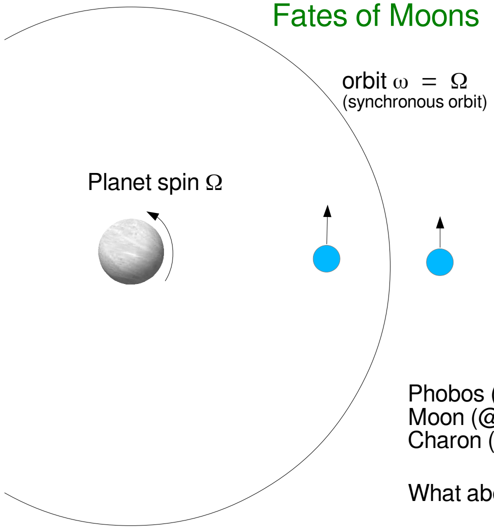
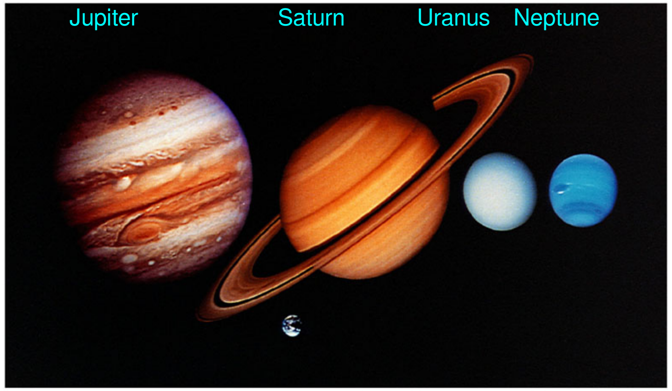
Fates of Moons



Phobos (@Mars): 7.6 hr
Moon (@Earth): 1 month
Charon (@Pluto): 6 day

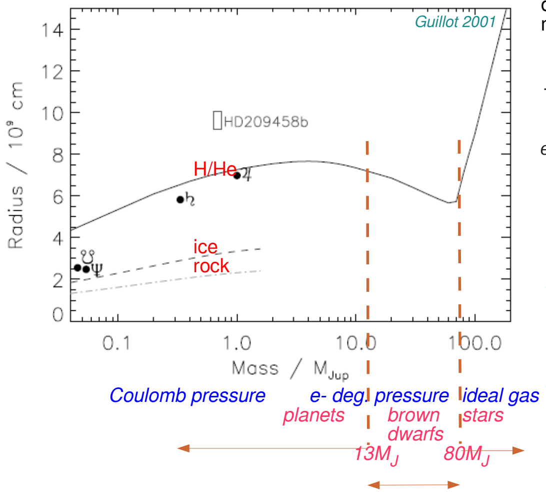
What about retro-grade moons?

Giant Planets



made mostly of H, He and H-compounds, no solid surface
99.5% planet mass, 99.8% solar system angular momentum

Giant planets border stars



Equation of state determines mass-radius relation

Ideal gas: $P \propto \rho T$
+Fusion: $T_{core} \sim Const$
$\rightarrow R \propto M$

el. degeneracy: $P \propto \rho^{5/3}$
$\rightarrow R \propto M^{-1/3}$

Coulomb: $\rho \sim Const$
$\rightarrow R \propto M^{1/3}$

Working definition: Brown-dwarfs are 'failed' stars that cannot ignite hydrogen (but can burn deuterium); hence $M < 80\, M_J$ ($0.08\, M_\odot$)

Planets are formed in disks around stars. Planets cannot burn deuterium (10^6 K); hence $M < 13\, M_J$

Are planets just gas balls like stars? Probably not.

Jupiter & Saturn: largely degenerate H & He, mean ρ = 1.3 & 0.7 g/cm^3
- -- hydrogen metallic (conductive) below certain depth (?)
- -- core: solid, heavy metal + ices

Jupiter's core: < 10 M_E (or 0?); Saturn's core: ~ 13 M_E (15% of mass)

Uranus & Neptune: largely ices (H_2O, CH_4, NH_3), mean ρ = 1.2 & 1.7 g/cm^3
- -- relatively thin gaseous H & He envelope
- -- mostly icy + rocky core

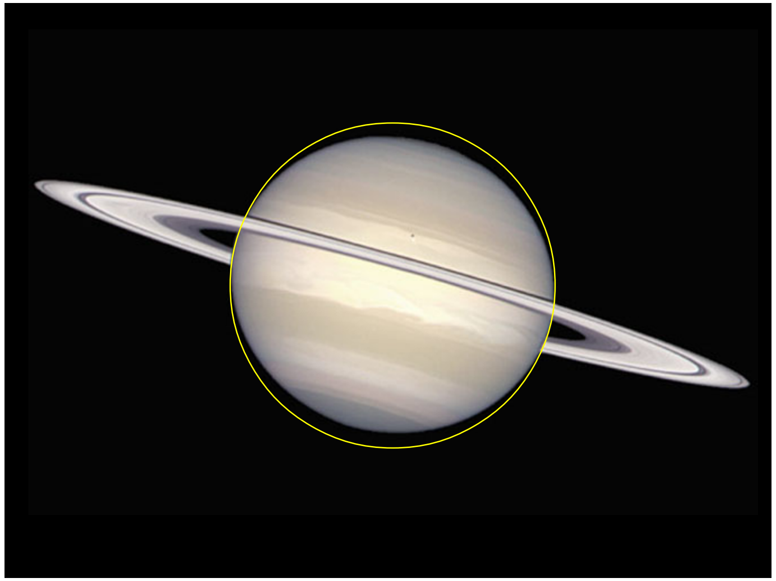
Why do we care about the solid cores?

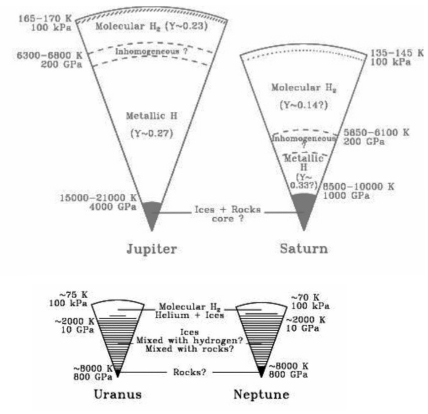
Formation of giant planets likely starts with a solid core – unlike stars

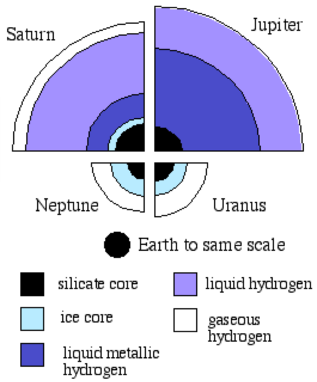
How do we figure out about the cores? Spin it!

core: a high density central region
spherical body: gravitational potential is independent of density profile
but when the planet rotates, it oblateness depends on $\rho=\rho(r)$

$$\Phi(\theta) = -\frac{GM}{r}\left[1 - \left(\frac{R}{r}\right)^2 J_2 P_2(\cos\theta) - \left(\frac{R}{r}\right)^4 J_4 P_4(\cos\theta) - \ldots\right]$$







Cores of giant planet are likely primordial and do not form by gravitational settling.
Did Jupiter melt part of its core?

Energy budget for giant planets

Absorb solar flux: $(1-A)4\pi R_o^2 \sigma T_o^4 \times \frac{\pi R_p^2}{4\pi a^2}$

Emit blackbody flux: $4\pi R_p^2 \sigma T_p^4$

$$T_p = (1-A)^{1/4} \left(\frac{R_o}{2a}\right)^{1/2} T_o$$

	Jupiter	Saturn	Uranus	Neptune
passive T_p	113K	83K	60K	48K
actual T_p	130K	95K	59K	59K
$L_{total}/L_{received}$	1.7	1.8	1.0	2.6

3 sources of planetary intrinsic luminosity: primordial + settling + radio-active

Jupiter: **primordial heat** + He settling relative to H
(very long thermal time-scale: ~10^9 yrs)

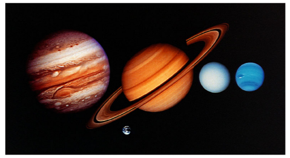
Saturn: primordial heat + He settling relative to H

Uranus: no additional source required

Neptune: Do require add'l source; but so similar to Uranus, so why?

--- *what about gravitational contraction?* No, already shrunk
--- *terrestrial planets: radio-active elements*
--- *how much energy can you gain by separating H & He?*

Gas giant atmospheres

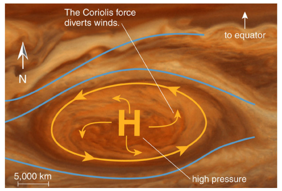


All 4 have deep atmospheres with mostly H_2 & He

(fractions in % by volume, not by mass)

	J	S	U	N	Sun
H	88	97	83	74	86
He	11	3	15	25	14
CH_4	0.2		2	1	
	0.02 NH_3				
	0.0001 H_2O				

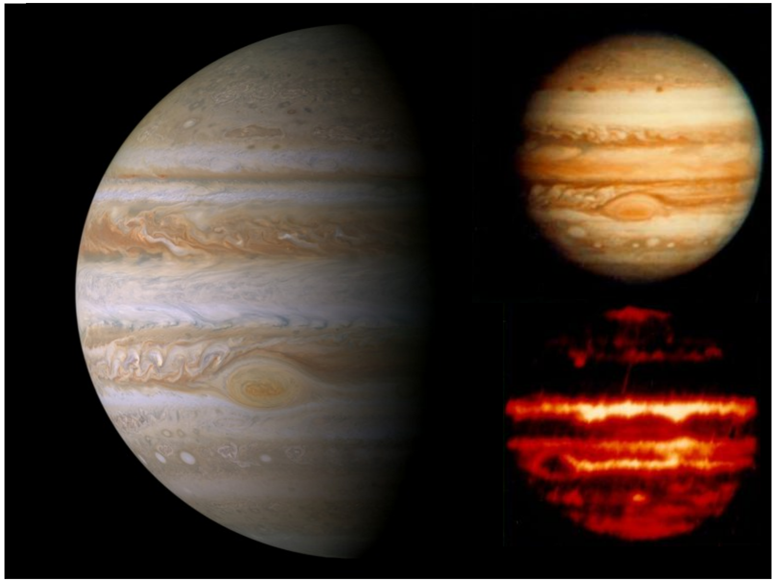
helium settling (S) — no helium settling (U, N)

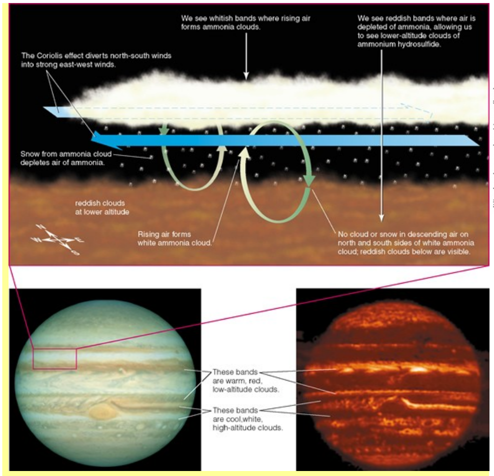


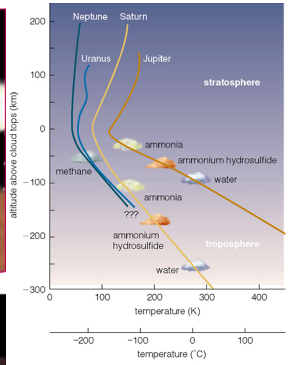
1) Trace gases condense into **clouds** at diff. temperature
Clouds are also passive tracers of local wind pattern

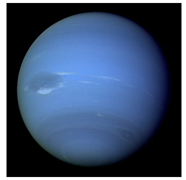
2) Jupiter, Saturn & Neptune have strong **zonal winds** (up to 500 m/s)
zonal winds driven by solar irradiation,
a combination of cold pole -- hot equator pressure gradient & Coriolis force:
great red-spot of Jupiter: a giant anti-cyclonic vortex, surprisingly long-lived
cyclone: $2\,\mathbf{V} \times \Omega = -\nabla P/\rho$; tornado: $V^2/r = -\nabla P/\rho$

3) Uranus: uniquely bland & sedate (no internal heat flux, obliquity 97 deg)









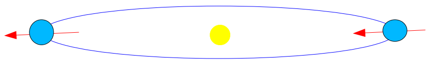
Other cool points?

1) magnetic fields: all 4 have appreciable B fields, Jovian aurorae,

   Jupiter's magnetic influence extends past Saturn orbit
   generation of these fields -- primordial or dynamo?

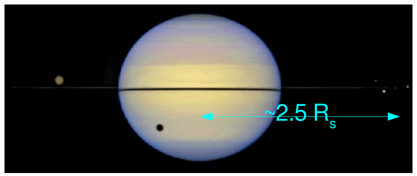
2) seasons:

   Uranus: 97.92° inclined relative to orbit, very weird seasons!

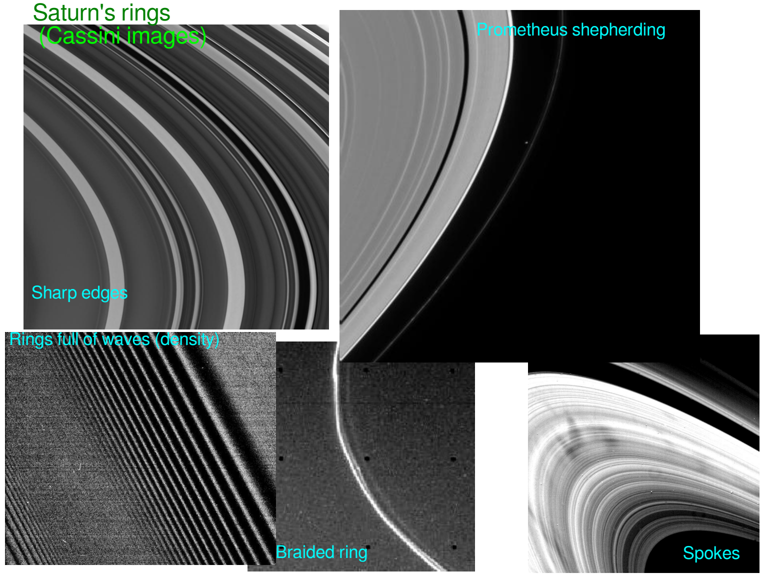


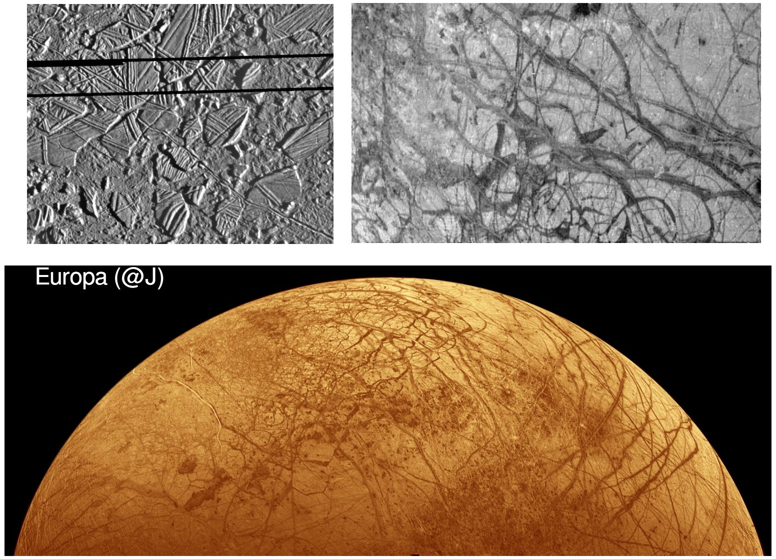
3) rings & satellites: all 4 have rings and many satellites
   rings: sandy or icy dust and some boulders, 2.5 planet radii (~Roche radius)
   -- H/R ~ 10^{-6} *(a razor blade?)*
   --- gaps: shepherding moons
   -- origin: tidally disrupted satellites
   or primordial?

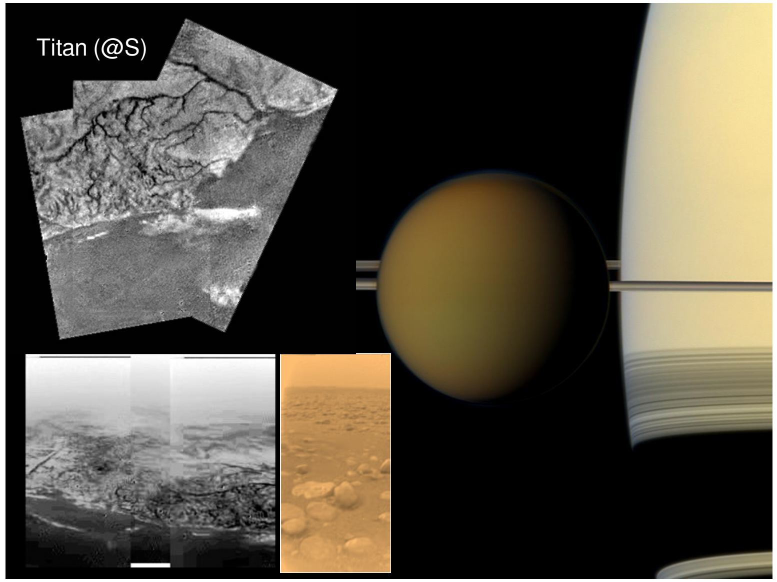
   Satellites: worlds of their own
   captured (Phoebe) or formed in-situ
   Europa (@J): cracky surface
   underground H_2O ocean
   Titan (@S): smoggy atmosphere
   surface H-compound ocean?



Saturn's rings
(Cassini images)




Europa (@J)


Titan (@S)