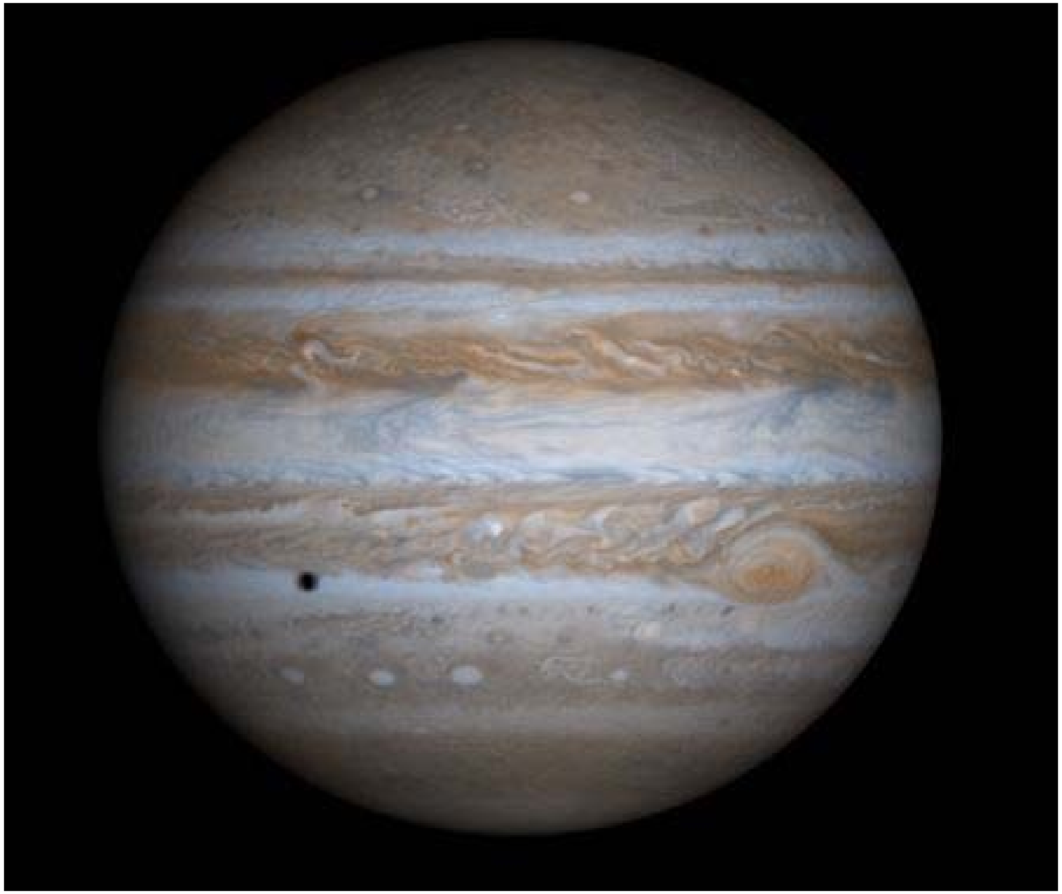
Interior of the gas planets



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Jupiter and Saturn are failed stars (by a large margin)

Uranus and Neptune are the wettest planets in the solar system

Properties of Jupiter and Saturn

	Jupiter	Saturn
Equatorial radius [km]	71,500	60,300
Flattening	1 / 15.7	1 / 9.8
Mass / Earth mass	318	95
Mean density [kg m^{-3}]	1330	690
Rotation period [h]	9.9	10.7
Equatorial gravity [ms^{-2}]	22.9	9.1
Surface temperature [K]	124	95
Emitted/absorbed power	1.7	1.8

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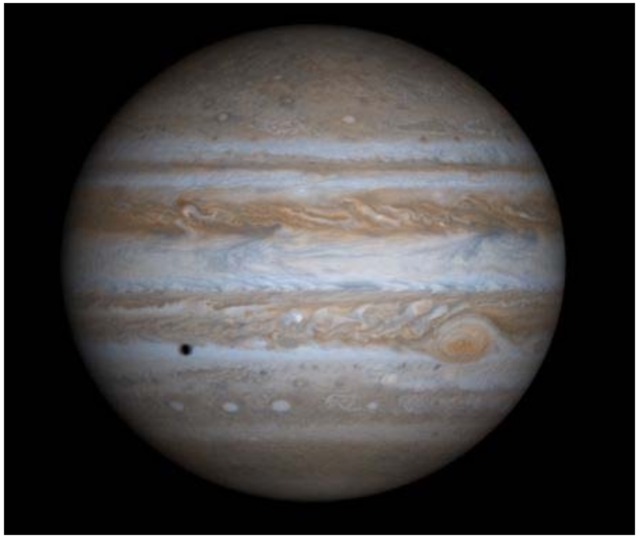
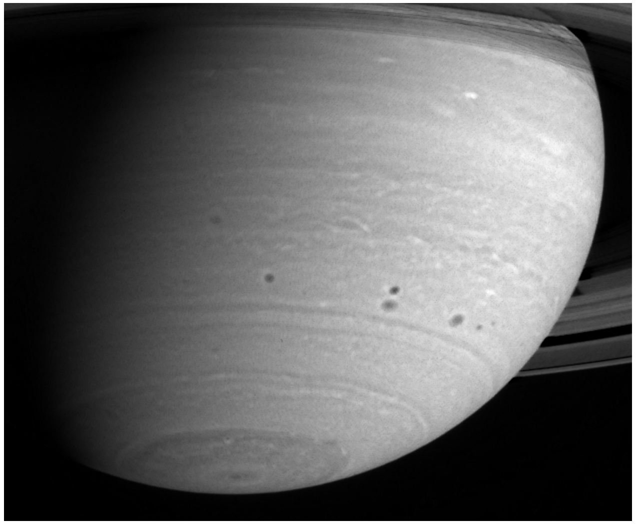
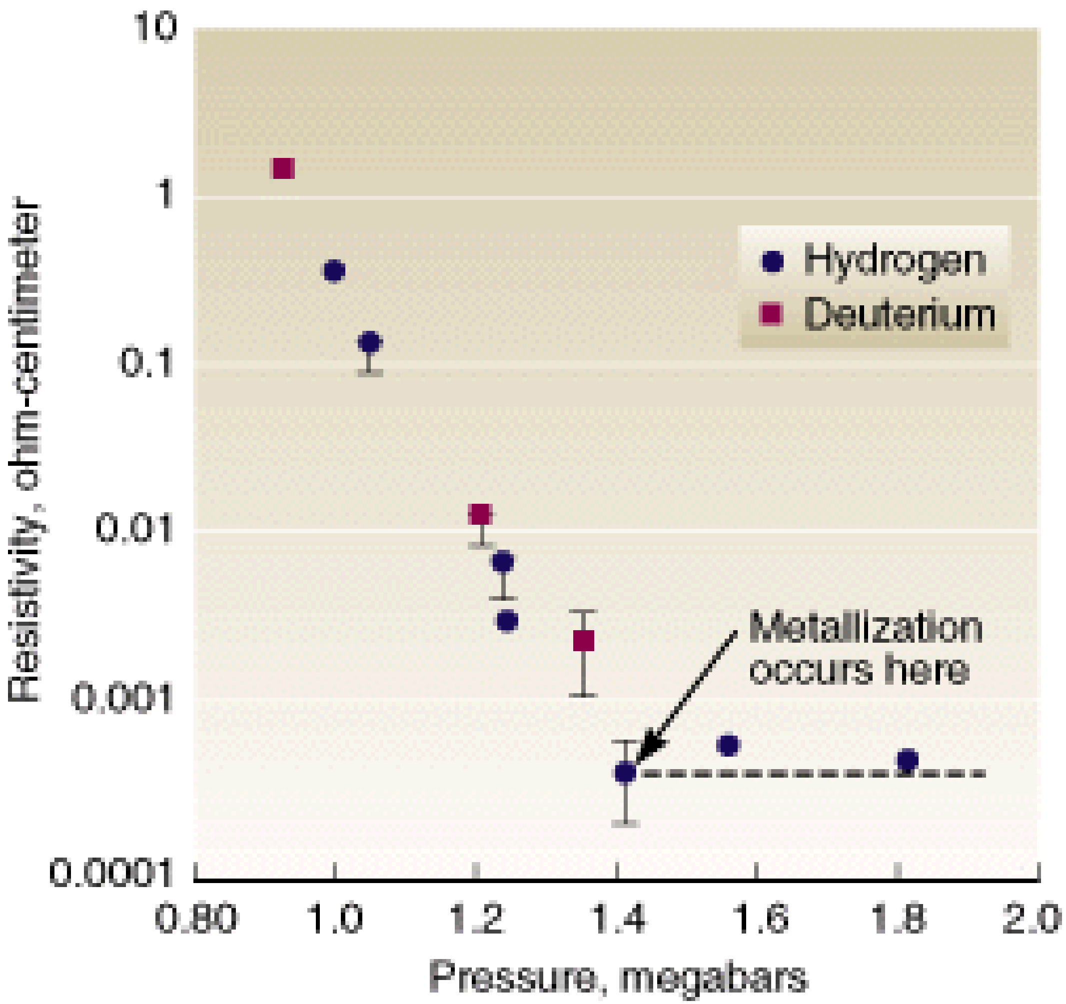
Atmospheric composition

	Jupiter	Saturn
H_2	0.75	0.9
He	0.24	0.10?
H_2O	0.001	0.001
CH_4	0.001	0.002
NH_3	0.002	0.001





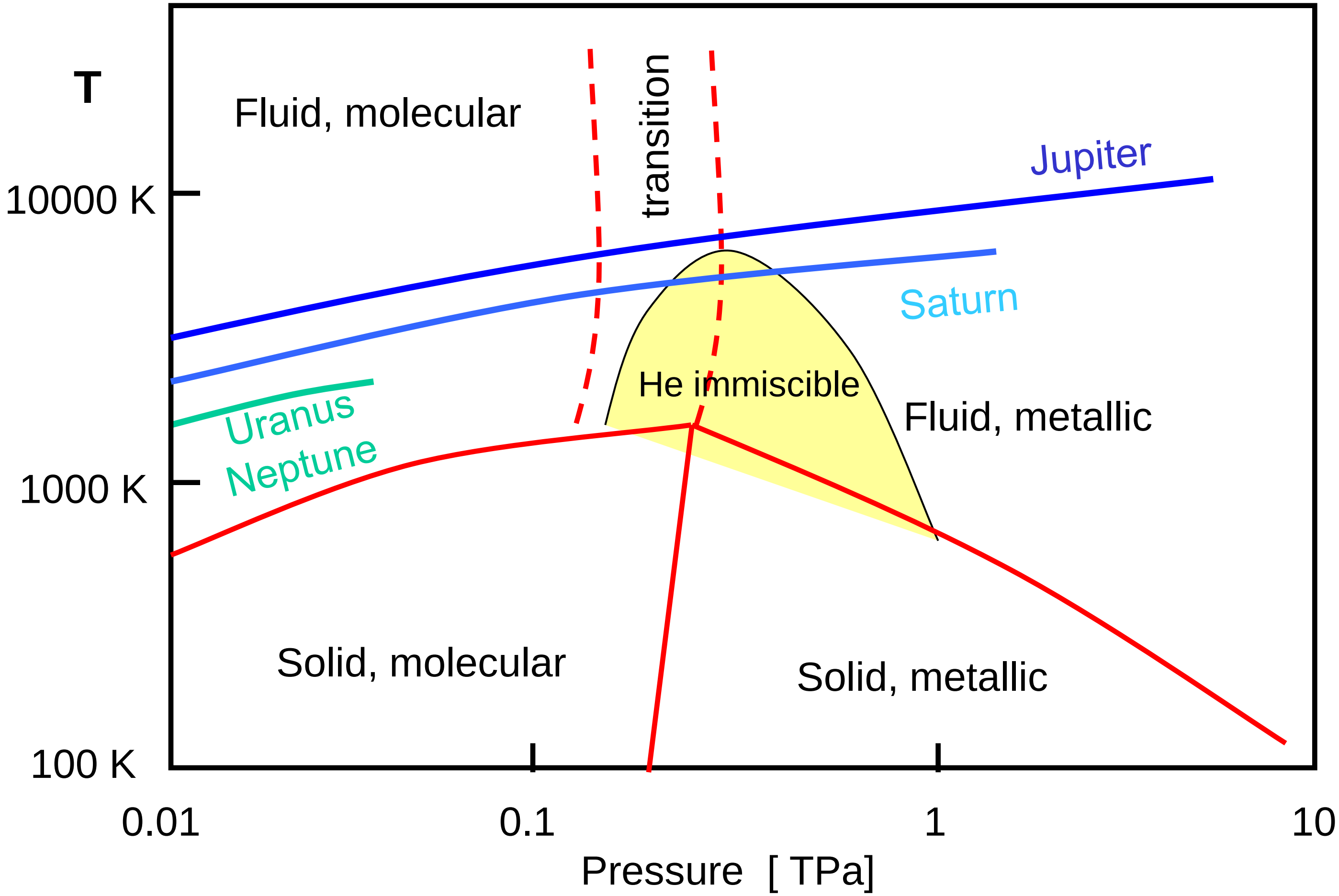
Transition to metallic hydrogen



Quantum mechanical calculations suggested that solid or fluid hydrogen becomes metallic at high pressure, i.e. has free electrons and becomes a good electrical conductor.

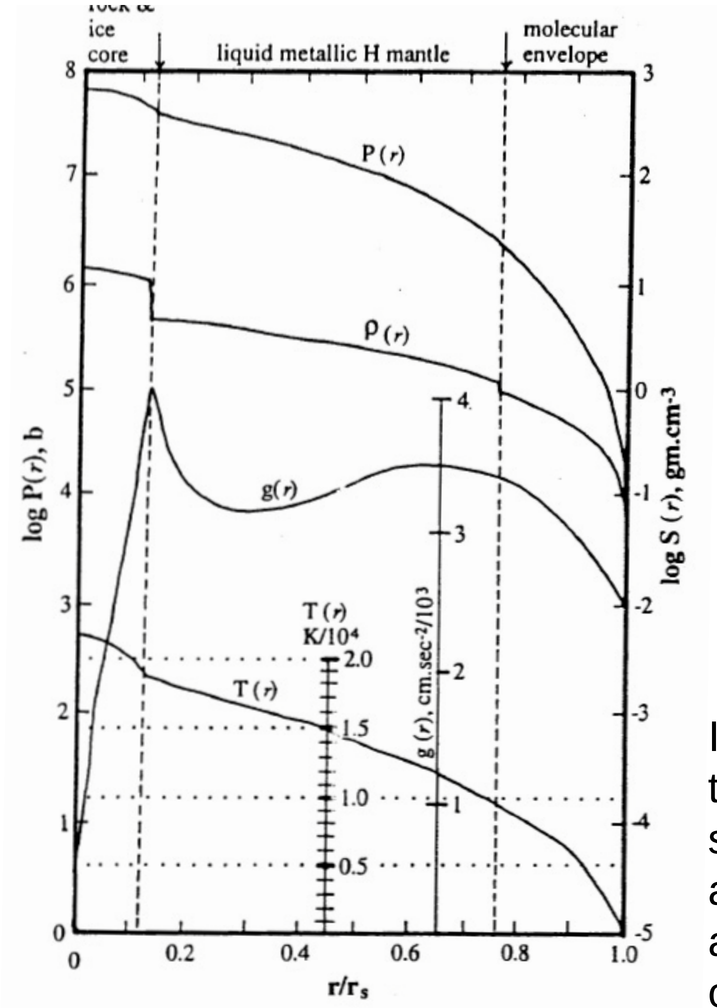
In shock wave experiments it was possible to measure the conductivity. The experiments show that metallization occurs between 1 and 1.4 Mbar (100 – 140 GPa).

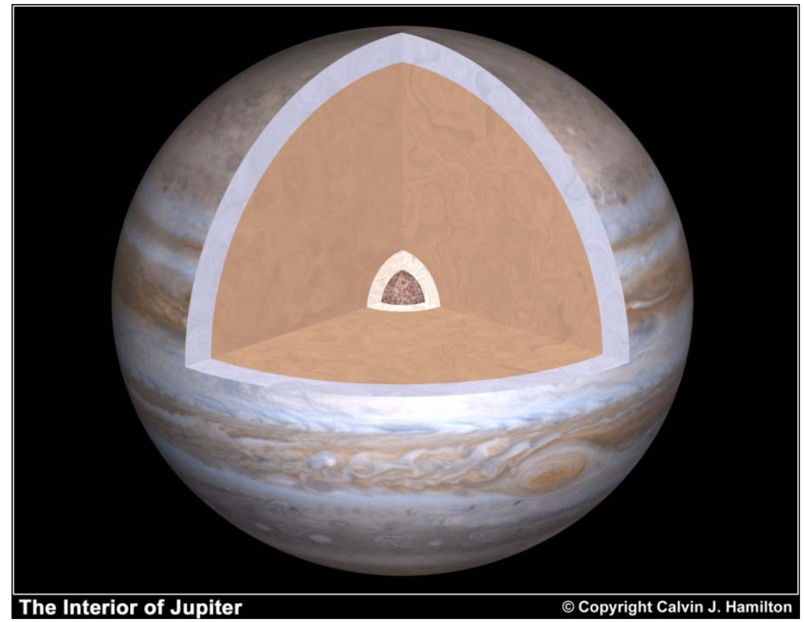
Phase diagram of hydrogen



The temperature and pressure conditions in the gas planets are included, calculated with the assumption of an adiabatic temperature gradient starting at the observed surface temp.

Interior of Jupiter

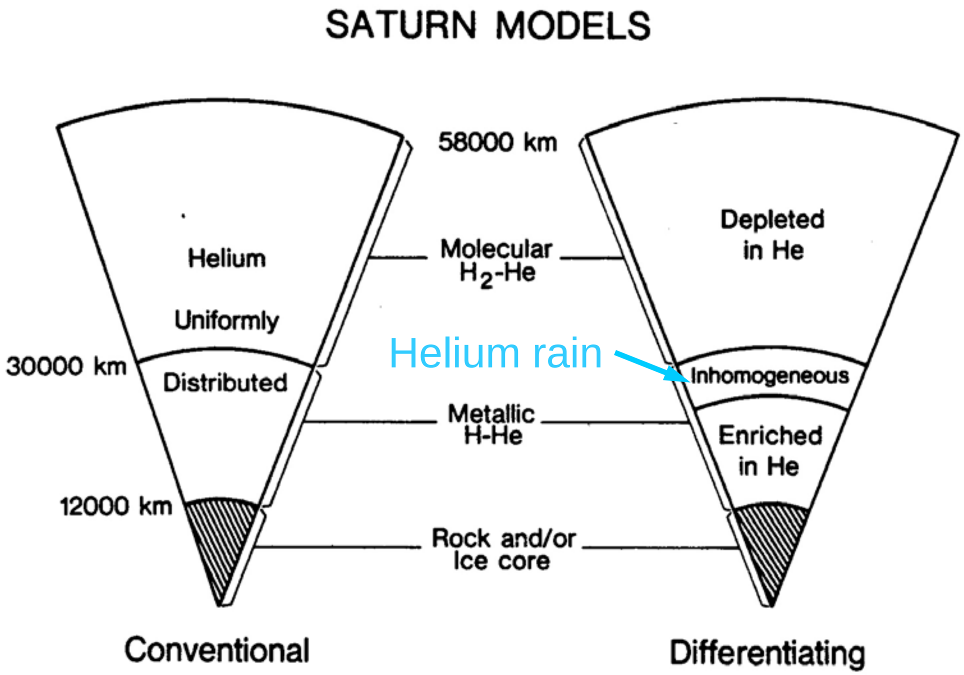




Interior models for Jupiter (and Saturn) are based on the phase diagram and a theoretical equation of state - ρ(p,T) - for hydrogen-helium mixtures and the assumption of adiabatic temperature variation. They are constrained by the requirement to fit the observed flattening and the gravity coefficients J_2, J_4.

A small rocky core of a few Earth masses is not required by the geophysical data for Jupiter (but for Saturn), but is likely in any case, because a sizeable solid nucleus may be required to be present first in order to accrete H_2 and He onto it by gravitation.

Interior of Saturn



The principal structure of Saturn is similar to that of Jupiter. Because pressure is lower, the boundary between metallic and molecular hydrogen is deeper (half the planetary radius) and the rocky core may be bigger (14 Earth masses).

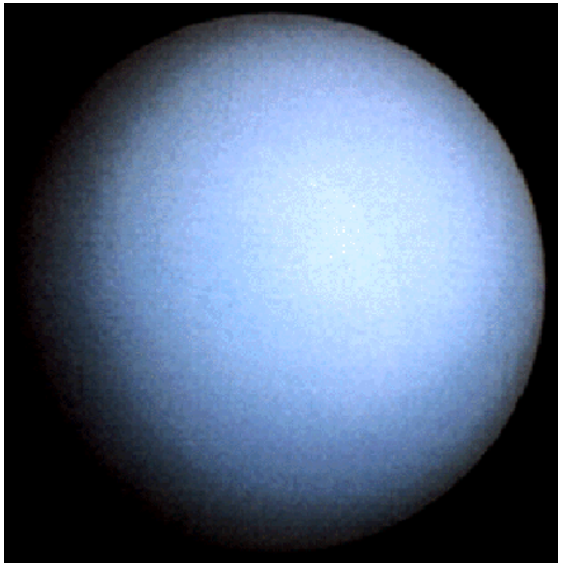
An important difference may be that at the top of the metallic hydrogen region, He becomes immiscible in Saturn, where temperatures are lower than in Jupiter (compare slide 5.4).

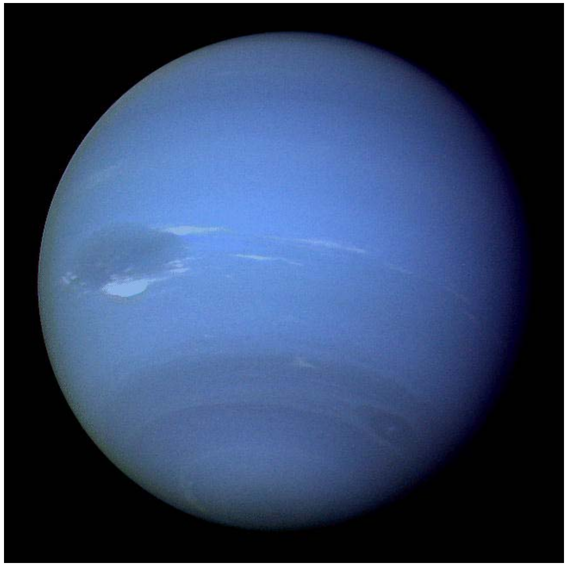
In this region, He may separate and form rain drops that sink and dissolve again at greater depth in the metallic H-region.

⇒ He becomes depleted also in the molecular hydrogen region, which mixes with the top of the metallic region

⇒ Extra gravitational energy is released. This could explain the large excess luminosity of Saturn, which is more than what theoretical models based on cooling and contraction predict.

Properties of Uranus and Neptune





	Uranus	Neptune
Equatorial radius [km]	25,400	24,600
Flattening	1 / 44	1 / 58
Mass / Earth mass	14.5	17.1
Mean density [kg m^{-3}]	1320	1640
Rotation period [h]	17.2	16.1
Equatorial gravity [ms^{-2}]	8.7	11
Surface temperature [K]	53	52
Emitted/absorbed power	1.06	2.6
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Atmospheric composition		
H_2	0.83	0.83
He	0.15 ?	0.15 ?
CH_4	0.02	0.02
NH_3	0.0001?	?

Interior of Uranus and Neptune

Uranus and Neptune cannot be made mostly of H + He which dominate in the atmosphere. Because of their low mass (lower gravtitation), the mean density should in that case be much lower than that of Saturn.

The region below 70% of the planetary radius is a supercritical fluid consisting mainly of H_2O (plus NH_3 and CH_4). Ionic electrical conductivity allows for a dynamo to operate in this region and generate the observed magnetic fields.

A rocky core has probably around one Earth mass.

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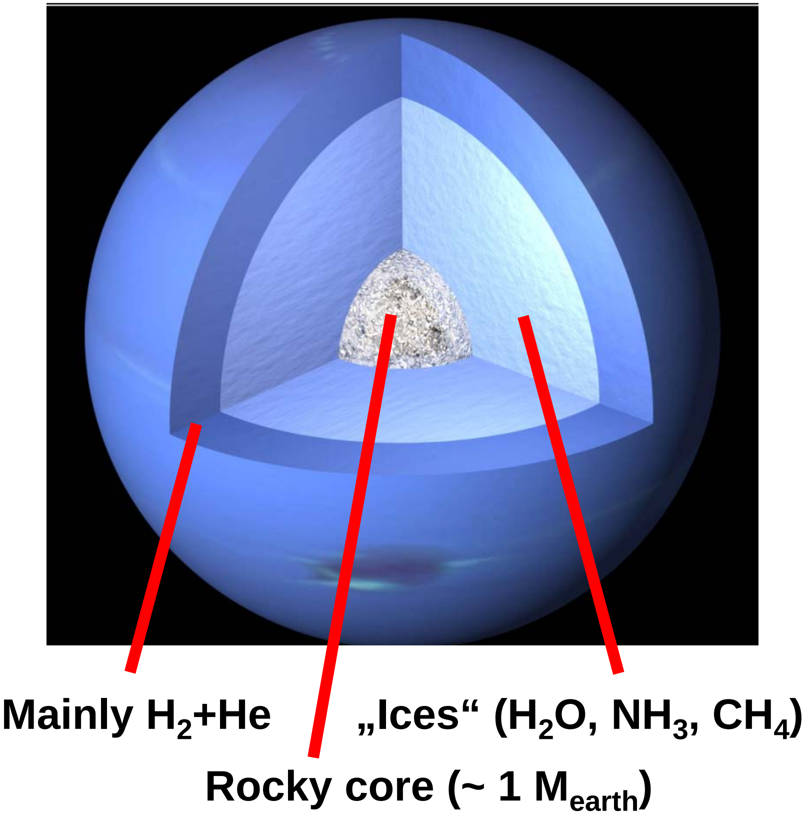
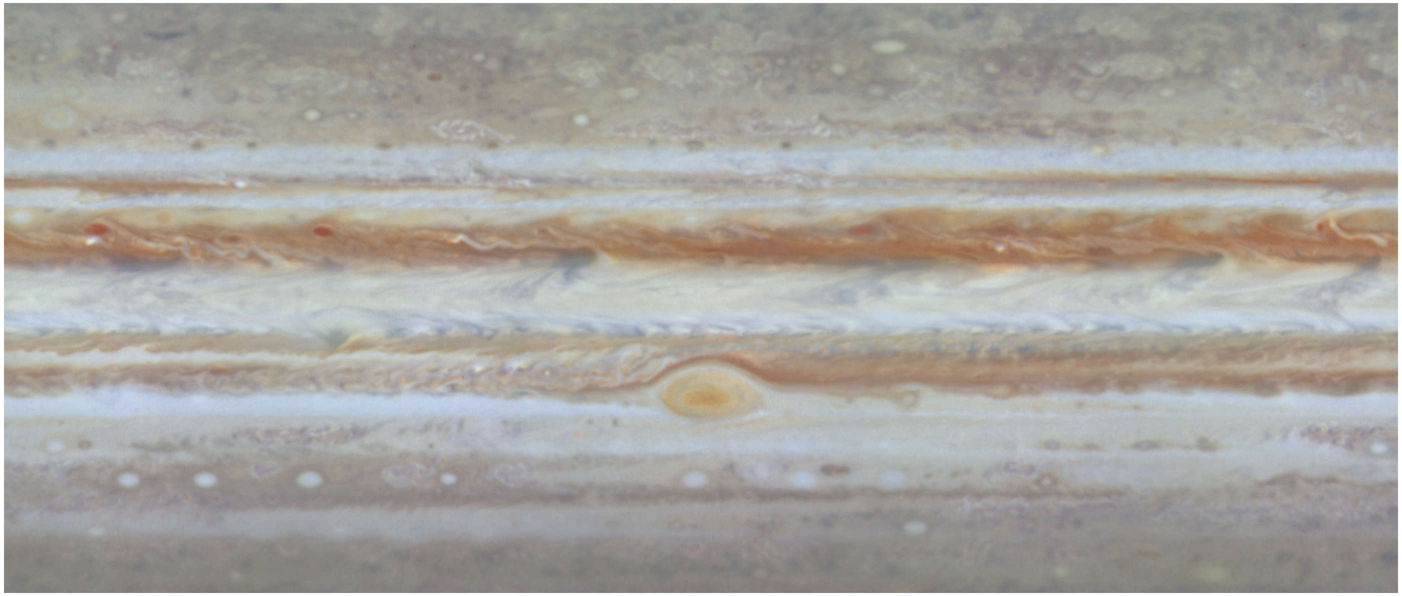
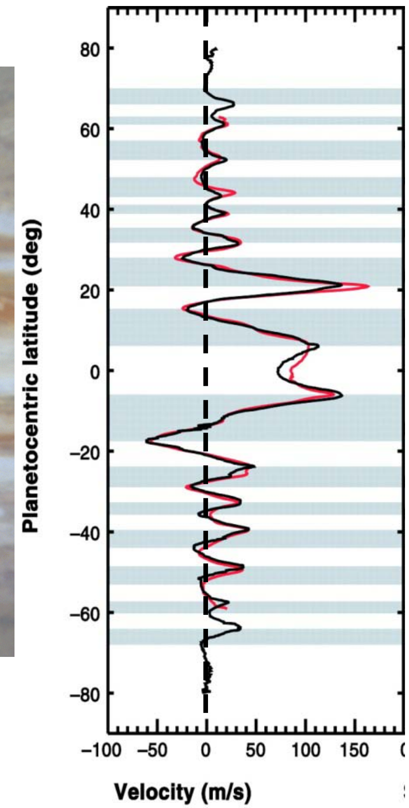


Jupiter: zonal flow





Strong zonal winds are associated with the latitudinal zones and bands, with velocities up to 150 m/sec, alternating in direction. The zonal velocity is larger than the velocity of the superimposed eddies.

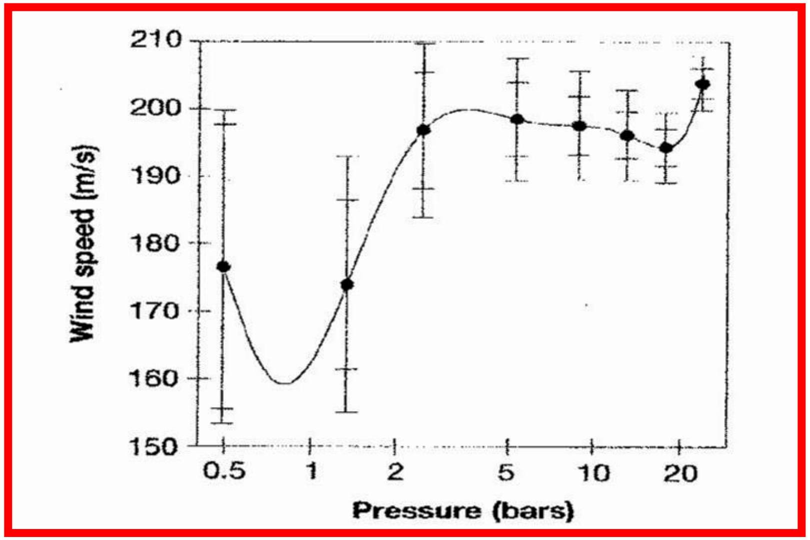
Wind speed and pattern has hardly changed in 25 yr.

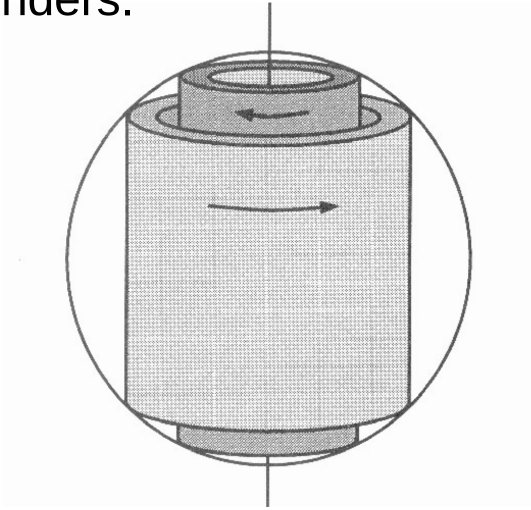
Jupiter: zonal flow

Two concepts for origin of the zonal flow:

(1) Meteorological phenomenon of a shallow atmospheric layer, powered by solar heat.

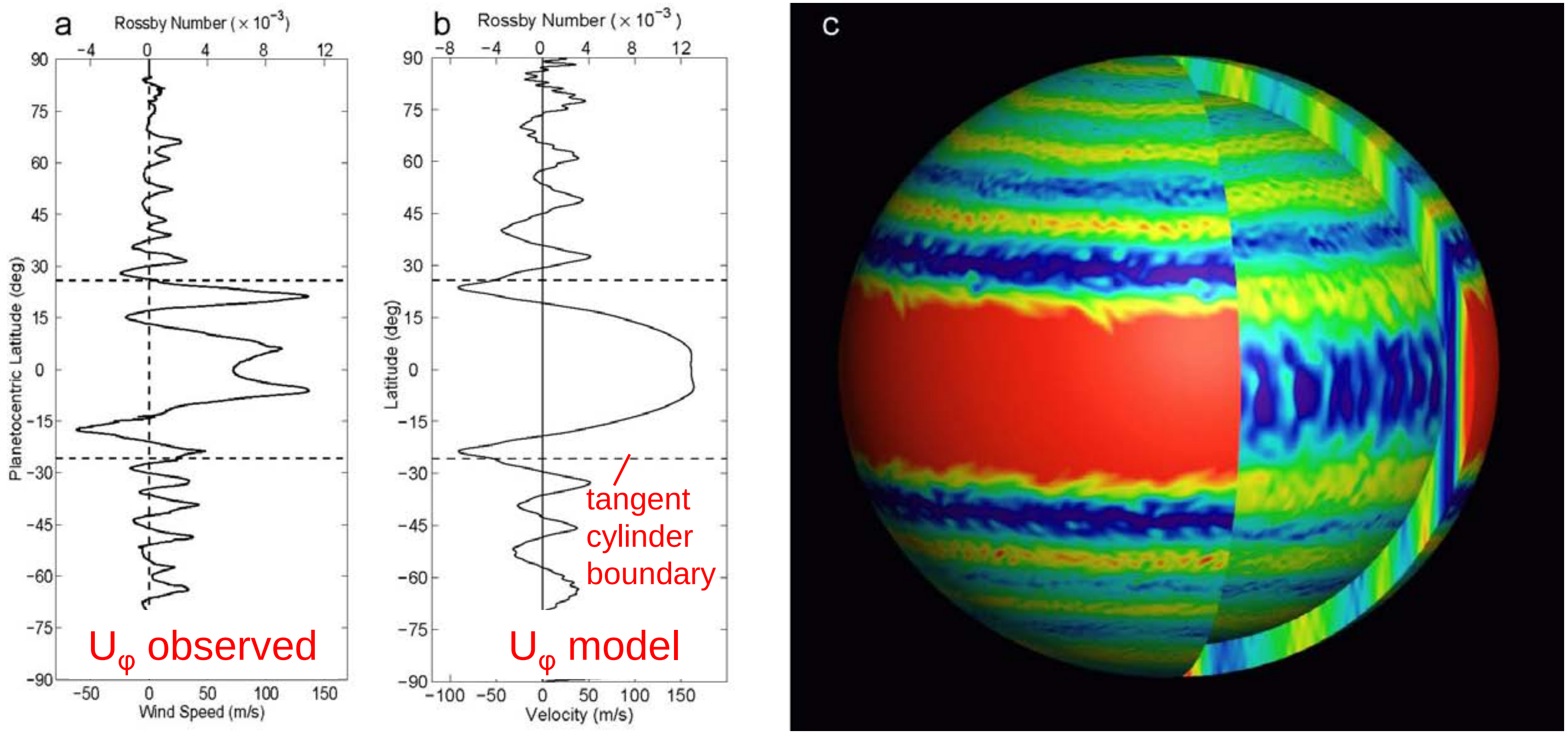
(2) Expression of convection in the deep interior, driven by Jupiter's internal heat. By inertial effects in the rapidly rotating deep molecular hydrogen shell, convective energy is transferred into differential rotation of co-axial cylinders.





Observation by the Galileo probe that the wind speed does not decrease with depth below the cloud deck (up to the 20 bar pressure level, ~ 200 km depth) supports the 2nd hypothesis.

A deep convection model for driving zonal flow



Convection model for Jupiter (Heimpel, Aurnou & Wicht, 2005) with a thin convecting shell (r_i/r_o=0.85) representing the molecular hydrogen layer. Colors in c) show u_φ. On the surface U_φ has the right magnitude with strong prograde flow near the equator and weaker alternating at higher latitude. The incompressible model does not explain the observed asymmetries and ignores the strong density variations with radius. Nonetheless it supports the hypothesis of internal origin of the zonal jet flow at the surface of the gas planets.