



- Last Homework before Exam (HW#4) is due Friday at 11:50am.
- Nighttime observing has 6 more nights. Check the webpage.
- 1<sup>st</sup> exam is October 10<sup>th</sup>, less than 2 weeks away!
- Justin will have an extra office hour Thursday (10/9) before exam– 4:00 to 5:00pm.
- I will have an extra office hour Wednesday (10/8) before exam– 10:30 to 11:30am.

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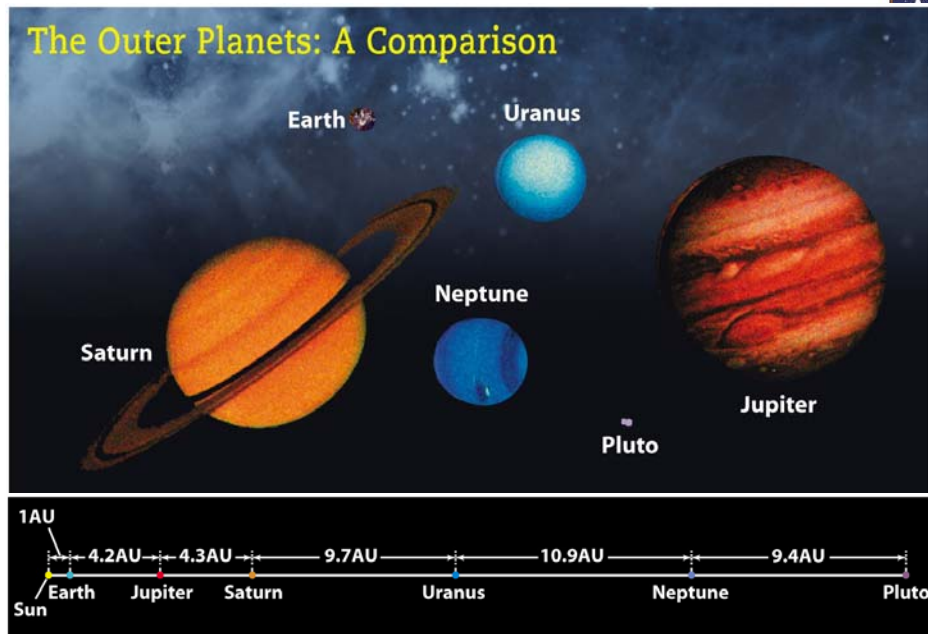


## Outline

- Jupiter
  - Shortest day
  - It's all about atmosphere and pressure
  - Why do the Jovians keep their Hydrogen and Helium?
- Saturn
  - Rings
- Uranus
- Neptune
- Pluto
  - different

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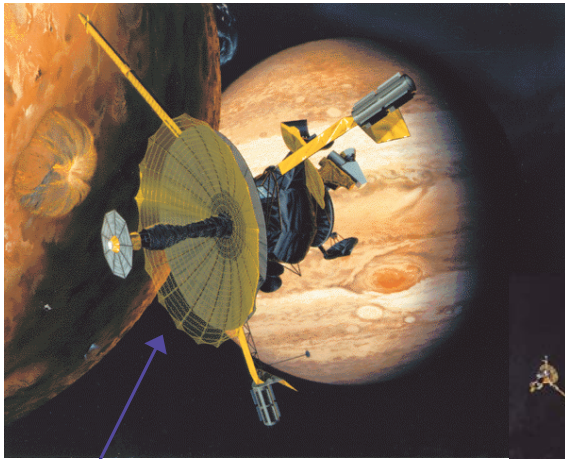
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### Earth – Jupiter comparison

Biggest and most massive planet, has the largest gravity, has the largest number of moons (>61), yet has the shortest day in Solar System.	Radius	11.2 Earth
	Cloud-top gravity	2.54 Earth
	Mass	318 Earth
	Distance from Sun	5.20 AU
	Eccentricity	0.048
	Tilt	3.12 °
	Albedo	0.51
	Year	11.88 Earth years
	Solar day	9 hours 55 minutes

# The Galileo Spacecraft (1989 – 2003)



How the main antenna *should* have looked

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First atmospheric probe

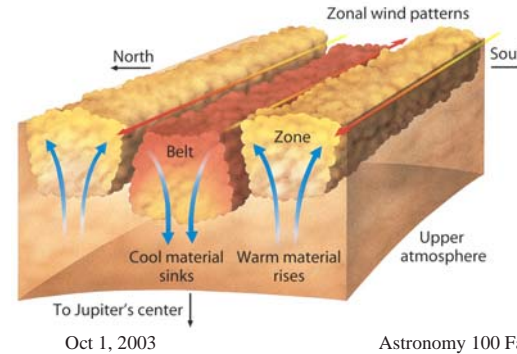


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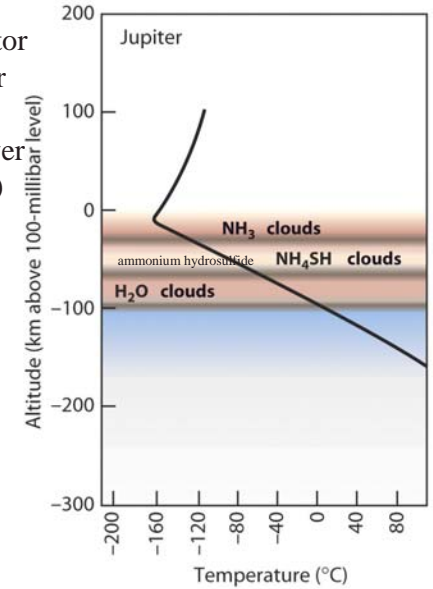
# The Outer Atmosphere of Jupiter



- Alternating cloud bands parallel to equator
- Clouds mainly ammonia, methane, water
- Atmosphere mainly hydrogen
- Differential Rotation– poles 5 mins slower
- Velocities alternate (speed ~ 600 km/hr)
- Dramatic shear patterns results



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# Jupiter Atmosphere Movie



<http://www.solarviews.com/raw/jup/vjupitr2.mov>

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# Composition of Planetary Atmospheres



the result of a competition:

*heat* vs *gravity*

**Heat**

gas atoms in random motion

– hotter = faster

– at each T, heavier atoms slower than lighter

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# Why Light Gasses on Jovian Planets?



Jupiter (& Jovians) **mostly** hydrogen and helium  
Lightest atoms  
Few heavy elements

Terrestrial Planets mostly heavy elements  
Very little hydrogen and helium

Why?  
Key factors:

Jovians larger  
– more mass  
– stronger **gravity**

Jovians farther away  
– Sunlight less intense  
– lower **temperature**

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# Planetary Atmosphere Composition



Bottom line: different outcomes in gravity vs heat struggle

- Inner planets  
Hotter: H, He atoms faster than escape speed  
“leak” away = “evaporate”
- Outer planets:  
gravity stronger and atoms slower  
H, He remain

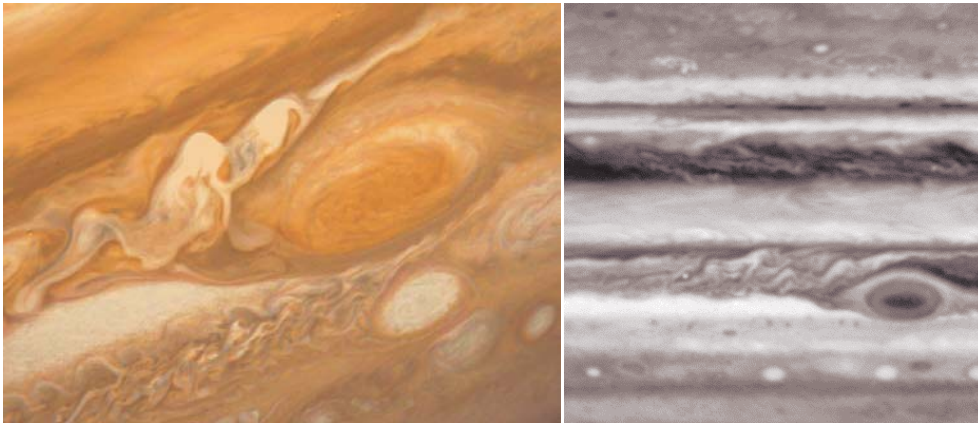
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# The Great Red Spot



- A huge storm 25,000 km across – twice size of the Earth!
- First observed > 300 years ago!



Voyager 1 image

Cassini images

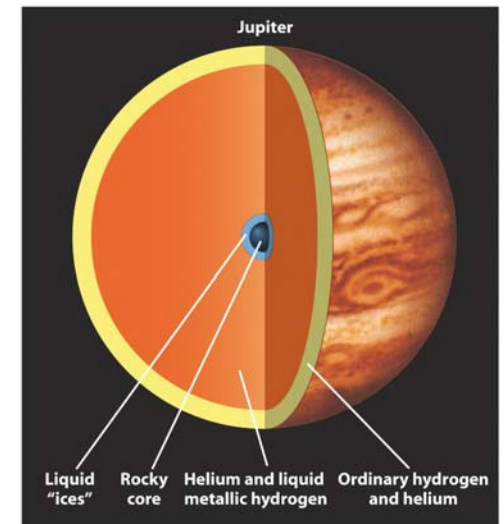
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# Jupiter's Interior



- Although mostly gas, by 20,000 km, the pressure is 3 million atmospheres!
- This makes helium and hydrogen metallic
- Effectively, a “failed star”
- Produces about 1.7x as much heat as received from Sun
- Source: gravitational contraction
- Helps drive cloud motions and storms



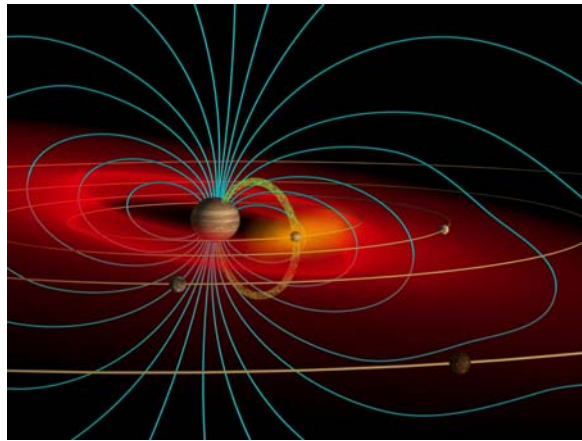
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# Jupiter's Magnetosphere and Trapped Radiation Belts



- Liquid metallic hydrogen core – so strong magnetic field
- 14x stronger than Earth's surface field at cloud tops
- About 30 million km across
- Plasma torus associated with each of the Galilean moons (esp. Io)



J. Spencer

## Voyager 1 crossing into Jupiter's magnetosphere

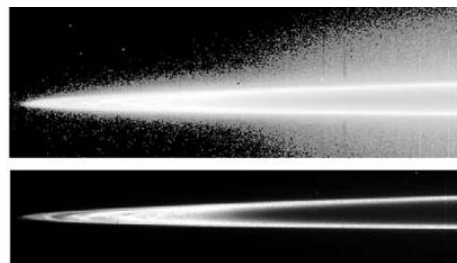
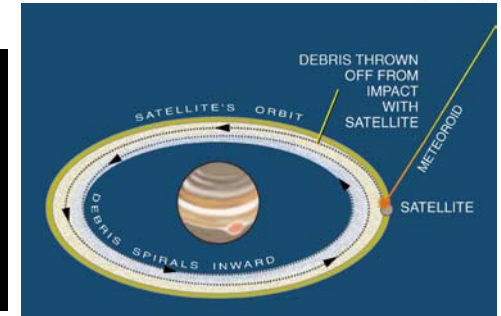
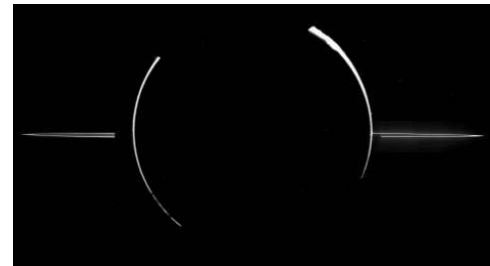
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# Jupiter's Rings



- Discovered by Voyager 1 (1979)

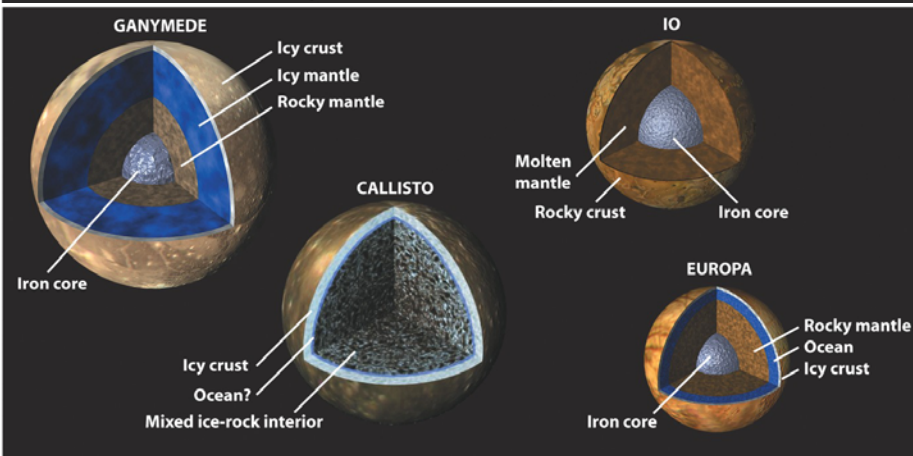
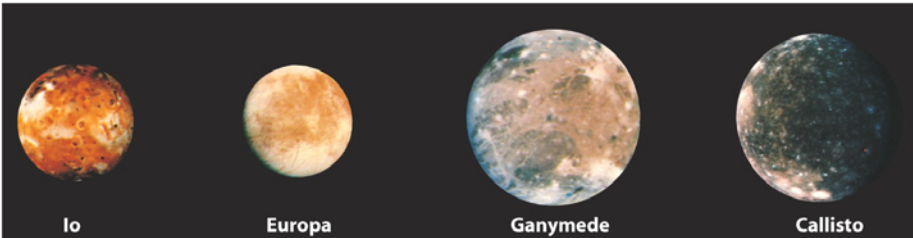


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<http://www.jpl.nasa.gov/galileo/status980915.html>

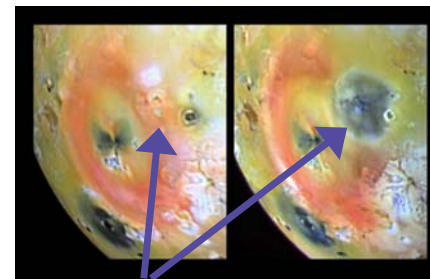
# The Galilean Moons



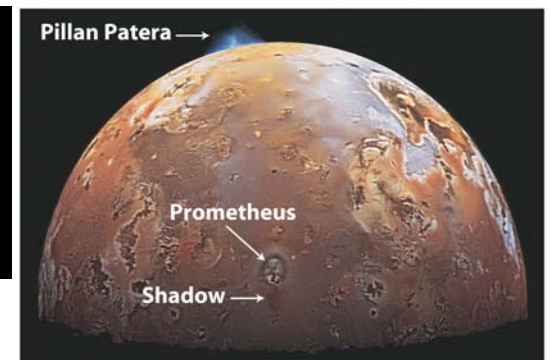
# Io



- Innermost Galilean moon – the “pizza moon”
- Sulfur/sulfur dioxide on surface; silicate lava flows?
- Voyager 1 discovered presence of volcanoes
- Internal heating by Jupiter's tides
- Atmospheric gases ripped off by Jupiter's magnetic field – ion torus



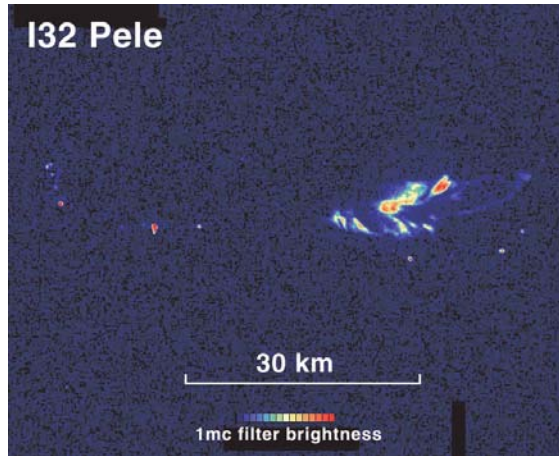
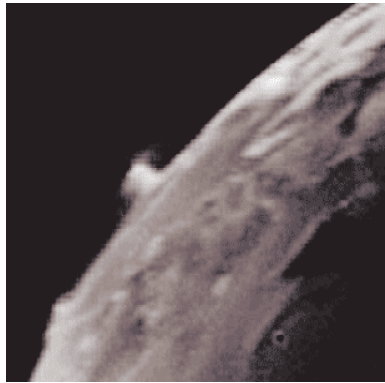
Pillan Patera eruption Before & after



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# Io– Volcano Activity



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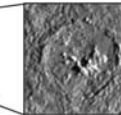
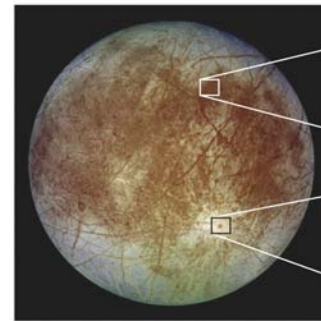
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<http://www.solarviews.com/cap/jup/PIA02596.htm>  
<http://www.solarviews.com/cap/jup/ioplume3.htm>

# Europa



- Icy crust 5 km thick
- Evidence for deep (50 km!) liquid water ocean beneath crust, remains liquid from tidal forces from Jupiter
- Cracks and fissures on surface – upwelling?
- Few impact craters
- Life???

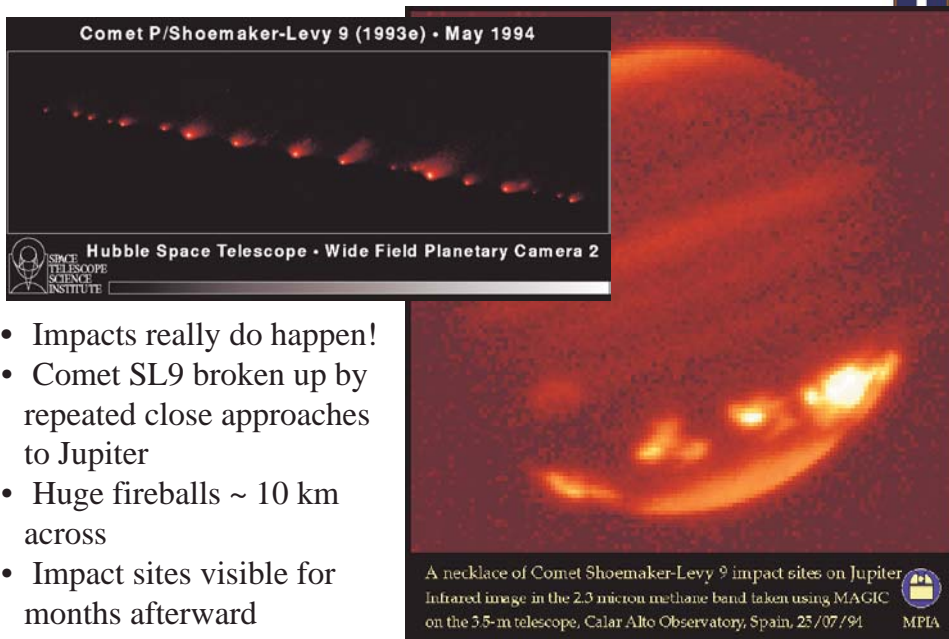


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Galileo

# Comet Shoemaker-Levy 9's Impact (1994)

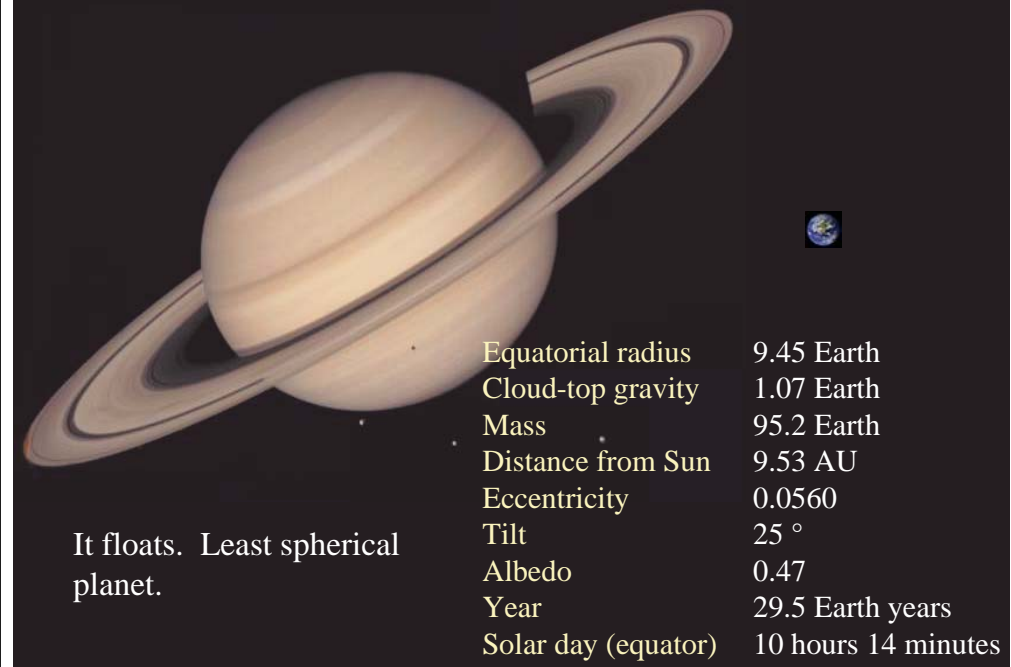


- Impacts really do happen!
- Comet SL9 broken up by repeated close approaches to Jupiter
- Huge fireballs ~ 10 km across
- Impact sites visible for months afterward

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# Earth – Saturn comparison



# Saturn



- The Lord of the Rings
- Broad atmosphere banding is similar to Jupiter
- At least 30 moons, of which only 7 are spherical
- <http://www.solarviews.com/raw/sat/vsaturn1.mpg>

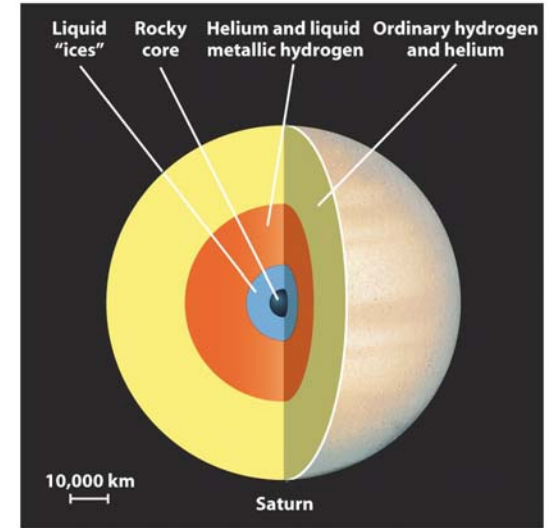
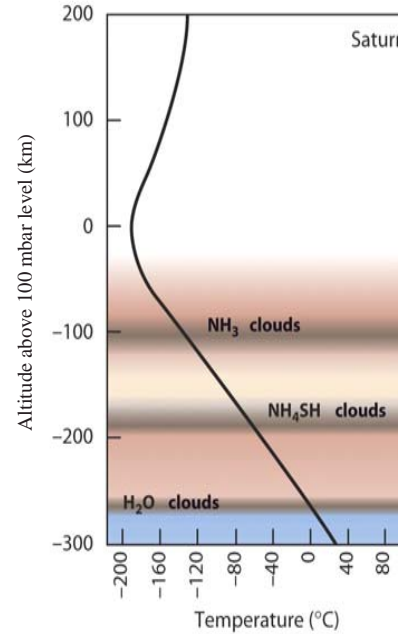


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<http://www.solarviews.com/cap/sat/saturn.htm>

# Saturn's Atmosphere and Interior

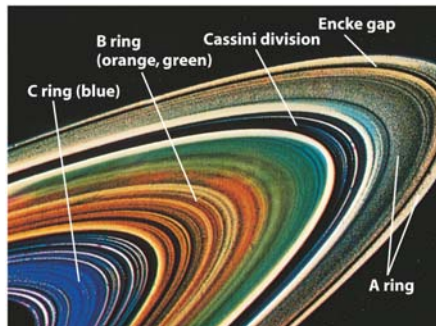
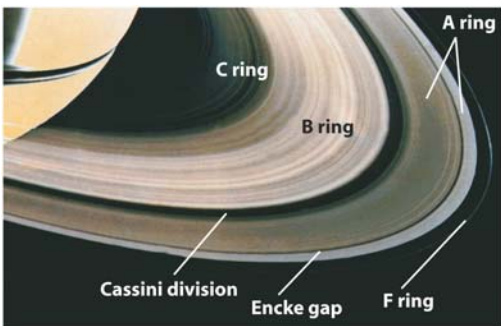


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# Saturn's Rings



- <http://www.solarviews.com/raw/sat/spoke.mov>
- High albedo > 0.80
- Mostly composed of ice and ice coated rocks
- About 2km thick, but 90000 km in diameter
- Largest pieces are about 10m, as small as sand grain



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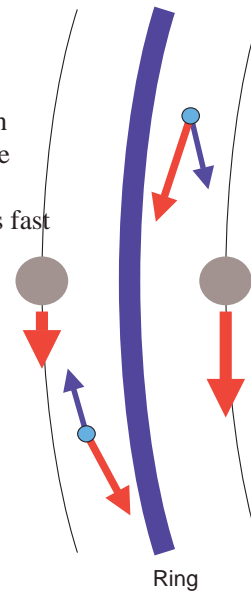
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False color image

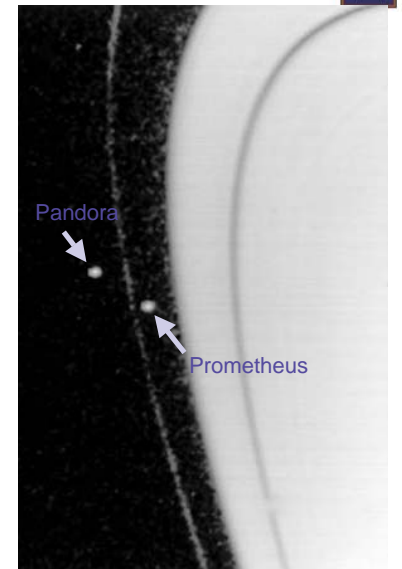
# Shepherd Moons



- Outer moon moves more slowly
- Decelerates fast particles



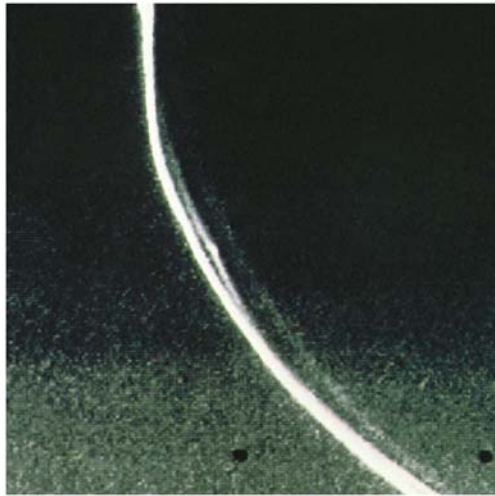
- Inner moon moves faster
- Accelerates slow particles



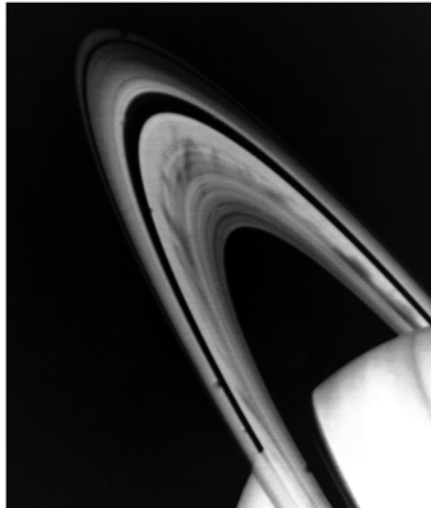
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## “Braiding” and “Spokes” on Saturn’s Rings



Effect of the magnetic field, which is 2/3 of the Earth’s



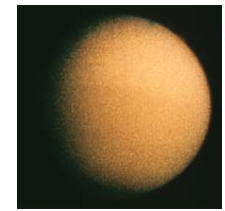
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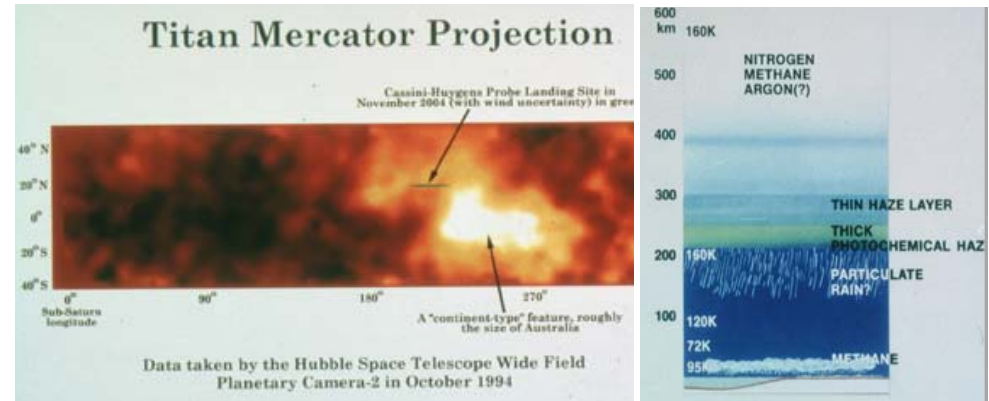
## Titan



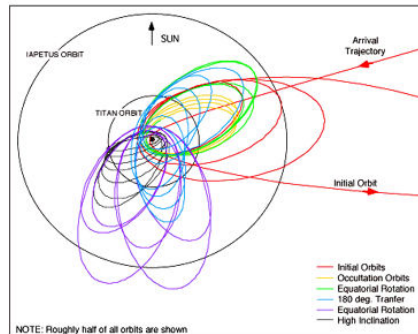
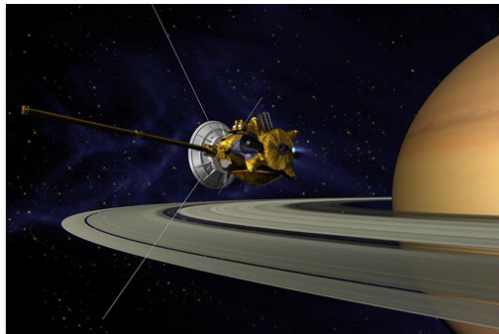
- Saturn’s largest moon
- Discovered 1655 by Christaan Huygens
- Dense nitrogen/methane atmosphere
- Liquid ethane – lakes/oceans?
- Organic compounds – life?
  - Probably not – too cold: 95 K



Titan’s atmosphere



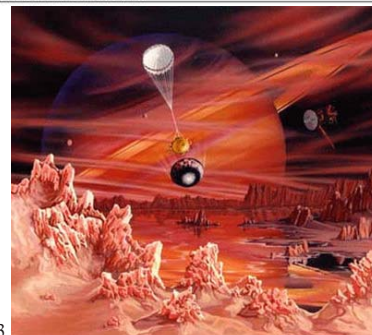
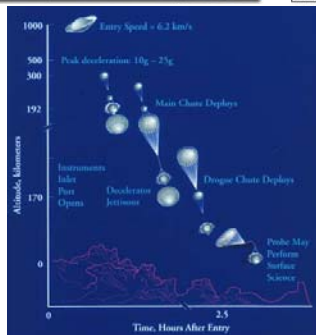
## Cassini-Huygens



Arrival at Saturn  
July 1, 2004

Huygens Probe  
descent to Titan  
November 4, 2004

Oct 1, 2003



## Earth – Uranus comparison



Most tilted  
axis with  
respect to the  
orbit.

Equatorial radius	4.01 Earth
Cloud-top gravity	0.90 Earth
Mass	14.5 Earth
Distance from Sun	19.2 AU
Eccentricity	0.047
Tilt	98.25 °
Albedo	0.6
Year	84.0 Earth years
Solar day	16 hours 30 minutes (retrograde)

# Atmosphere

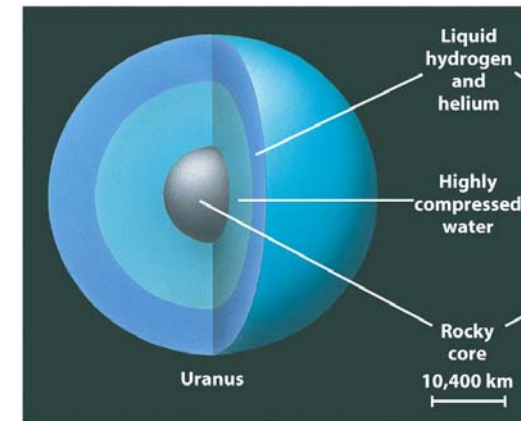


- The atmosphere of Uranus is composed of 83% hydrogen, 15% helium, 2% methane and small amounts of acetylene and other hydrocarbons.
- Temperature in the atmosphere is so low, that methane ice crystals form clouds.
- Methane absorbs red, making the planet bluish.
- The atmosphere is arranged into clouds running at constant latitudes, similar to the orientation of the more vivid latitudinal bands seen on Jupiter and Saturn.

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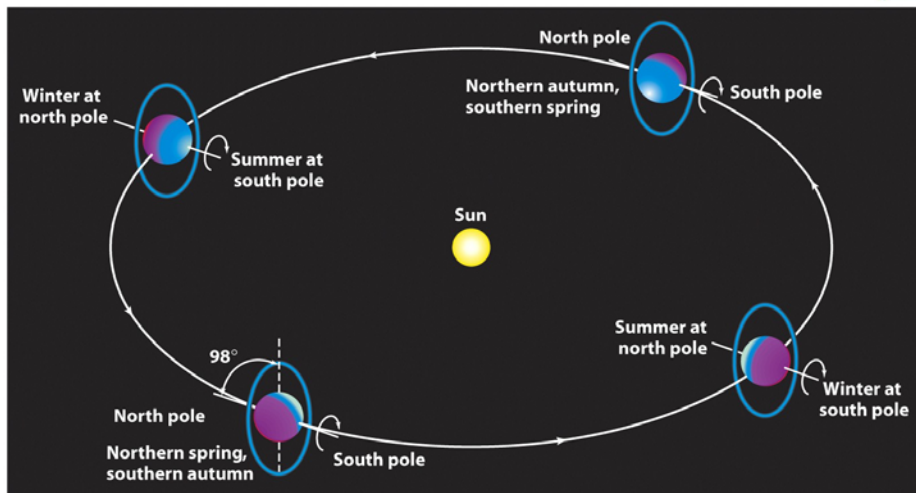
# Interior



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# Seasons on Uranus Last a Long Time



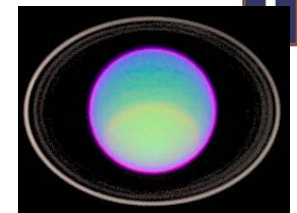
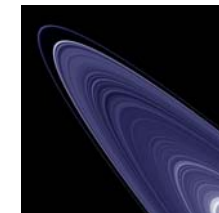
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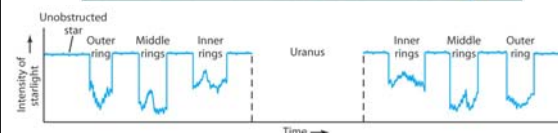
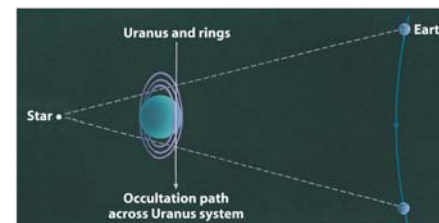
# Uranus's Ring System



- Discovered 1977 from Earth during occultation of star SAO 158687
- Later observed close-up by Voyager 2 (1986)
- Rings are dark, narrow, dusty (methane ice)



Hubble Space Telescope  
Infrared image



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<http://www.solarviews.com/eng/uranus.htm>



# Moons of Uranus

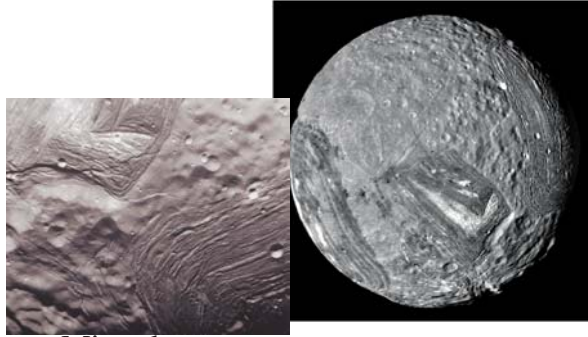


- 5 major satellites (Titania, Ariel, Umbriel, Oberon)
- 10 minor ones discovered by Voyager 2
- 5 additional minor ones discovered since then



Titania  
(largest)

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Miranda  
(smallest of the 5)

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# Earth – Neptune comparison



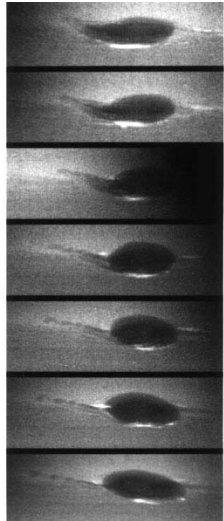
Record for fastest winds.

Equatorial radius	3.88 Earth
Cloud-top gravity	Earth
Mass	17.1 Earth
Distance from Sun	30.1 AU
Eccentricity	0.009
Tilt	28°
Albedo	0.41
Year	164.8 Earth years
Solar day	19 hours 6 minutes

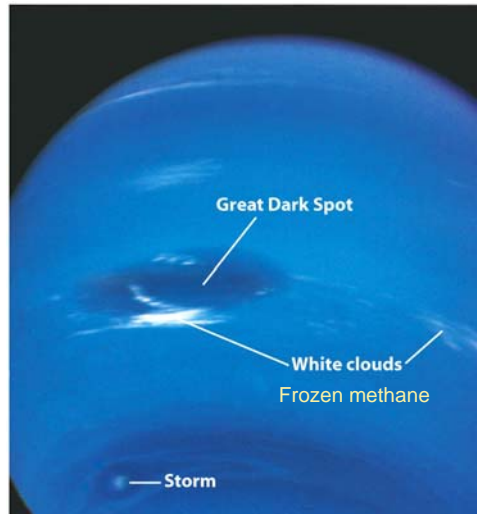
# Neptune's Atmosphere



- Hydrogen, helium, methane (can see features)– banded like Jupiter
- Wind speeds ~ 300 km/hr
- Large storm like Great Red Spot on Jupiter (but now dissipated).

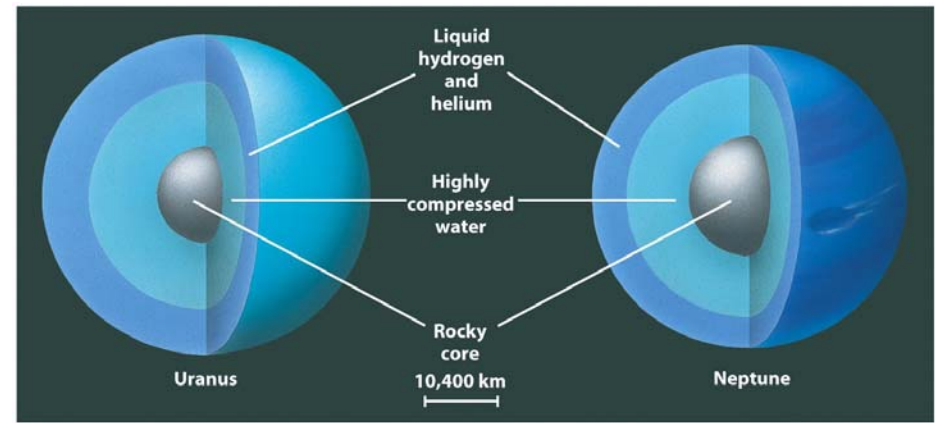


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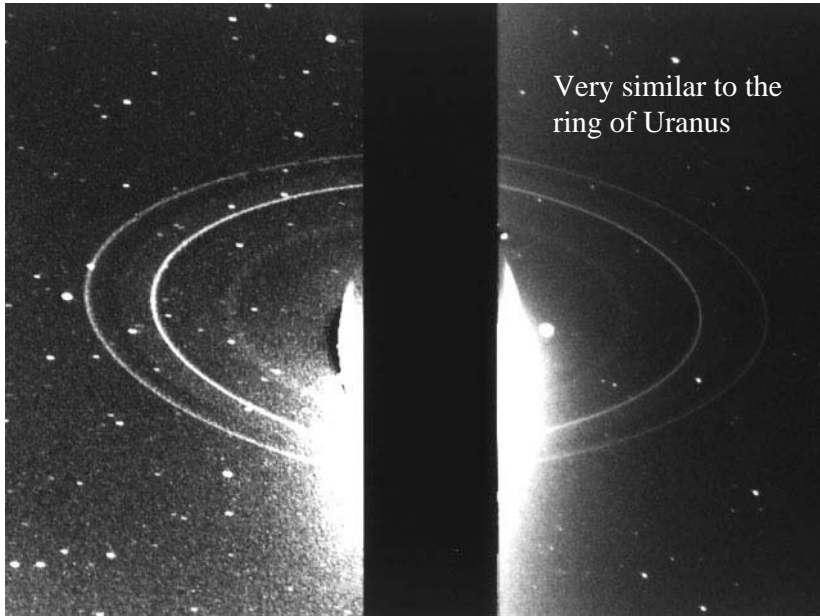
# Interiors of Uranus and Neptune



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## Neptune's Rings



Voyager 2  
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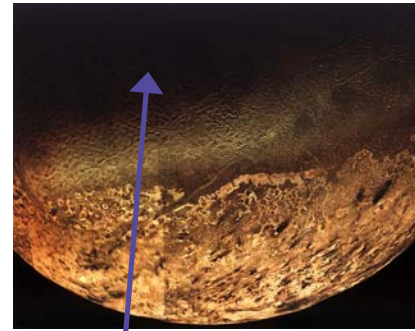
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## Triton



- Eight moons known (mostly captured)
- Largest is Triton
  - Retrograde motion around Neptune
  - Thin nitrogen atmosphere
  - Geysers with high-altitude shear
  - Bizarre “cantaloupe terrain”
  - Surface frozen methane/nitrogen
  - Evidence of geologic activity (few craters)

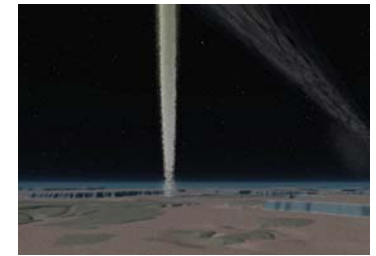
<http://www.solarviews.com/raw/nep/geyser.mov>



“Cantaloupe terrain”  
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Nitrogen “geyser”



Artist's conception – W. Myers

## Earth – Pluto - Charon comparison



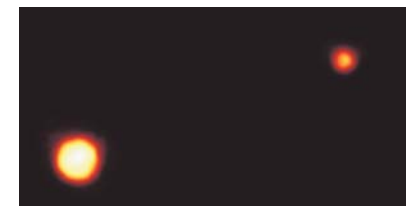
Smallest planet or largest Kuiper belt object. Coldest planet. Has biggest moon relative to itself and the largest tilt of orbit around Sun.

Radius	0.19 Earth
Surface gravity	0.055 Earth
Mass	0.002 Earth
Distance from Sun	39.5 AU
Eccentricity	0.249
Tilt	118°
Albedo	0.5
Year	248.6 Earth years
Solar day	6.39 Earth days (retrograde)

## Pluto's Surface



- <http://www.solarviews.com/raw/pluto/vpluchar.mpg>
- The only planet not yet visited by a spacecraft
- Reconstructed from Charon eclipses and more recently observed directly by Hubble Space Telescope (1996)
- Largest range of albedo yet observed in Solar System
  - Dark areas – rock
  - Light areas – frost
- Surface features > 500 km in size



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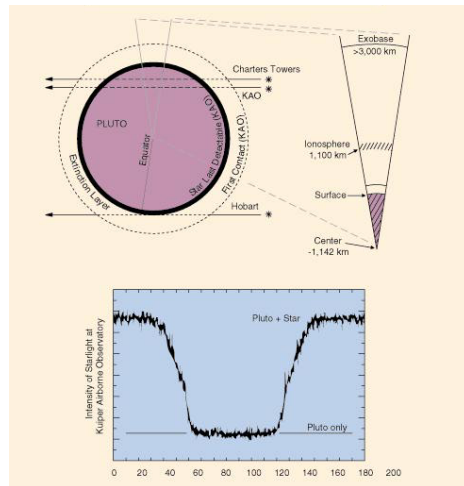
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<http://www.solarviews.com/cap/pluto/hstpluto.htm>

# Pluto's Atmosphere

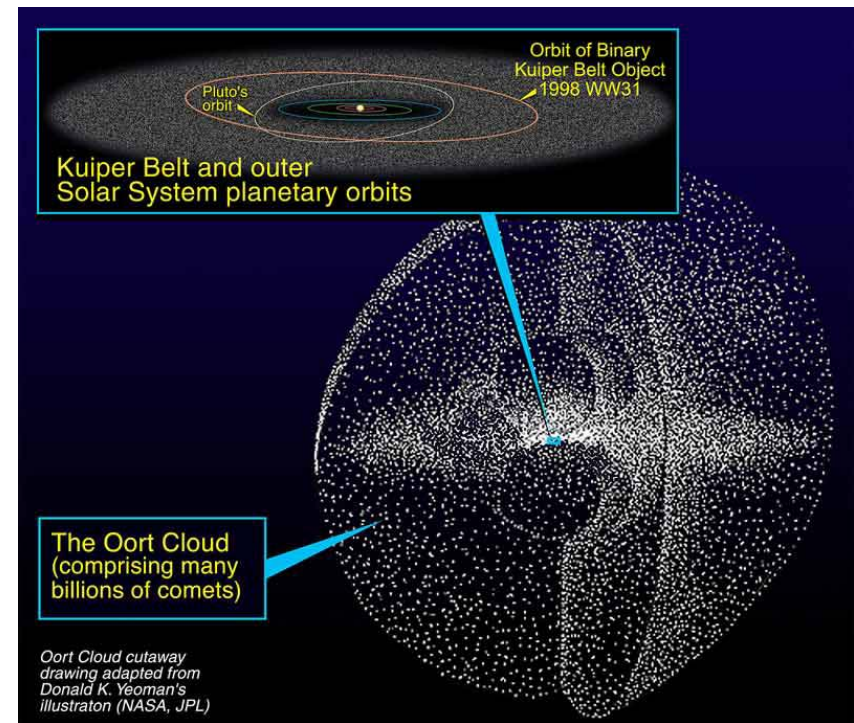


- Observed when Pluto occults background stars
- Consists mostly of nitrogen (90%) and methane
- Alternately freezes and sublimates as Pluto-Sun distance changes
- Current surface temperature ~ 40 K !!!
- Will re-freeze in ~ 2020
- Currently appears to be getting warmer though Pluto is moving away from perihelion (!?)



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# New Horizons Mission to Pluto and the Kuiper Belt



Currently planned launch in 2006 (if funding continues)

<http://pluto.jhuapl.edu>  
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