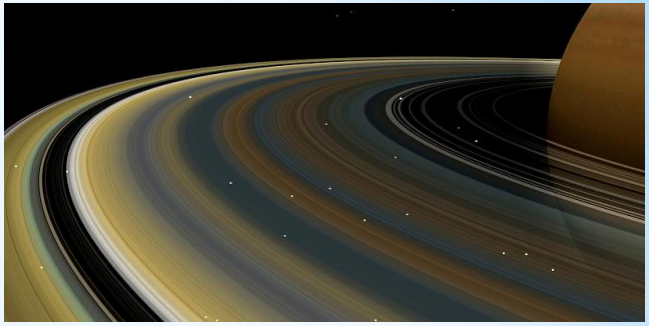
Saturn



Saturn's Rings

- The darker rings could contain carbon compounds
- These rings are also not uniform in how they are filled because they are all separate ringlets
- *Daniel Kirkwood* (in 1866) realized one of the major gaps in the rings called the *Cassini's Division*
- Saturn's moon *Enceladus* orbits slower (1/3rd the time) than the rings and if materials get caught in that pathway, they are pulled out over time due to this drag and it creates a gap in the ring spacing
- Saturn has other moons that could be contributing to the same effect different distances away from the planet
- There are gaps that are not caused by the moons and are still up for discussion

Saturn



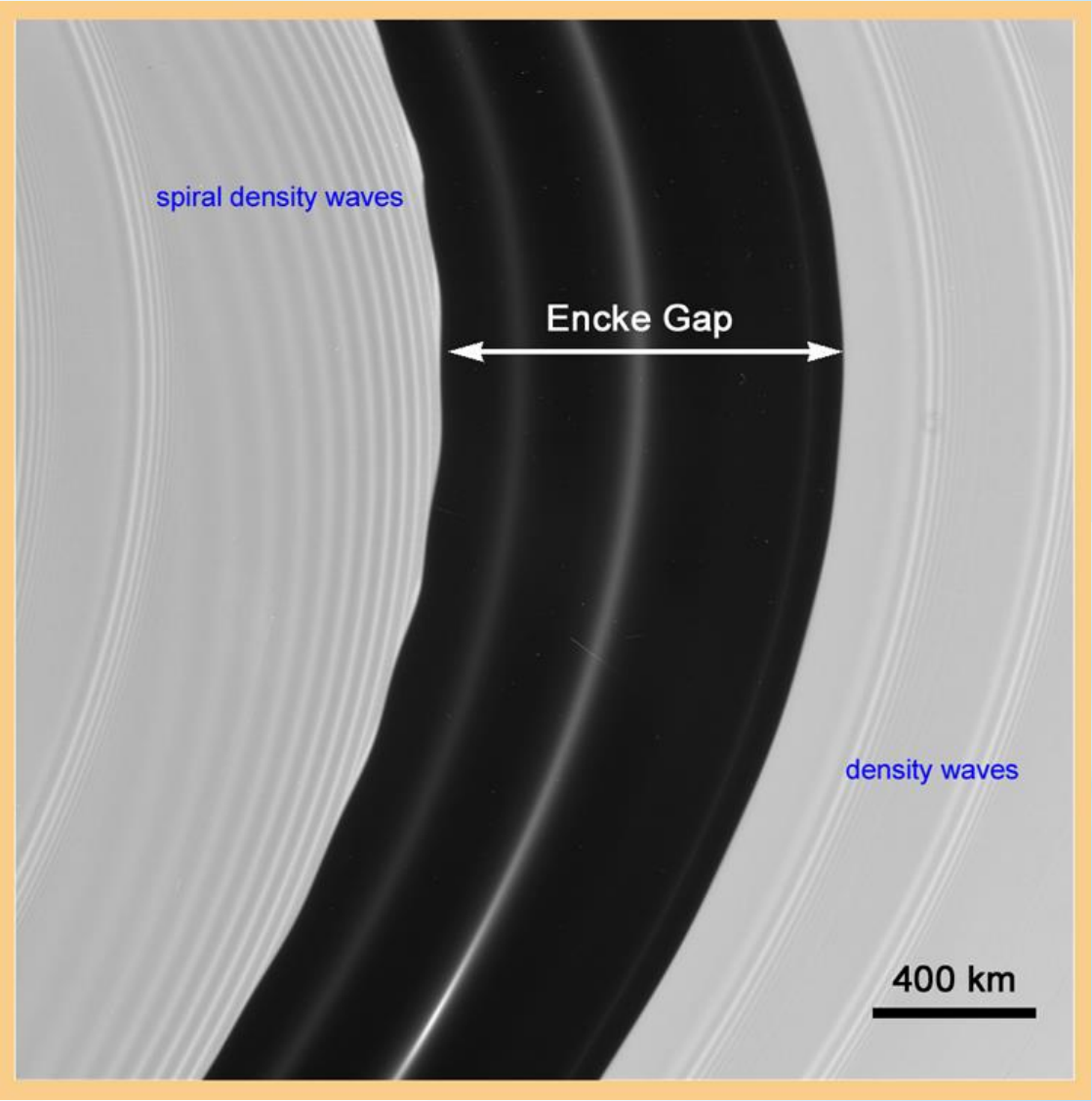
Saturn's Rings

- Other small gaps could be from complex interactions between the ring particles and the tiny moons that orbit within the rings
  - Moonlets – less than 100 km in size that still orbit a planet
- They cause gravitational waves that spread through the rings and cause *spiral density waves*
  - Its similar to tapping surface water and seeing the ripples except that those are circular and because the rings orbit at different velocities, it causes them to spiral
- These spiral density waves seem to create the narrow rings and minor gaps

Saturn

Saturn's Rings

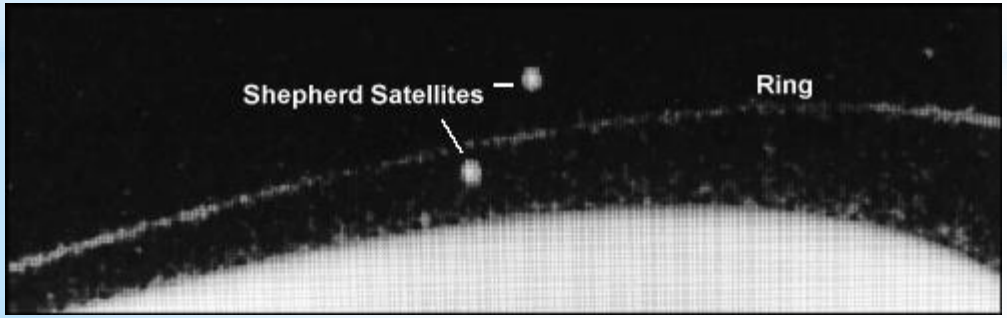
- Spiral density waves

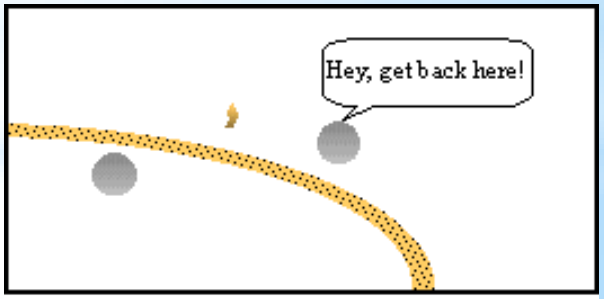


Saturn

Saturn's Rings

- Another possibility… if two moonlets move along orbits that lie very close together, their combined gravitational force may deflect ring particles into a narrow stream between them
- These are called shepherding satellites
- After more research, it looks like Uranus could be home to shepherding satellites, too





Shepherd satellites use their gravity to keep disk particles in line.

Saturn

Saturn's Rings

- Earlier in the 1900s, astronomers thought the rings were from material left over after the planets formed
  - maybe failed to be condensed with the rest of the planet??
- Astronomers know now that the rings are short-lived because they get trapped by both gravity and magnetism which can cause the particles to spiral and collide, sending them into the atmosphere
- Due to the amount of moons and the pulls between them, they can collide from time to time and add to the debris of the rings
- This would pull them closer to the planet (where gravity is stronger) and they'll snap into pieces

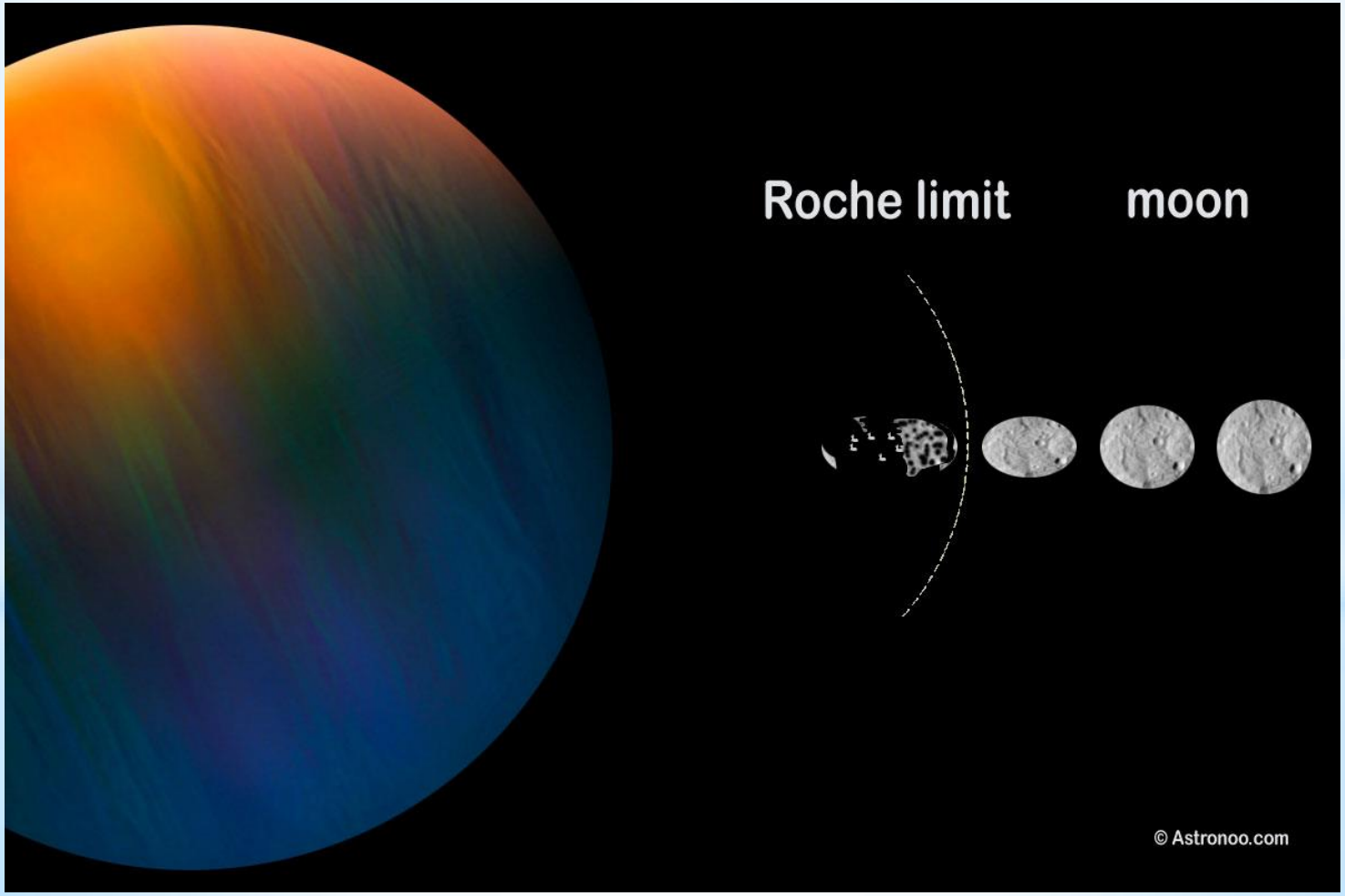
Saturn

Saturn's Rings

- Roche Limit – the limit of which is 2.44 planetary radii away from the planet where a tide becomes so large that an object of the same density of the planet would break apart due to that fatal force
- When a moon or other object gets too close to the planet, it gets ripped apart by gravity
- The inner rings could be evidence of this reaction and the debris is remains of an old moon, comet, or other object
- The fact that the ringlets have different compositions supports this idea
- This only works for objects bound by *gravity*
- *Chemically* bound objects wouldn't be affected

Saturn

Saturn's Rings



Saturn

Saturn's Moons

- Saturn has one really large moon and 61 other small ones
  - At this point…
- These all orbit in a parallel motion to the equator
  - Just like a mini solar system
- These moons have cores made up of primarily ice so their densities average lower than the Galilean Satellites

Saturn

Saturn's Moons

- *Titan* is the largest Saturnian moon
  - 5000 km diameter
  - Slightly bigger than Mercury
  - Usually compared to Callisto and Ganymede
  - Because it's so cold, it has its own atmosphere from the gases moving so slow and getting caught by the gravity pull
  - Atmosphere: nitrogen
  - In 2005, NASA used the probe *Cassini* radar and infrared to start mapping its surface
  - The *Cassini* probe released a secondary probe to touch down on the surface and it did, catching photographs and images of rock formations made out of frozen methane and other hydrogen compounds

Saturn

Saturn's Moons

- *Titan* is the largest Saturnian moon
  - The methane is liquidized by the atmosphere and radar maps show lakes of this liquid near the poles
- Many of the other moons show craters from bodies striking them
- Some have smooth finishes from water flooding to the surface and freezing to be rock hard (94 K or -290˚F)

Uranus

Introduction

Alright, let's get this out of the way…

- Pronounced (u-RAIN-us) officially
  - Named around the same time as the element *uranium*, so it follows a similar pronunciation
- Scientists have changed its pronunciation to (ur-IN-us) for the sake of the conflict with the English language, so that's why they say it different

Uranus

Introduction

- Diameter is about 4x Earth
  - Significantly smaller than Jupiter and Saturn, but bigger than Earth
- Mass is about 15x Earth
- Sits about 19 AU from the Sun
- Really tough to study from Earth because of how far away it really is
- Shines with a bright blue or blue/green appearance
- There are some faint cloud bands (thanks *Voyager I*) but its primarily flawless on the surface

Uranus

Introduction

- Unknown to the ancients, so it doesn't follow the name system like the rest
- Discovered by Sir William Herschel of Germany in 1781
  - Amateur astronomer at best, but hey, he found a planet ☺
  - Would hunt for comets and when he found Uranus, that's what he thought it was at first
- To honor King George III of Germany, it held the name *Georgium Sidus* (George's Star) for a while
- It got overturned to Uranus, the Greek god of the heavens and that's what stands today

Uranus

Structure

- Rich in hydrogen and hydrogen compounds
  - Primarily water and methane
  - Thank you spectra
- The methane is what gives this planet the deep blue color
  - Originally thought to be the nitrogen, but coldness of the temperatures allow methane to give the stronger color
  - The methane strongly absorbs red light so the blue gets reflected
- Using mass and volume calculations, Uranus's density is about 1.2 g/cm^3
  - This is about twice what Saturn is and almost to the same level as Jupiter

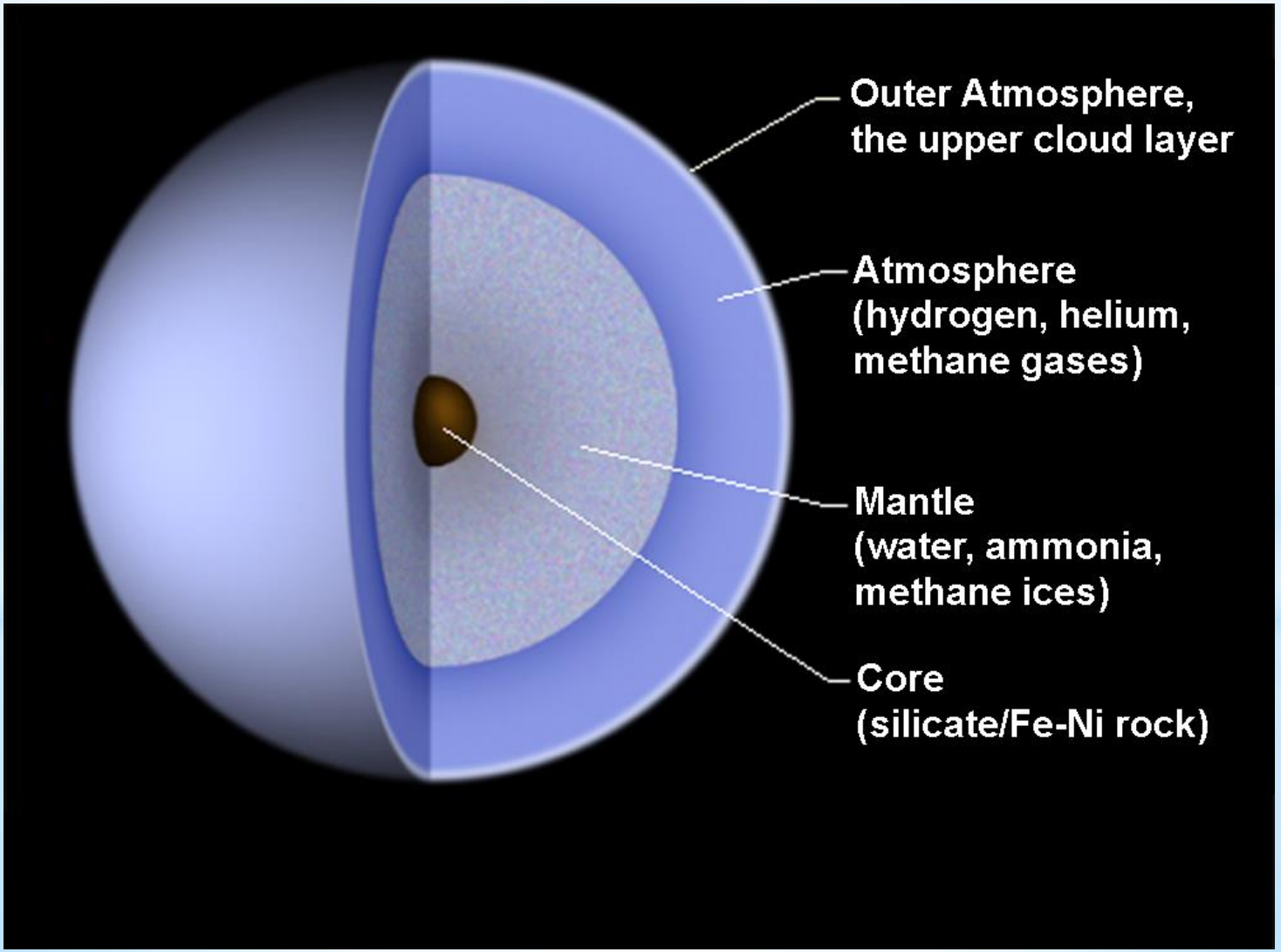
Uranus

Structure

- Because it's not quite Jupiter and more dense than Saturn, scientists have idealized that the composition isn't as hydrogen based, but isn't a lot of rock either
- Primarily frozen water and methane would calculate to give it that density
- Rotates every 17 hours, so bulges at the equator like Jupiter
- Could have a core of rock and iron, but that concept is becoming more and more unlikely to some astronomers…
  - This is really tough to study with it being that far away

Uranus

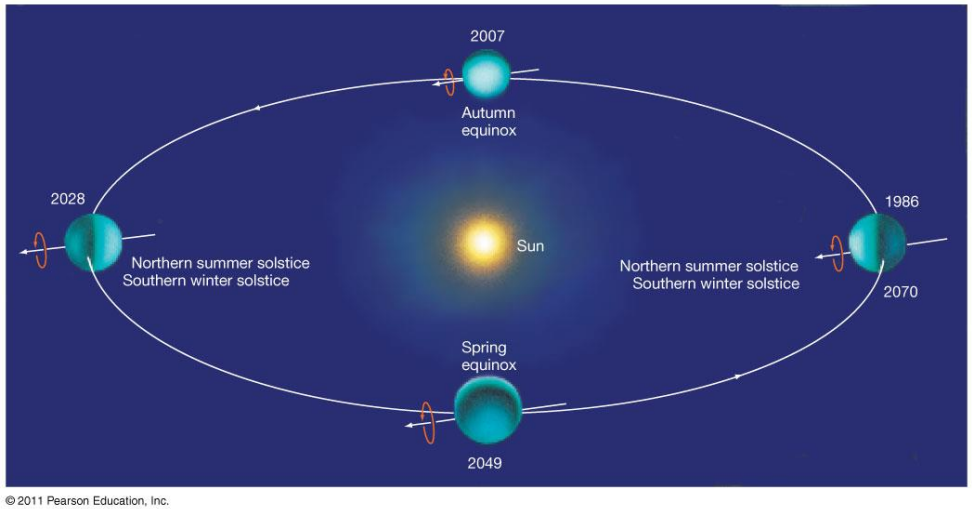
Structure

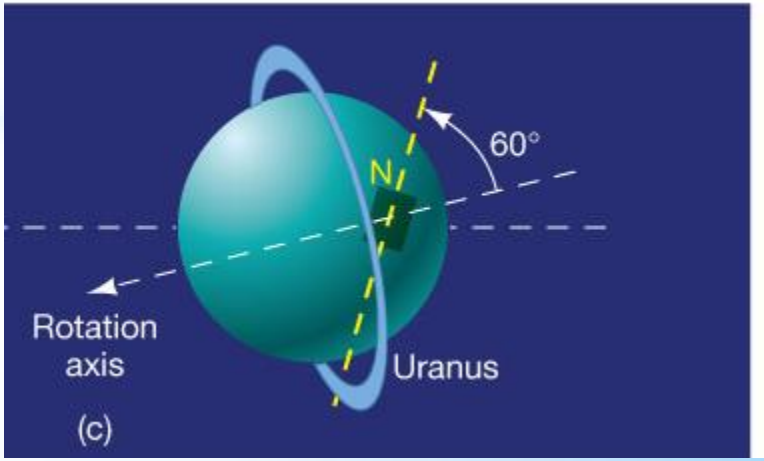


Uranus

Odd Tilt

- The axis tilt causes Uranus to run its equator almost perpendicular to the rotation
- Tilt is about 90˚
- 2 ideas…
  - Struck by a really large planetesimal which knocked it sideways and the debris became its family of moons
  - Tilted by gravity tugs from neighboring planets (especially Saturn)





Uranus

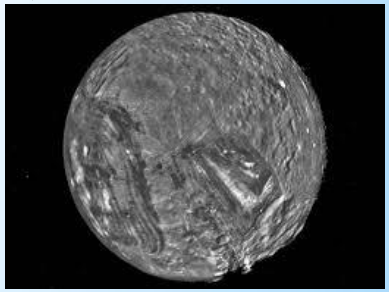
Odd Tilt

- Because of the axis, the day and night turns are completely different from the other planets
- This causes uneven heating and could explain the lack of cloud banding like Saturn and Jupiter

Uranus

Rings and Moons

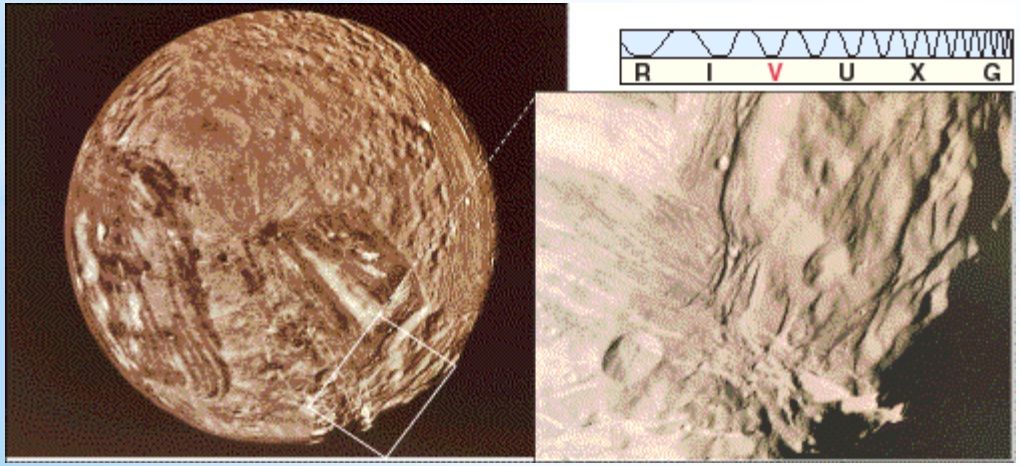
- Does have a set of really narrow rings
- Contain small particles no bigger than a meter (or so) in diameter
- These don't really contain ice, but rather dark substances that are carbon based
- Narrow bands are explained by the shepherding satellites it contains
- 5 fairly large moons, and several very small ones
- Home to the strangest moon in the solar system, *Miranda*

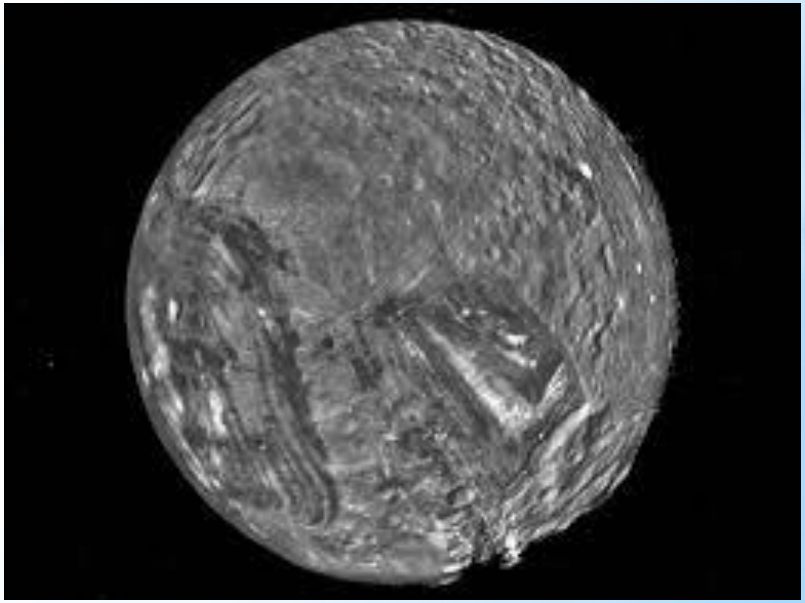


Uranus

Rings and Moons

- *Miranda* is the smallest of the 5 larger moons
- Has such a strange appearance unlike any other moon in the solar system
- Seems to have been shattered by a really strong collision, but the mutual gravity seemingly put the pieces back together, giving it this appearance





Neptune

Introduction

- Outermost planet of the solar system
- Size wise, very similar to Uranus
- 3.9x Earth in diameter and 17x in mass
- 30 AU from the Sun!
- Toughest to study
- Dark blue appearance… much darker than even Uranus
- Does have cloud bandss that are easier to see than Uranus
- Has a Great Dark Spot
  - Just like Jupiter's Great Red Spot… only darker blue
  - Same cause and set up

Neptune

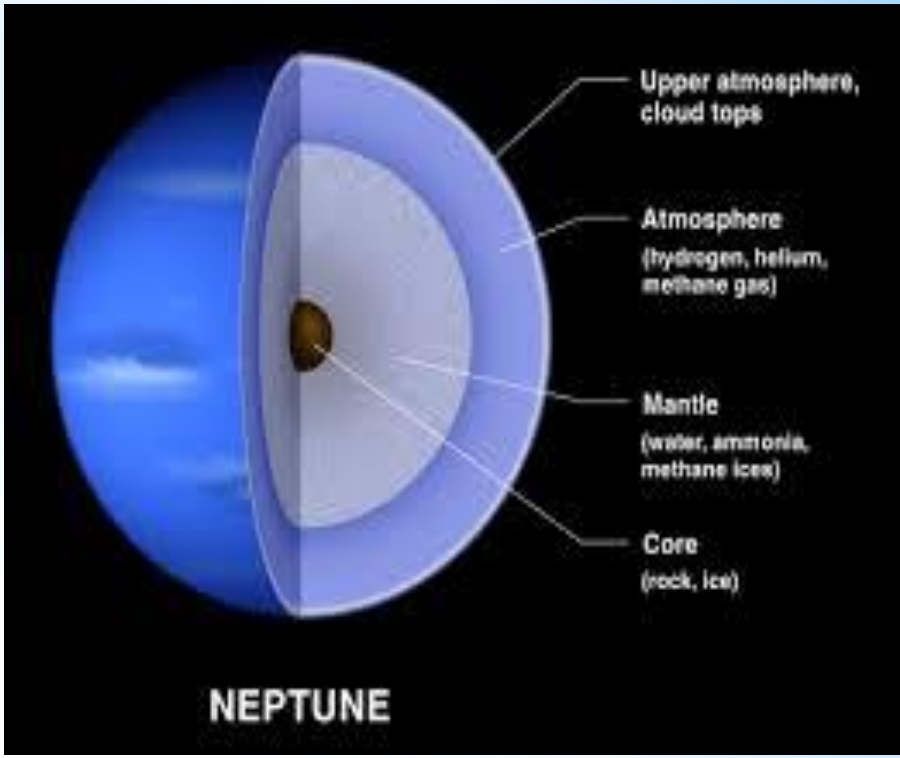
Introduction

- Named for the Roman god of the sea
  - *Anticipated* by English astronomer, John Adams and French astronomer, Urbain Leverrier in 1840s
  - Later confirmed, but not after a lot of struggles with the technicalities of who discovered it
  - Long story short, both astronomers received credit

Neptune

Structure

- Similar to Uranus
  - Water and methane composition
- Density of 1.67 g/cm^3



- The probability for silicon and iron are higher with Neptune due to the higher density and similar volume
- This core is still slightly smaller than Earth's but definitely showing signs that it is present in the center of this planet

Neptune

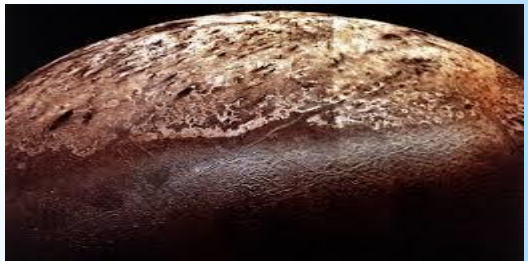
Atmosphere

- The blue color on Neptune is methane related just like Uranus, it's just a bolder color due to the temperature
- This is why these two planets look almost identical
- Neptune does have distinct cloud belts
- The radiation released by Neptune (just like Jupiter) causes the gases to warm slightly and then the pull of the rotation creates the cloud bands
- The winds in these systems are extremely intense
  - 2200 km/hr! (That's 1200 miles per hour!!)
- Pictures taken in the 1990s from the Hubble showed that the Great Dark Spot was gone, but it reappeared in the recent years

Neptune

Rings and Moons

- Does have rings, but very narrow
- Made up of debris from colliding objects like comets or other small satellites
- Really difficult to see from Earth
- Some rings contain “clumps” of particles that could be from a gravitational fix in the orbits
- 6 small moons orbit close to the planet with several others out at further distances
- 1 of the larger moons, Triton, is nearly as big as Europa



Neptune

Rings and Moons

- Triton rotates clockwise which is opposite what the planet does
- There are thoughts of it being a surviving icy planetesimal from the inside of Kuiper's belt
- This one (due to its size and gravity pull) has an atmosphere, too
- The surface is covered in wrinkles (like a cantaloupe) with craters and dark spots from minor volcanic work inside