The Giant Planets [10]

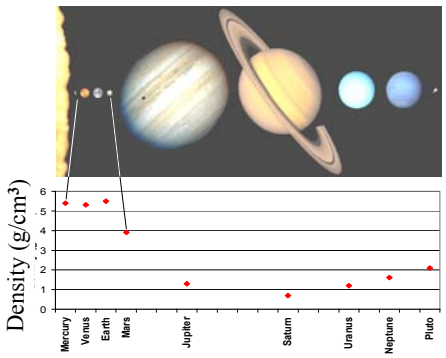
	Distance (au)	Period (yrs)	Diameter	Mass	Rotation (hrs)	Tilt (deg)
Earth	1	1	1	1	24.0	23
Jupiter	5.2	11.9	11.2	318	9.9	3
Saturn	9.5	29.5	9.4	95	10.7	27
Uranus	19.2	84.1	4.0	14	17.2	98
Neptune	30.1	164.8	3.9	17	16.1	29

[Table 10.3]

- Jupiter, Saturn often the brightest "stars" in the sky
- Telescopes from Earth give good views .

- But (again) spacecraft:
  - Pioneer 10, 11 (1973,74)
  - Voyager 1,2 Grand Tours (1977…)
  - Galileo (Jupiter orbiter + atmospheric probe. 1995)
  - Cassini-Huygens (orbiter/probe, arrive Saturn 2004)

Bambi meets Godzilla



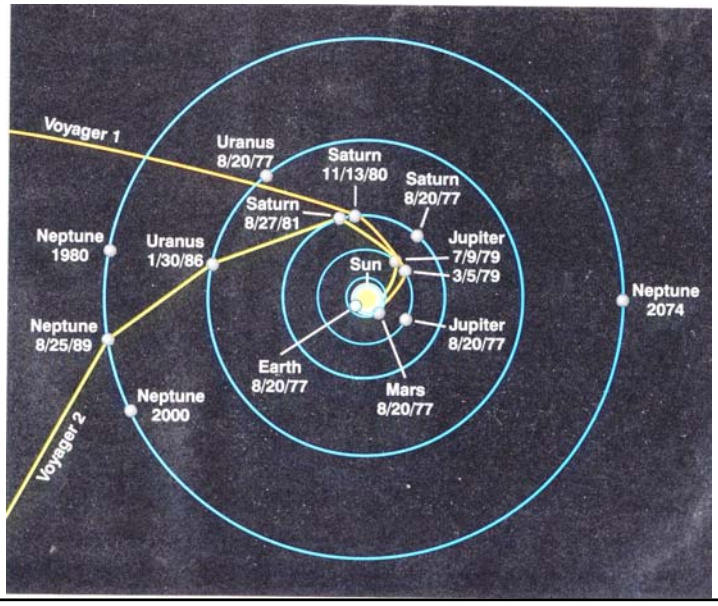
Terrestial *vs*. Giant - Size & Density

Composition of Atmospheres

- By number of atoms/molecules

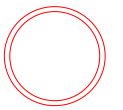
	Jupiter	Saturn	Uranus	Neptune	Outer Solar System Total	Sun
H_2	90%	97%	83%	74%	93%	86%
He	10	3	15	25	7	14
CH_4	0.2	0.2	2	1		

The Grand Tour of the Solar System (late 1970's)

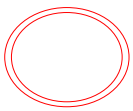


Determining the interior structure

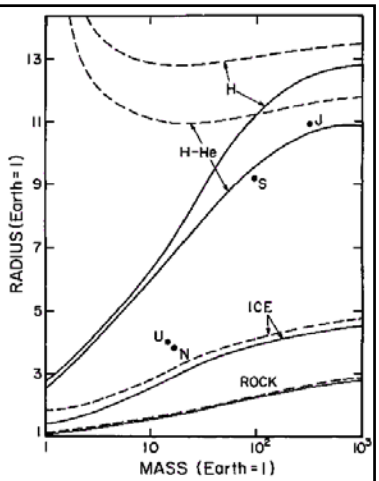
- Jupiter ~3x more massive than Saturn, but only slightly larger.
  - Greater pressure ➔ greater density ➔changes in state of atoms, molecules.
  - For objects 3x more massive than Jupiter, increasing M ➔ decreasing R.
  - Sun is larger than Jupiter because it has an internal energy source to heat it up.



Spherical shell of matter:
Acts as if all mass at central point.



Oblate shell: does not.

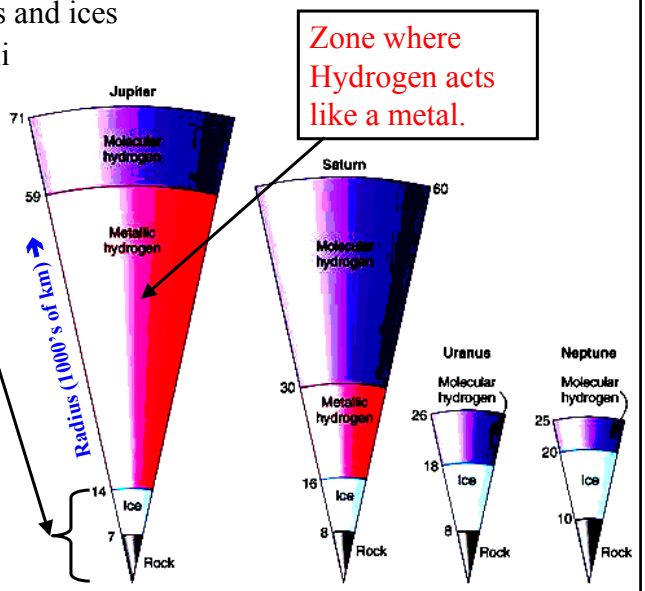


- Can use orbits of moons, spacecraft to determine oblateness
  - depends in turn on internal structure, rigidity

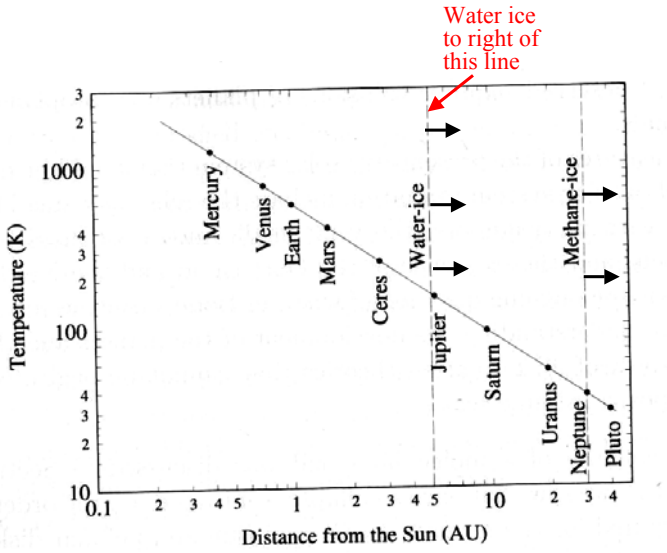
Implies gas giants have dense cores

- thick "soup" of rocks and ices
- inner 20-25% of radii
- 15 earth masses for Jupiter,
- 13 for Saturn, Uranus & Neptune.

- So core makes up much of planet for Uranus & Neptune.



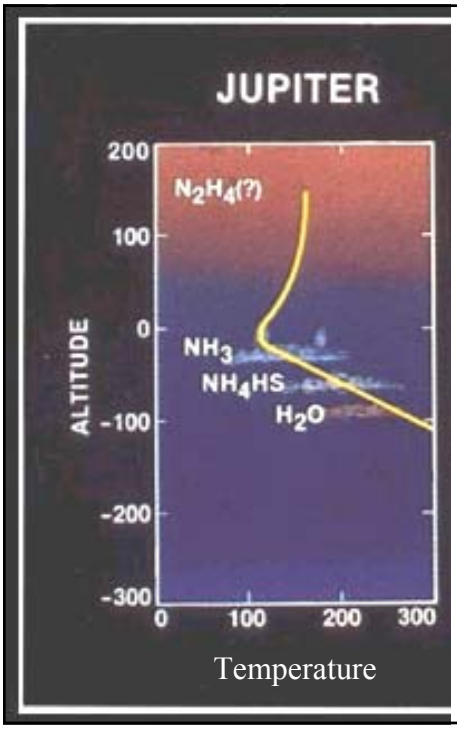
Temperature Structure of the Early Solar Nebula



Jupiter

- Main constituents of gaseous atmosphere:
  - Hydrogen: 90%
  - Helium: 10%
  - Methane (CH_4): 0.2%
  - Ammonia (NH_3): 0.02%
- Clouds
  - Frozen ammonia
  - Cause of different colors is unknown

Rotating Jupiter



Atmospheric Structure

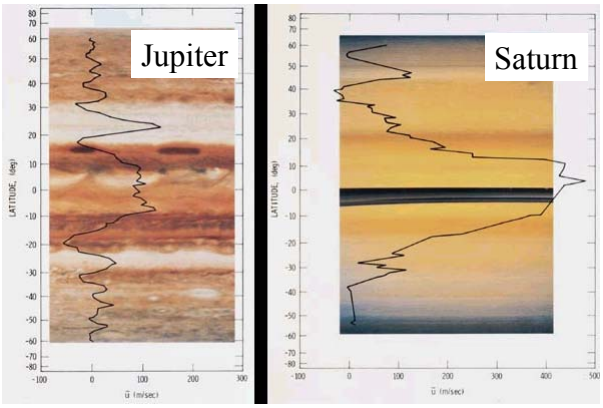
Cloud layers, in the Hydrogen-Helium atmosphere.

Ammonia

Water

[Fig 10.11]

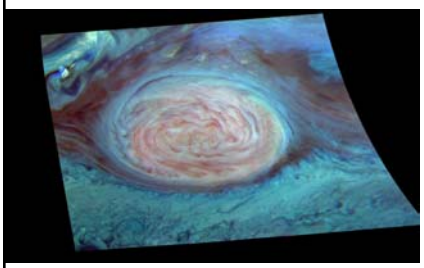
Strong winds, differential rotation



[Fig 10.14]

- Different than Earth
  - Fast spin
  - Absence of solid surface underneath.

Jupiter: The Great Red Spot

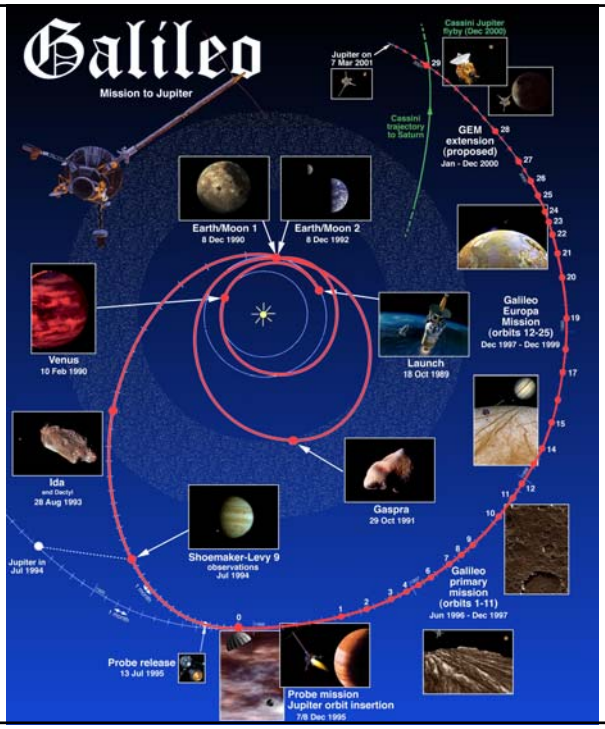


Color-coded image, showing which light is reflected off which type of clouds. Uses spectroscopy.
Blue = low clouds
Pink = high, thin clouds
White = high, thick clouds

This is a dynamic, evolving storm:
Movie red spot storm

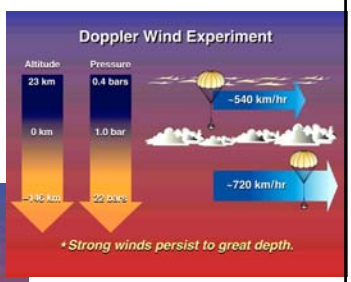
Long-lasting storm, first seen by Galileo in 1610.

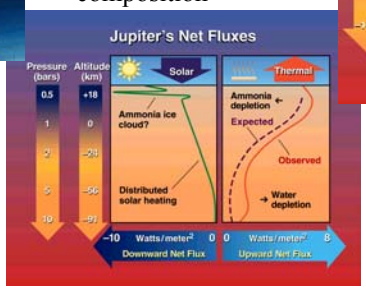
Earth sort of to scale:



Galileo mission to Jupiter (1995)

- Orbiter, still studying Jupiter's moons.
- Probe, parachuted into atmosphere
  - Studied, as function of altitude:
    - Penetration of sunlight
    - Temperature
    - Winds
    - Cloud chemistry
    - Atmospheric composition

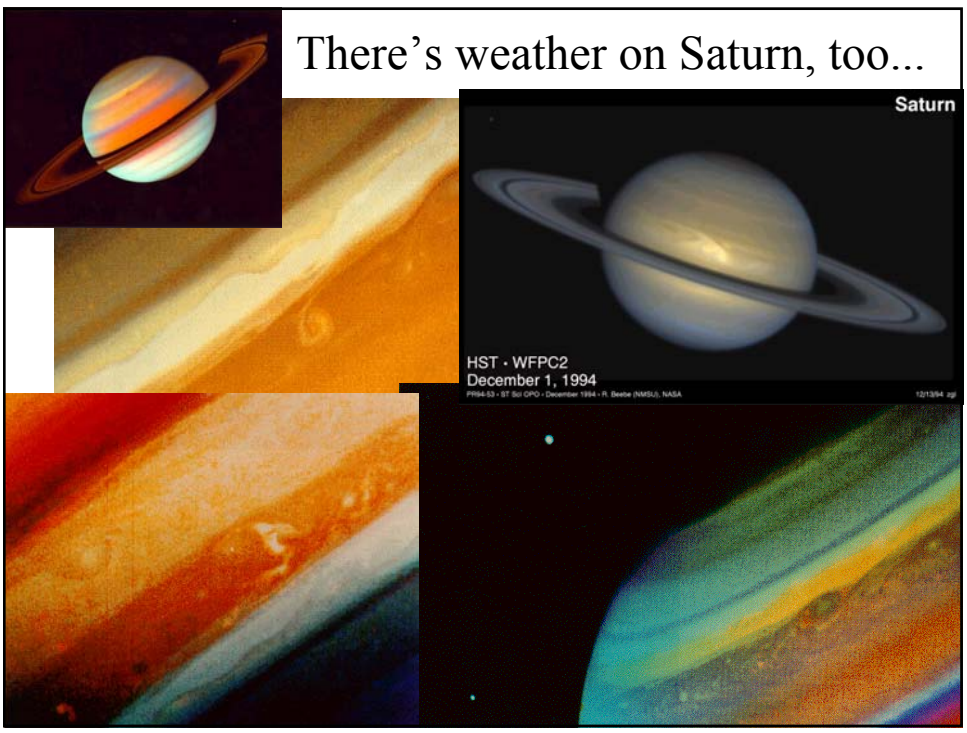




Jupiter's heat sources

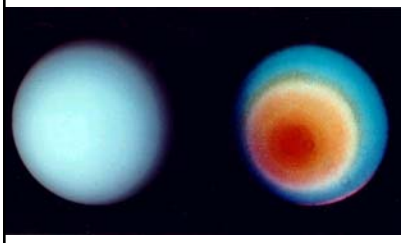
- 50% is from solar energy
- But other 50% comes from internal heating
  - This is gravitational energy released when Jupiter formed.
  - Currently stored in interior as heat energy.
  - Slowly being radiated away.
  - Plus maybe some continuing energy release from contraction.
- Similar effect in Saturn
  - But additional effect of same magnitude from ongoing differentiation.
    - Separation of H from He.

There's weather on Saturn, too...

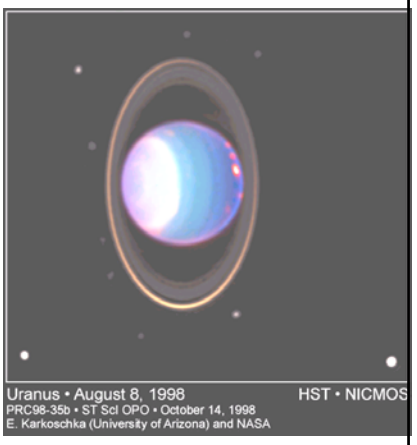


Uranus

View from Voyager 2, in 1986



False-color image emphasizing "Dark Spot"

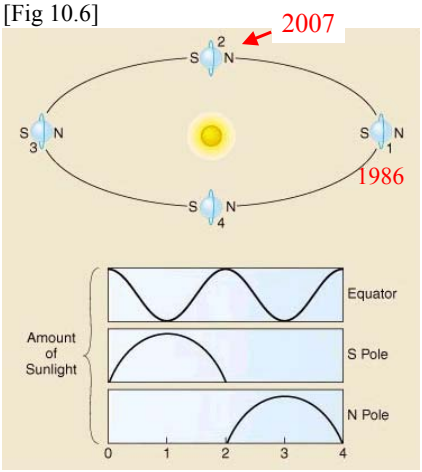


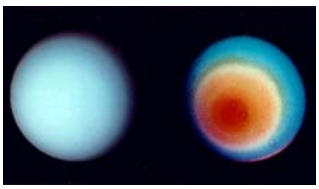
Clouds, seen in infra-red.

Seasons of Uranus

84-year Sidereal Period

[Fig 10.6]

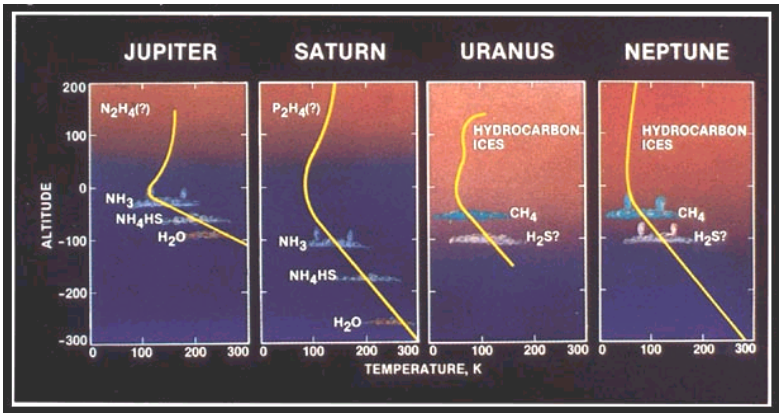




Dark spot due to seasonal heating

Atmospheres

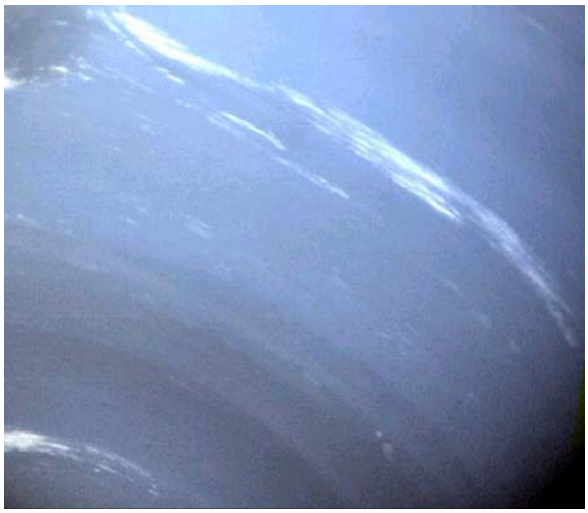
	Jupiter	Saturn	Uranus	Neptune	Outer Solar System Total	Sun
H_2	90%	97%	83%	74%	93%	86%
He	10	3	15	25	7	14
CH_4	0.2	0.2	2	1		



Methane

[Fig 10.11]

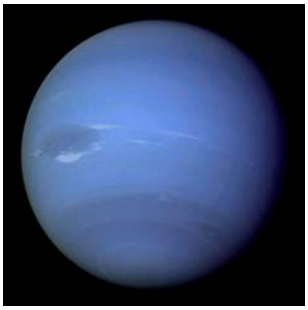
Methane Clouds on Neptune



Blue color is due to methane (CH_4) gas.

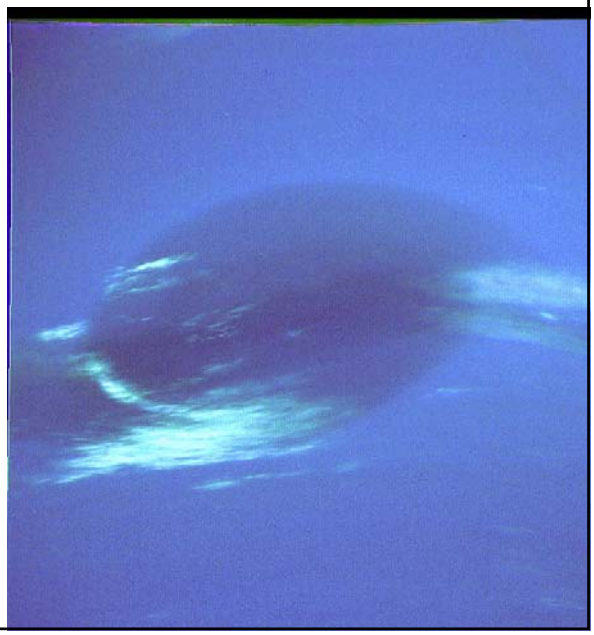
White clouds are methane ice crystals, ~ 70 km above denser part of atmosphere.

Taken by Voyager 2 from a distance of 590,000 km.



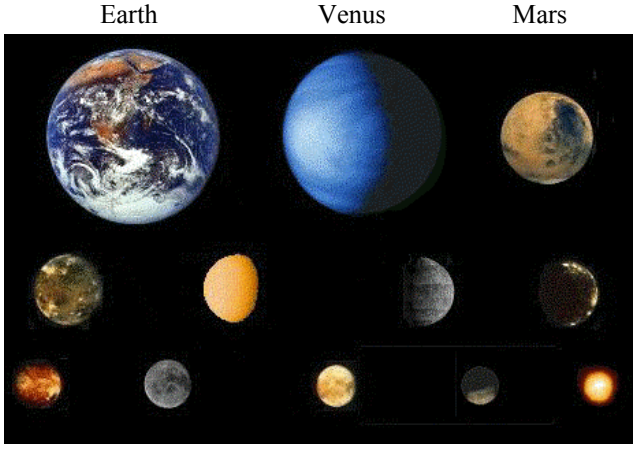
- Anti-cyclone similar to Great Red Spot on Jupiter.
- About same size as Earth.
- Moved across Neptune's surface at 700 km/hr.
- Seen by Voyager (1989), then disappeared.

Neptune's Great Dark Spot



Some planets and moons

shown in correct relative sizes

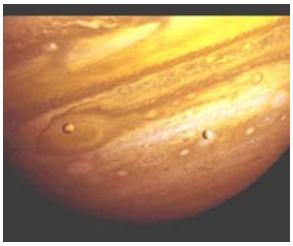


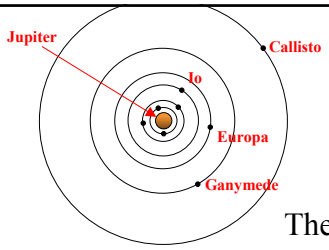
Planets:
orbit around Sun

Moons:
orbit around planets

The Moons of Jupiter

28 known satellites
– a miniature Solar System





The Galilean Satellites

Io

Europa

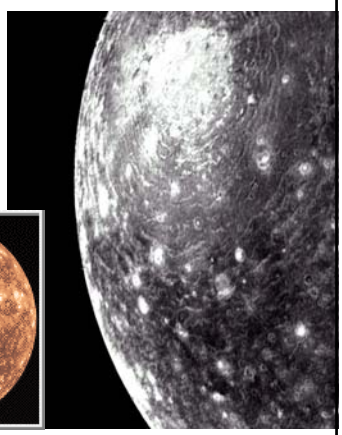
Ganymede

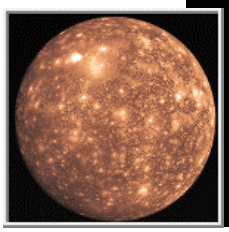
Callisto

	Diameter (Moon=1)	Mass (Moon=1)	Semi-major axis (km)
Callisto	1.4	1.5	1,883,000
Ganymede	1.5	2.0	1,070,000
Europa	0.9	0.7	671,000
Io	1.0	1.2	422,000

	Diameter (km)	Relative Mass	Density (g/cm^3)	% Reflectivity
Moon	3476	1.0	3.3	12
Callisto	4820	1.5	1.8	20
Ganymede	5270	2.0	1.9	40
Europa	3130	0.7	3.0	70
Io	3640	1.2	3.5	60

Callisto

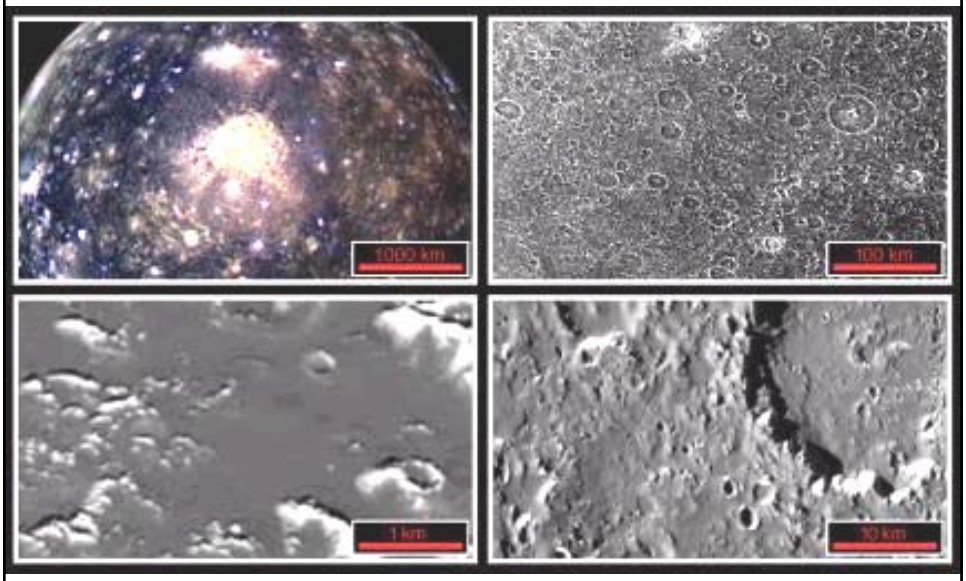


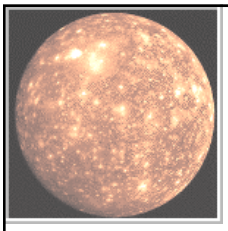


Callisto

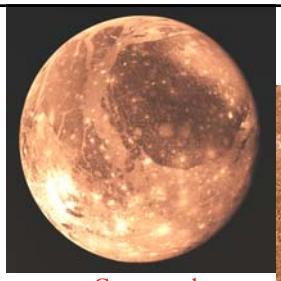
- Orbital period: 17 days
- Tidal locking with Jupiter
- Surface temperature = -140° C
  - appears to be mostly ice.
  - 1.8 x density of water
- Many impact craters.
- Not well differentiated
  - Close Galileo flybys ➔ gravitational field ➔ no dense core.
- Geologically dead for 4 billion yrs.

Zooming in on Callisto





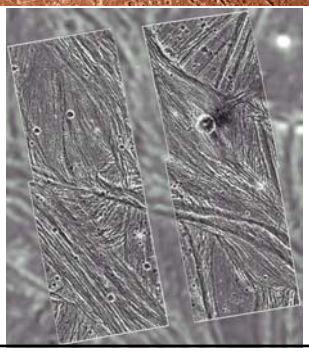
Callisto



Ganeymede

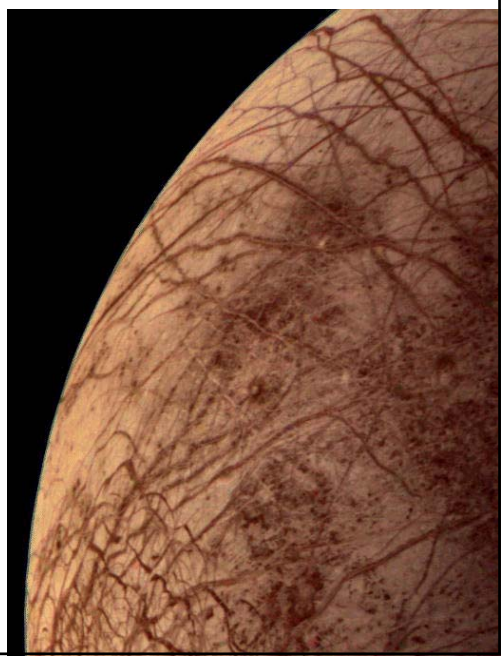
Ganeymede

- Largest satellite in Solar System
- Fewer impact craters than Callisto
  ➔ geologically active.
- Differentiated
  - Rock, metal core.
    - Magnetic field present.
- Mantle, crust made of ice
  - Volcanic flows, but water rather than lava.
  - Ridges, valleys due to compression of crust.
- Ganymede is closer to Jupiter than is Callisto
  - Tidal forces may drive this geological activity.

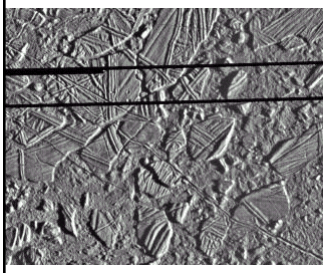


Europa

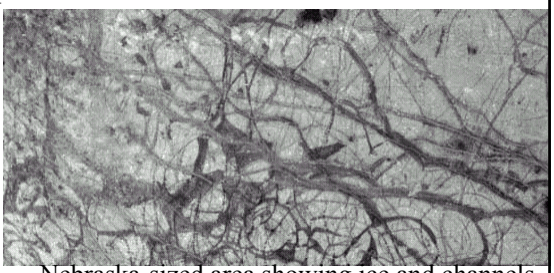
- *Not* made of ice.
  - Density similar to Moon
- Heating by Jupiter probably the reason.
- Tidal forces keep it geologically active.
- But covered by layer of water ice.
  - Appears to be “pack ice” on top of an ocean.
  - Water must be warmed by heat from Europa’s interior.



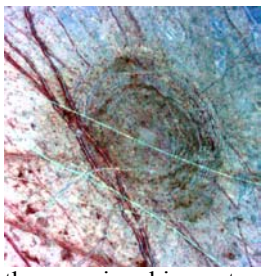
Europa’s surface



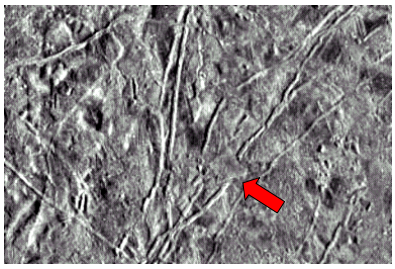
Ice rafts



Nebraska-sized area showing ice and channels.



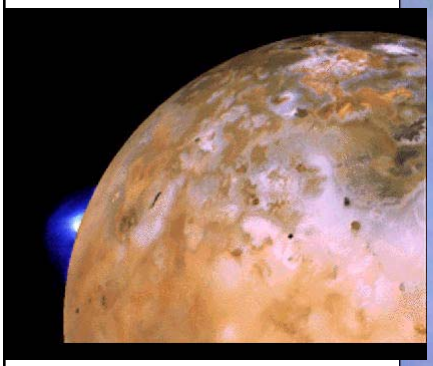
+ the occasional impact crater

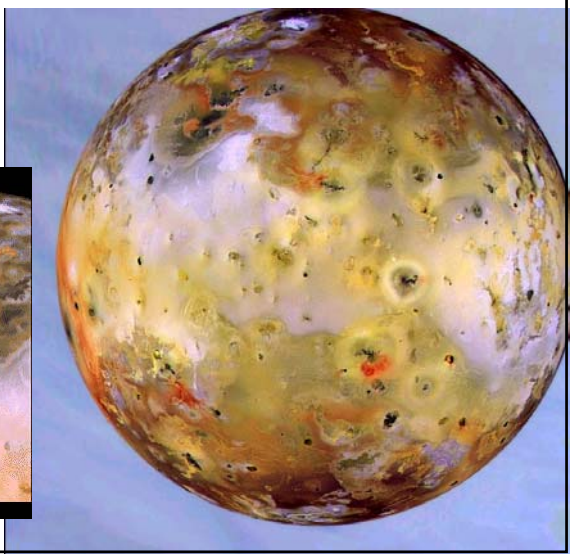


Ice flow cutting across ridge

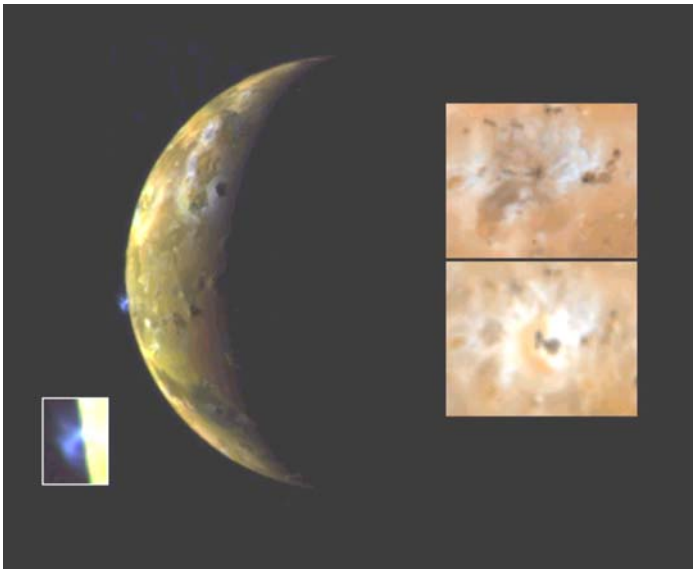
Io

- Closest to Jupiter (of Galilean Satellites)
  - Strongest tidal forces.
- Active volcanoes
  - hot silicate lava, similar to Earth.



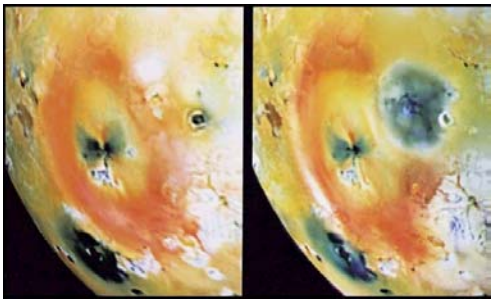


Volcano on Io

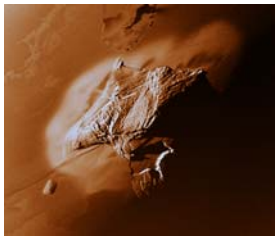


Io in Rotation/Volcanoes Erupting

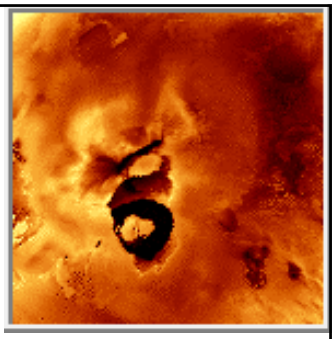
More Io



Images of same region, 5 months apart.

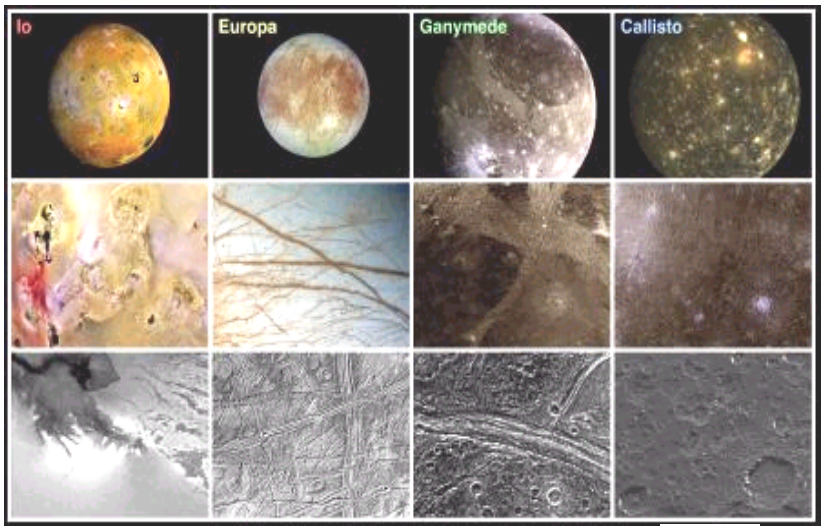


Haemus Mons -
a volcanic cone



Loki Patera
Thought to be a liquid sulphur lake with a solid sulpher raft.

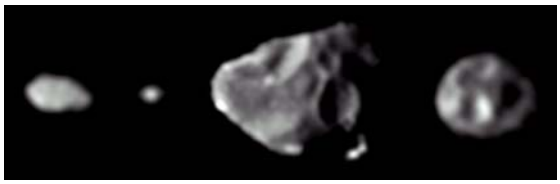
Landscapes on the Galilean Satellites



To Jupiter

The Innermost Moons of Jupiter

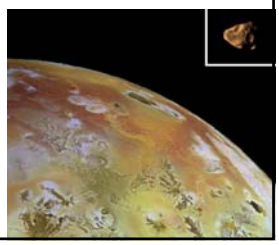
All are tidally locked to Jupiter



	Metis	Adrastea	Amalthea	Thebe	(Io)
Size (km)	40	20	270x166x150	116	3630
Mass (kg)	10^{17}	$2x10^{16}$	$7x10^{18}$	$7x10^{17}$	$9x10^{22}$
Orbit radius (km)	128,000	129,000	181,000	222,000	422,000

Inside Jupiter's "Roche limit".

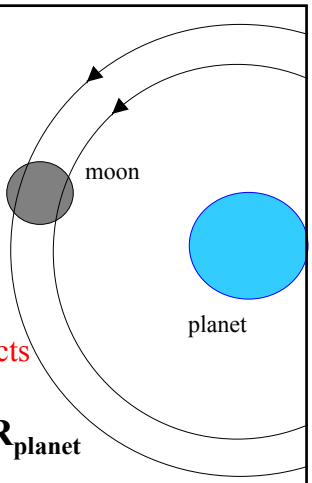
Galileo flyby… Nov. 5, 2002



Amalthea & Io

The Roche limit

- For an extended body in orbit around another body :
  - $P^2 = a^3$ ➔ different parts of extended body have different orbital periods.
  - So body tends to be torn apart.
  - But self-gravity tends to hold it together.
- Roche's limit is where these two opposing effects are balanced:



$$R_{Roche} = 2.5\,(\rho_{planet}/\rho_{moon})^{1/3}\,R_{planet}$$

where ρ = mean density.

R_{planet} = radius of planet.

- Expressed in terms of density and R_{planet} in order to cancel out terms referring to size and mass of moon and mass of planet.

…and Jupiter's outer satellites

	Semimajor Axis (km x 1000)	Diameter (km)
Metis	128	20
Adrastea	129	40
Amalthea	181	200
Thebe	222	90
Io	422	3630
Europa	671	3138
Ganymede	1070	5262
Callisto	1883	4800
Leda	11090	15
Himalia	11480	180
Lysithea	11720	40
Elara	11740	80
Ananke	21200	30
Carme	22600	40
Pasiphae	23500	40
Sinope	23700	40

[Appendix 8]

Captured asteroids?

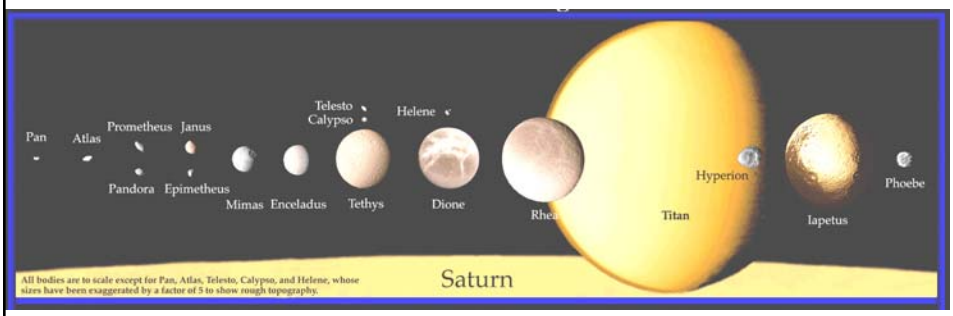
Why in two groups??

Retrograde Orbits

+ 10 more found since 1999

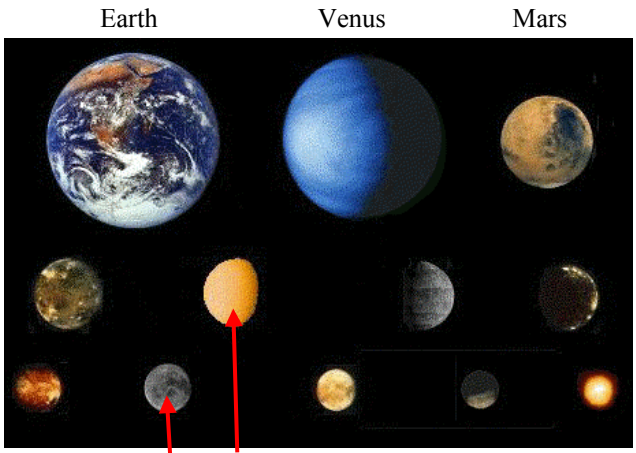
The Saturn System

Saturn's satellites

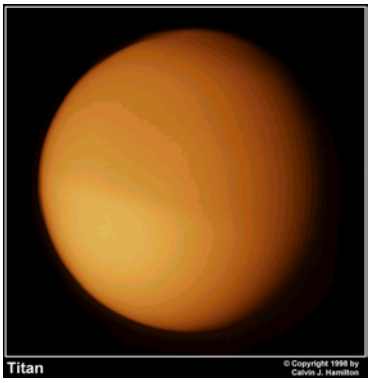


Some planets and moons

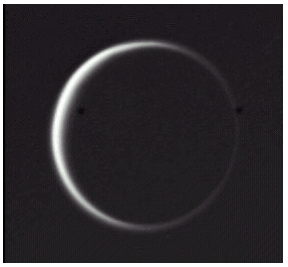
shown in correct relative sizes



Titan



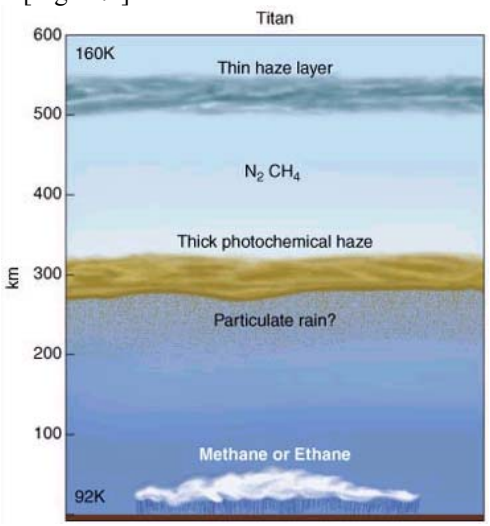
In visible light, from Voyager


Looking back at Titan

- Composition: half ice, half rock.
- Has an atmosphere, with many similarities to Earth's.

Titan's atmosphere

[Fig 11.2]

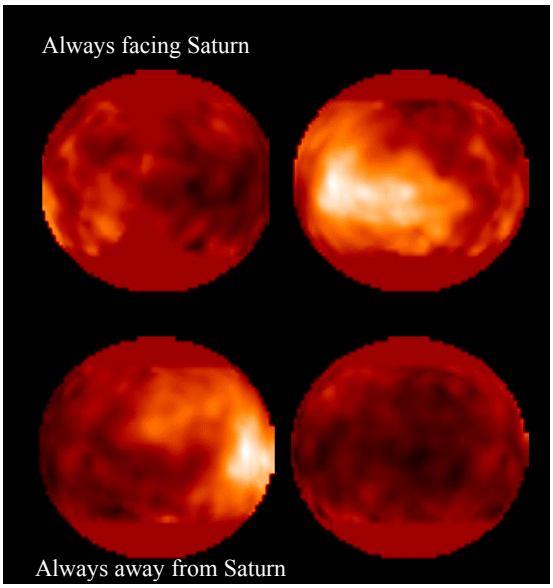


- Density about same as Earth's
  - 1.6 bars at surface
- Primarily N_2, but also:
  - carbon monoxide (CO)
  - methane (CH_4)
  - ethane (C_2H_6)
  - propane (C_3H_8)
  - hydrogen cyanide (HCN)
    - a building block of DNA
  - C_2N_2, HC_3N
- Thick photochemical smog obscures surface.
- Surface temp = -180^o C

What little we know about Titan's surface

- Infrared images showing 4 faces of Titan
  - From HST
  - See through the haze.
- Titan is tidally locked to Saturn
- Solid brick-red shows regions that could not be imaged through the haze.

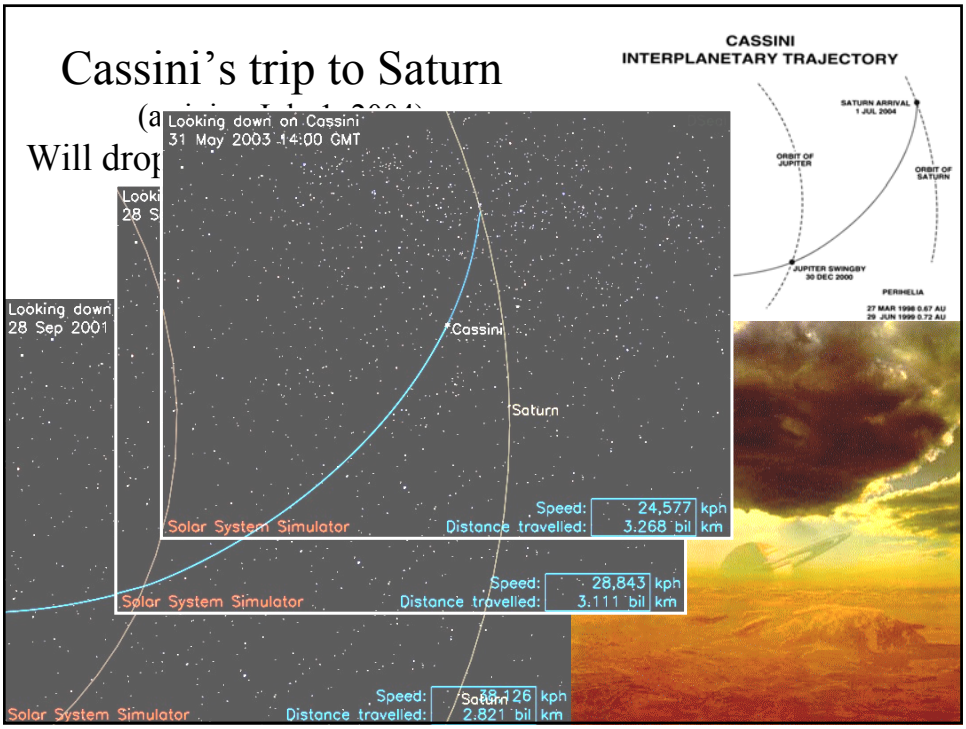
Thought to have land masses and ethane oceans



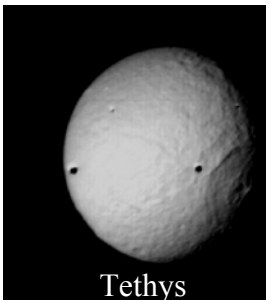
Cassini's trip to Saturn

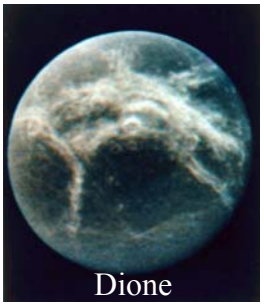
(a

Will drop

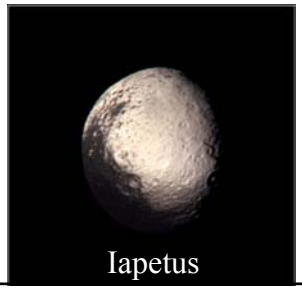


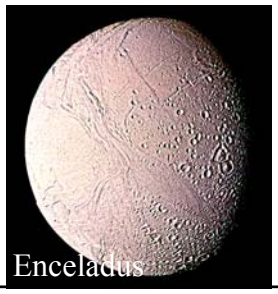
The other 5 major moons of Saturn


Tethys


Dione

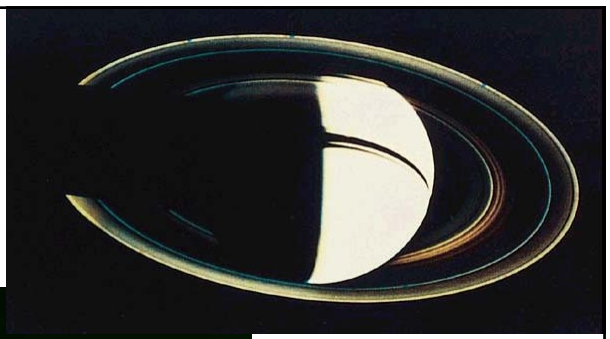

Rhea

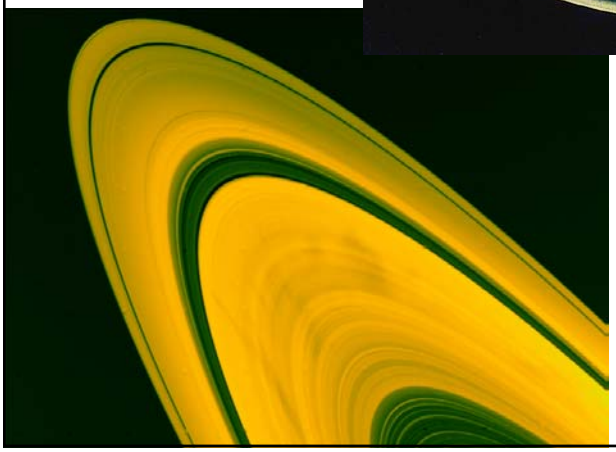

Iapetus


Enceladus

Saturn's rings, top & bottom

70,000 km wide, only 20m thick!

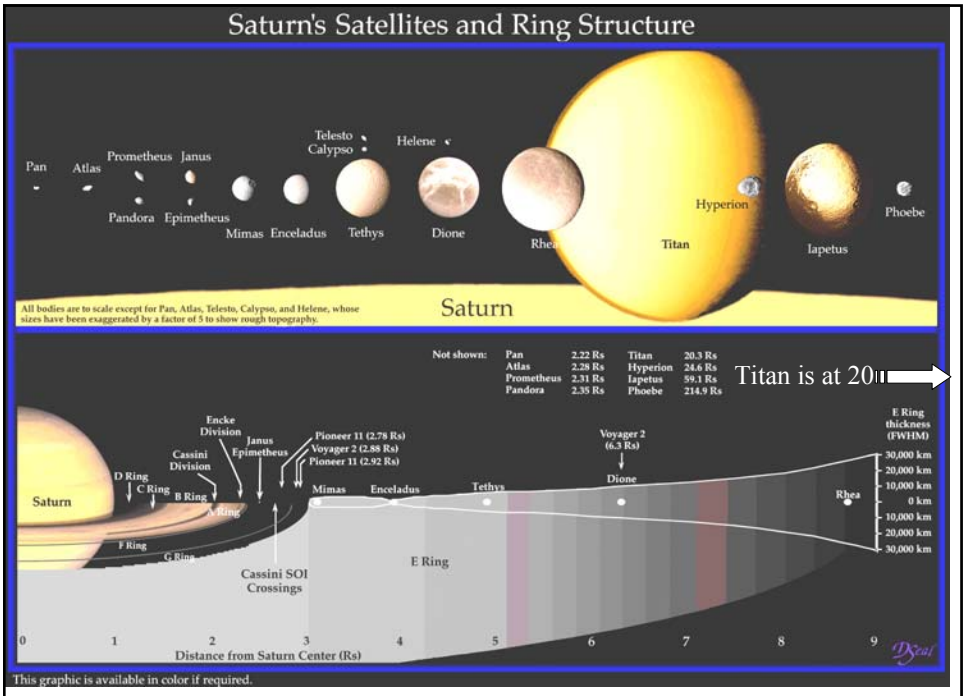




Bottom view, showing the light that is *not* reflected by the rings.

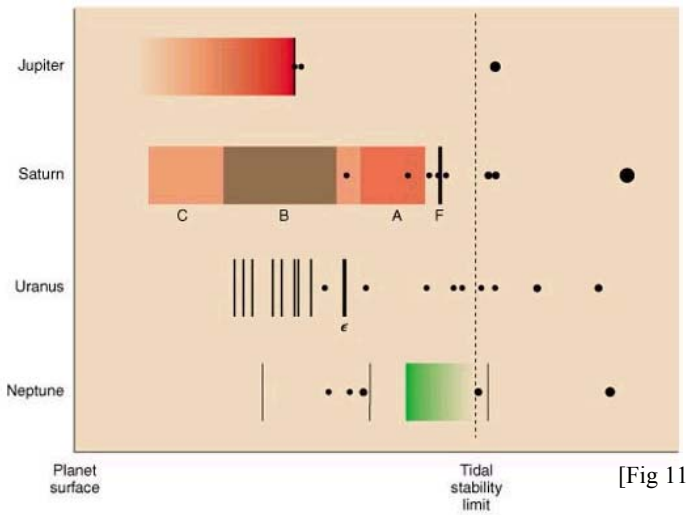
Color-enhanced top view, showing "spokes", of unknown origin.

The Spoke Show



Roche's limit and the Rings

Large objects cannot form in this region,
or get broken up even if they do form.



[Fig 11.17]

(Roche limit)

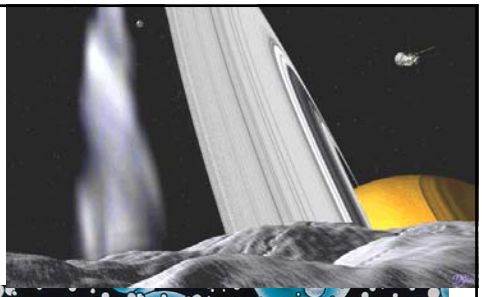
Satellite-Ring Interactions

- Many small satellites none-the-less found in rings.
- Their gravitational interaction shapes the rings:
  - Cause gaps in rings.
    - Swept out through gravitational resonances
      - – *cf.* Orbital periods with 2:1 or 3:2 ratios, etc.
      - – or small moons move directly in gaps.
  - Keep rings from spreading out and dissipating
    - *Shepherd* moons: contain material in rings immediately adjacent to orbit of moon.

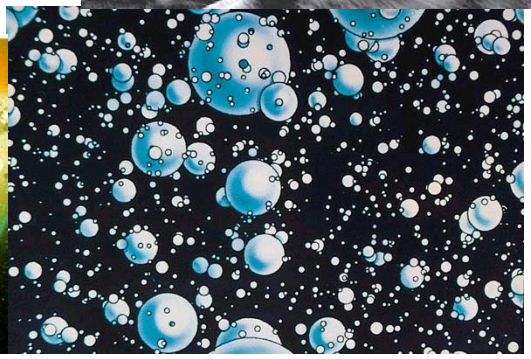
What are the rings made of?

Ice
+ a pinch
of dust.

View from Pandora (one of the "shepherd" satellites, including the "braided" F ring) →



Dynamic Ephemeral Bodies



Rings only1 km thick

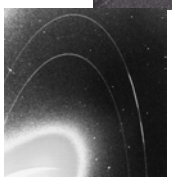
[Fig 11.19]

All 4 Jovian planets have rings

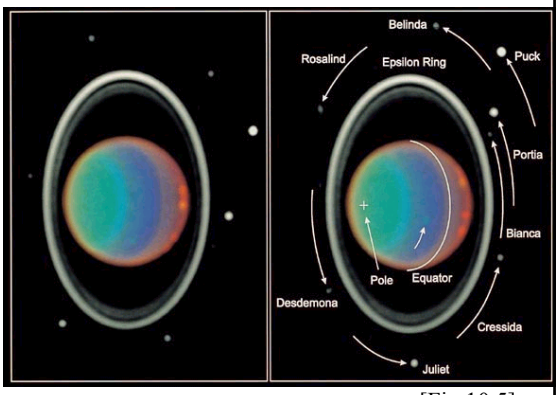
Jupiter's ring
Imaged by Galileo probe

⇦ Uranus ⇨

[Fig 11.20]

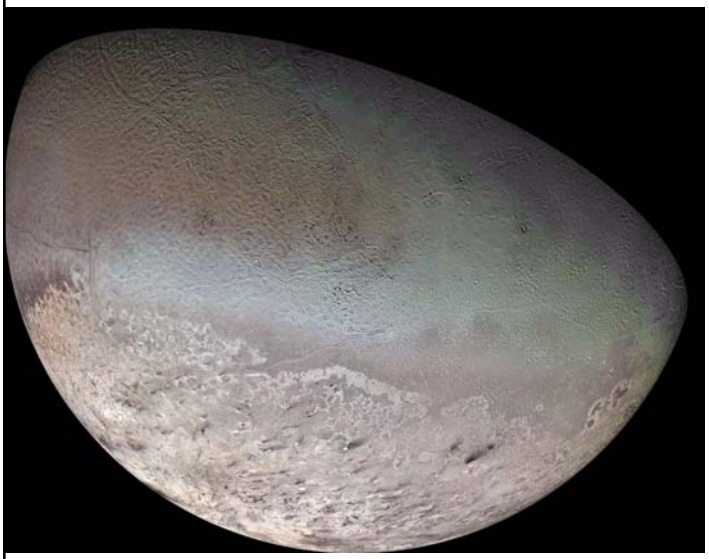


Neptune
[Fig 11.21]



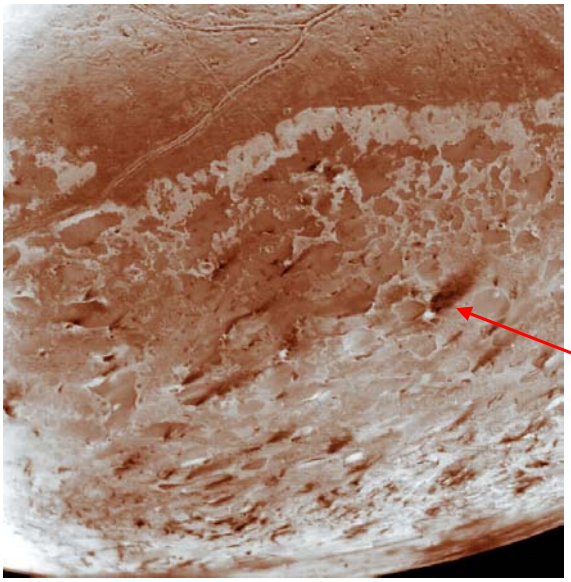
[Fig 10.5]

Triton - the largest moon of Neptune



- 2700 km diameter (0.8 x Moon)
- Probably 75% rock, 25% ice.
- N_2 atmosphere
- Retrograde orbit
- Rotation axis tilted 157^o from Neptune's axis.
- Many similarities to Pluto.

An erupting ice volcano on Triton

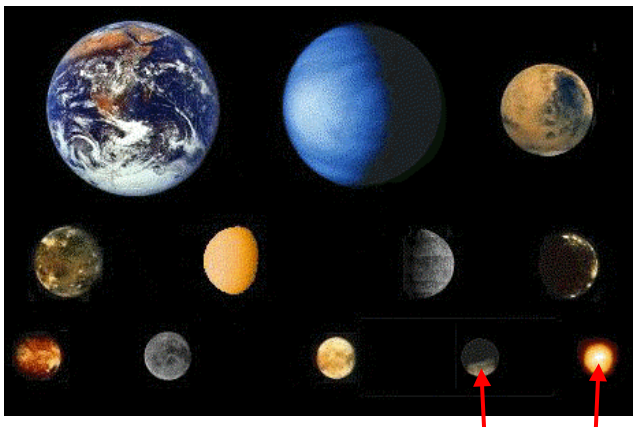


Voyager picture

Volcanic plume
- rises 8 km above surface
- extends 140 km downwind.
- due to sunlight thawing surface.

Some planets and moons

shown in correct relative sizes



Planets:
orbit around Sun

Moons:
orbit around planets

Pluto

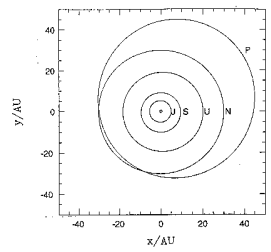
Our best images of Pluto: HST movie.

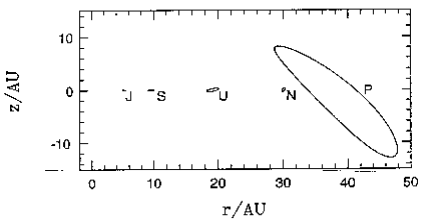
- Charon
  - discovered in 1978
  - half the size of Pluto
  - Pluto previously thought to be much larger.

[Fig 11.16]

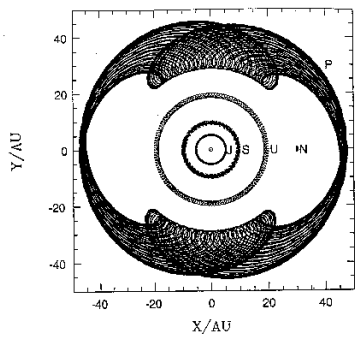
- Pluto & Charon both in synchronous rotation
  - always show same faces to each other
- Pluto's inclination = 118° (i.e. tipped on its side)
  - but Charon orbits in Pluto's equatorial plane.
- Pluto's orbit crosses Neptune's
  - Triton has retrograde rotation, etc.
  - *Is there a connection??*

NO





- Z component of each planet's position plotted against simultaneous distance from Sun.



- Pluto's orbit relative to Neptune, projected into plane of solar system.
- Pluto's weird path is due to 3:2 resonance with Neptune.