



- Last Homework before Exam (HW#4) is due Friday at 11:50am.
- Nighttime observing has 6 more nights. Check the webpage.
- 1st exam is October 10th, 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.

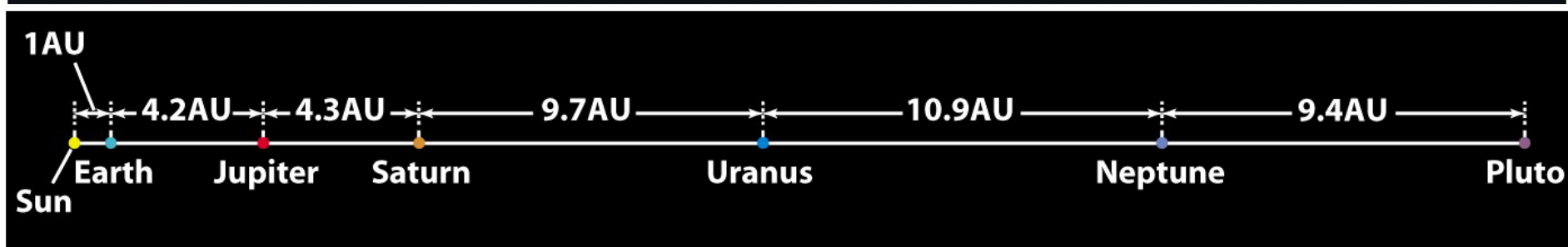
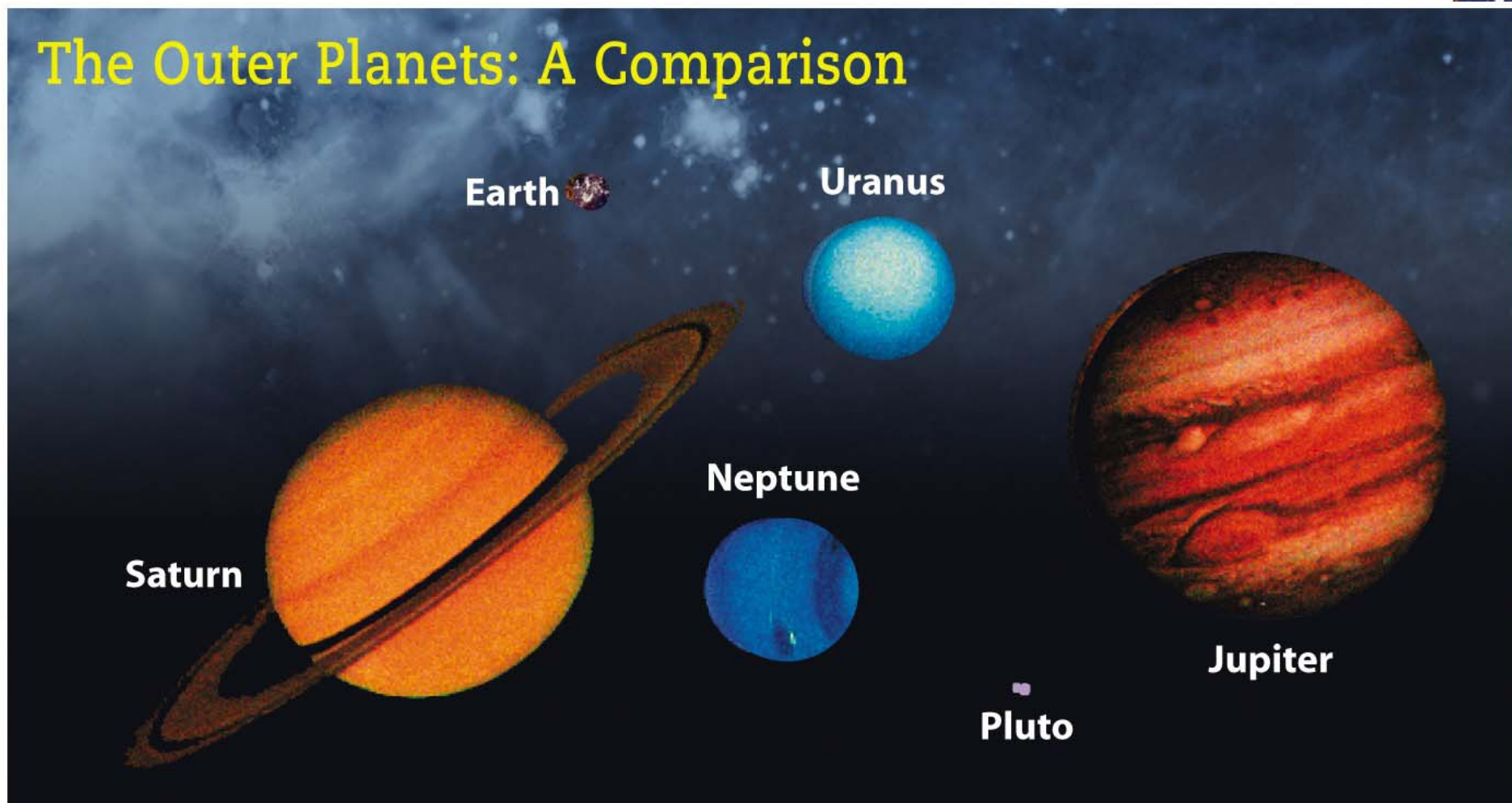


Outline

- 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



The Outer Planets: A Comparison



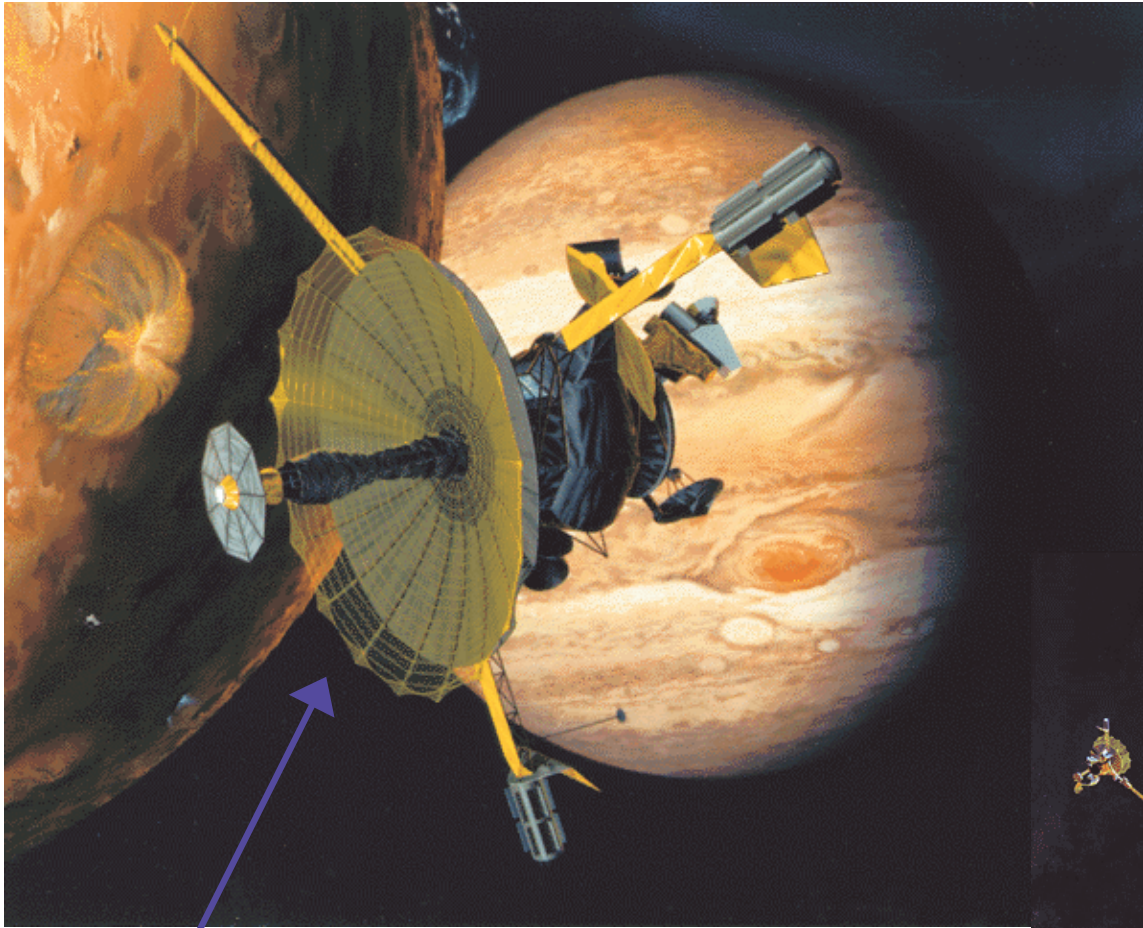
Earth – Jupiter comparison



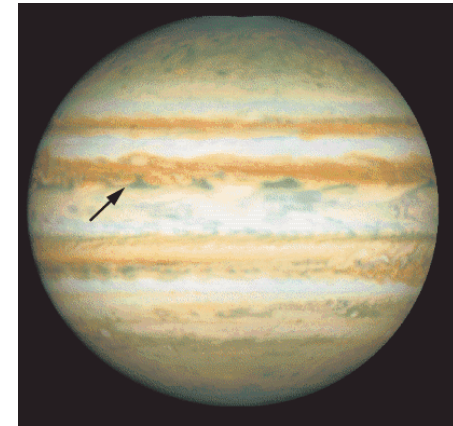
Biggest and most massive planet, has the largest gravity, has the largest number of moons (>61), yet has the shortest day in Solar System.

Radius	11.2 Earth
Cloud-top gravity	2.54 Earth
Mass	318 Earth
Distance from Sun	5.20 AU
Eccentricity	0.206
Tilt	3.12 °
Albedo	0.52
Year	11.88 Earth years
Solar day	9 hours 55 minutes

The Galileo Spacecraft (1989 – 2003)



How the main antenna
should have looked



First atmospheric probe



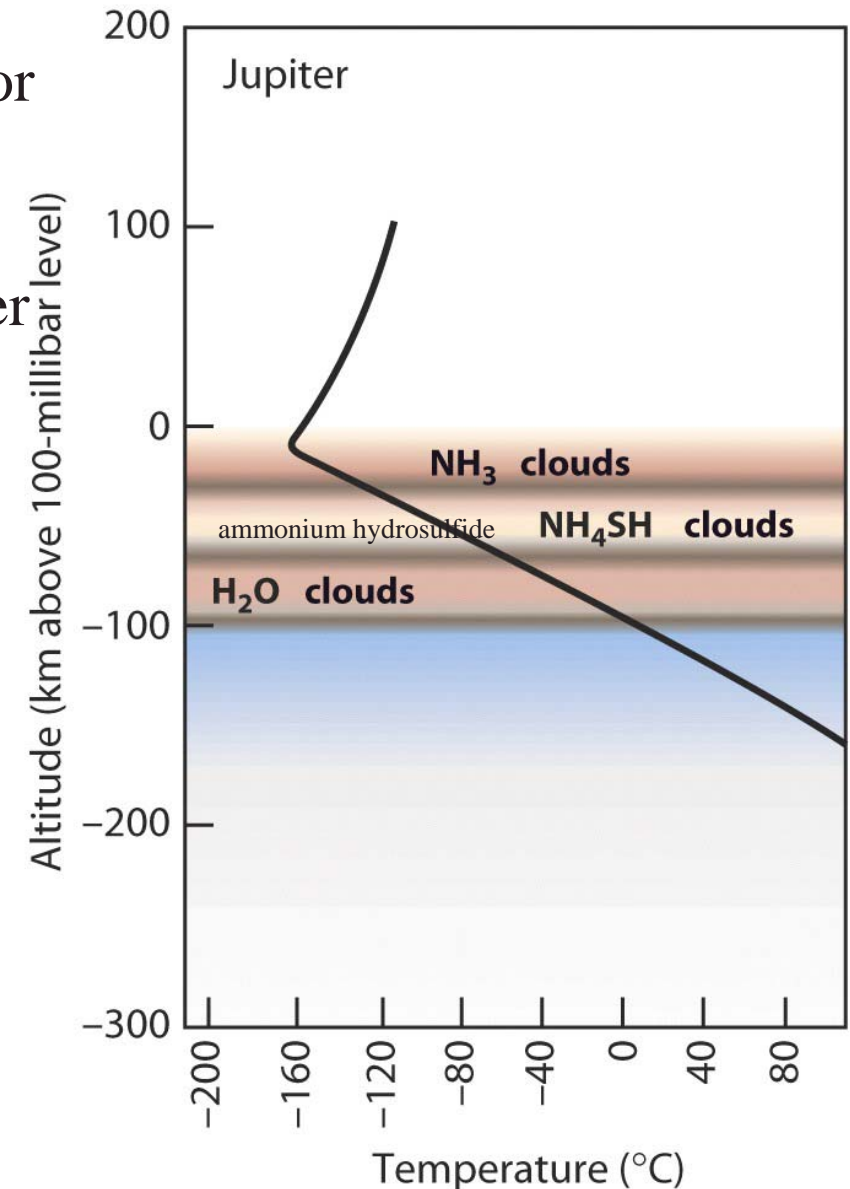
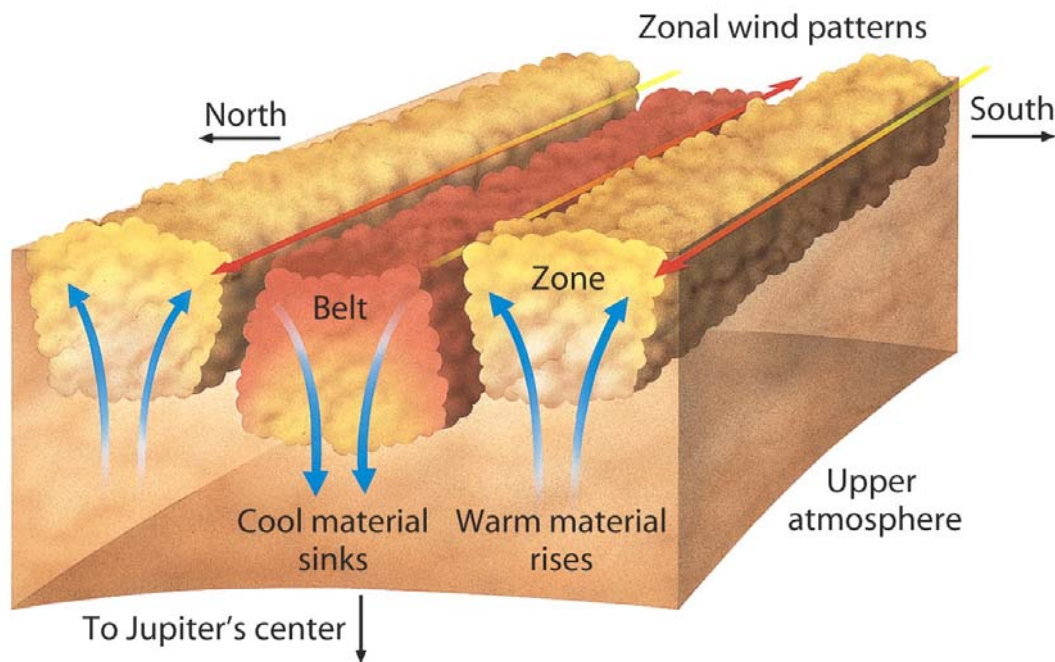
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The Outer Atmosphere of Jupiter



- 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>

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

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**

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

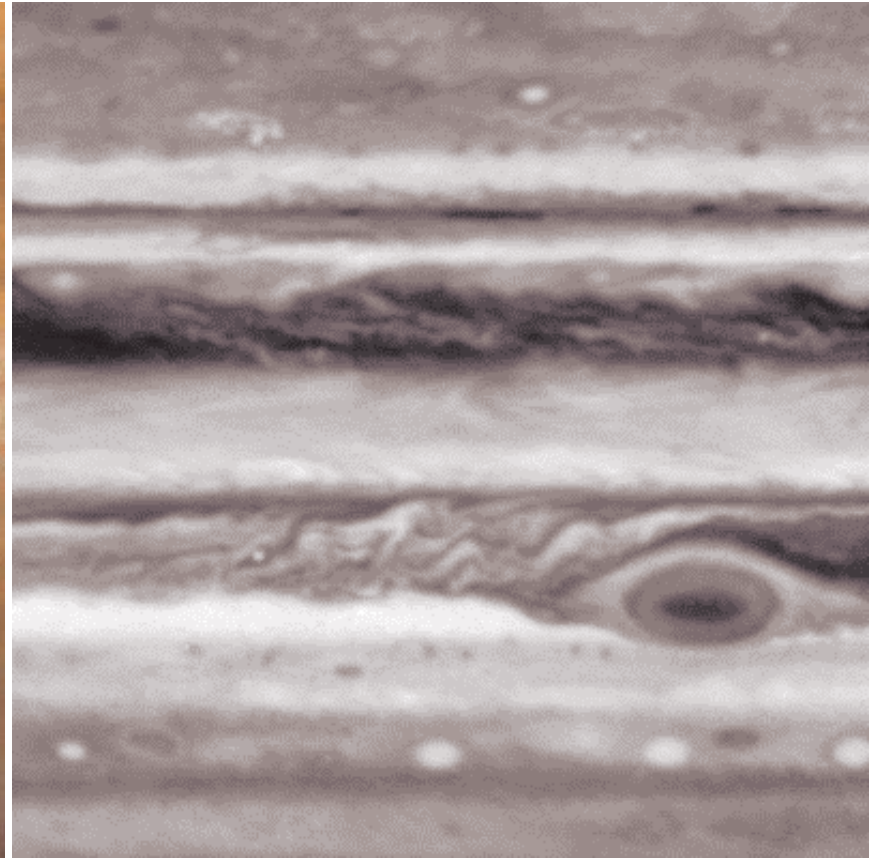
The Great Red Spot



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



Voyager 1 image

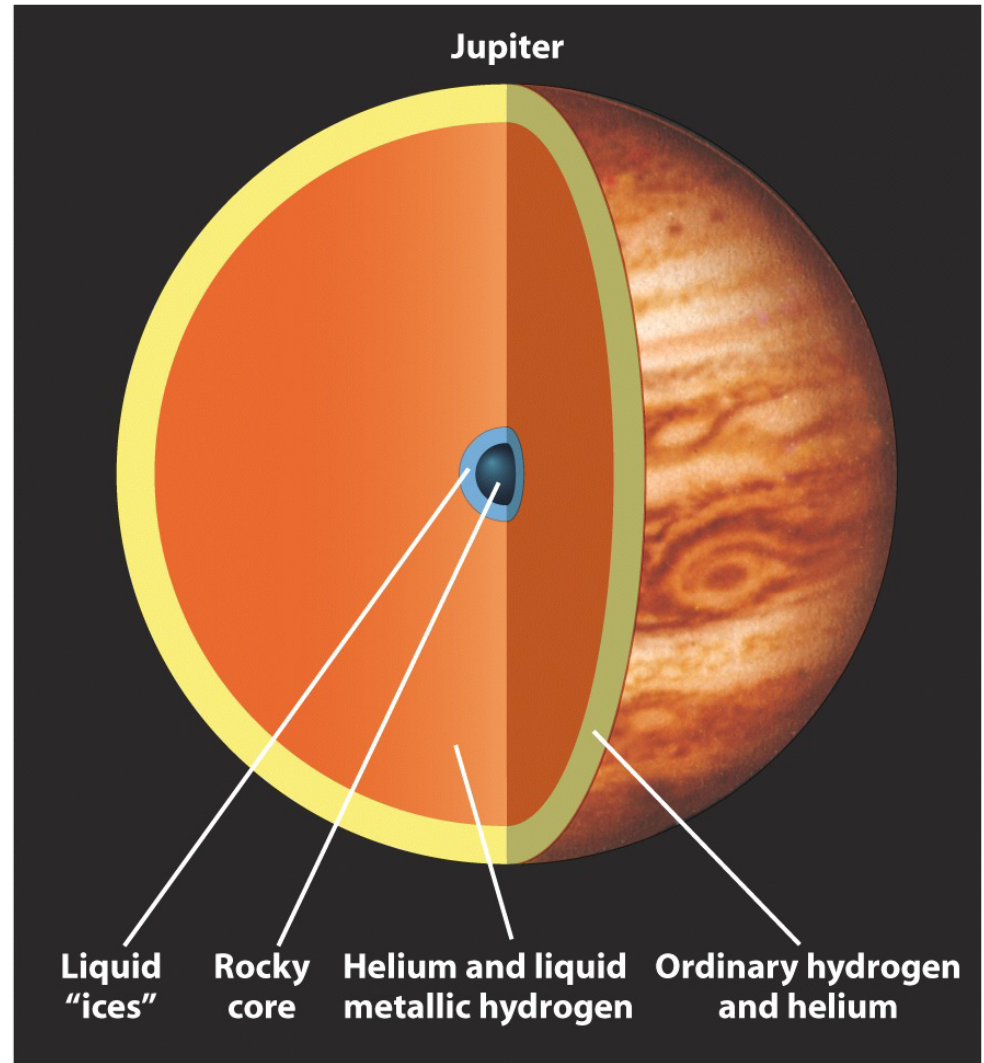


Cassini images

Jupiter's Interior



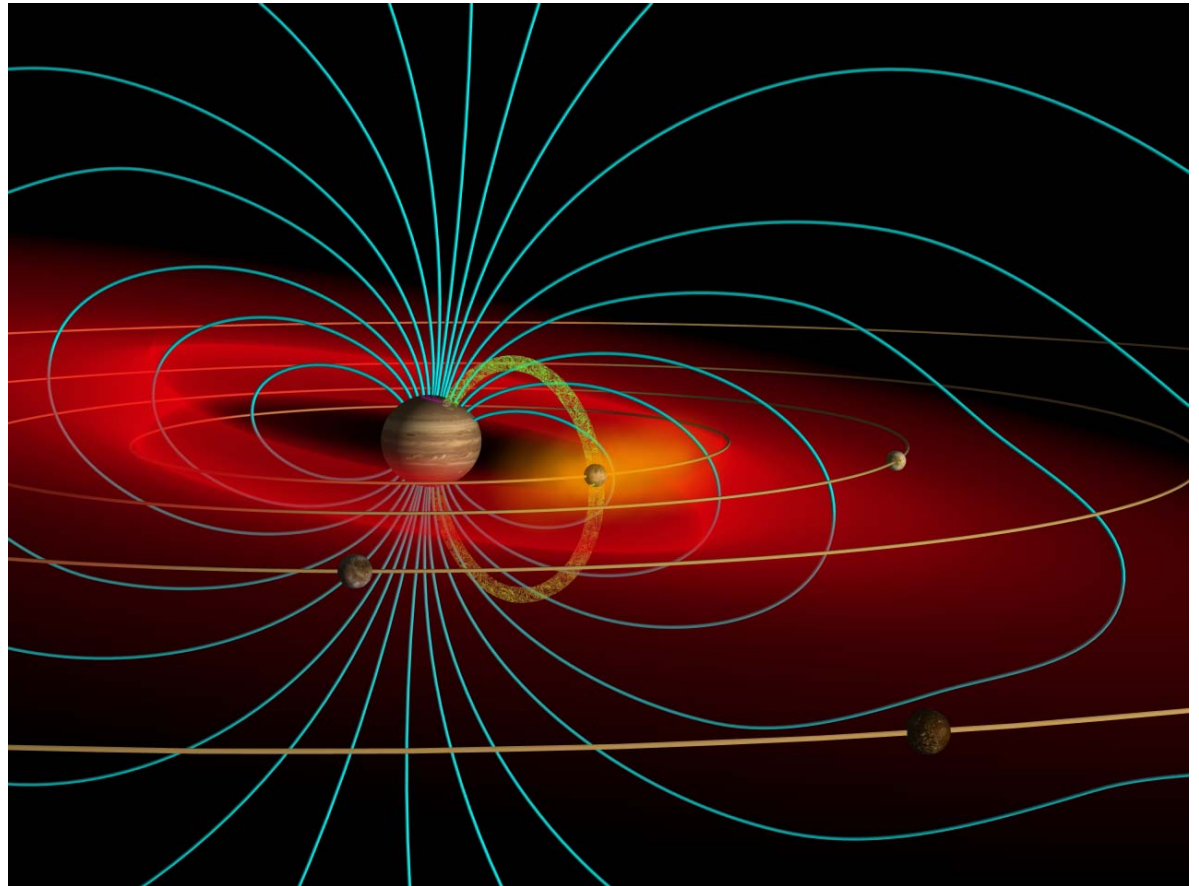
- Although mostly gas, by 20,000 km, the pressure is 3 million atmospheres!
- This makes helium and hydrogen metallic
- Effectively, a “failed star”
- Produces about 1.7x as much heat as received from Sun
- Source: gravitational contraction
- Helps drive cloud motions and storms



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

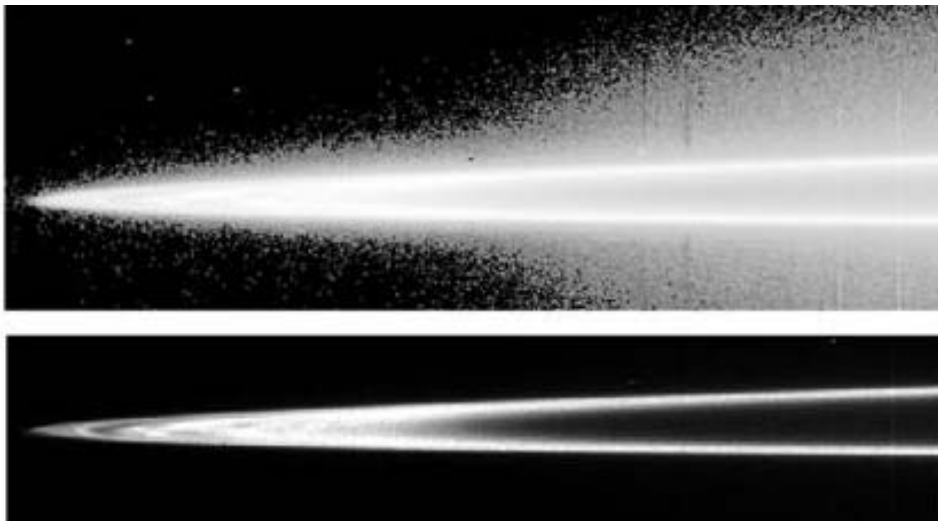
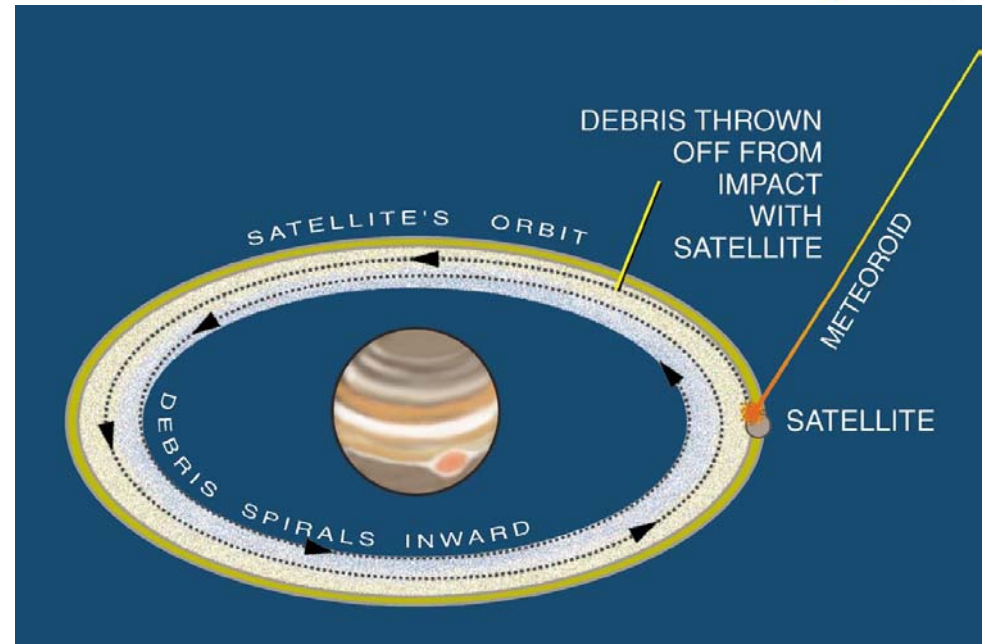
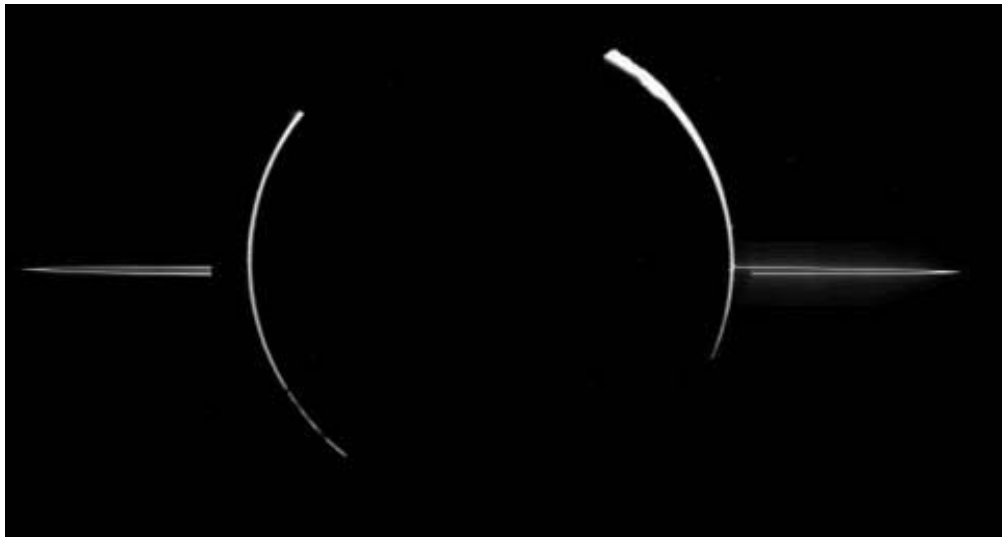
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Jupiter's Rings



- Discovered by Voyager 1 (1979)



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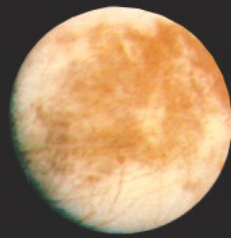
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<http://www.jpl.nasa.gov/galileo/status980915.html>

The Galilean Moons



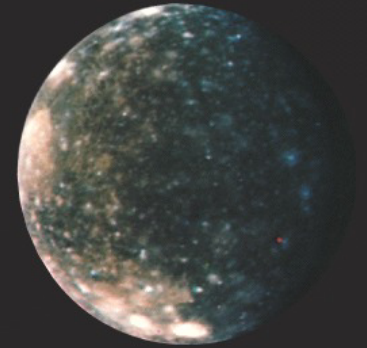
Io



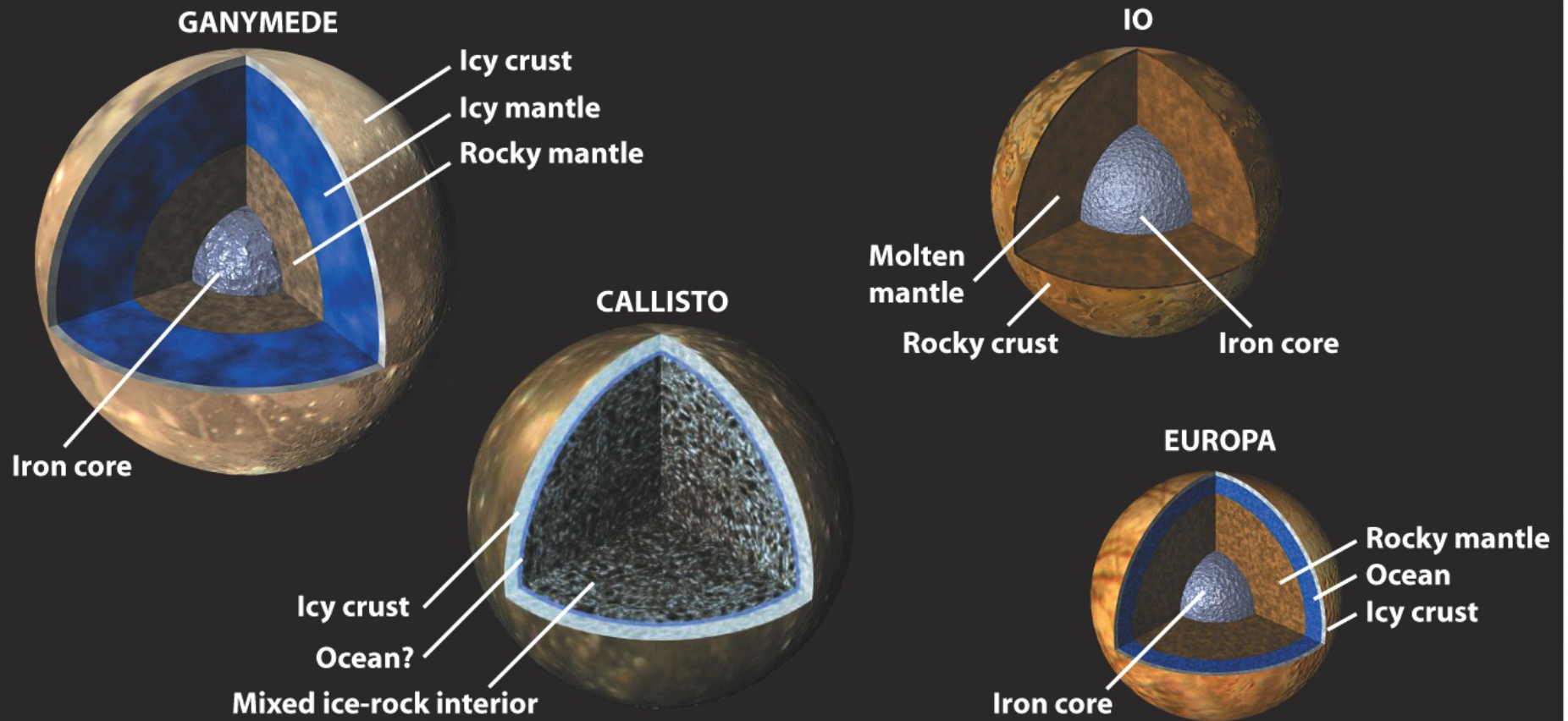
Europa



Ganymede



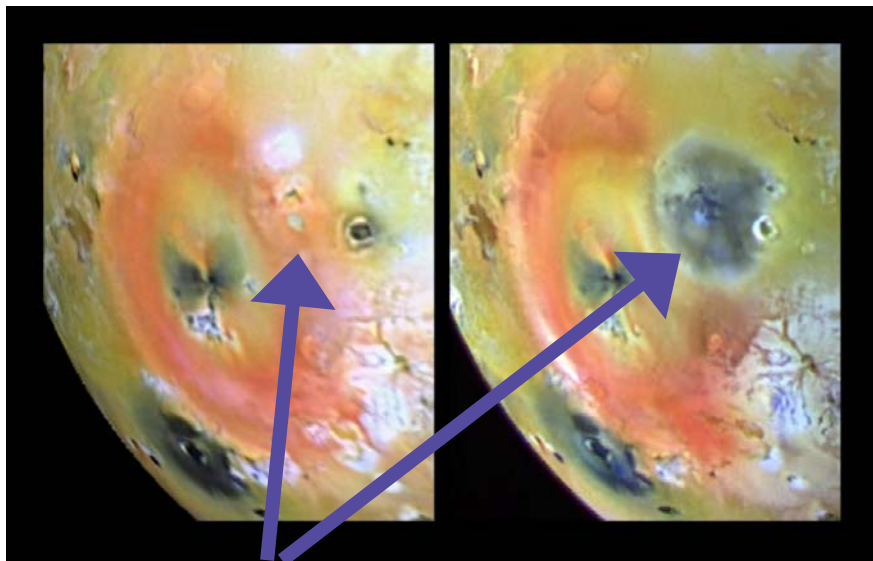
Callisto



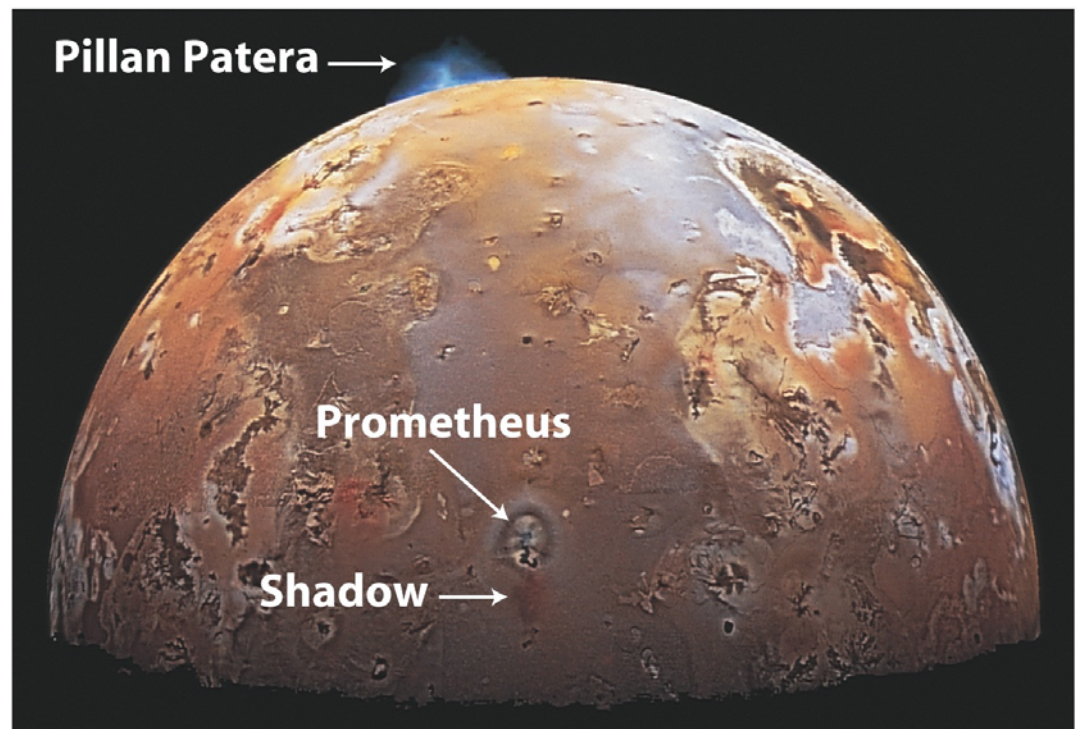
Io



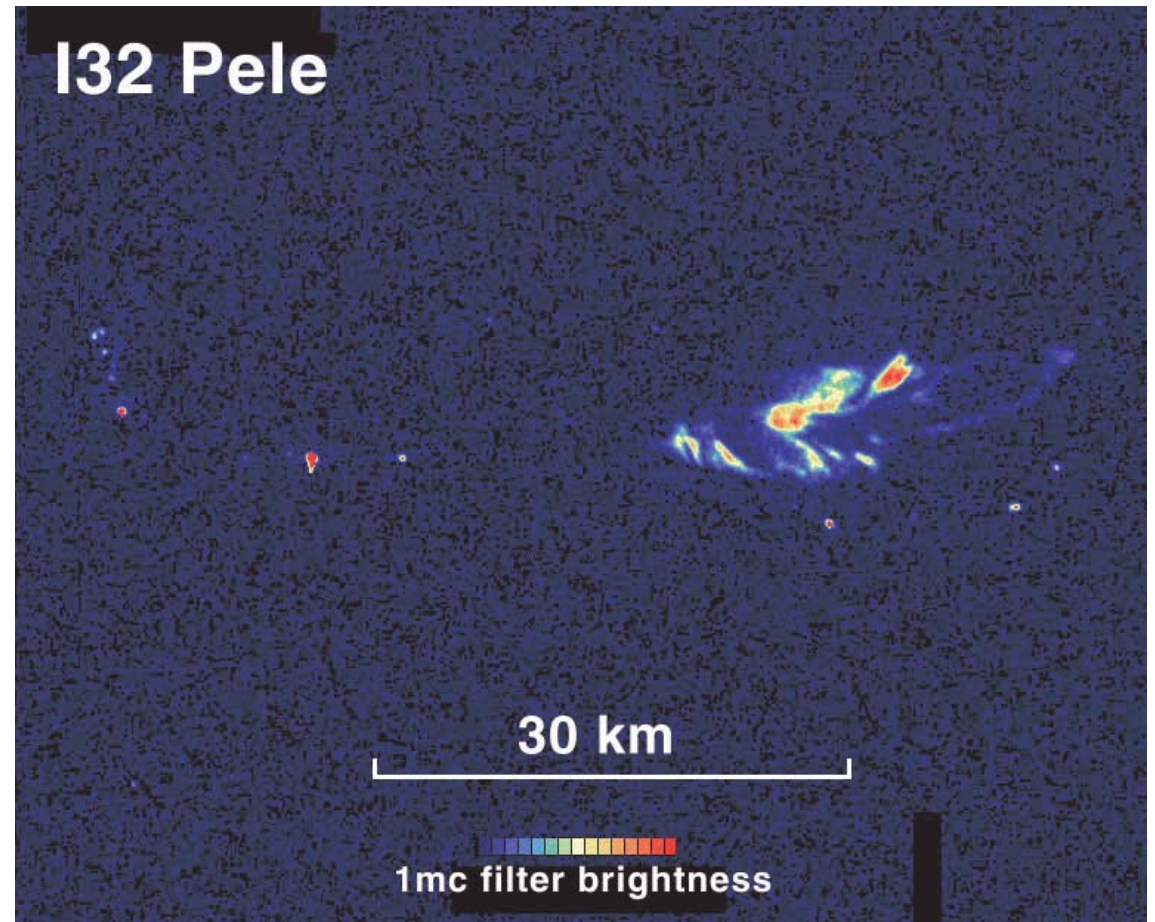
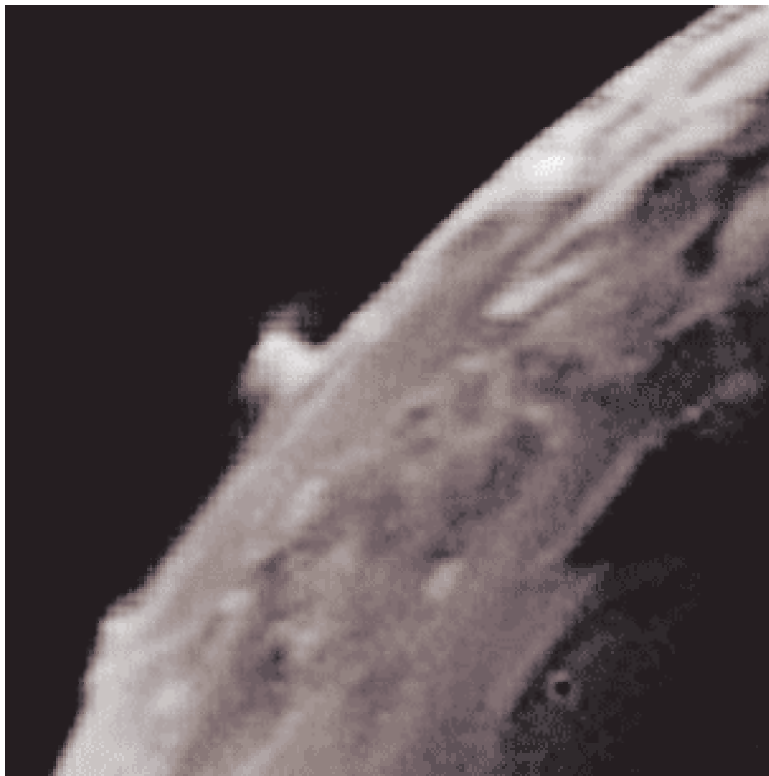
- Innermost Galilean moon – the “pizza moon”
- Sulfur/sulfur dioxide on surface; silicate lava flows?
- Voyager 1 discovered presence of volcanoes
- Internal heating by Jupiter’s tides
- Atmospheric gases ripped off by Jupiter’s magnetic field – ion torus



Pillan Patera eruption
Before & after



Io– Volcano Activity



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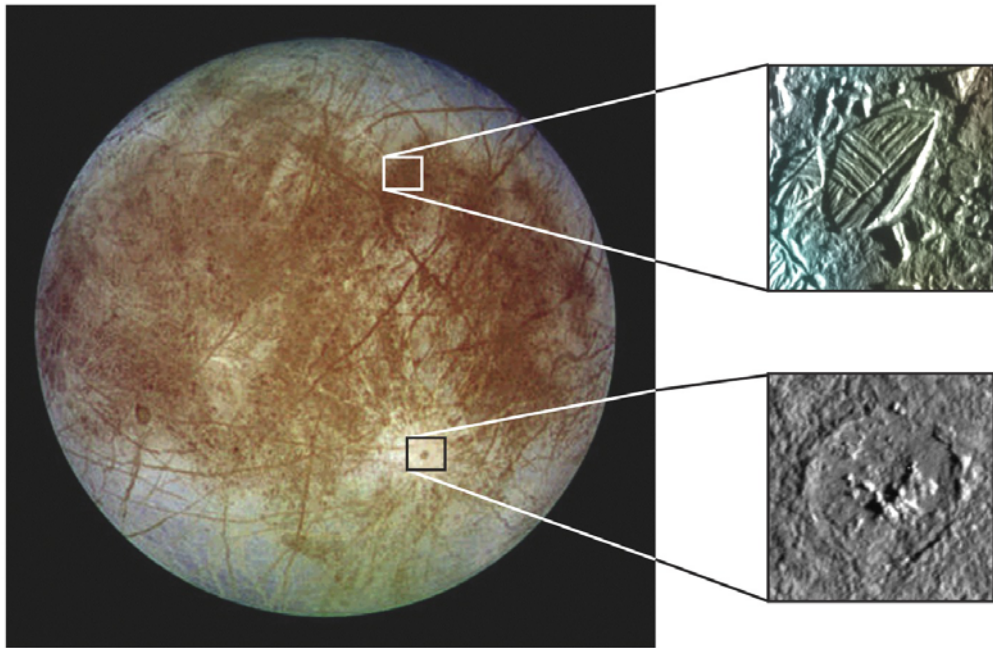
<http://www.solarviews.com/cap/jup/PIA02596.htm>

<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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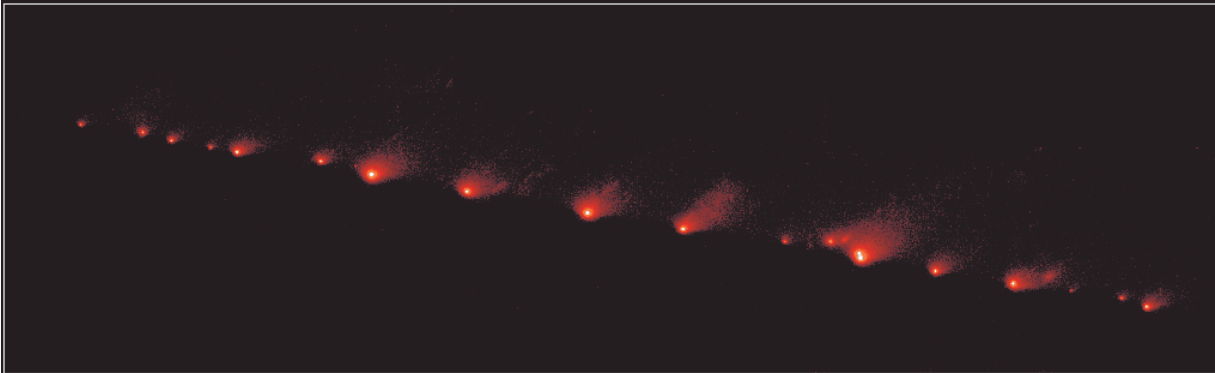
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Galileo

Comet Shoemaker-Levy 9's Impact (1994)

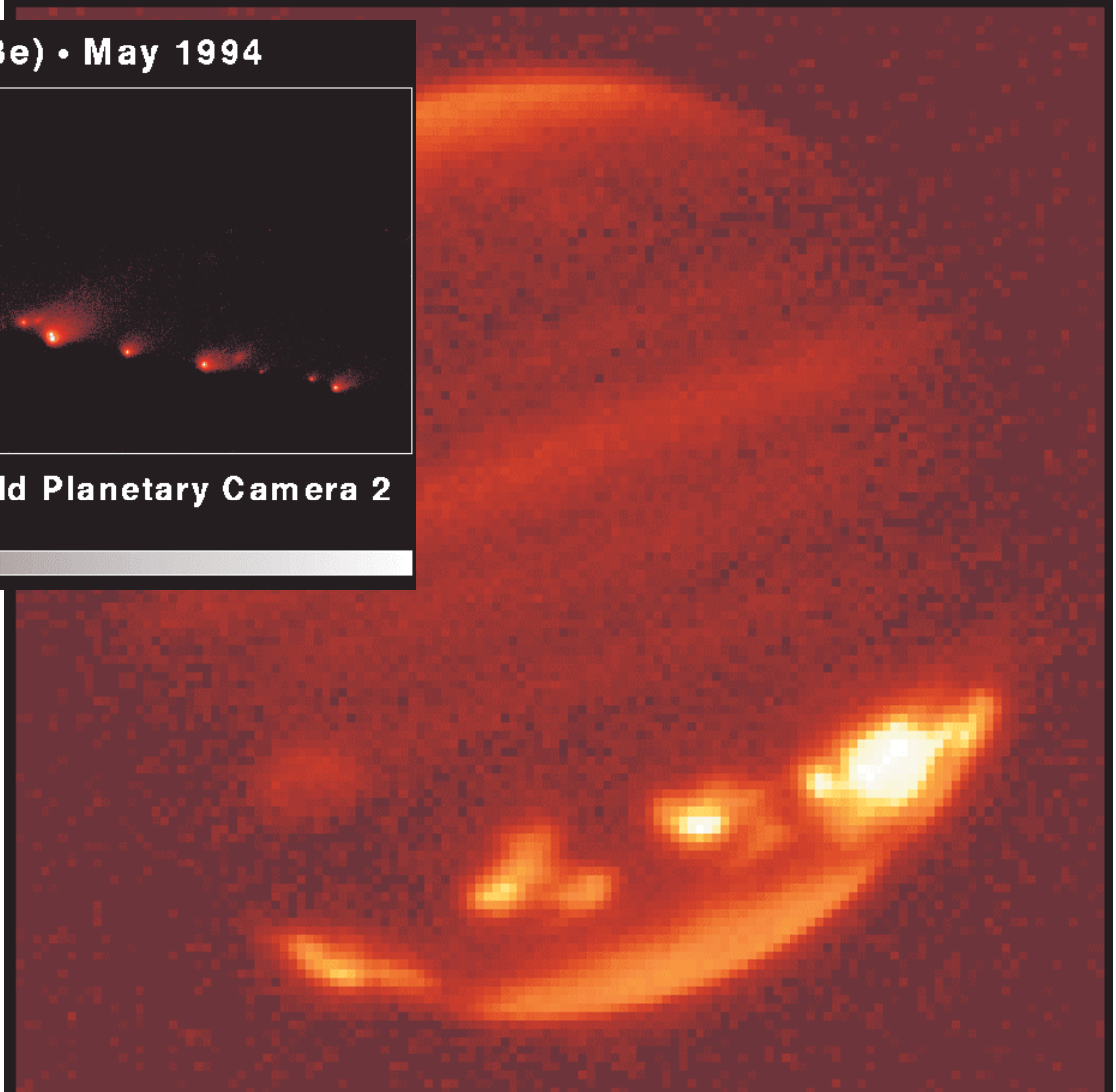


Comet P/Shoemaker-Levy 9 (1993e) • May 1994



Hubble Space Telescope • Wide Field Planetary Camera 2

- 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

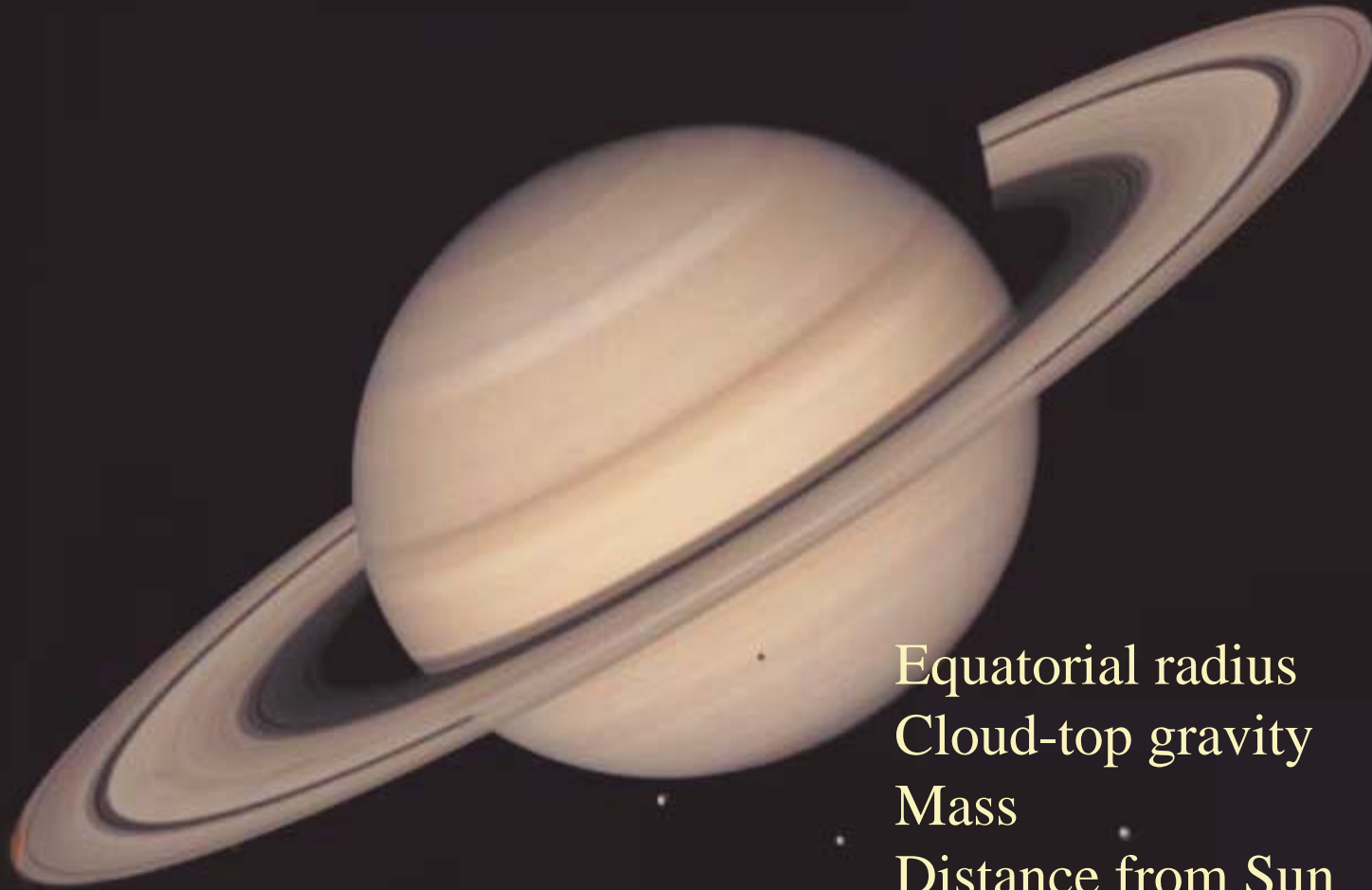


A necklace of Comet Shoemaker-Levy 9 impact sites on Jupiter
Infrared image in the 2.3 micron methane band taken using MAGIC
on the 3.5-m telescope, Calar Alto Observatory, Spain, 25/07/94



MPIA

Earth – Saturn comparison



It floats. Least spherical planet.

Equatorial radius	9.45 Earth
Cloud-top gravity	1.07 Earth
Mass	95.2 Earth
Distance from Sun	9.53 AU
Eccentricity	0.0560
Tilt	25 °
Albedo	0.47
Year	29.5 Earth years
Solar day (equator)	10 hours 14 minutes

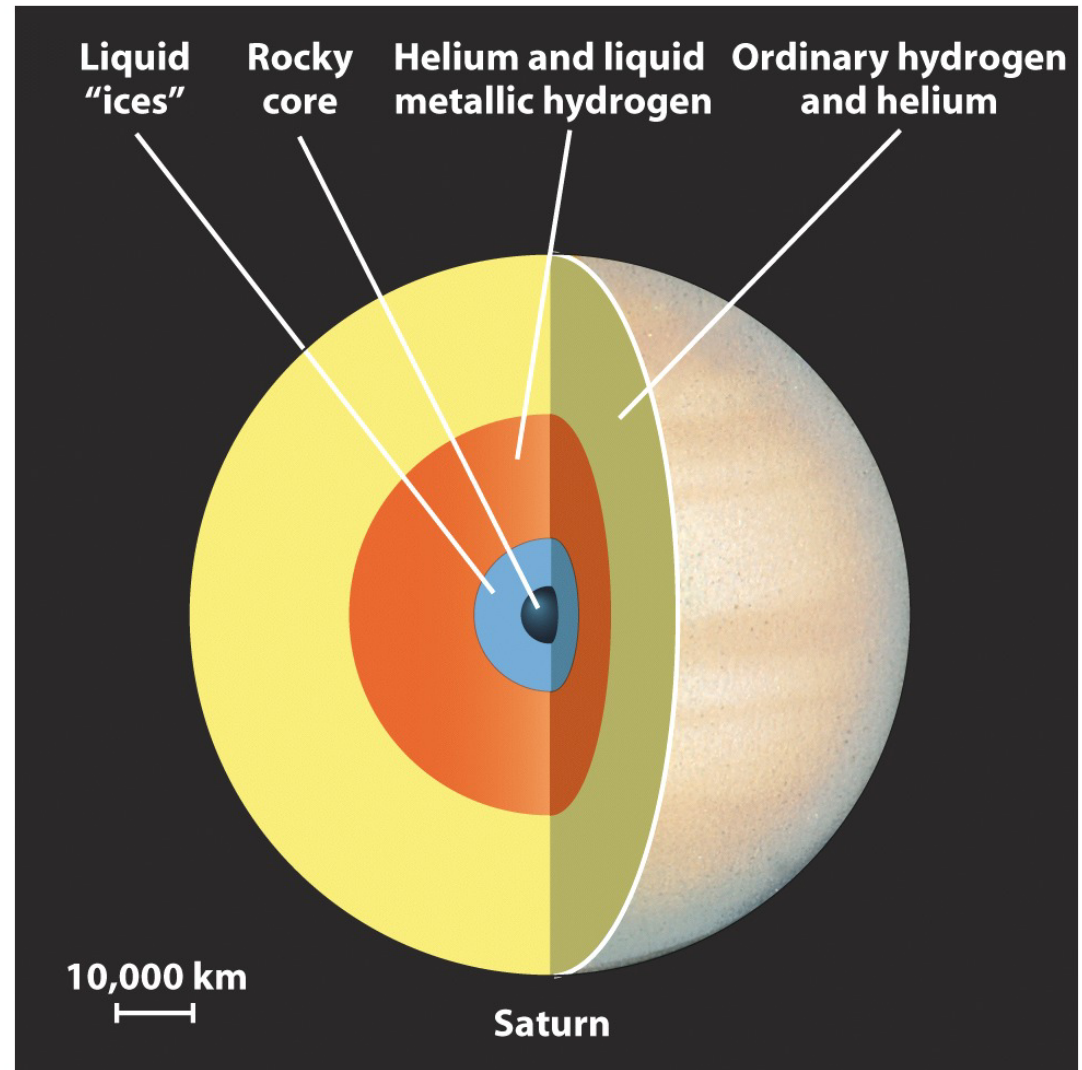
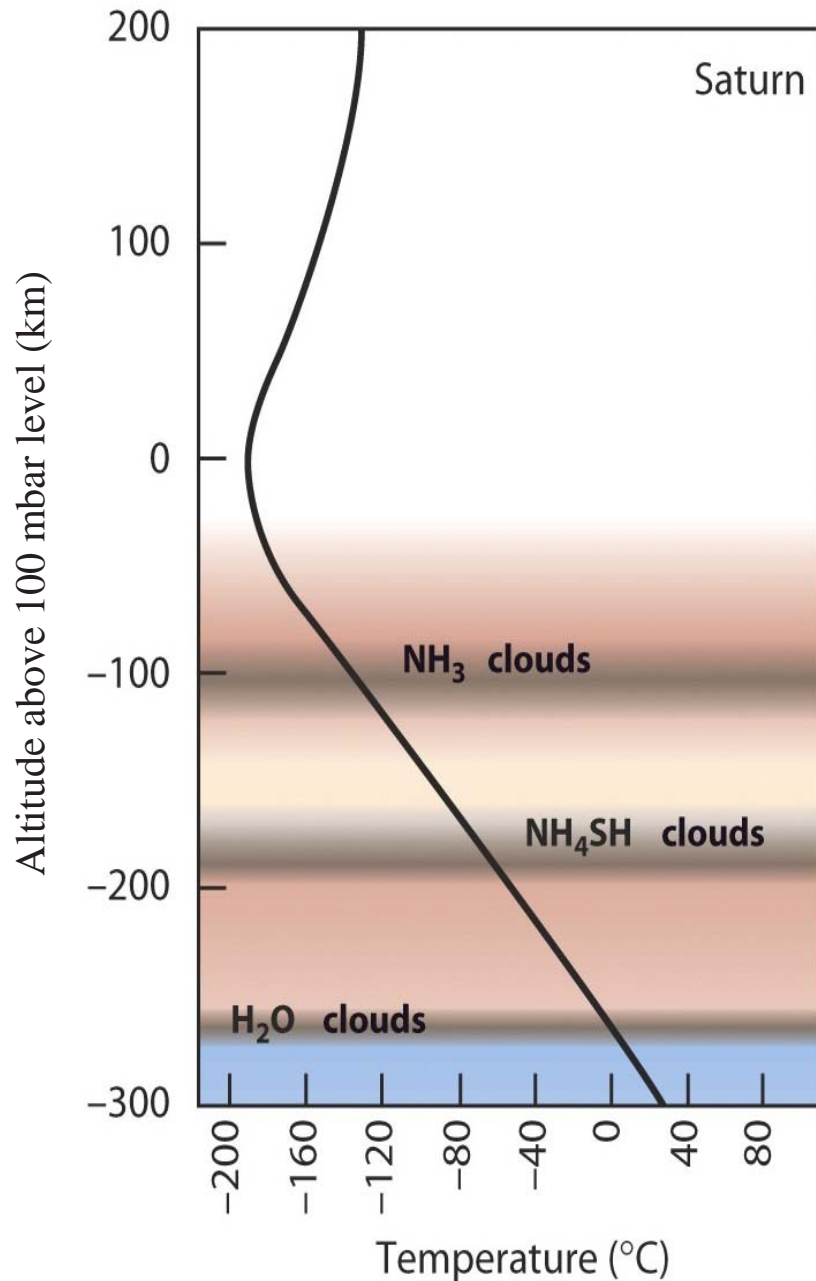
Saturn



- 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/ra/sat/vsaturn1.mpg>



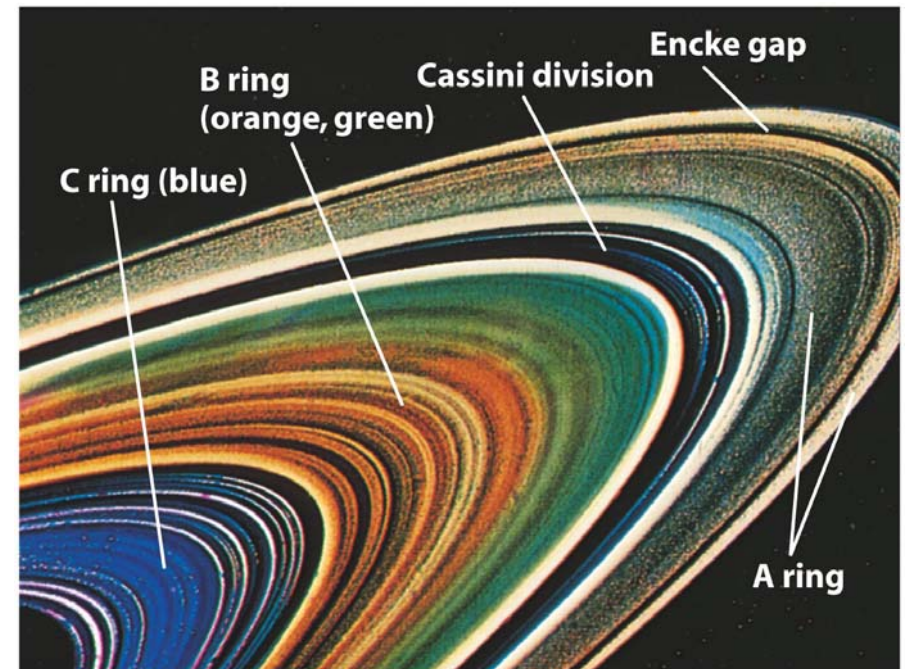
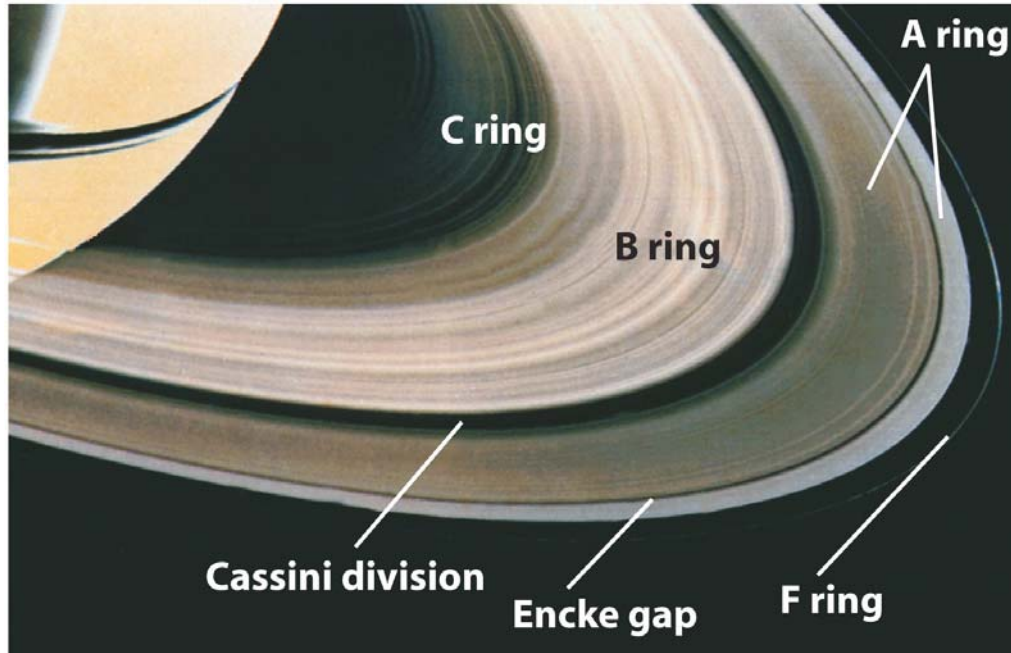
Saturn's Atmosphere and Interior



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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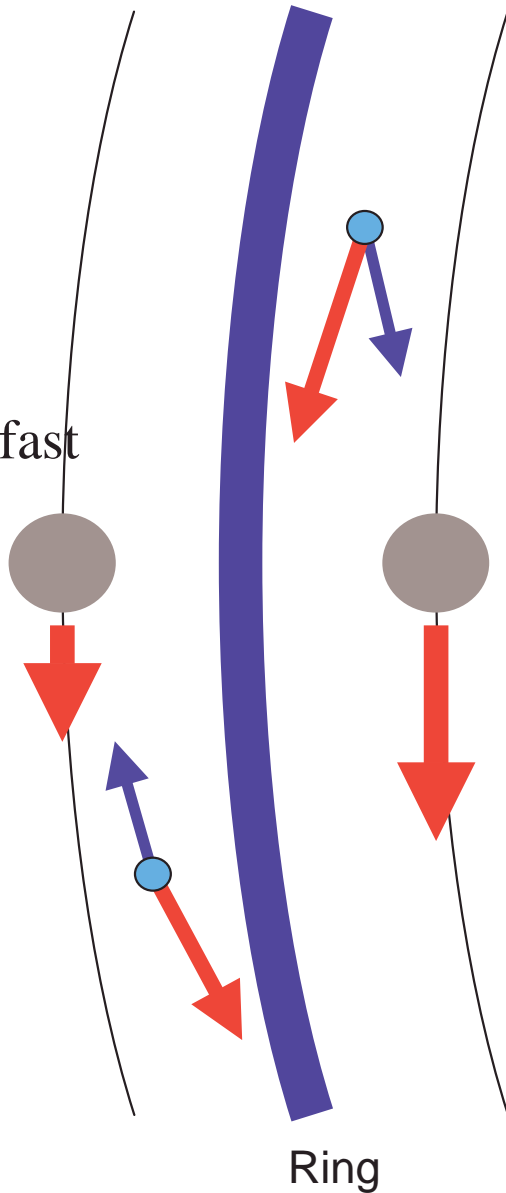
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False color image

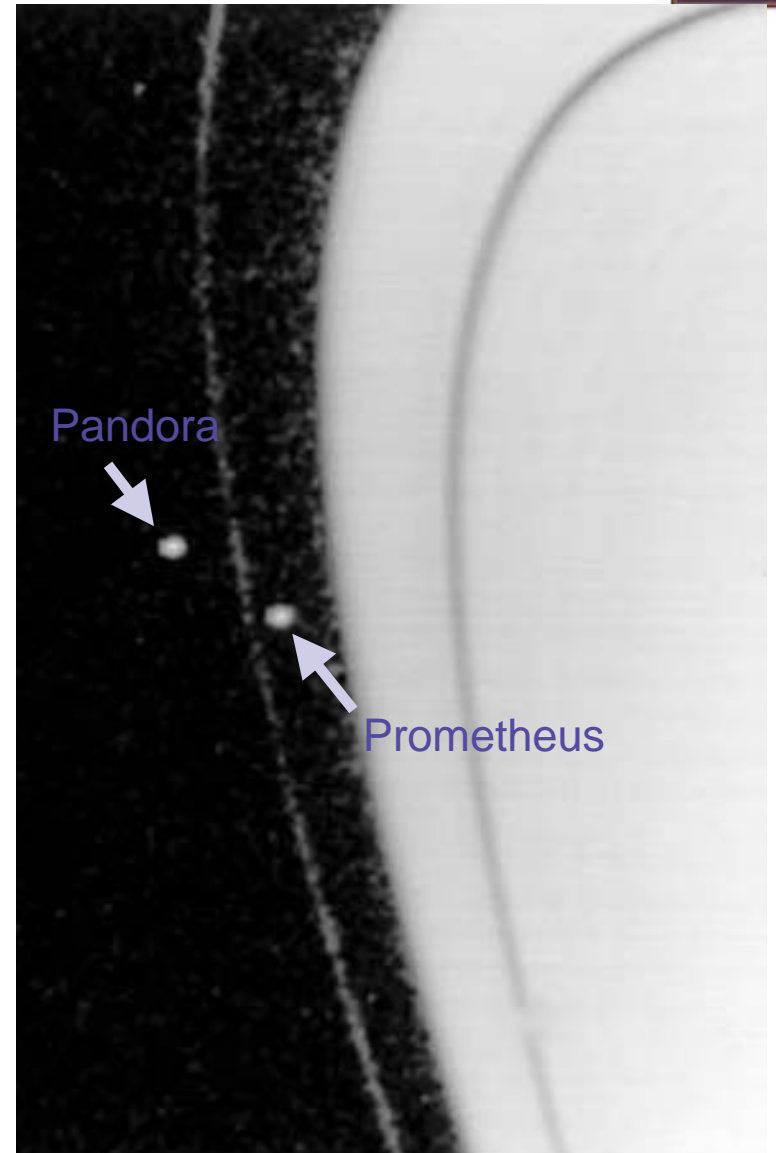
Shepherd Moons



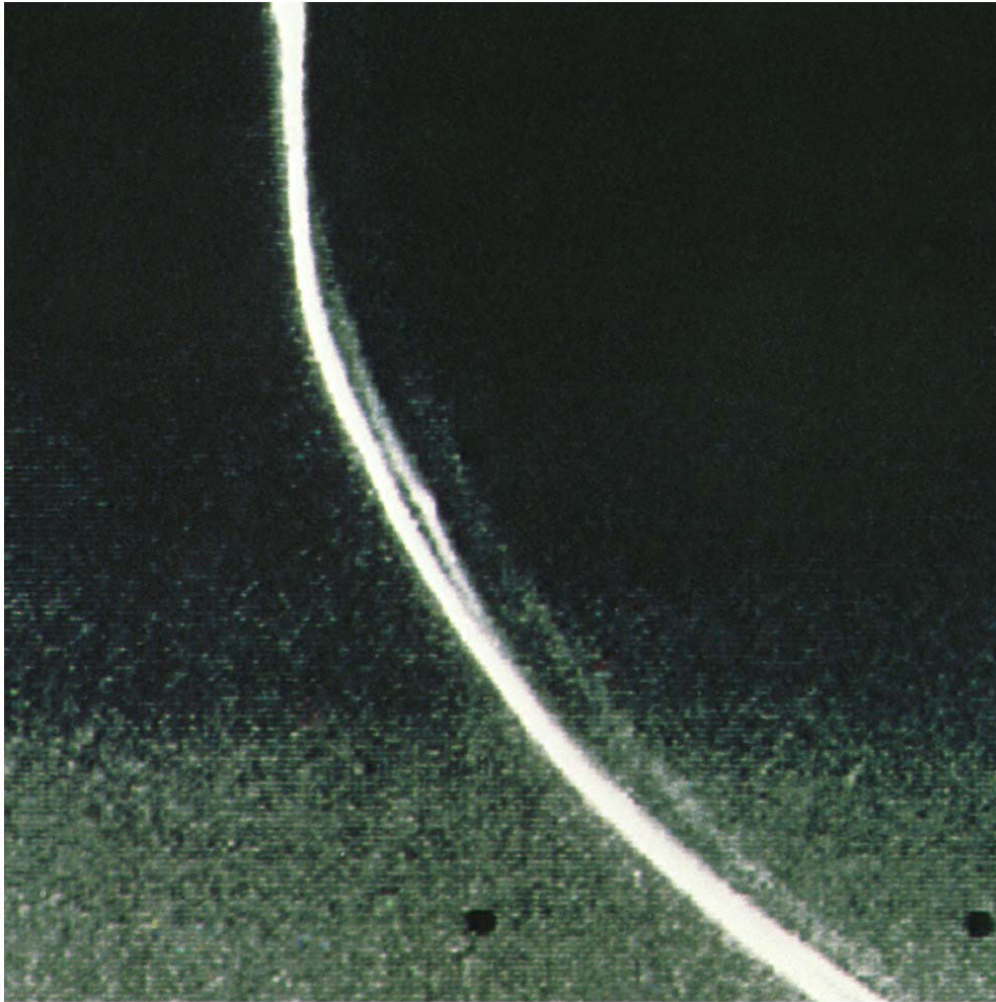
- Outer moon moves more slowly
- Decelerates fast particles



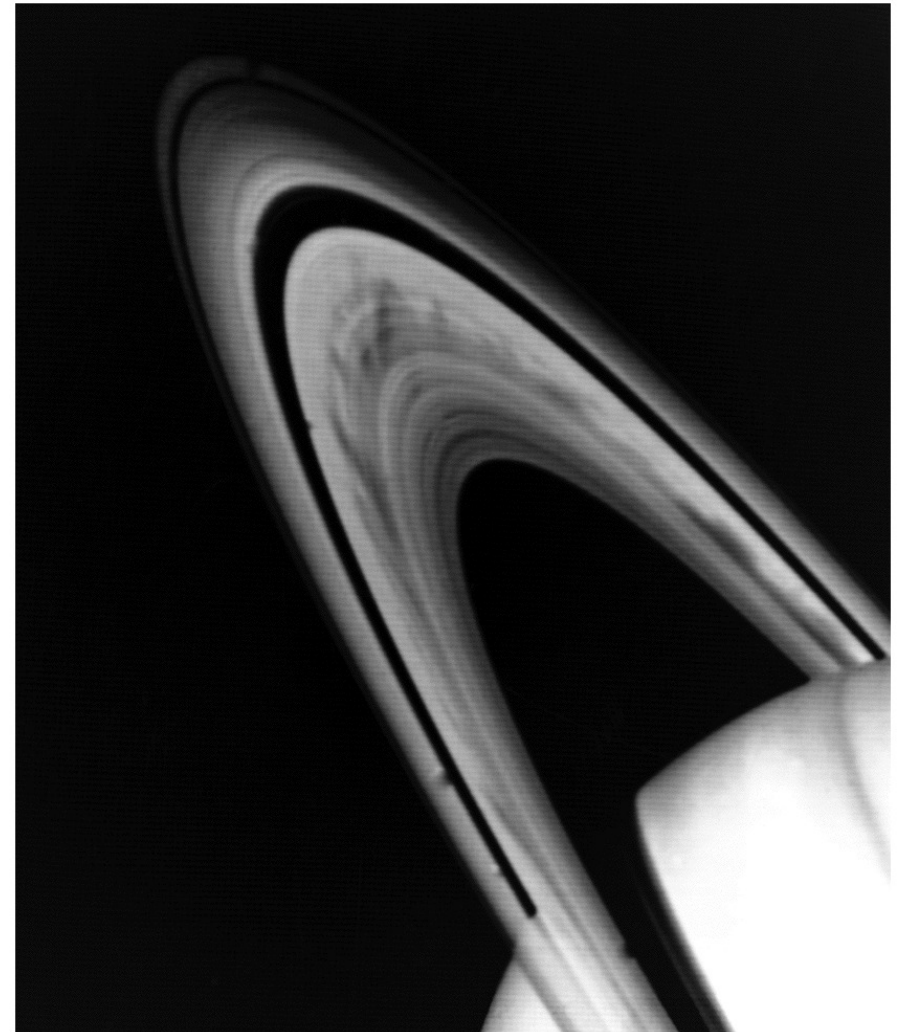
- Inner moon moves faster
- Accelerates slow particles



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



Effect of the magnetic field,
which is $\frac{2}{3}$ of the Earth's

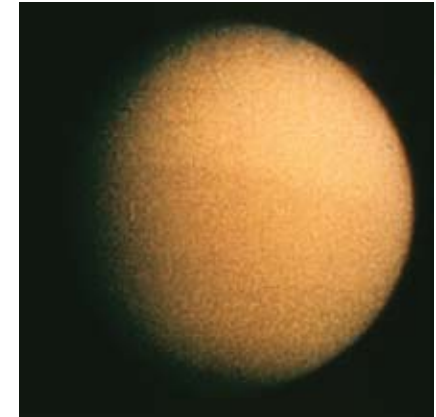


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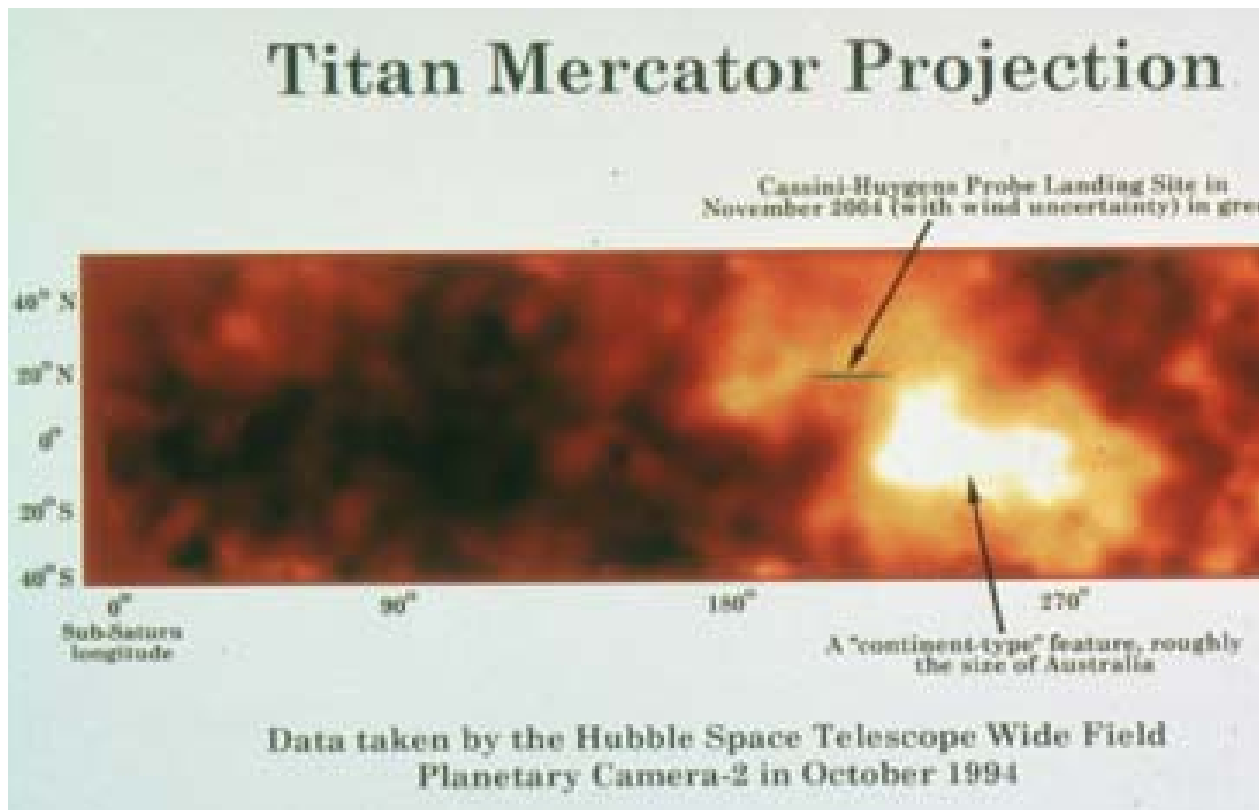
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Titan

- 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

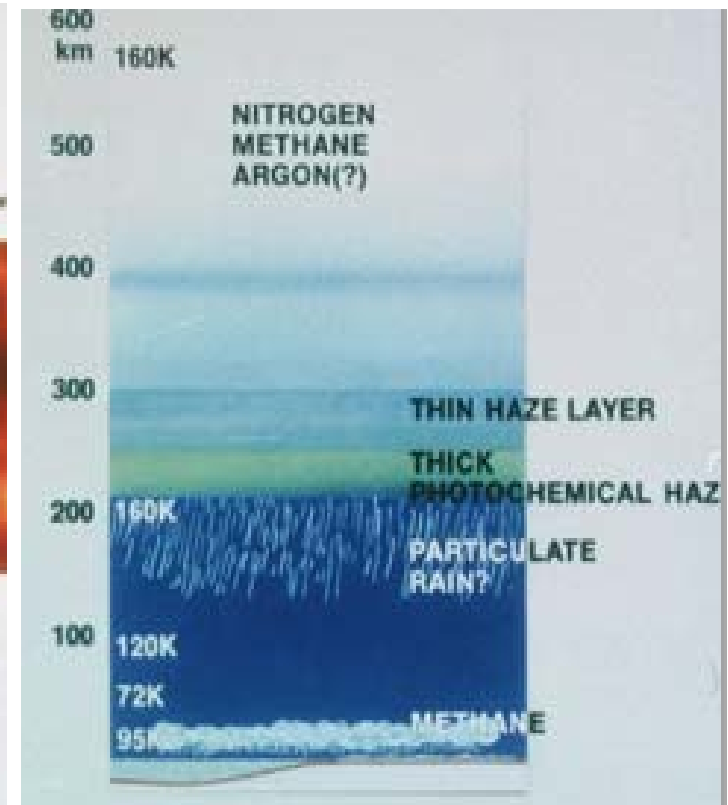


Titan's atmosphere

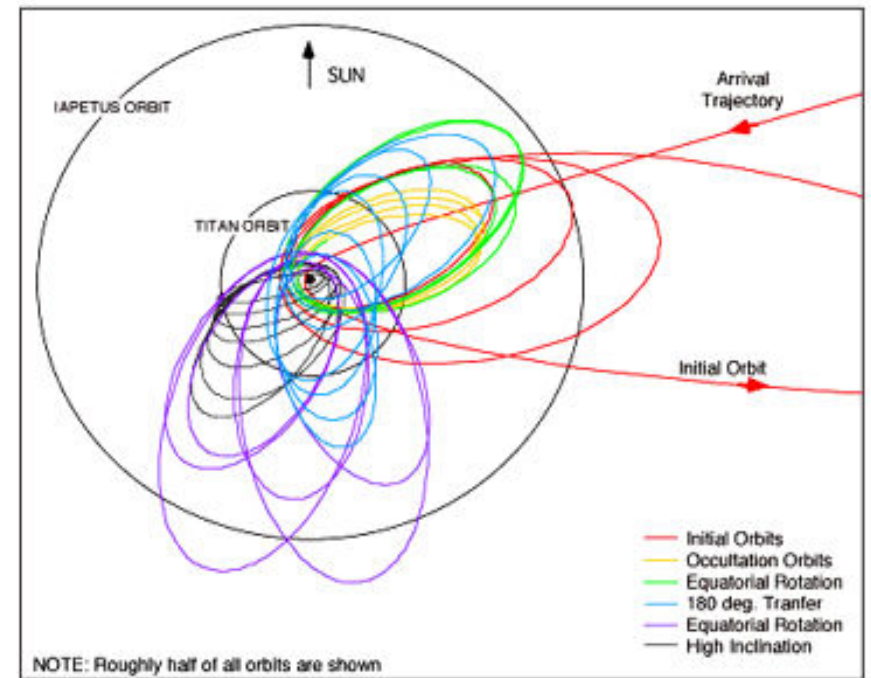
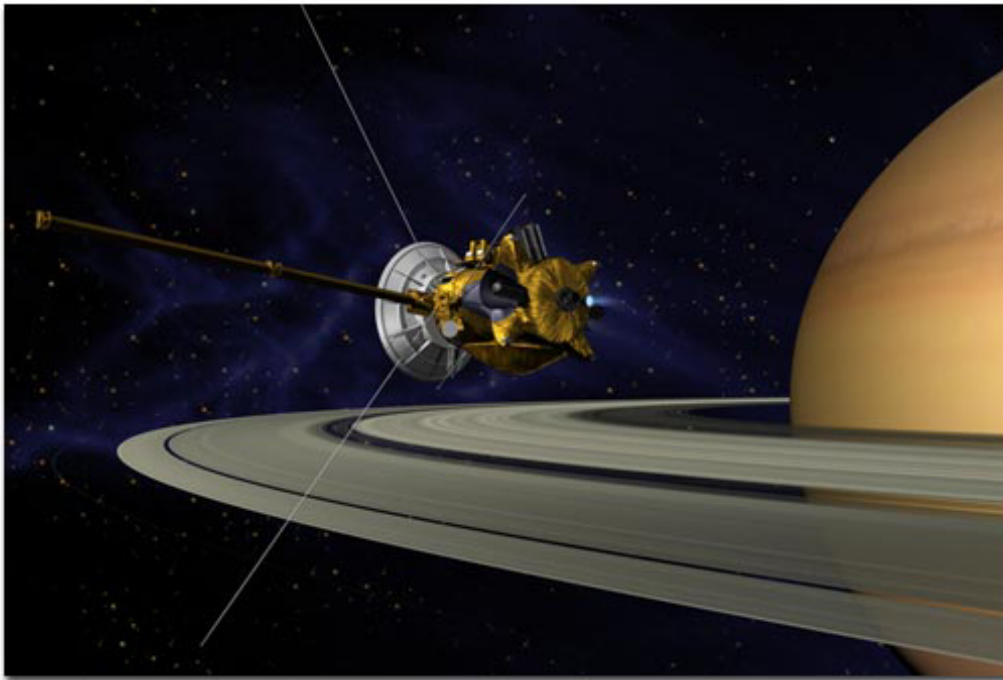


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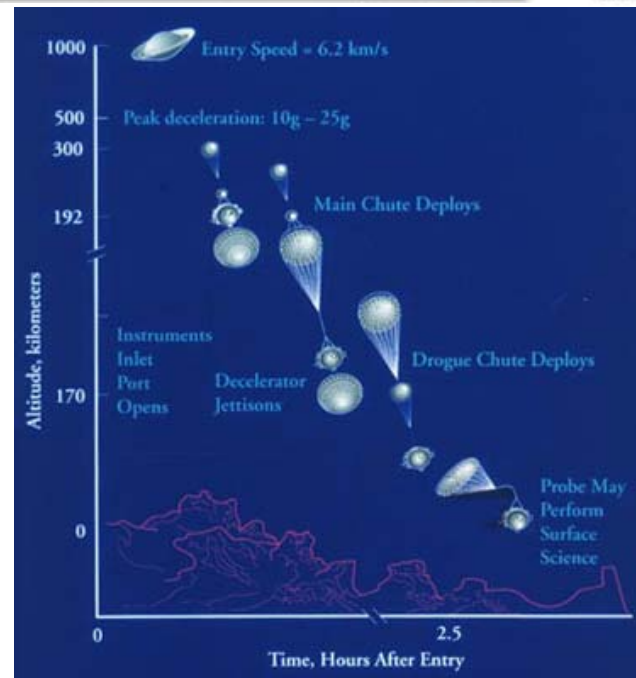
Cassini-Huygens



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.

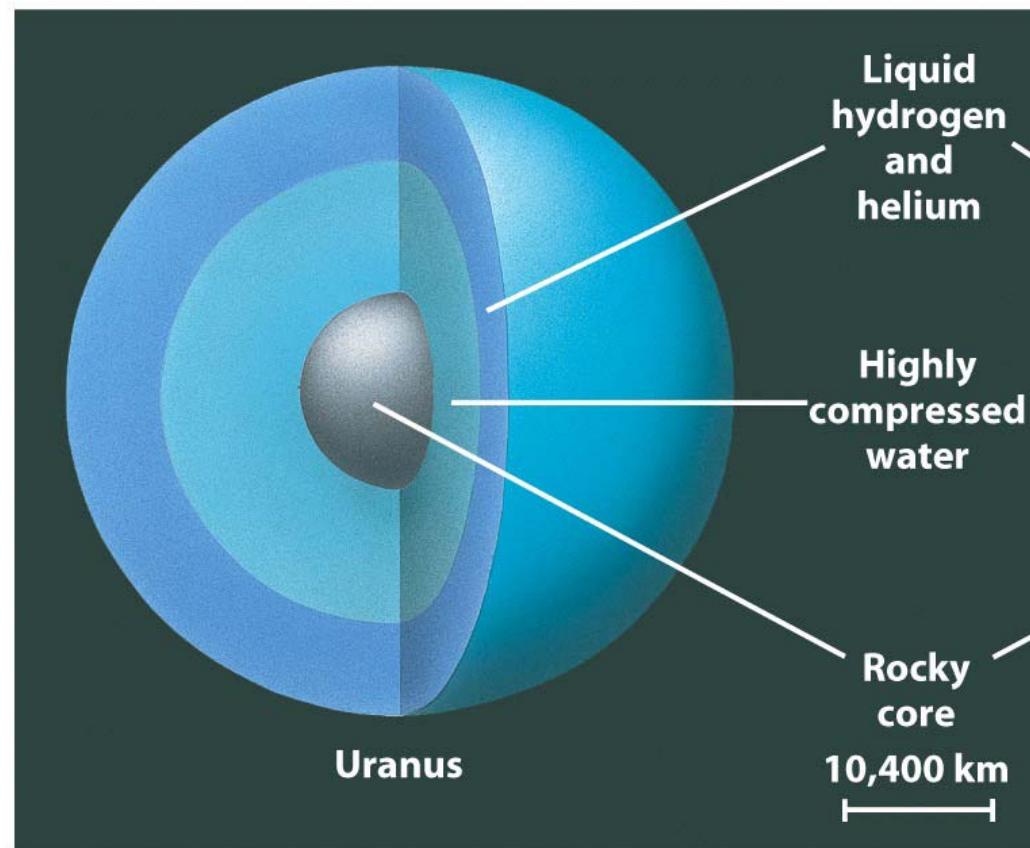
Equatorial radius	4.01 Earth
Cloud-top gravity	0.90 Earth
Mass	14.5 Earth
Distance from Sun	19.2 AU
Eccentricity	0.047
Tilt	98.25 °
Albedo	0.6
Year	84.0 Earth years
Solar day	16 hours 30 minutes (retrograde)



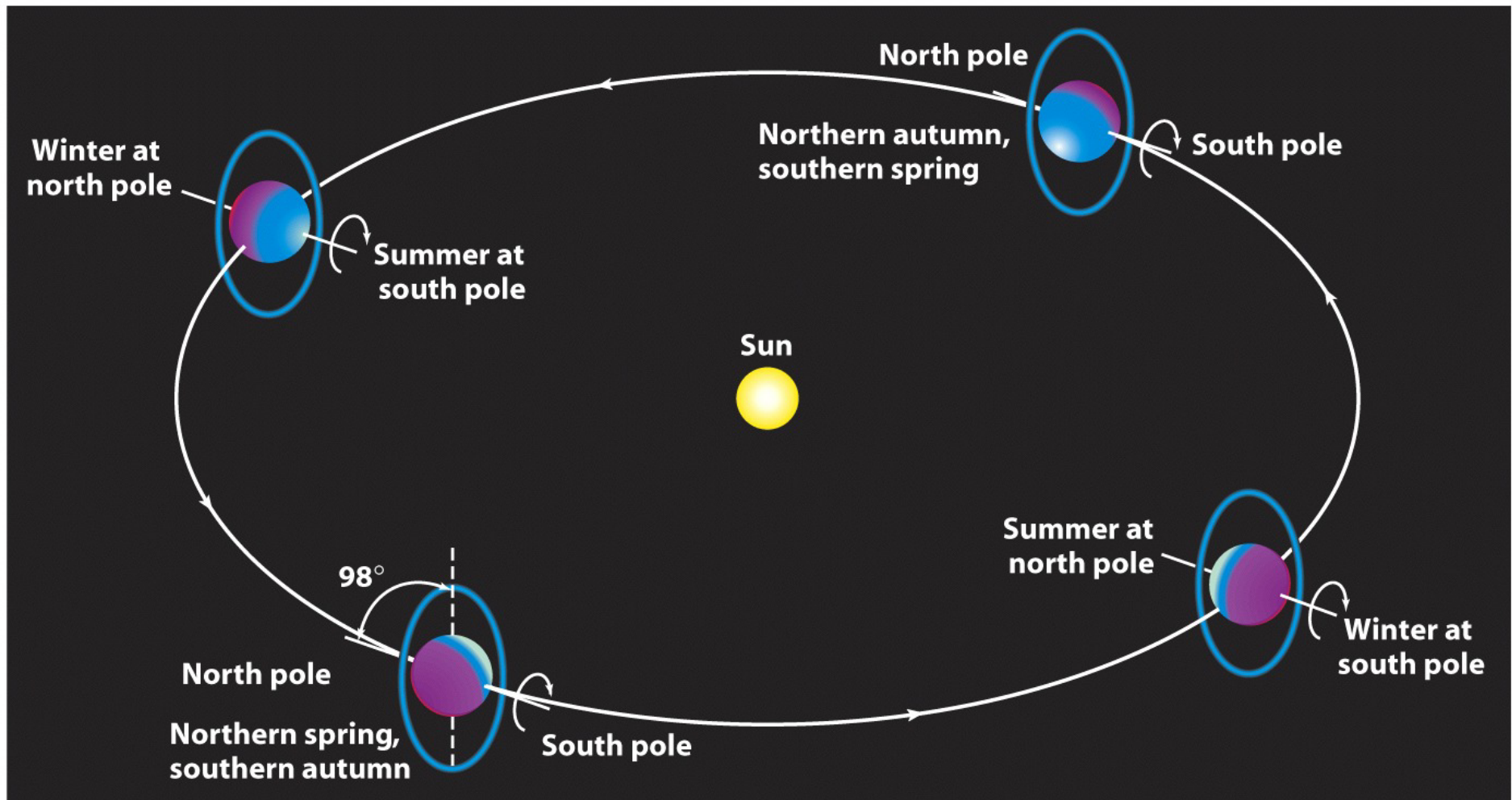
Atmosphere

- 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.

Interior

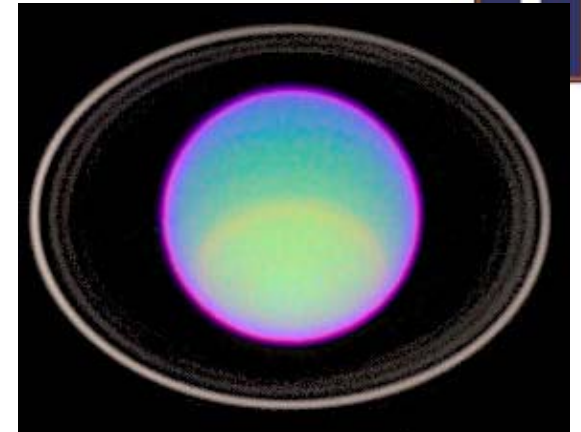
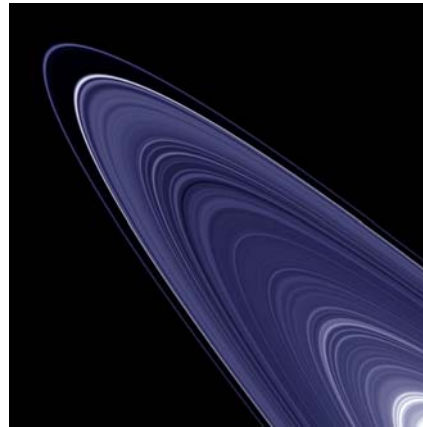


Seasons on Uranus Last a Long Time

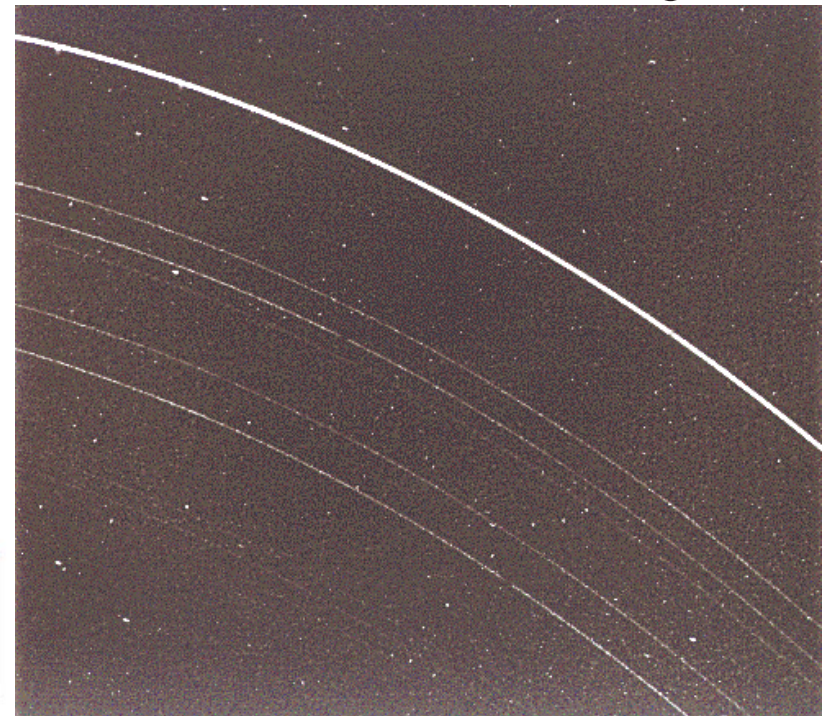
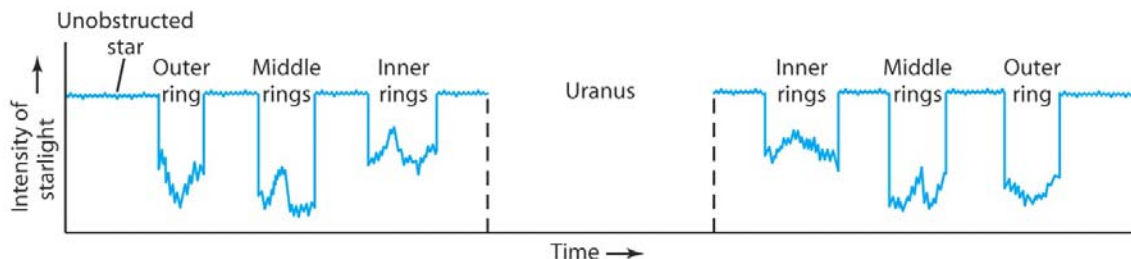
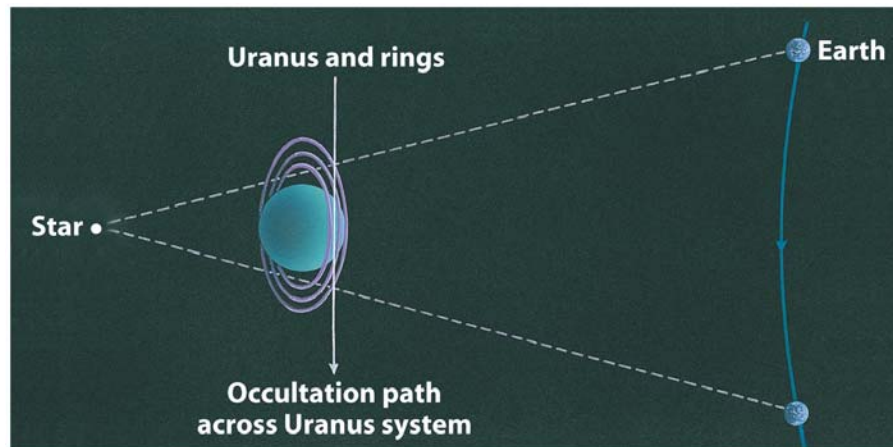


Uranus's Ring System

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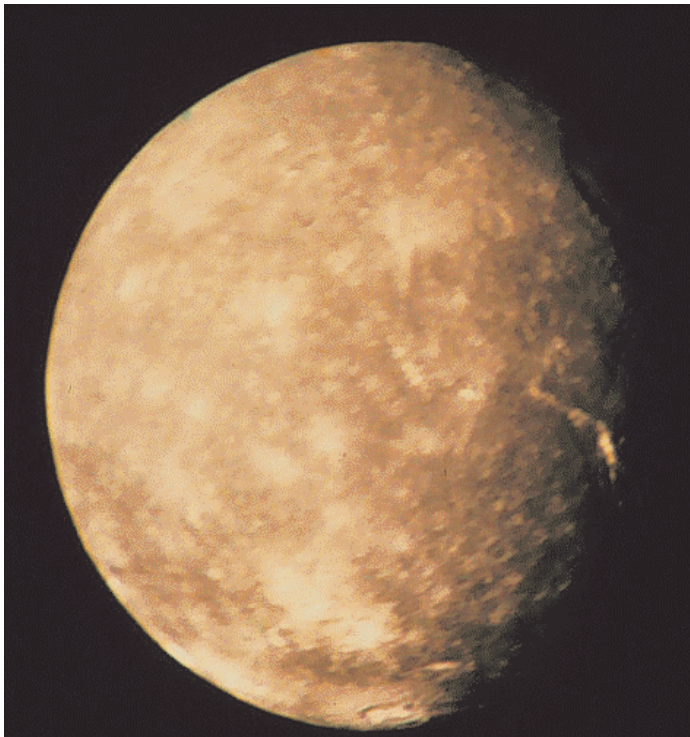
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<http://www.solarviews.com/eng/uranus.htm>

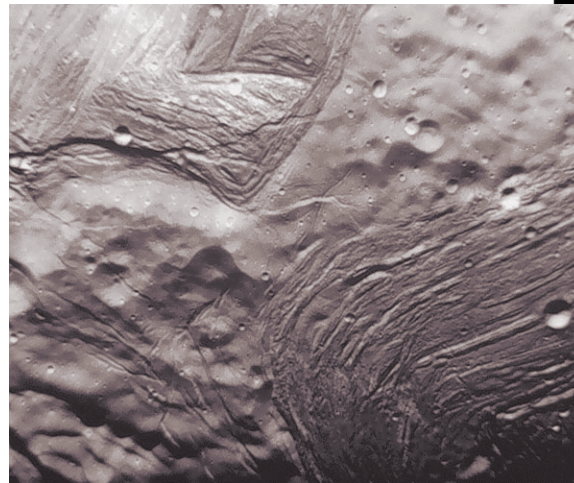
Moons of Uranus



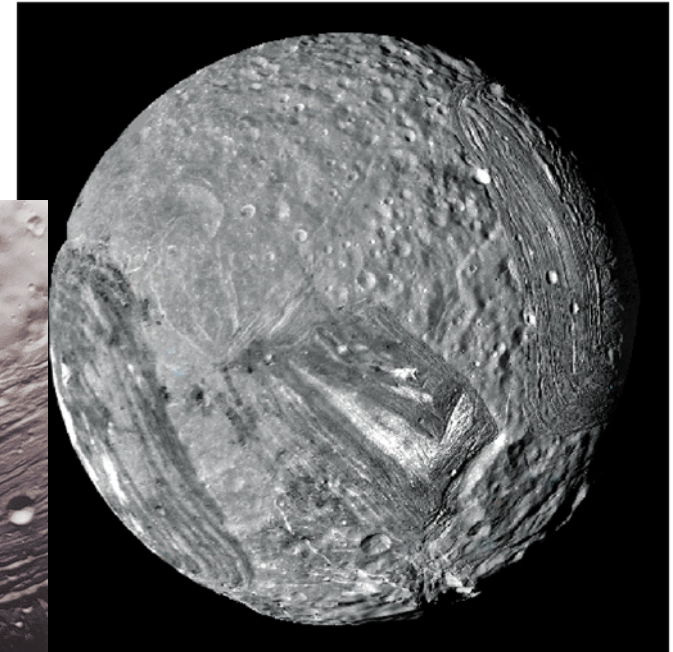
- 5 major satellites (Titania, Ariel, Umbriel, Oberon)
- 10 minor ones discovered by Voyager 2
- 5 additional minor ones discovered since then



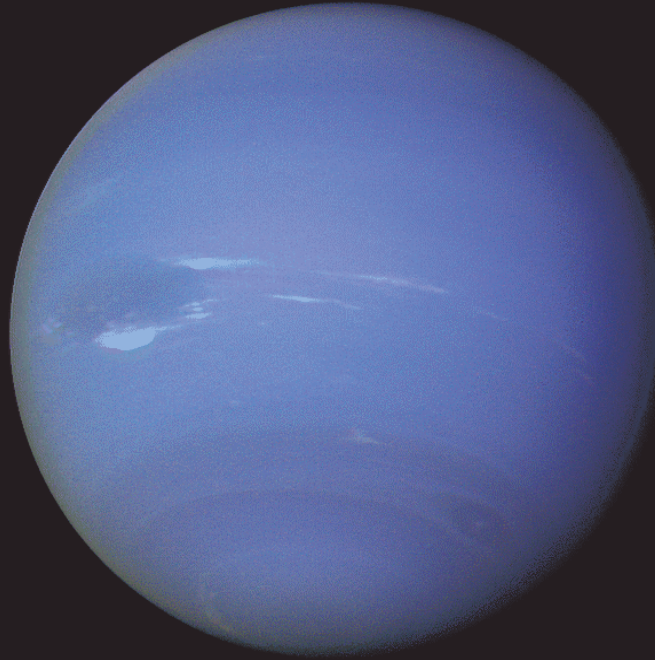
Titania
(largest)



Miranda
(smallest of the 5)



Earth – Neptune comparison



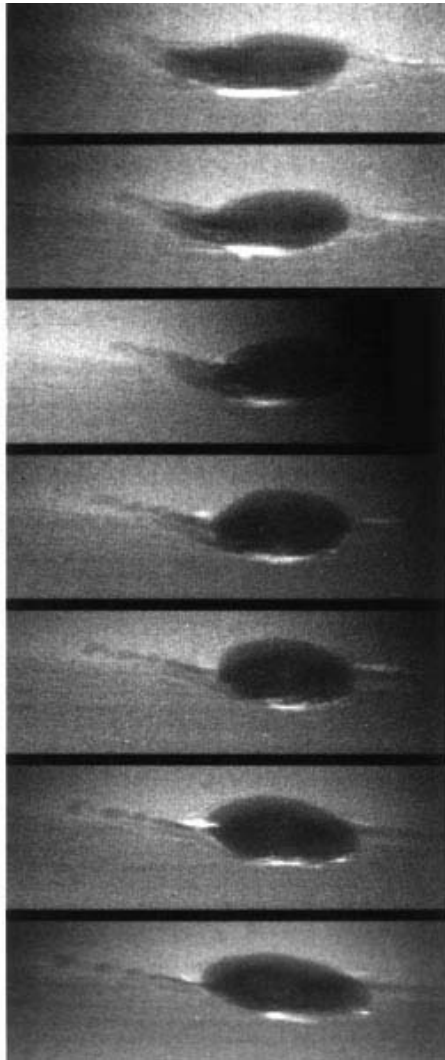
Record for fastest
winds.

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

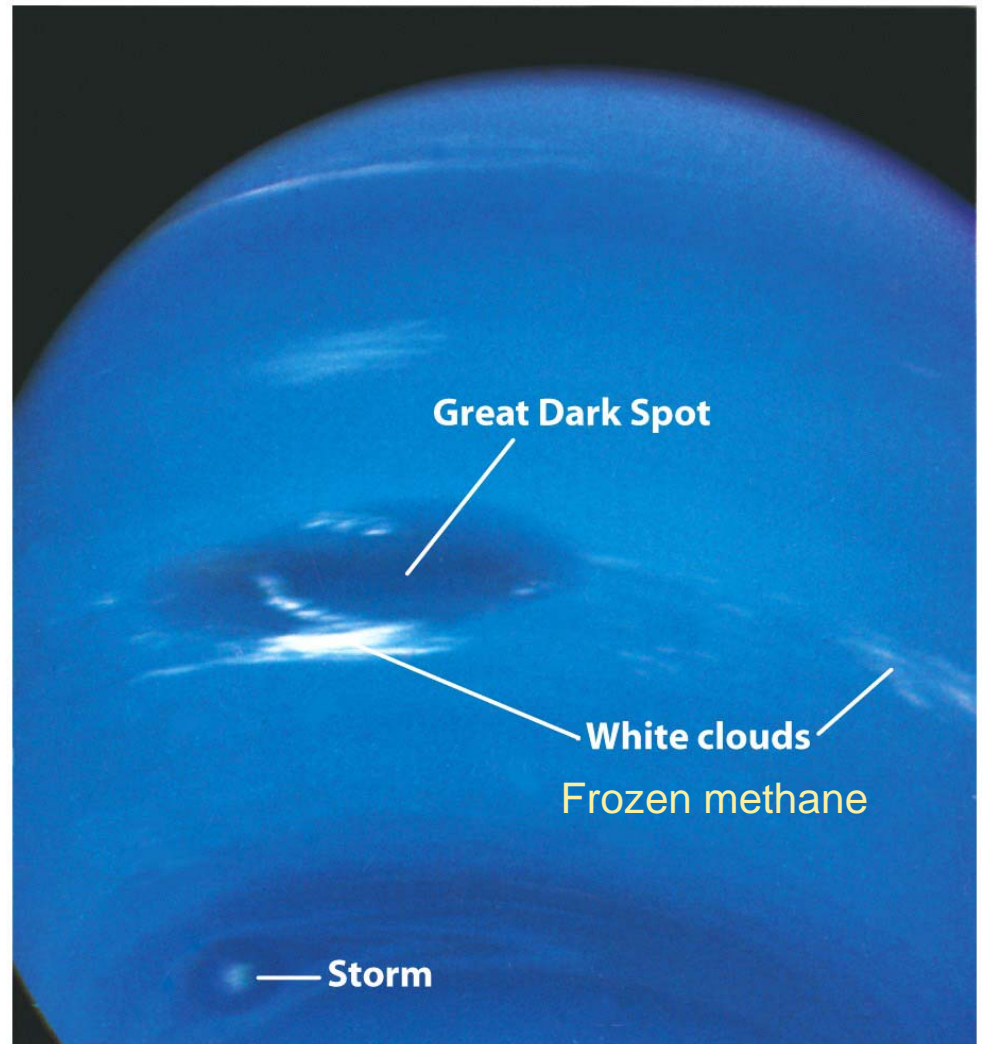
Neptune's Atmosphere



- 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).

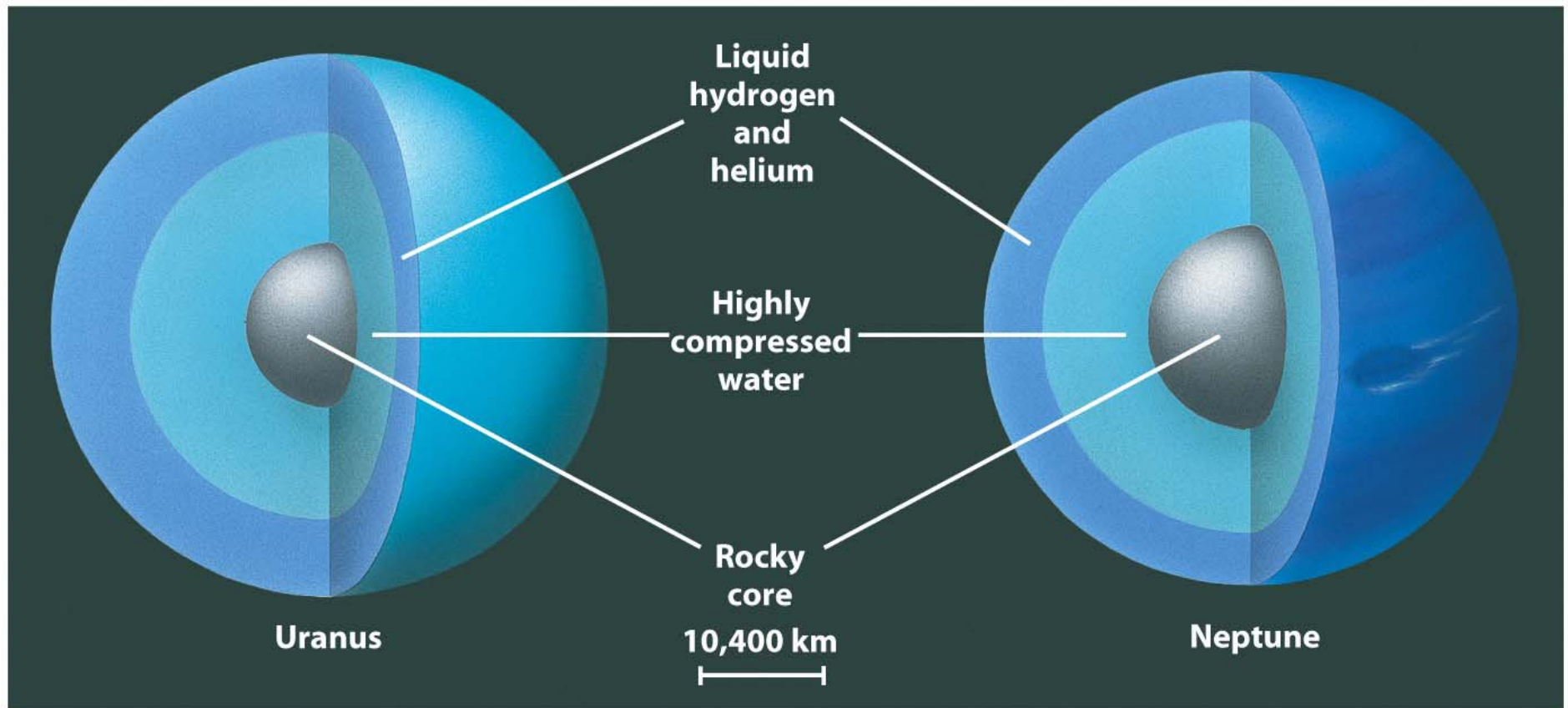


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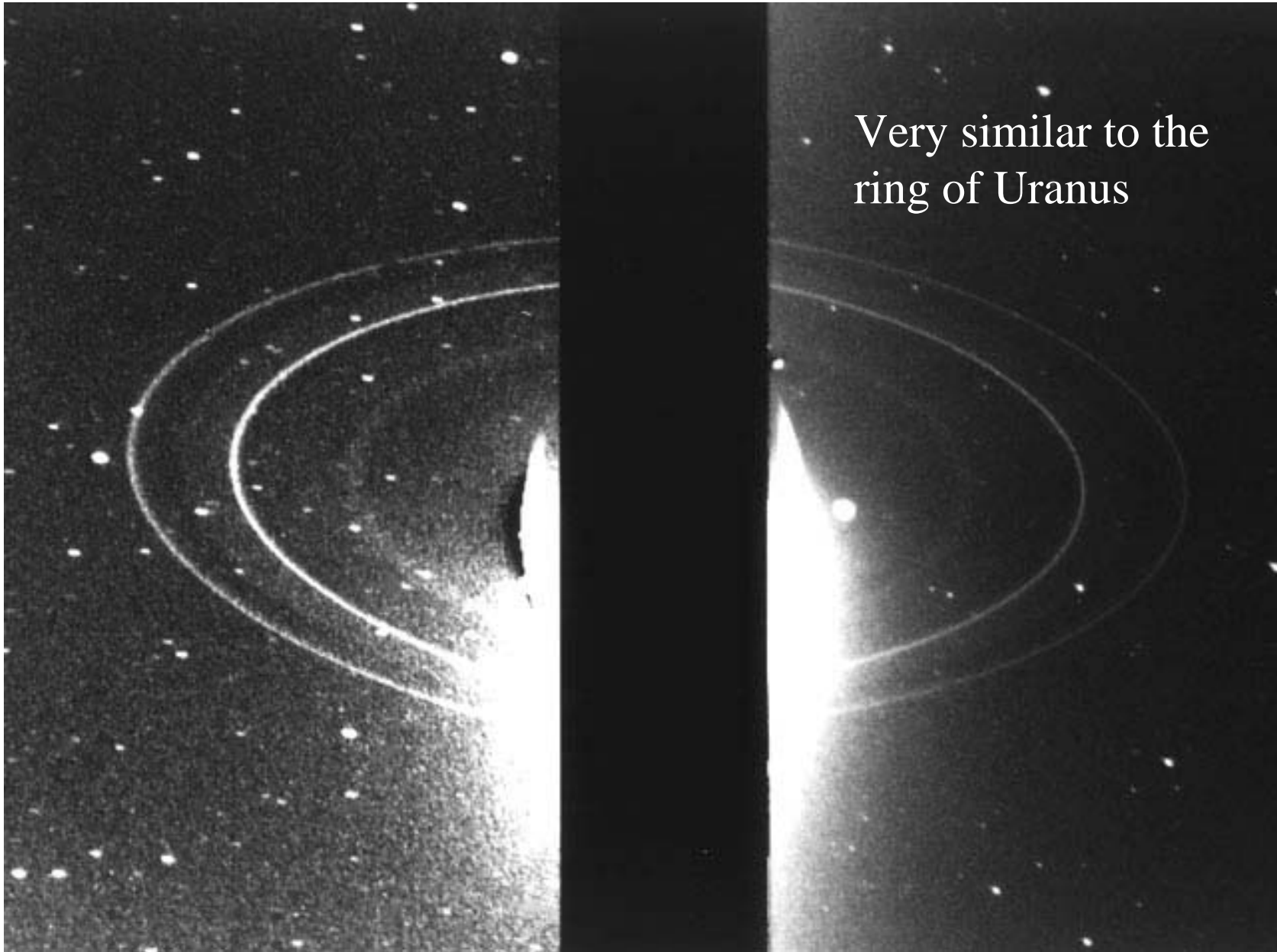


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Interiors of Uranus and Neptune



Neptune's Rings



Voyager 2
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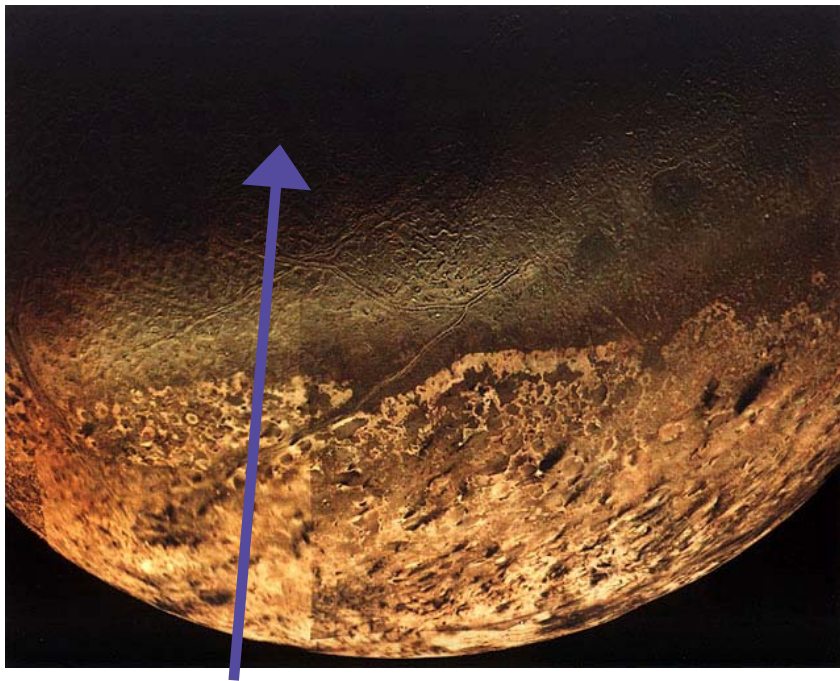
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Triton

- 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)

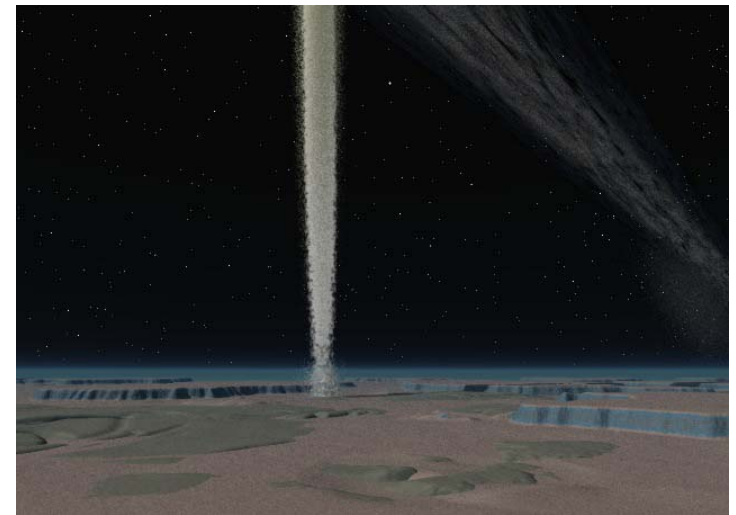


<http://www.solarviews.com/raw/nep/geyser.mov>



“Cantaloupe terrain”
Oct 1, 2003

Nitrogen “geyser”



Artist's conception – W. Myers

Earth – Pluto - Charon comparison



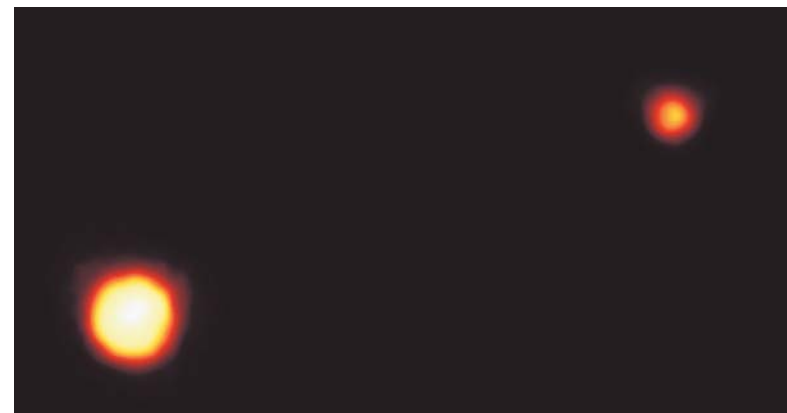
Smallest planet or largest Kuiper belt object. Coldest planet. Has biggest moon relative to itself and the largest tilt of orbit around Sun.

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

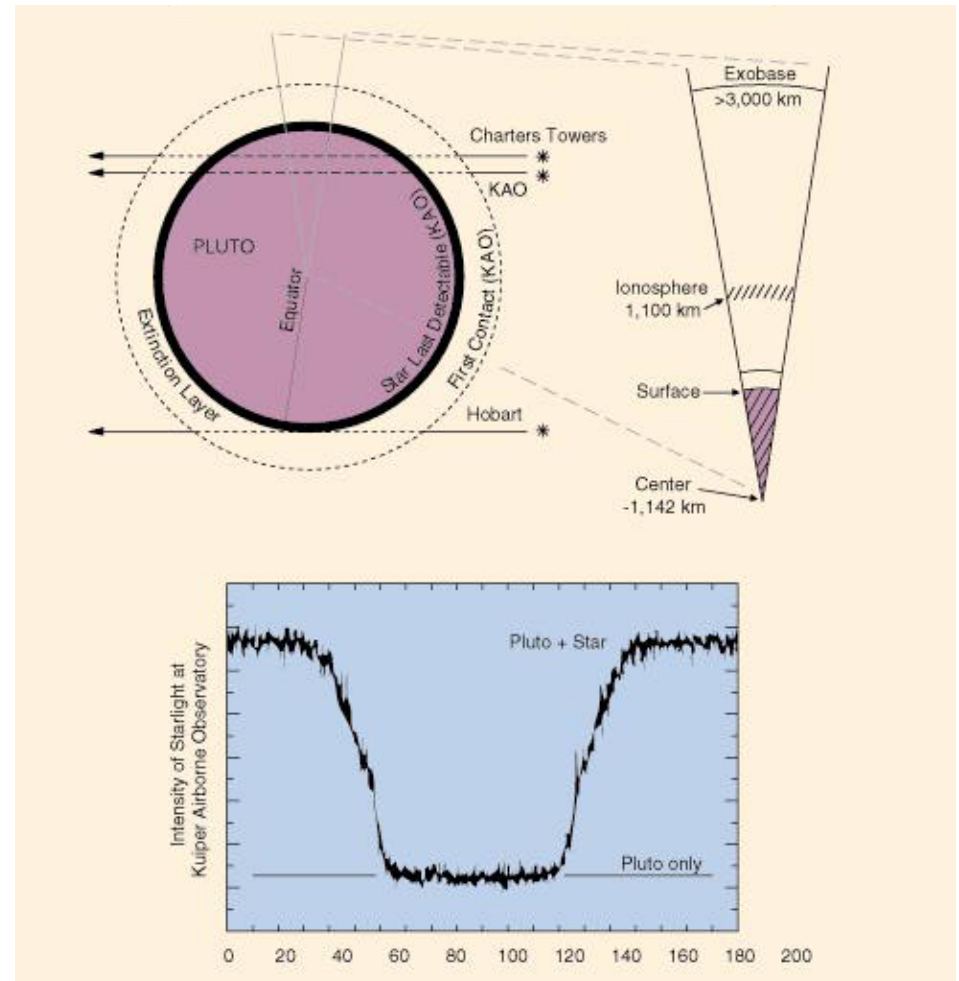
- <http://www.solarviews.com/raw/pluto/vpluchar.mpg>
- The only planet not yet visited by a spacecraft
- Reconstructed from Charon eclipses and more recently observed directly by Hubble Space Telescope (1996)
- Largest range of albedo yet observed in Solar System
 - Dark areas – rock
 - Light areas –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



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 (!?)





The Oort Cloud
(comprising many
billions of comets)

*Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
Illustration (NASA, JPL)*

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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