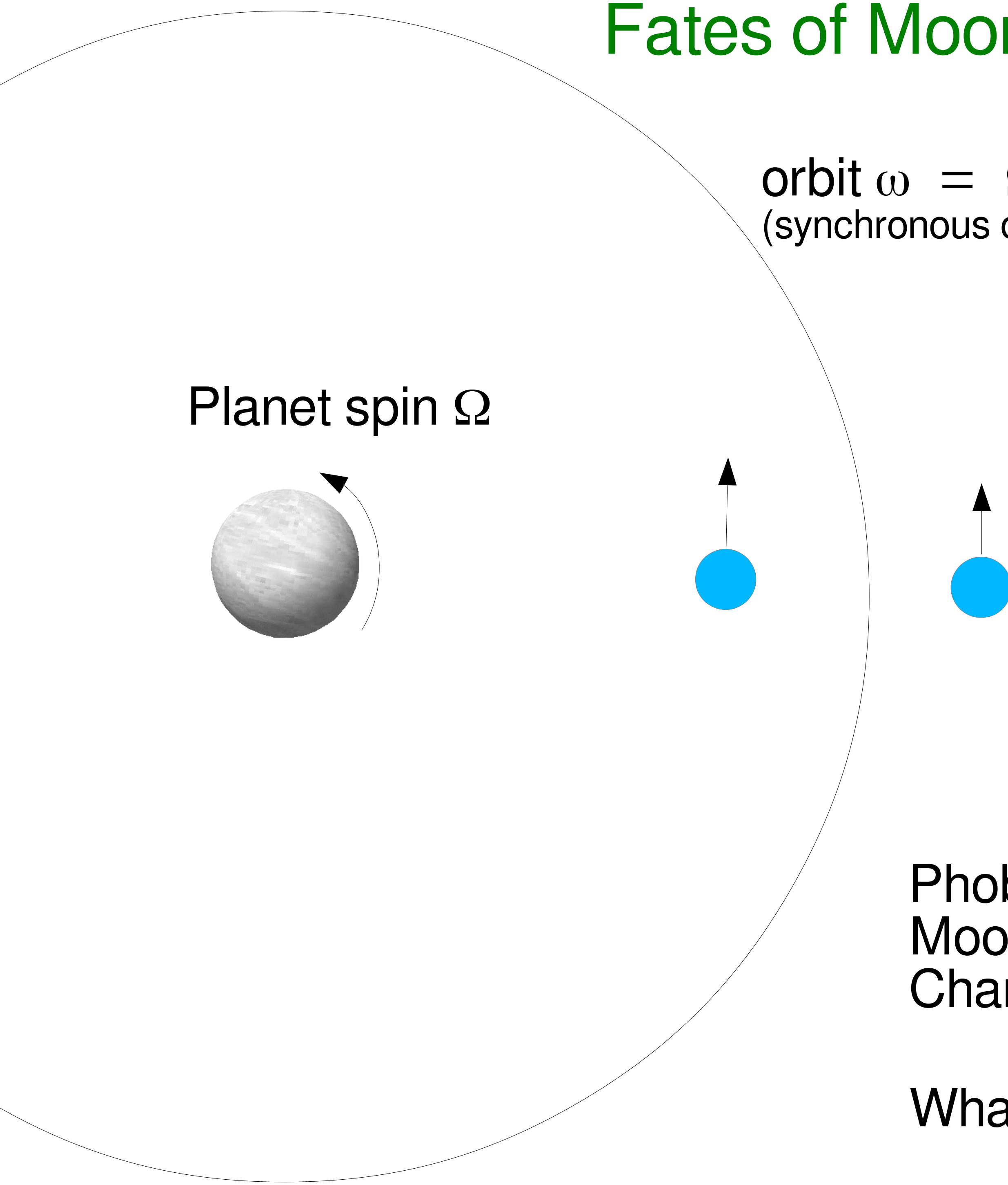
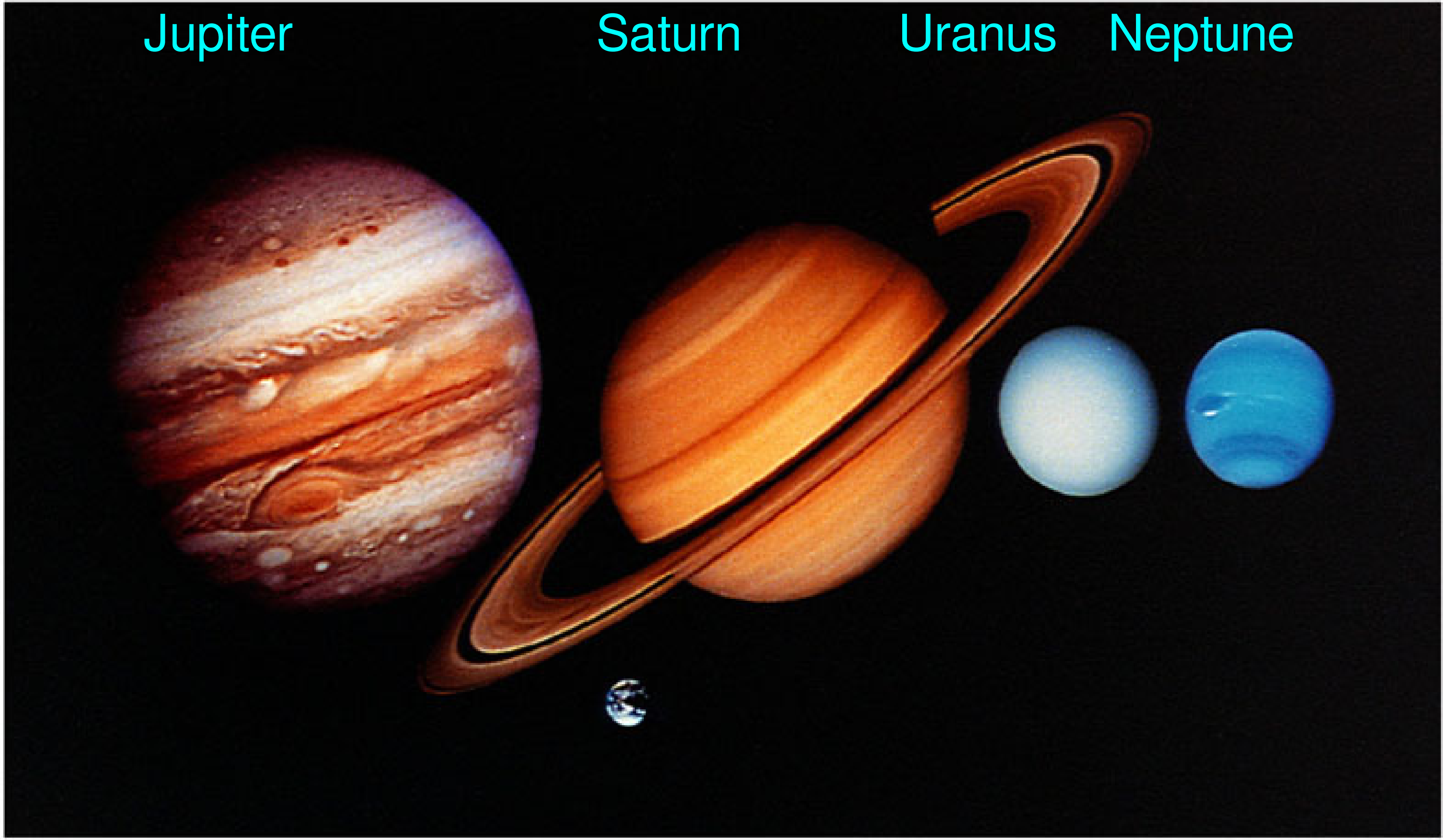
Fates of Moons



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

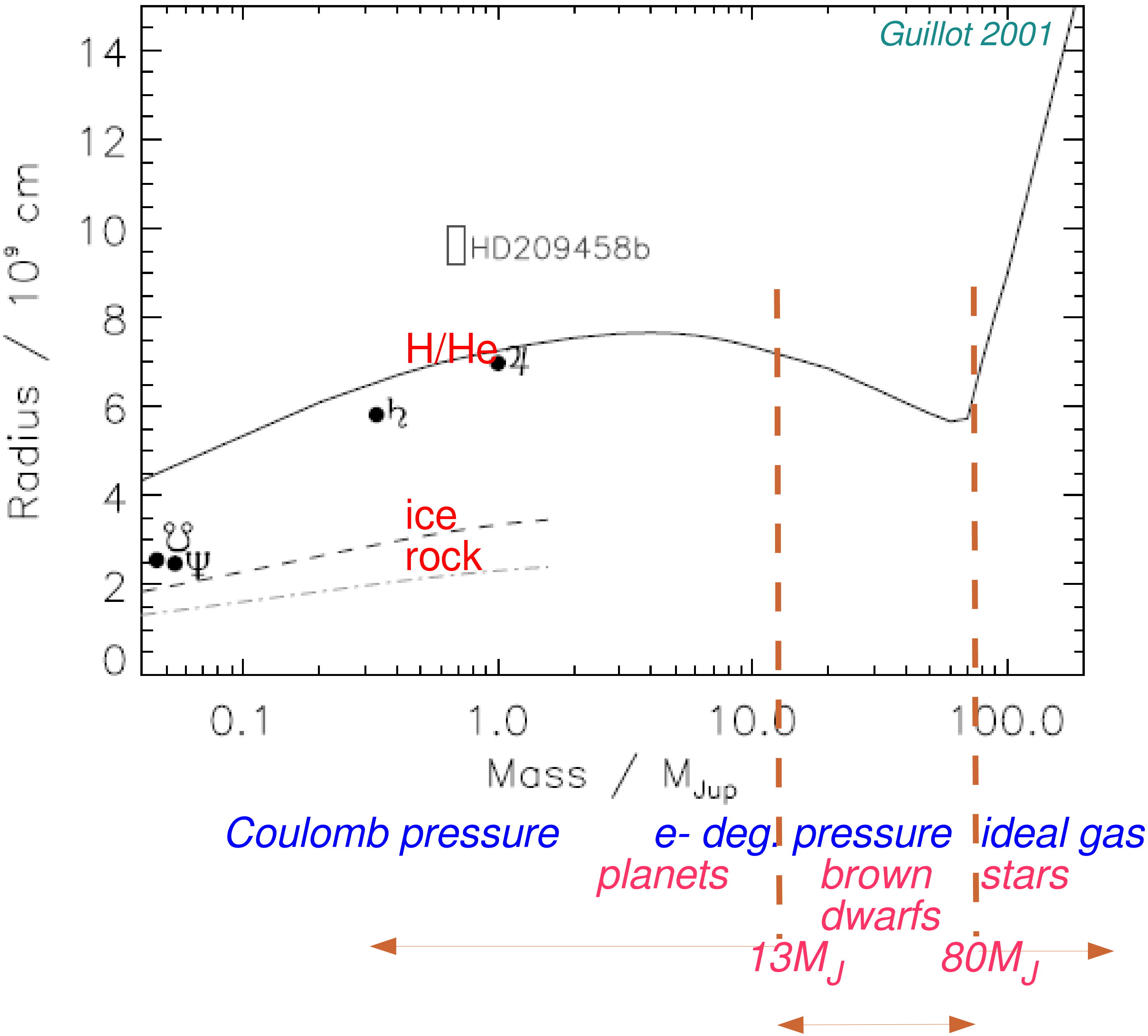
What about retro-grade moons?

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

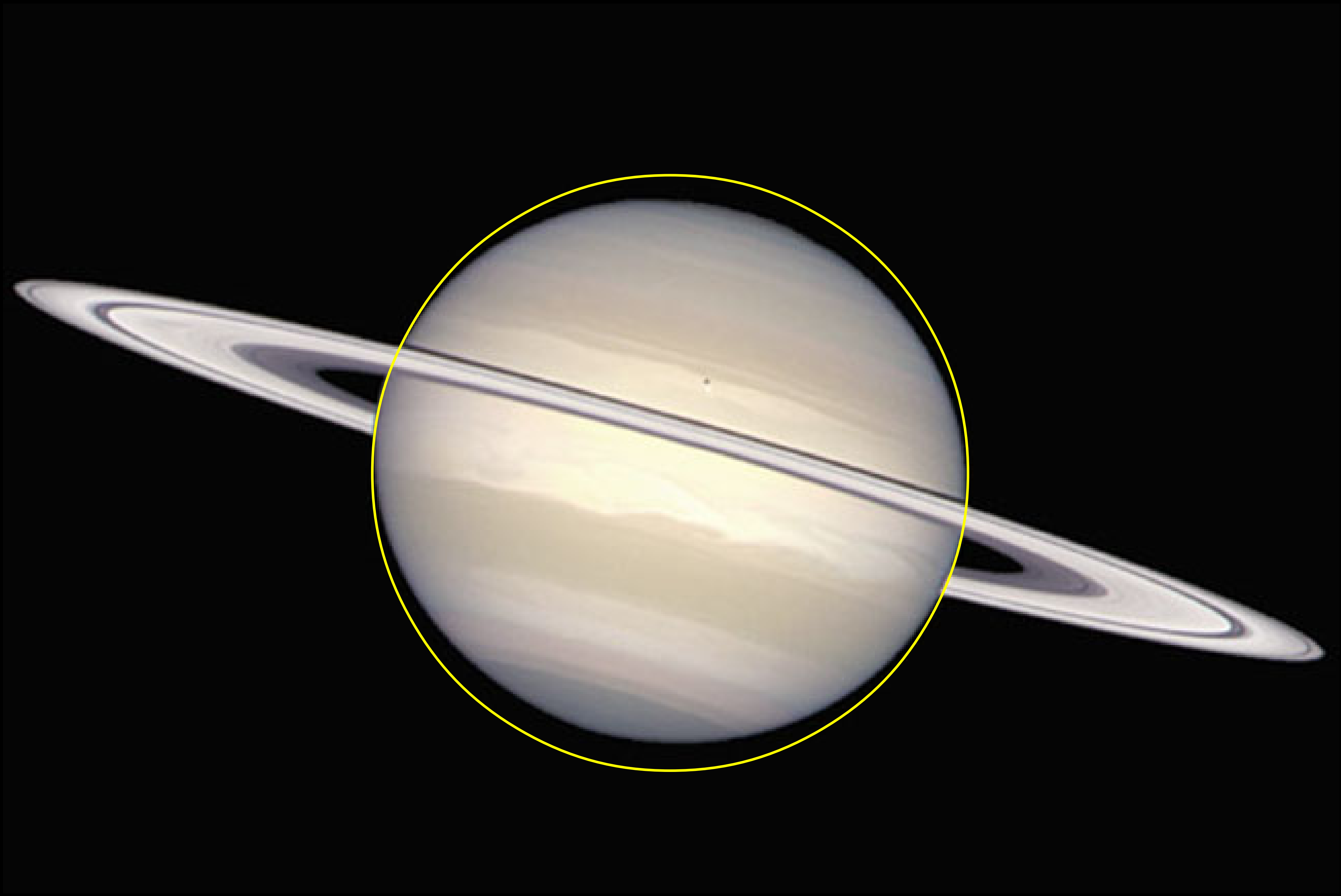
Why do we care about the solid cores?

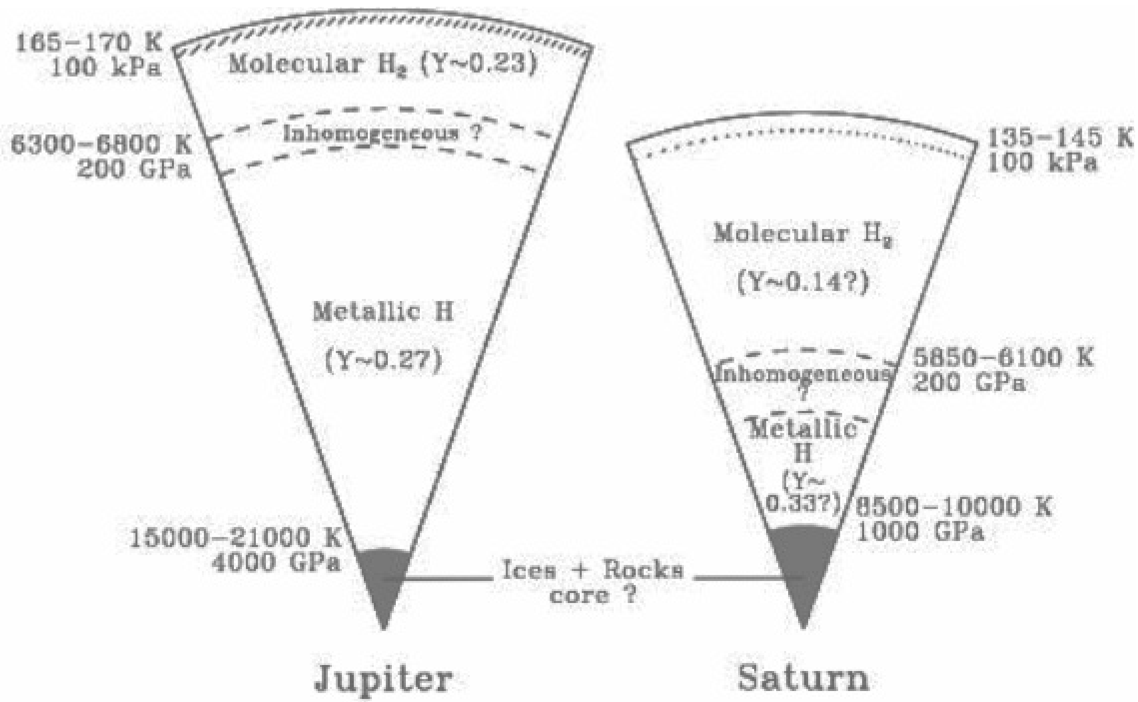
Formation of giant planets likely starts with a solid core – unlike stars

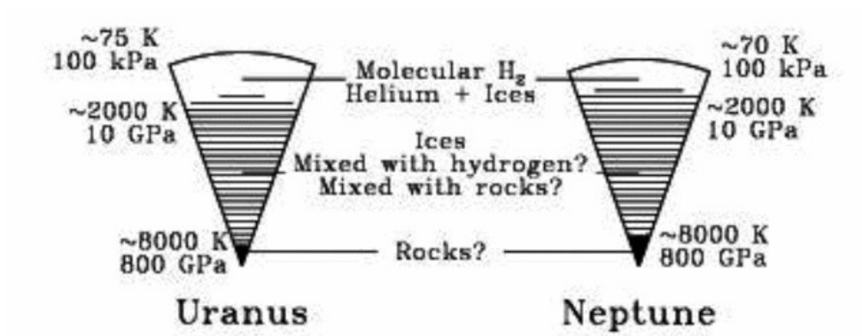
How do we figure out about the cores? Spin it!

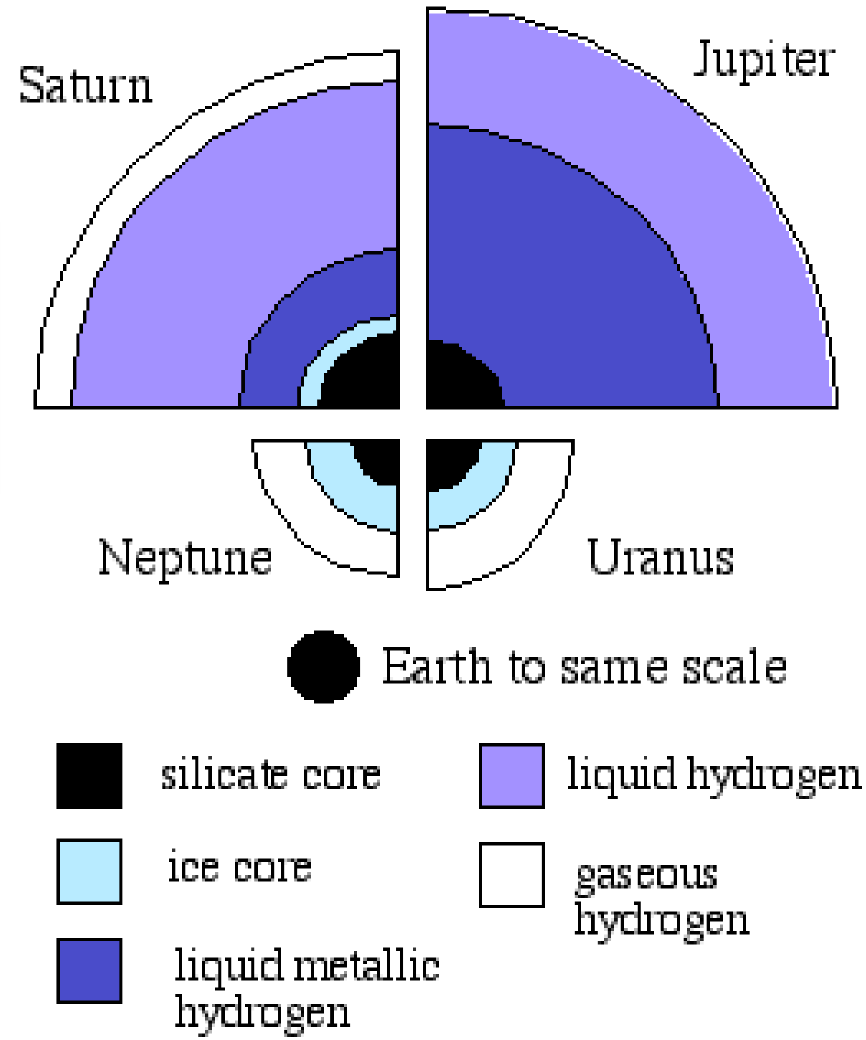
core: a high density central region
spherical body: gravitational potential is independent of density profile
but when the planet rotates, it oblateness depends on $\rho = \rho(r)$

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









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)

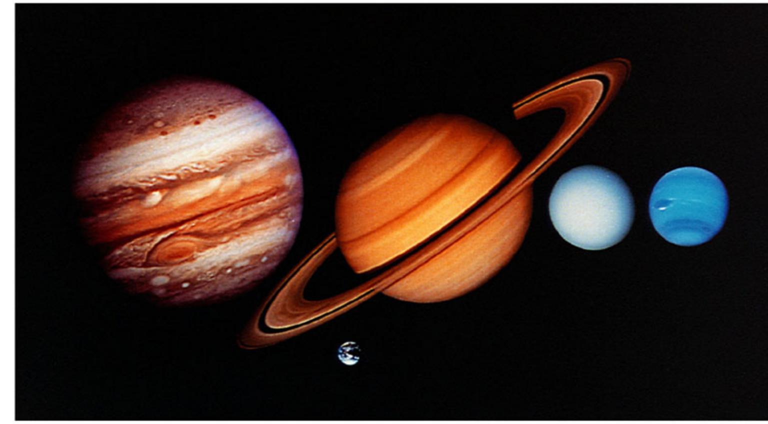
Saturn: primordial heat + He settling relative to H

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

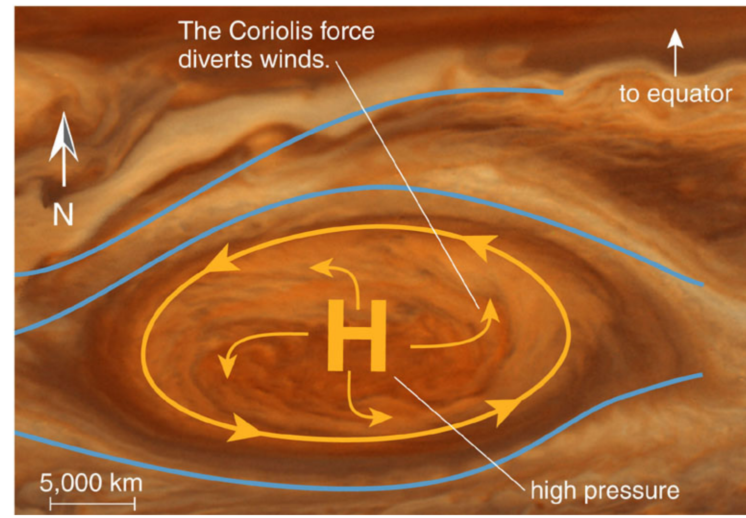


All 4 have deep atmospheres with mostly H_2 & He

(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				

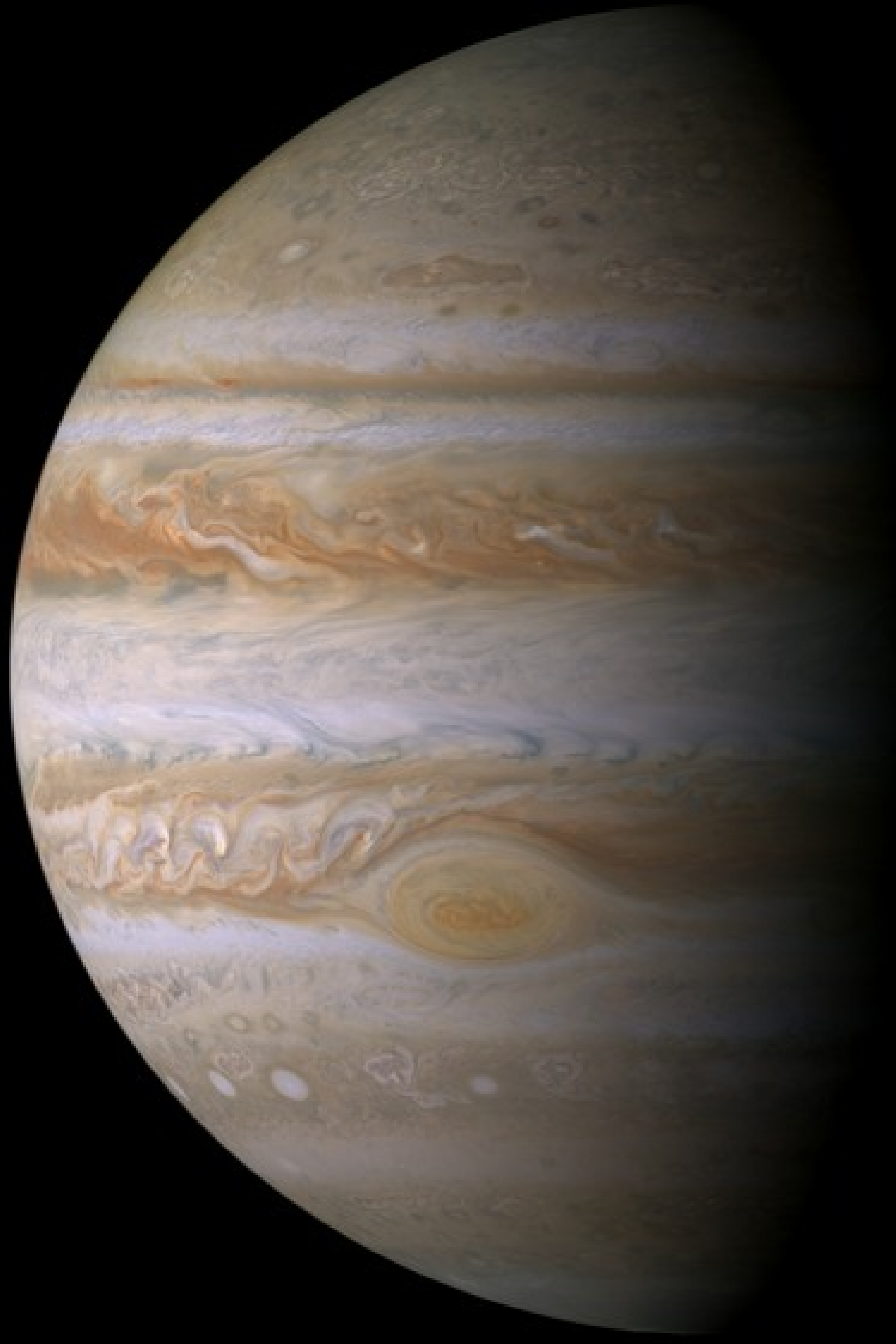
helium settling (S)   no helium settling (U, N)

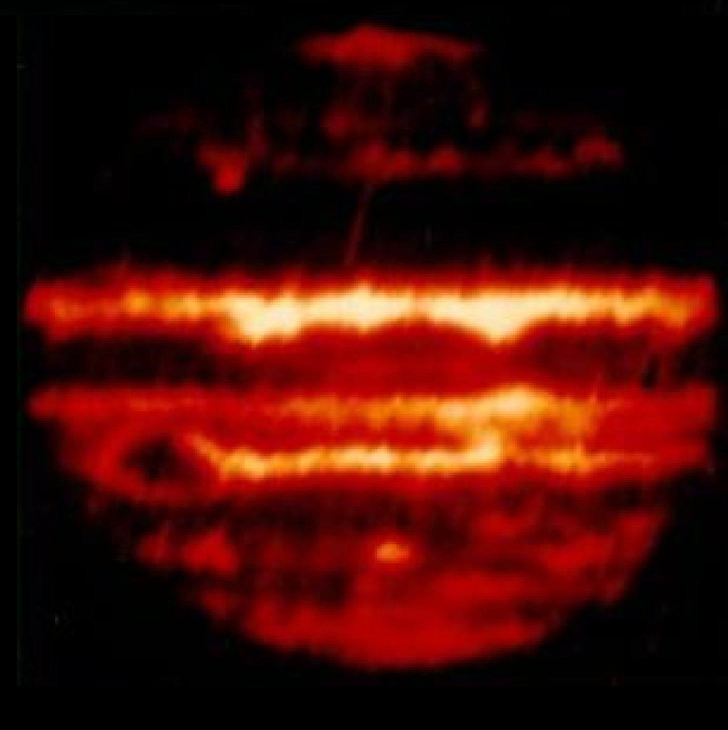


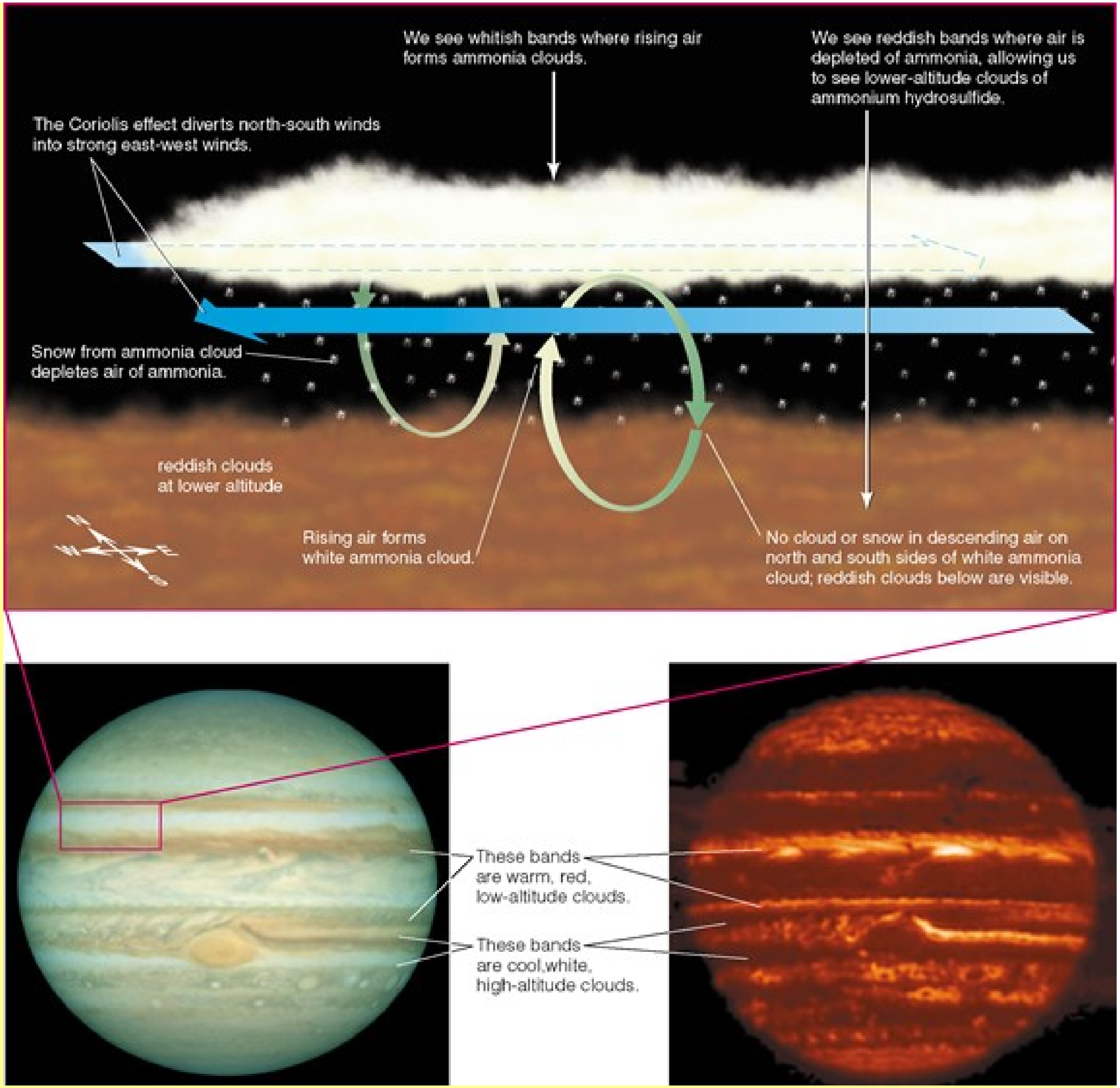
1) Trace gases condense into **clouds** at diff. temperature
Clouds are also passive tracers of local wind pattern

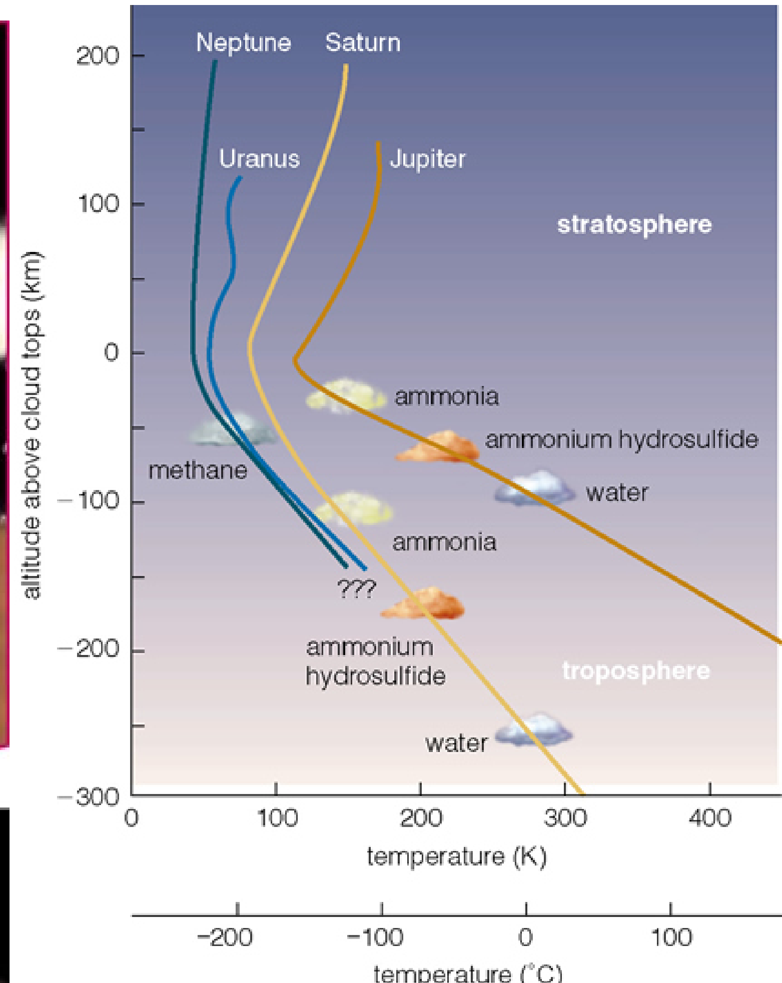
2) Jupiter, Saturn & Neptune have strong **zonal winds**
(up to 500 m/s)
zonal winds driven by solar irradiation,
a combination of cold pole -- hot equator pressure gradient & Coriolis force:
great red-spot of Jupiter: a giant anti-cyclonic vortex, surprisingly long-lived
cyclone: $2\,\mathbf{V} \times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

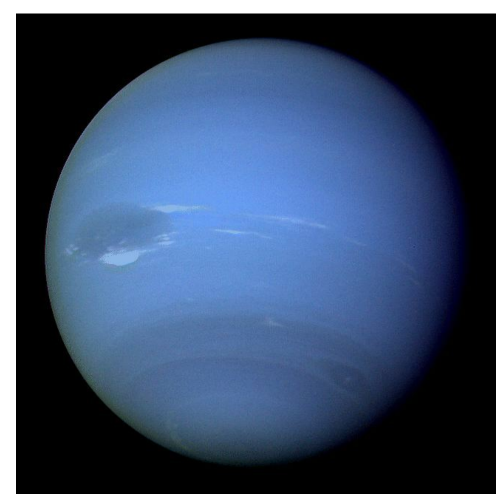
3) Uranus: uniquely bland & sedate (no internal heat flux, obliquity 97 deg)






We see whitish bands where rising air forms ammonia clouds.
We see reddish bands where air is depleted of ammonia, allowing us to see lower-altitude clouds of ammonium hydrosulfide.
The Coriolis effect diverts north-south winds into strong east-west winds.
Snow from ammonia cloud depletes air of ammonia.
reddish clouds at lower altitude
Rising air forms white ammonia cloud.
No cloud or snow in descending air on north and south sides of white ammonia cloud; reddish clouds below are visible.
These bands are warm, red, low-altitude clouds.
These bands are cool,white, high-altitude clouds.


Neptune
Saturn
Uranus
Jupiter
stratosphere
troposphere
ammonia
ammonium hydrosulfide
water
methane
ammonia
???
ammonium hydrosulfide
water
altitude above cloud tops (km)
200
100
0
−100
−200
−300
0
100
200
300
400
temperature (K)
−200
−100
0
100
temperature (°C)



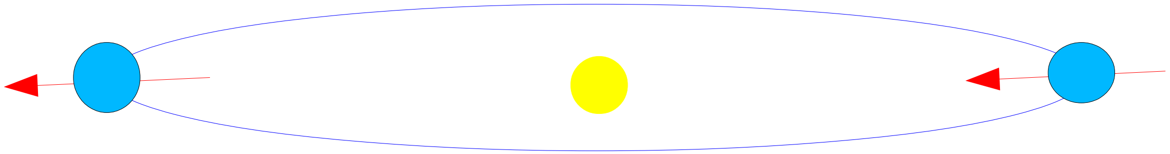
Other cool points?

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

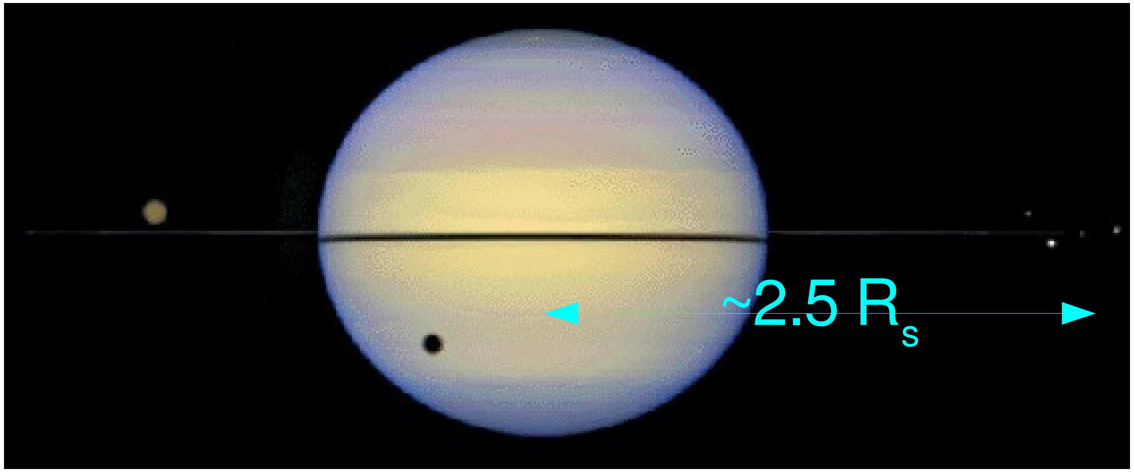
Jupiter's magnetic influence extends past Saturn orbit
generation of these fields -- primordial or dynamo?

2) seasons:

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

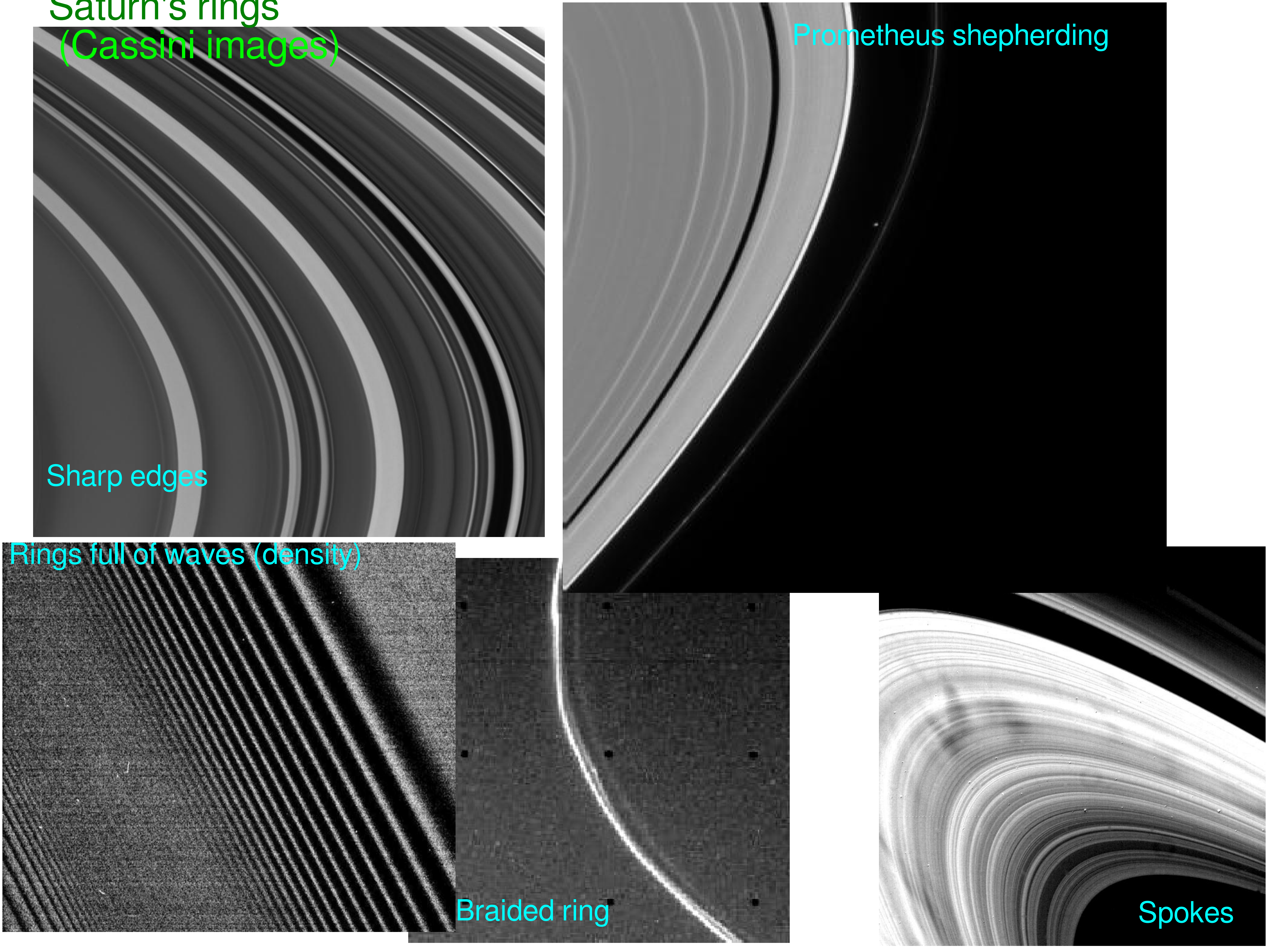


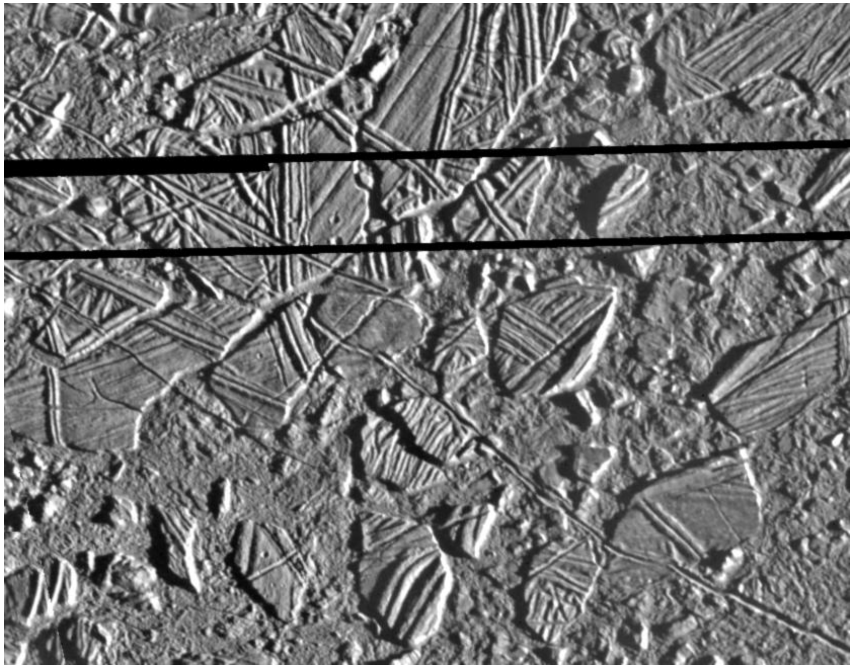
3) rings & satellites: all 4 have rings and many satellites
rings: sandy or icy dust and some boulders, 2.5 planet radii (~Roche radius)
-- $H/R \sim 10^{-6}$ *(a razor blade?)*
--- gaps: shepherding moons
-- origin: tidally disrupted satellites
or primordial?

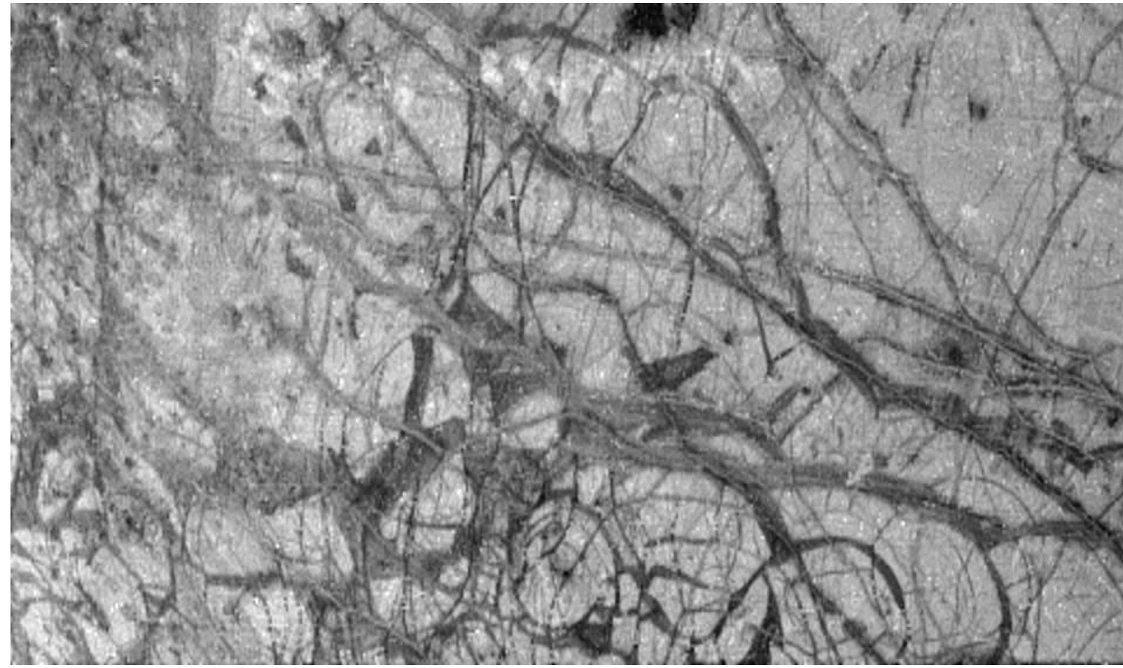


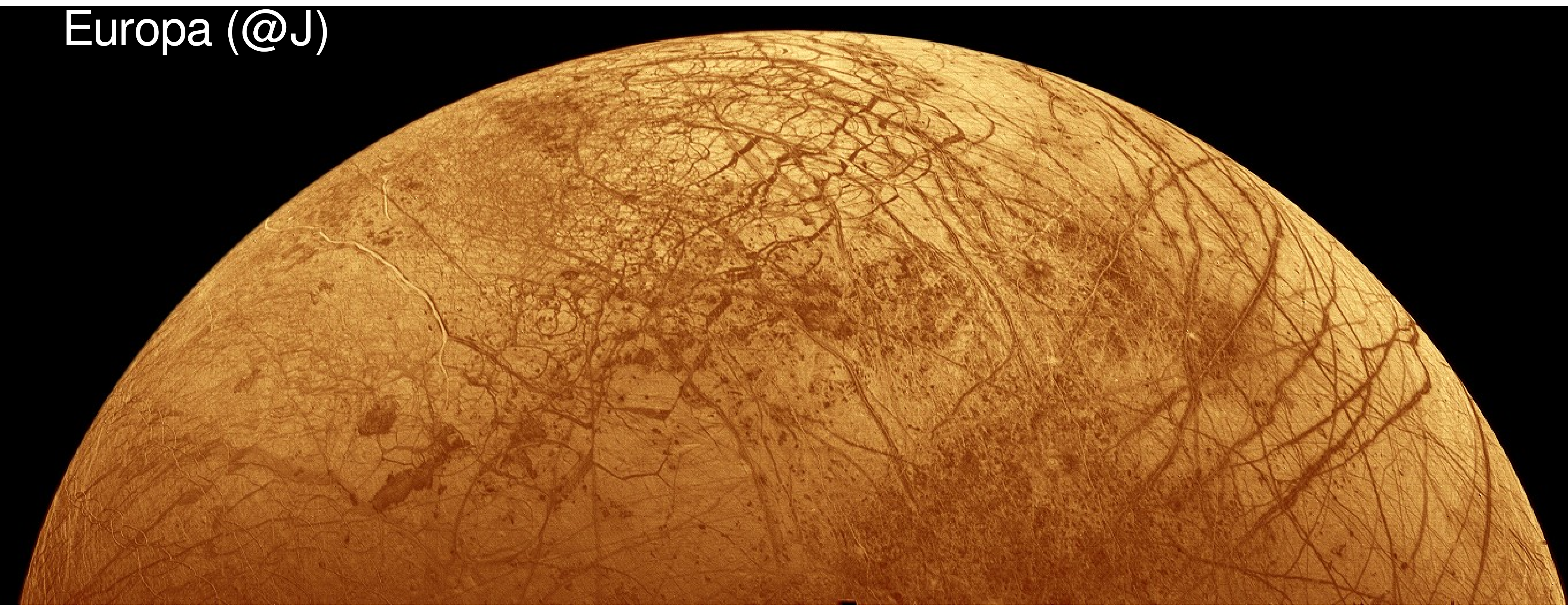
Satellites: worlds of their own
captured (Phoebe) or formed in-situ
Europa (@J): cracky surface
underground H_2O ocean
Titan (@S): smoggy atmosphere
surface H-compound ocean?

Saturn's rings (Cassini images)








Europa (@J)

Titan (@S)