Department of Physics and Astronomy

Astronomy 1X

Session 2007-08

Solar System Physics I

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5 lectures, beginning Autumn 2007

ASTRONOMY ASTROPHYSICS

UNIVERSITY of GLASGOW

Section 8: Key Features of the Jovian Planets

Jovian planets: **Jupiter, Saturn, Uranus and Neptune**

Terrestrial planets: **Mercury, Venus, Earth and Mars**

We can summarise the differences between them:

See Chapter 6, Table 6.2 Astronomy Today

See SSP2 Lectures

Terrestrial Planets	Jovian Planets
Lower mass, smaller radii	Higher mass, larger radii
Near the Sun	Distant from the Sun
[Higher surface temperature	Lower surface temperature]
Higher average density	Lower average density
H and He depleted	Abundant H and He
Solid surface	Gaseous / Liquid *
Slower rotation period	Rapid rotation period
No rings	Many rings
Few satellites	Many satellites

* Rocky core deep inside

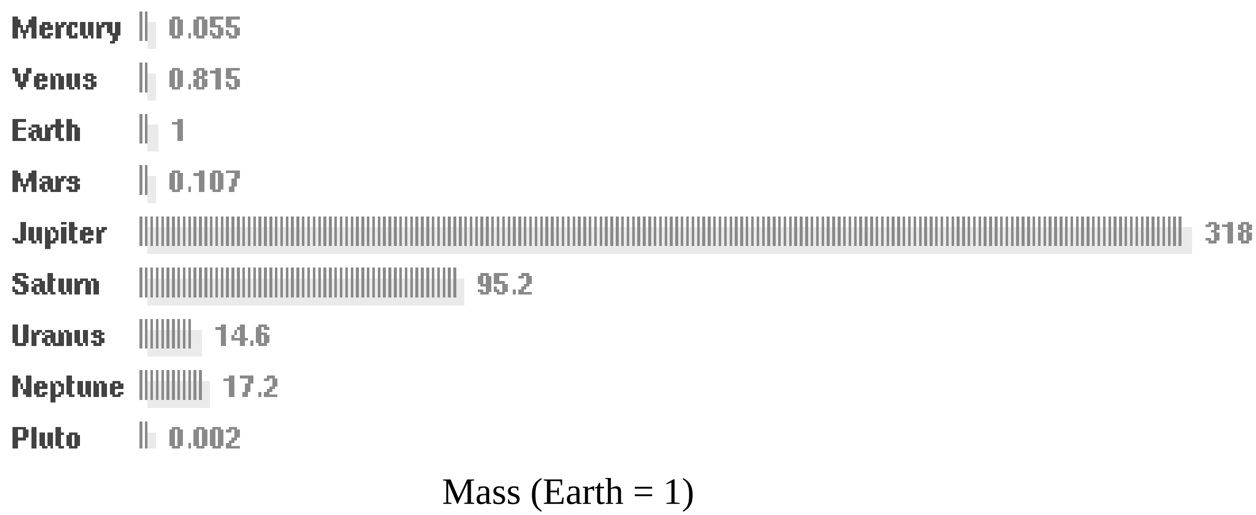
Section 1: A Tour of the Solar System

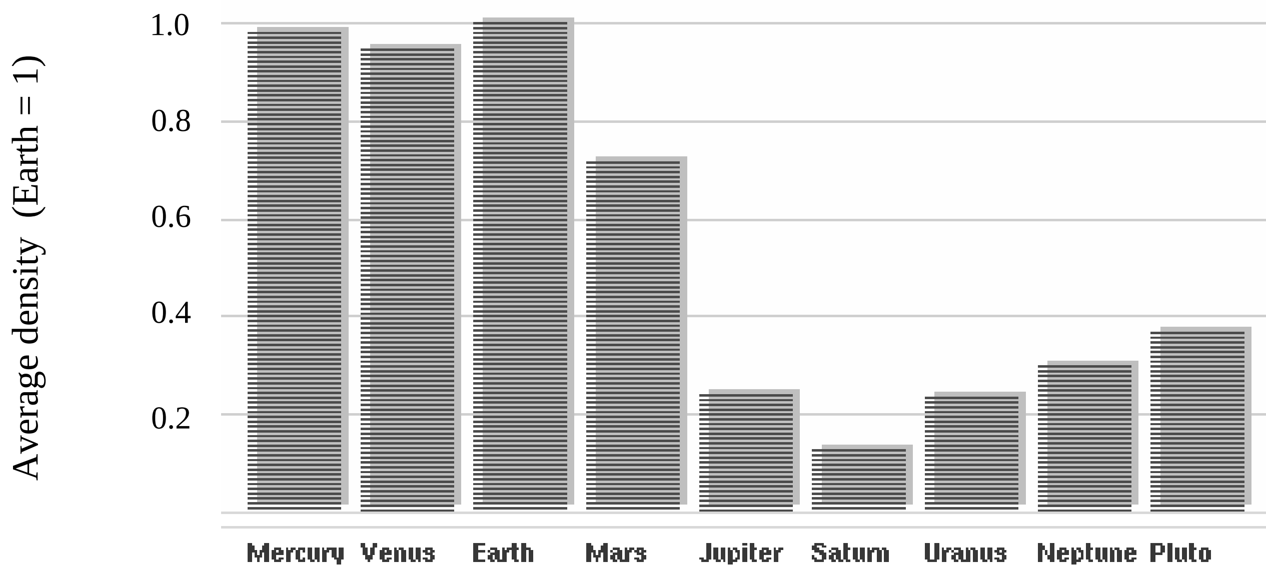
The Planets: some vital statistics:-

Name	Diameter*	(Earth=1)	Mass	(Earth=1)	Mean distance from the Sun	
Mercury	4880 km	(0.383)	3.302×10^{23} kg	(0.055)	5.79×10^{7} km	(0.387 AU)
Venus	12104 km	(0.949)	4.869×10^{24} kg	(0.815)	1.082×10^{8} km	(0.723 AU)
Earth	12756 km	(1.000)	5.974×10^{24} kg	(1.000)	1.496×10^{8} km	(1.000 AU)
Mars	6794 km	(0.533)	6.418×10^{23} kg	(0.107)	2.279×10^{8} km	(1.524 AU)
Jupiter	142984 km	(11.209)	1.899×10^{27} kg	(317.8)	7.783×10^{8} km	(5.203 AU)
Saturn	120536 km	(9.449)	5.685×10^{26} kg	(95.16)	1.432×10^{9} km	(9.572 AU)
Uranus	51118 km	(4.007)	8.682×10^{25} kg	(14.53)	2.871×10^{9} km	(19.194 AU)
Neptune	49528 km	(3.883)	1.024×10^{26} kg	(17.15)	4.498×10^{9} km	(30.066 AU)
Pluto	~2300 km	(0.18)	1.3×10^{22} kg	(0.0021)	5.915×10^{9} km	(39.537 AU)

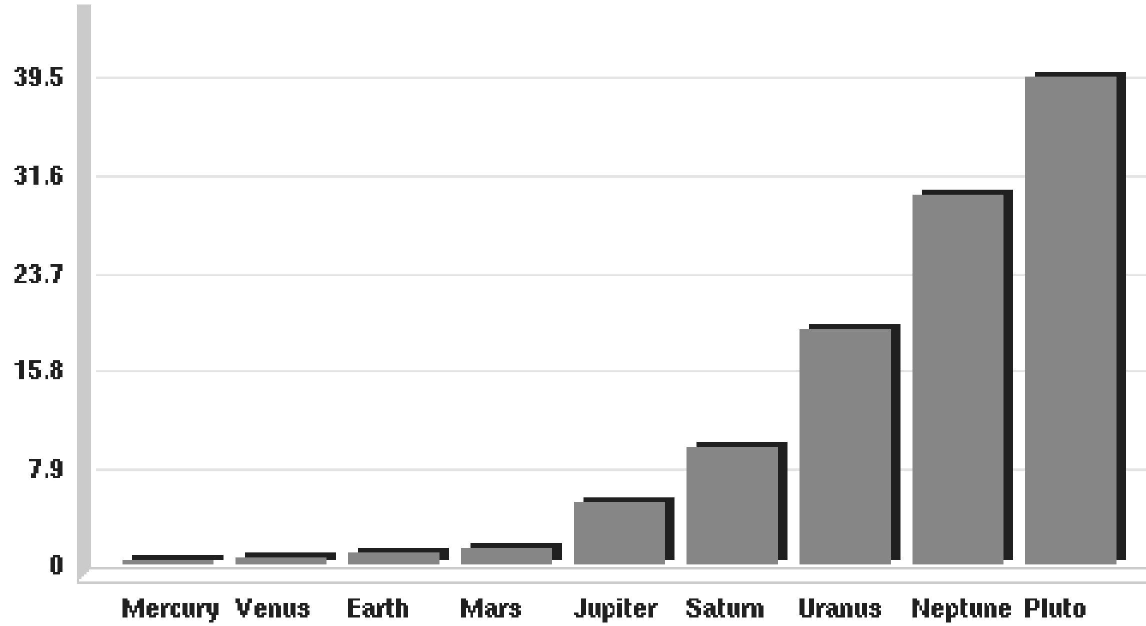
* Equatorial diameter

Comparative masses and densities of the planets

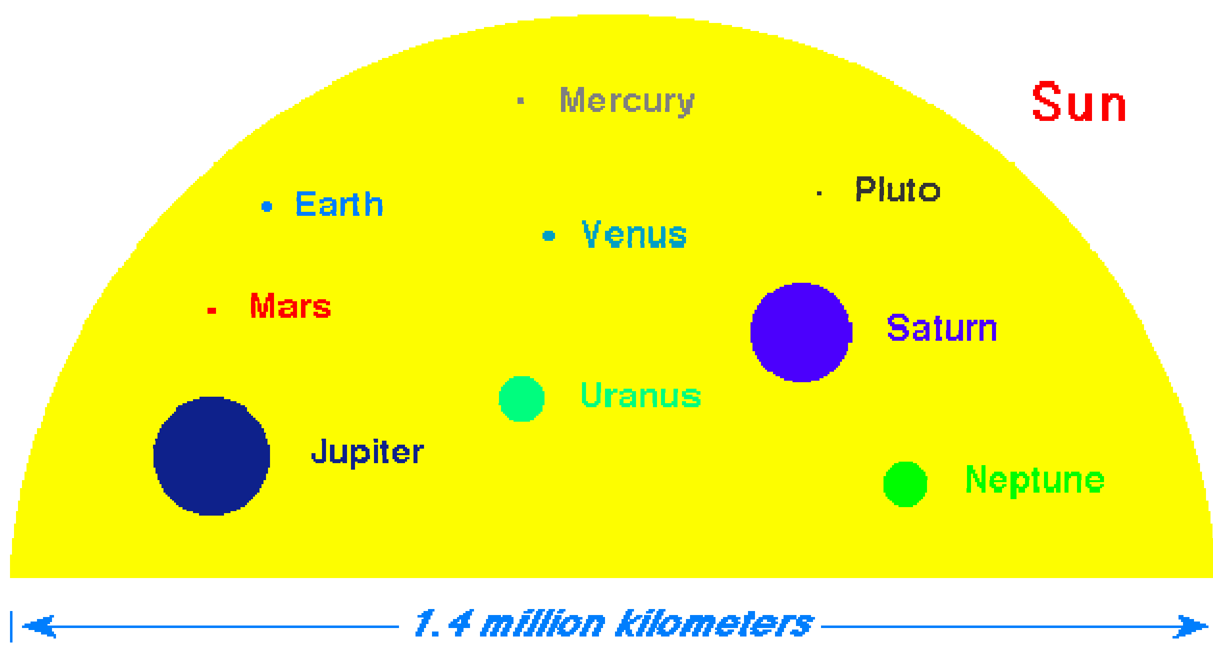




Comparative orbit sizes and diameters of the planets



Average distance from the Sun (AU)



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Abundance of H and He

We can use the results of Section 7 to estimate the temperature required for hydrogen and helium to escape from a planetary atmosphere:

$$T_{\rm esc} = \frac{1}{54}\frac{G\,M_P\,\mu\,m_H}{k\,R_P}$$

$$= \frac{6.673\times10^{-11}\times5.976\times10^{24}\times1.674\times10^{-27}\left(M_P/M_{\rm Earth}\right)\mu}{54\times1.381\times10^{-23}\times6.378\times10^{6}\left(R_P/R_{\rm Earth}\right)}\ {\rm K}$$

$$T_{\rm escape} = \frac{140\left(M_P/M_{\rm Earth}\right)\mu}{\left(R_P/R_{\rm Earth}\right)}\ {\rm K} \qquad (8.1)$$

- For molecular Hydrogen, $\mu = 2$ so the escape temperature for the **Earth** is **280 K**

  This explains why the Earth has not retained its atmospheric molecular hydrogen.

- When the solar system was forming, the inner part was too hot to retain lighter elements, such as H and He; these are absent from all terrestrial planet atmospheres. *(See also SSP2)*

- For, e.g. molecular Nitrogen, $\mu = 28$ so the escape temperature for the Earth is **3920 K**

  So the Earth's atmosphere *can* retain its molecular nitrogen.

Plugging in the numbers for the Jovian planets, for molecular **Hydrogen**; these escape temperatures are so high that the Jovian planets will *not* have lost their atmospheric hydrogen.

Planet	**Radius (Earth=1)**	**Mass (Earth=1)**	T_{esc}
Jupiter	11.209	317.8	7939 K
Saturn	9.449	95.16	2820 K
Uranus	4.007	14.53	1015 K
Neptune	3.883	17.15	1237 K

Internal structure of Jupiter

Upper atmosphere:

$90\%\ H_2$
10% He
$0.2\%\ CH_4$, ammonia, water

Lower atmosphere:

High pressure, density ‘squeezes’ H_2

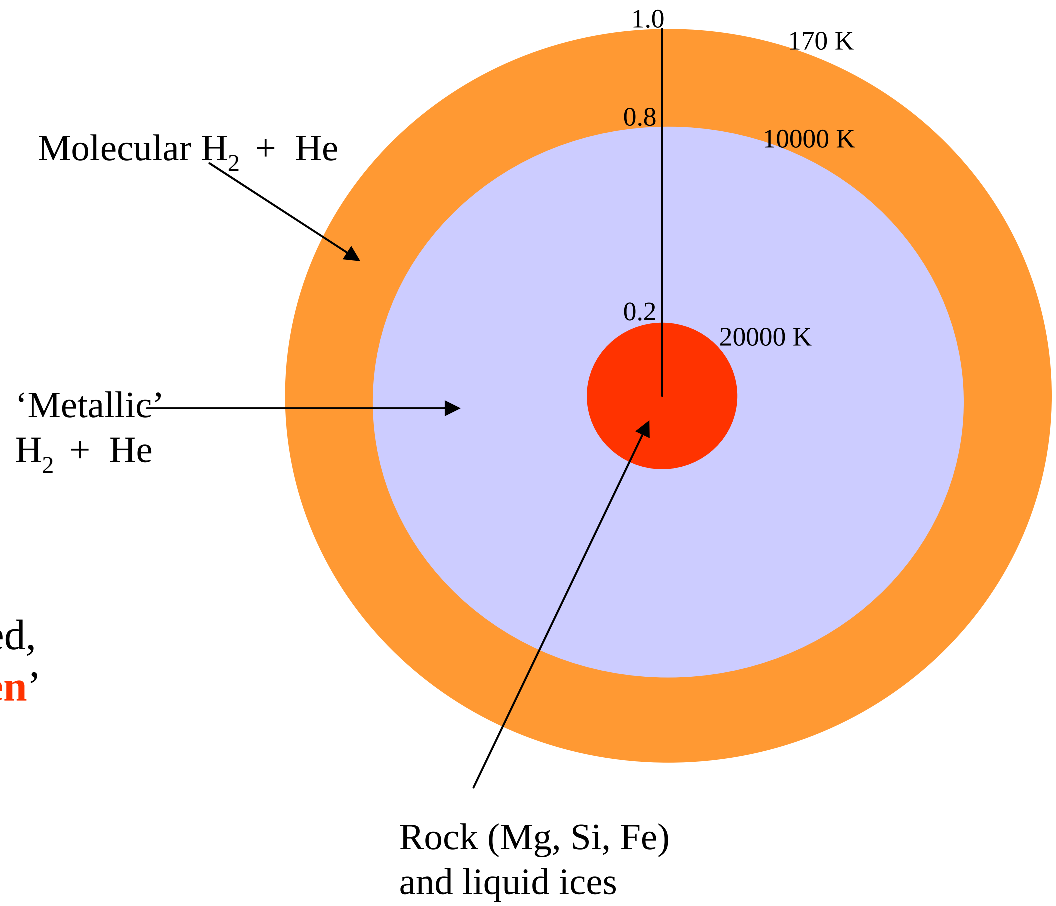
Molecular bonds broken; electrons shared, as in a metal – ‘**liquid metallic hydrogen**’

Core:

Dense, ‘soup’ of rock and liquid ‘ices’ (water, methane ammonia) of about 15 Earth masses

Evidence of **internal heating** – gravitational P.E. released during planetary formation (collapse of gas cloud)

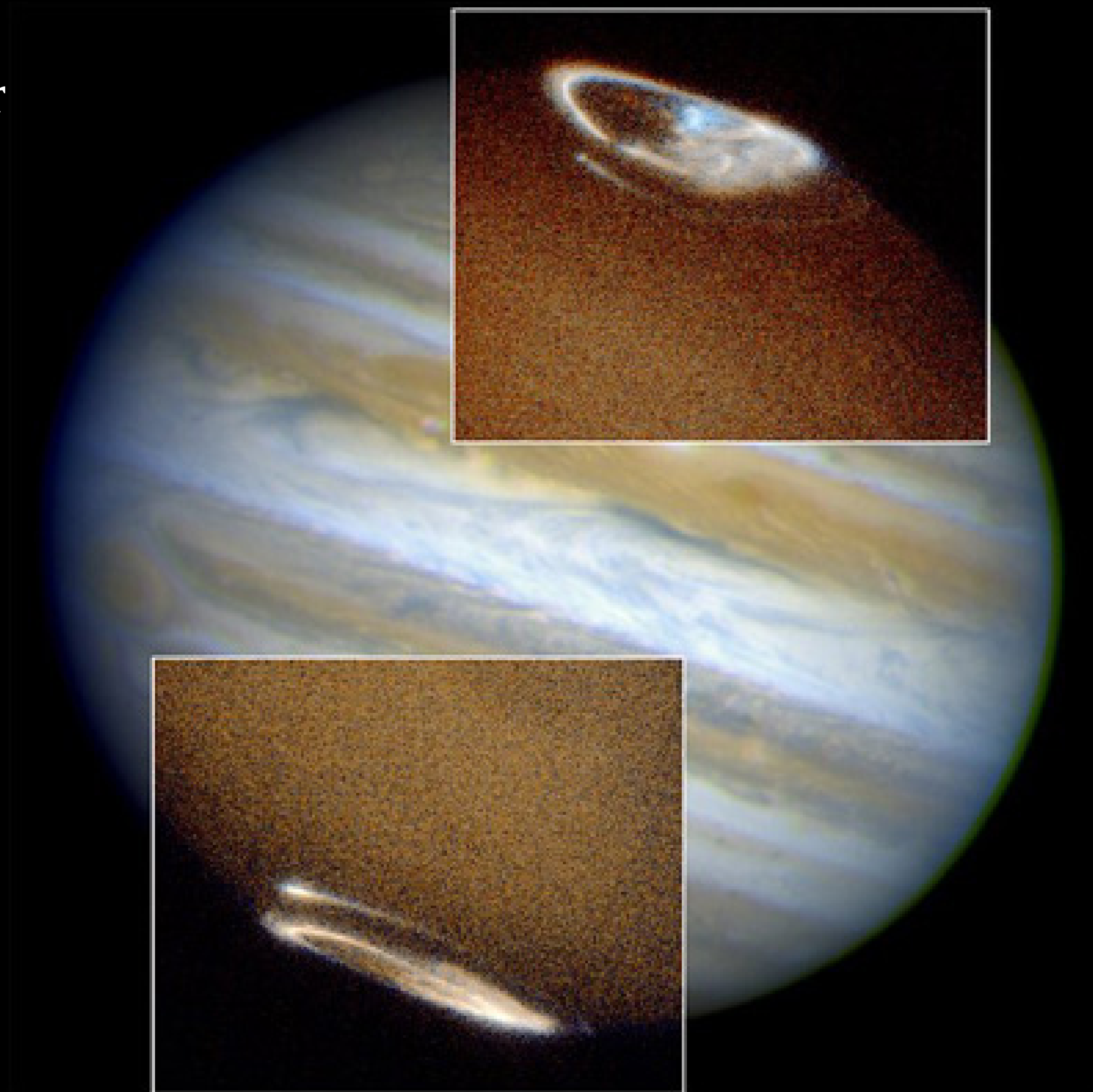
[see SSP2 and A1Y Stellar Astrophysics]



Metallic hydrogen gives Jupiter a **strong magnetic field** (19000 times that of the Earth)

See Chapter 11, Astronomy Today

Aurorae on Jupiter



Internal structure of Saturn

Upper atmosphere:

97% H_2
3% He
0.2% CH_4, ammonia, water

Lower atmosphere:

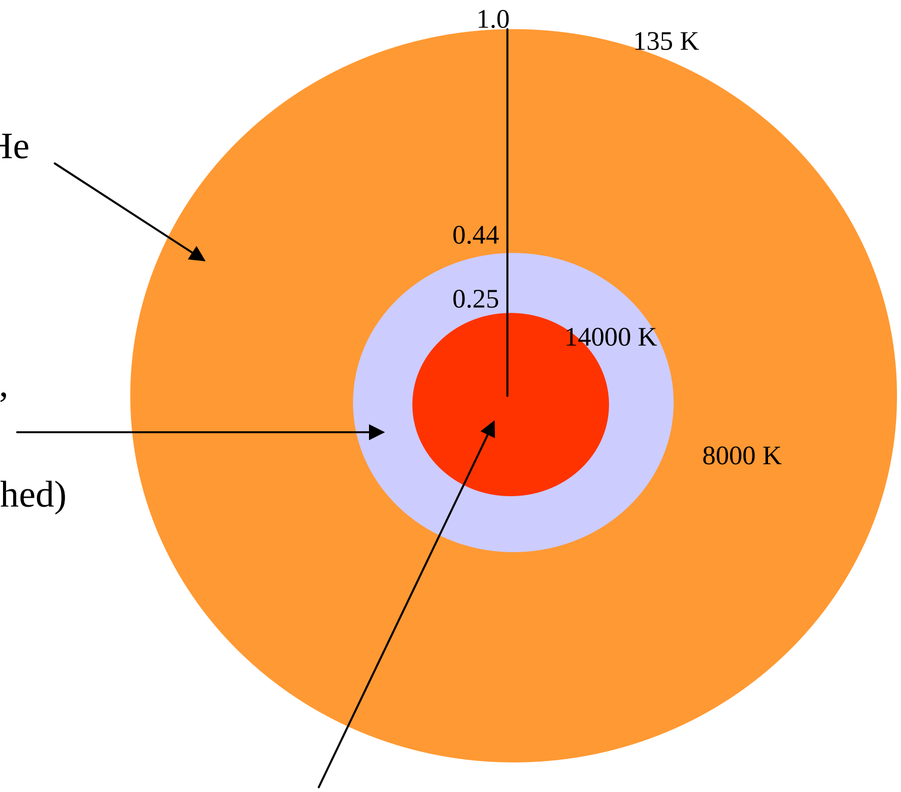
‘**liquid metallic hydrogen**’ (but at much greater depth than in Jupiter – due to lower mass and density)

Core:

Dense, ‘soup’ of rock and ‘ices’ (water, methane ammonia) of about 13 Earth masses

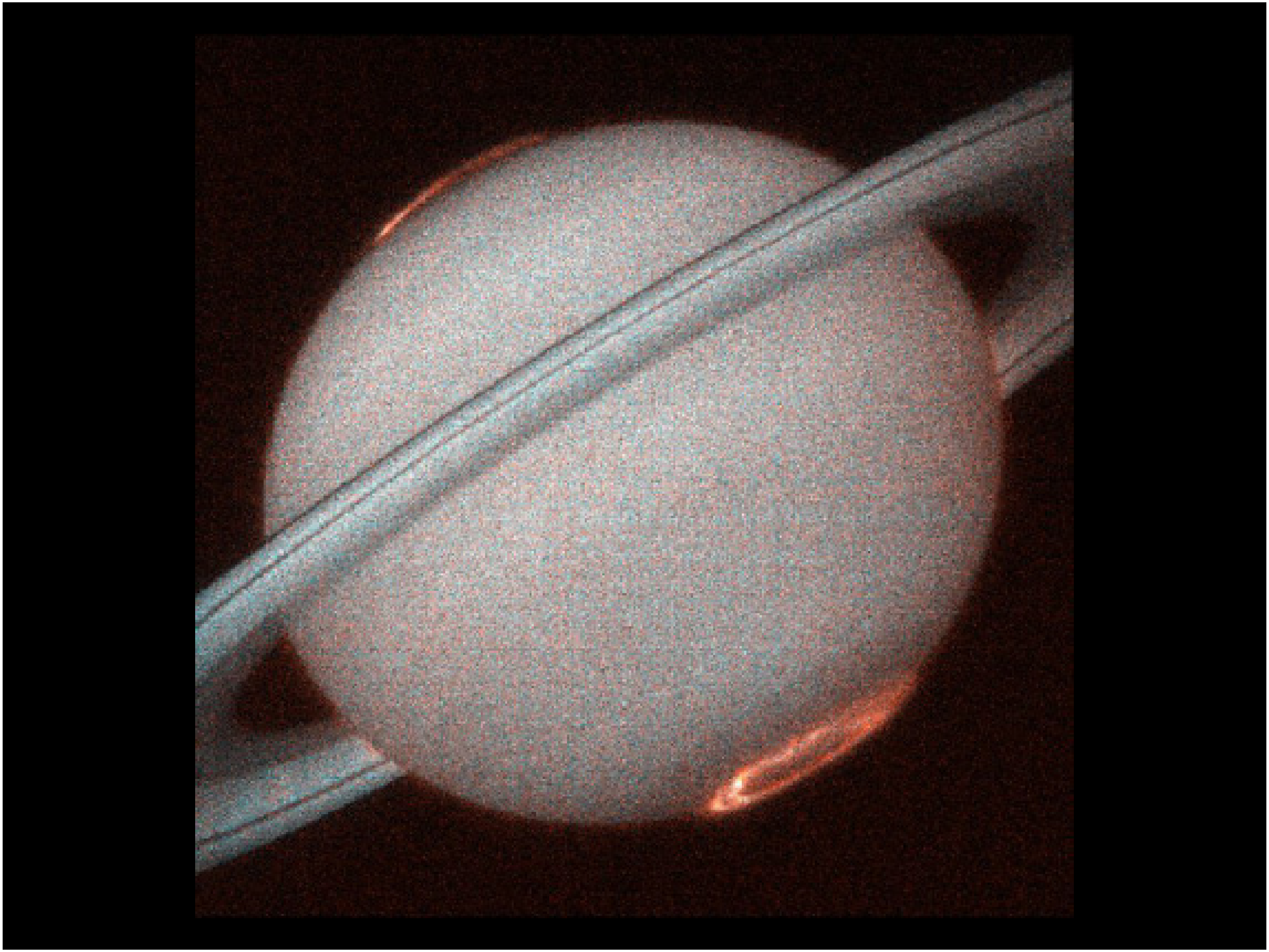
Internal heating **not entirely explained** by planetary formation; **extra heating** from release of P.E. as **heavier He sinks**.

Effect more pronounced for Saturn, as outer atmosphere cooler to begin with



Metallic hydrogen gives Saturn a **strong magnetic field** (but weaker than Jupiter’s)

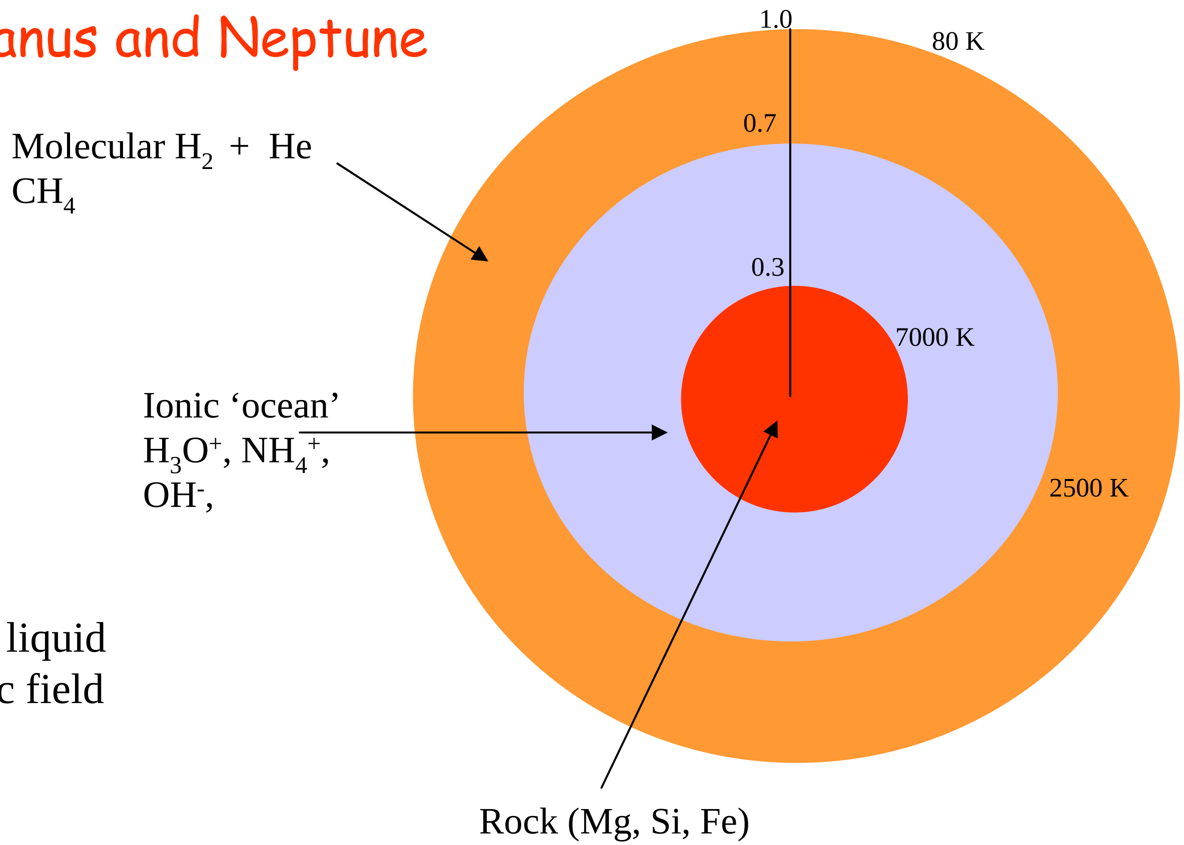
See Chapter 12, Astronomy Today



Internal structure of Uranus and Neptune

Upper atmosphere:

Uranus	Neptune
83% H_2	74% H_2
15% He	25% He
2% CH_4	1% CH_4



Lower atmosphere:

Pressures **not high enough** to form liquid metallic hydrogen; weaker magnetic field due to ionic 'ocean'

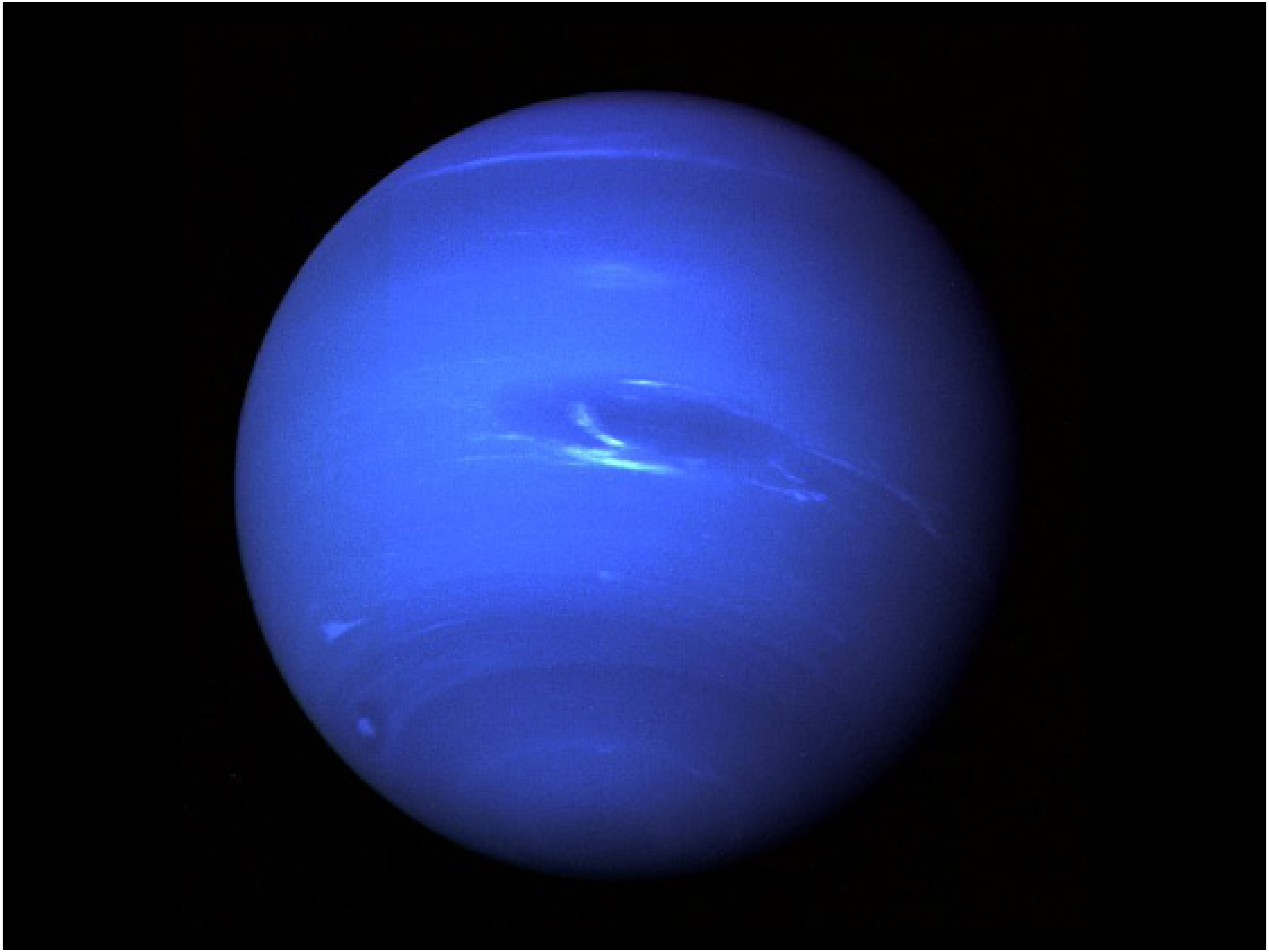
Core:

Dense, 'soup' of rock, also about 13 Earth masses

Internal heating also important – particularly for Neptune (similar surface temperature to Uranus, despite being 1.5 times further from the Sun)

Cores of Uranus and Neptune form much higher (70% to 90%) fraction of total mass, compared with Jupiter (5%) and Saturn (14%)

See Chapter 13, Astronomy Today

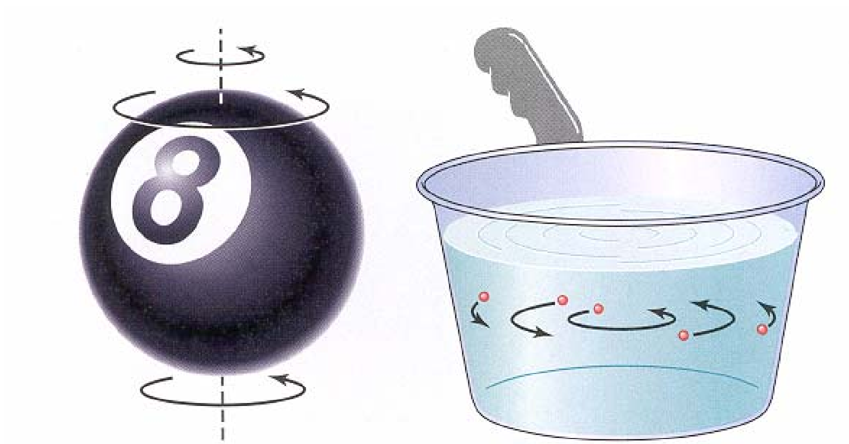


Rotation of the Jovian Planets

Jupiter, Saturn, Uranus and Neptune rotate very rapidly, given their large radii, compared with the terrestrial planets.

Also, the Jovian planets rotate ***differentially*** – not like a solid body (e.g. a billiard ball) but as a fluid (e.g. grains of rice).

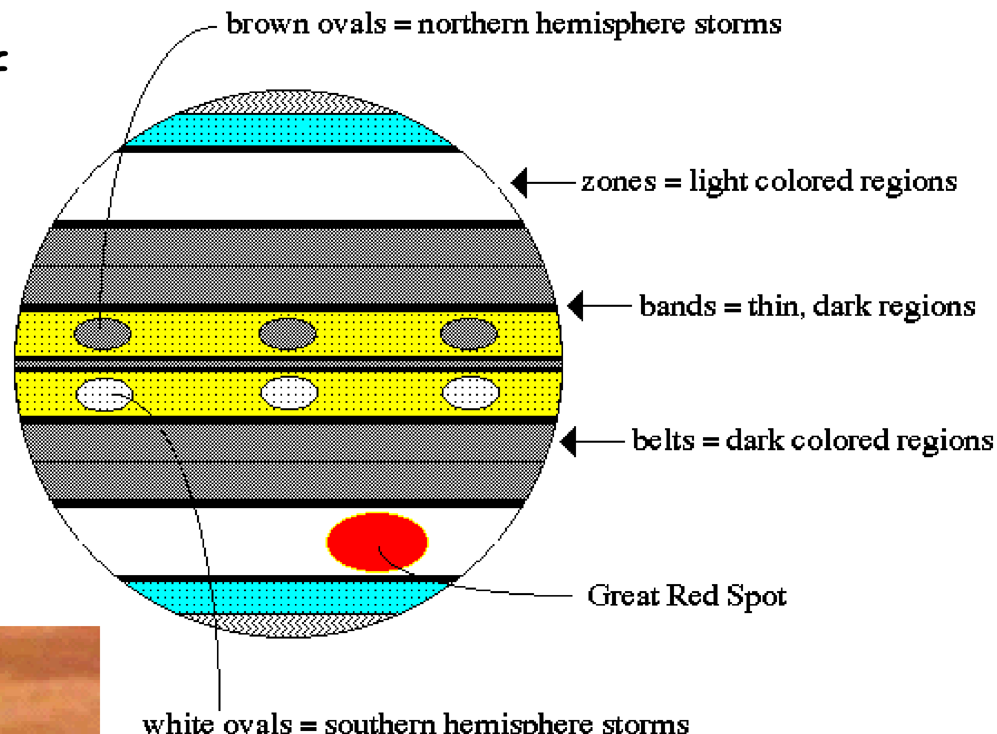
We see this clearly on Jupiter: cloud bands and belts rotate at different speeds



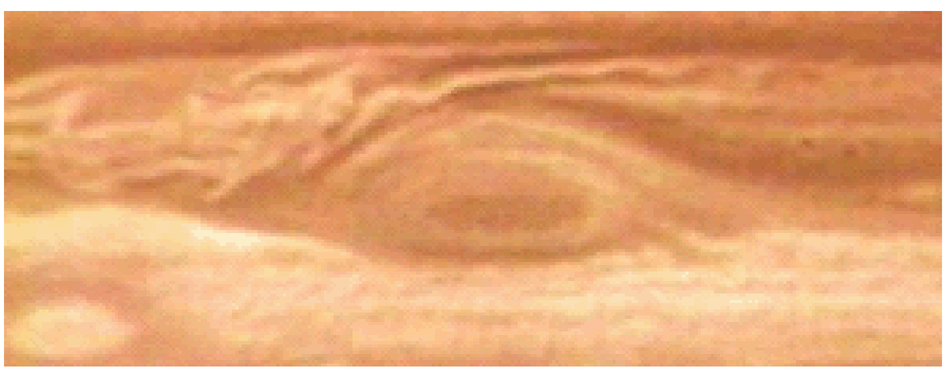
Planet	Rotation Period *
Mercury	58.6 days
Venus	243 days
Earth	24 hours
Mars	24 h 37 m
Jupiter *	9 h 50 m
Saturn *	10 h 14 m
Uranus	17 h 14 m
Neptune	16 h 7 m
Pluto	6.4 days

* At Equator

On Jupiter we also see that the cloud belts contain oval structures. These are storms; the most famous being the **Great Red Spot**. This is a hurricane which has been raging for hundreds of years. It measures about 40000km by 14000km



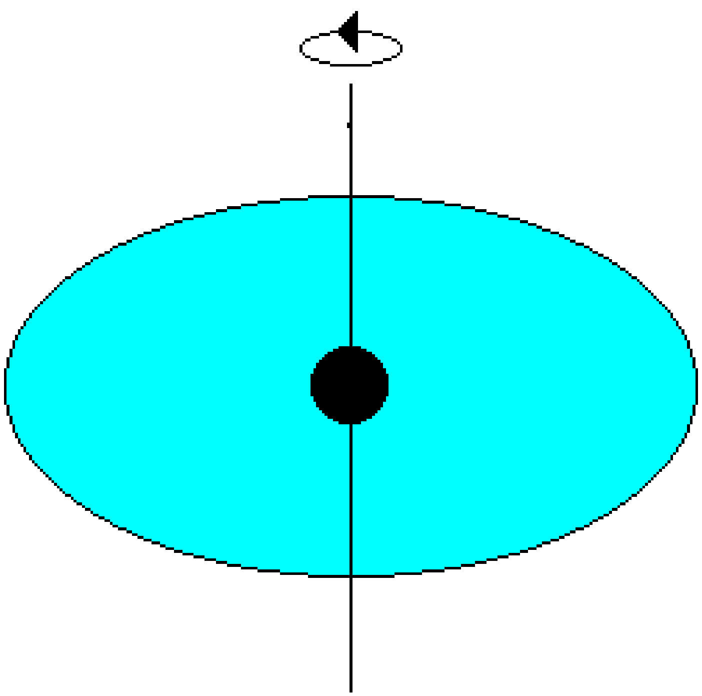
Winds to the north and south of the Great Red Spot blow in opposite directions; winds *within* the Spot blow **counterclockwise**, completing one revolution in about 6 days.



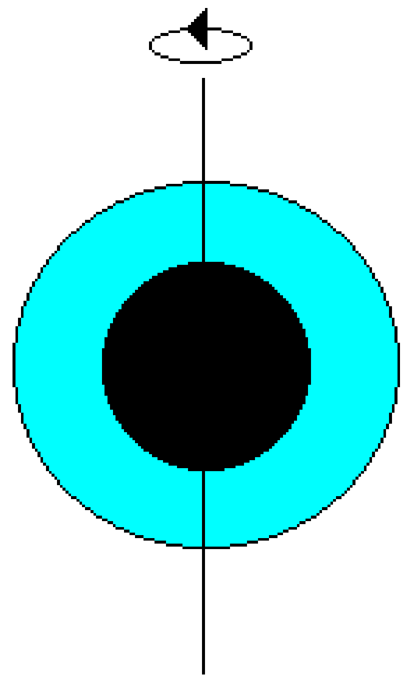
The Jovian planets are also significantly flattened, or **oblate**, due to their rapid rotation and fluid interior.

The effect is most pronounced for Jupiter and Saturn, which have relatively smaller cores

e.g. Jupiter's polar diameter = 133708km (6.5% less than equatorial diameter)



Smaller core: larger oblateness



Larger core: smaller oblateness