

Jovian planets

Jupiter } gas giants  
 Saturn }  
 Uranus } ice giants  
 Neptune }

More massive and larger than the terrestrial planets

but lower density  $0.7 - 1.7 \text{ g/cm}^3$

so also a different bulk composition

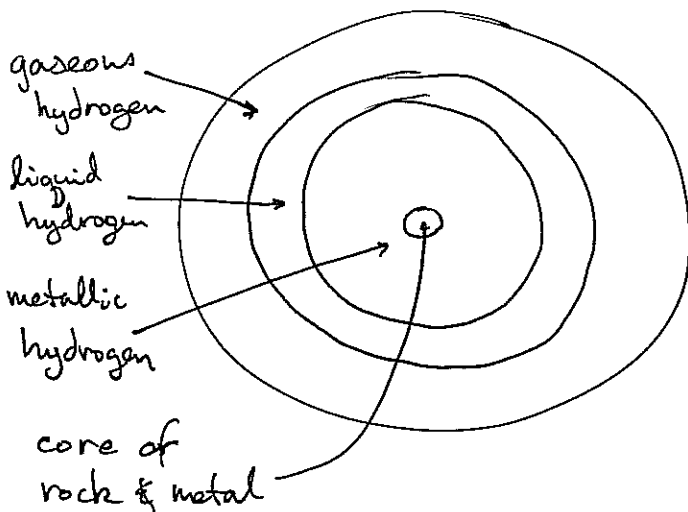
Jupiter & Saturn : mostly hydrogen & helium

Uranus & Neptune : mostly hydrogen compounds

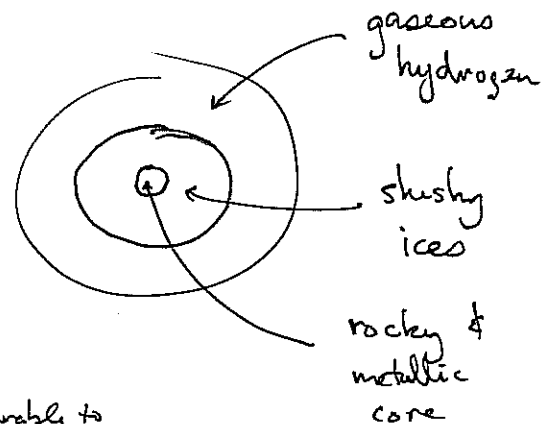
e.g.  $\text{H}_2\text{O}$  water  
 $\text{CH}_4$  methane  
 $\text{NH}_3$  ammonia

Interior structure

Gas giants



Ice giants



The cores are themselves comparable to or bigger than terrestrial planets

Energy release: with the exception of Uranus, the Jovian planets are emitting more energy (by a factor of  $\sim 2$ ) than they receive from the sun. This is powered by gravitational potential energy: Jupiter is still contracting (VERY slowly!); the helium is raining out of Saturn's atmosphere.

Atmospheres: Upper layers that we see are dominated by clouds of ammonia, methane, and other compounds.

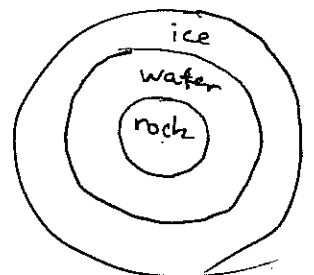
Each type of cloud appears at a different altitude where the temperature is favorable for that compound to condense. Each compound reflects different colors.

The atmosphere is broken into many bands with strong winds thanks to the coriolis effect: the Jovian planets spin rapidly.

Jovian planets grew large because they are big & cold, so they can hold onto the light gases hydrogen & helium that are very common.

Jovian planets form from swirling gas, like miniature solar nebulae. They have their own satellites (moons instead of planets) ~~and also rings~~ and also rings.

Moons of Jovian planets are cold and low density ( $\sim 2 \text{ g/cm}^3$ ) made of ice as well as rock & metal may often have a mantle of liquid water.



## Asteroids

Small, rocky objects orbiting the sun  
- the debris of planet formation

Irregularly shaped "rubble piles"

densities are lower than that of solid rocks,

implying lots of interstitial space: not monolithic boulders

Small asteroids are more common than big ones.

over 100,000 asteroids larger than 1 km are known

Sum of all their mass still much less than that of the moon  
(lots of little rocks do not add up to a lot of mass)

Surfaces typically old & heavily cratered

Most asteroids orbit between Mars & Jupiter.

Orbital resonances with Jupiter create gaps in the asteroid belt: sort of a messy version of Saturn's rings

Meteor: a "shooting star" - usually a grain of sand burning up in the Earth's atmosphere

Meteorite: the portion of a large meteor that makes it to the ground intact ("space rocks")

Meteoroid: a small rock in space ~~that~~ that is likely to become a meteor.

Meteorites can be rocky, metallic, a mix of rocky & metallic or primitive.

## Comets

Small, icy bodies orbiting the sun

- near primordial material

Comet nucleus often described as a "dirty snowball" -  
a combination of ice, rock, & tar

Low density, rubble pile construction with a hard exterior  
like the chocolate into which ice cream has been dipped

Most comets remain frozen far from the sun.

Only those few comets that cross the frost line and enter the  
inner solar system. These heat up and form an "apparition"

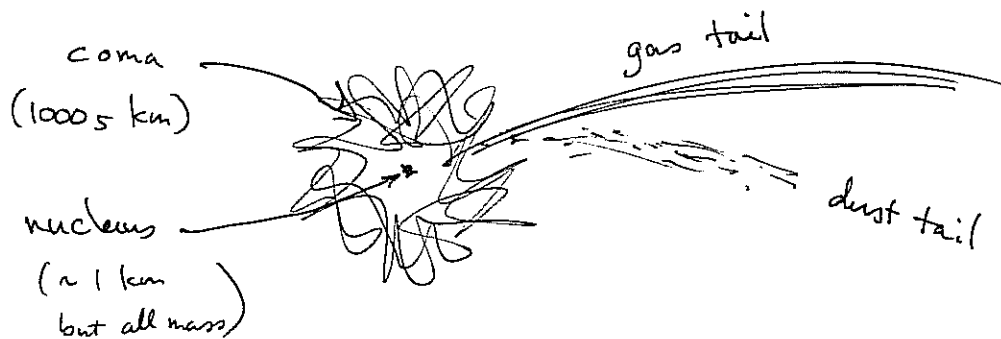
Heated ices leak into space, forming a coma

The coma is the fuzzy, temporary atmosphere that we see

The tail of the comet is material swept out of the coma

- always points away from the sun, as the solar wind  
is responsible for the sweeping  
that forms the tail.

Some comets develop separate dust and gas tails



Cometary orbits are typically very elliptical and  
inclined out of the plane of the ecliptic (unlike the planets)

Two reservoirs of comets:

1. the Kuiper Belt

- band of icy objects just beyond the orbit of Neptune (30-50 AU)
- sort of an outer asteroid belt of comets at the edge of the solar system
- contains most dwarf planets, like Pluto & Eris.

2. the Oort cloud

large but very diffuse, quasi-spherical distribution of comets.

extends MUCH further out, to  $\sim 50,000$  AU.

## Dwarf Planets

Objects orbiting the sun

- large enough to be made spherical by self-gravity
- not large enough to have swept clean their orbital zone

Most dwarf planets in the Kuiper Belt (Ceres, the largest asteroid, is the exception)

Pluto is just the first & most famous dwarf planet

- dozens of comparably large dwarf planets now known.

Cold & icy, have compositions & structure similar to Jovian moons

New Horizons recently discovered that the nitrogen atmosphere of Pluto is freezing out or escaping to space.

Also discovered that water ice is present on the surface.

# Exoplanets

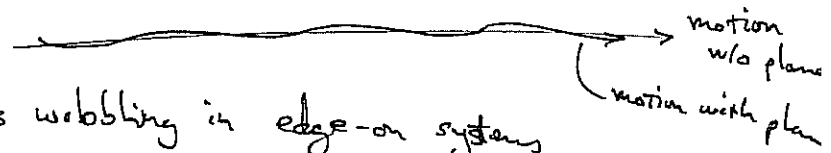
Planets around other stars

Many "Hot Jupiters" have been discovered - Jovian planets closer to their suns than Mercury. Does this make sense

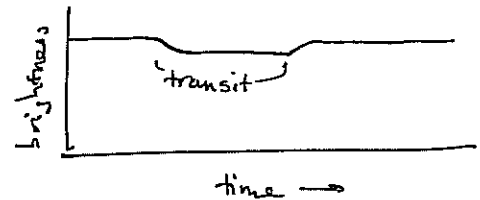
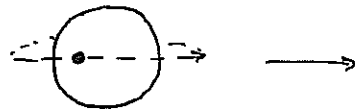
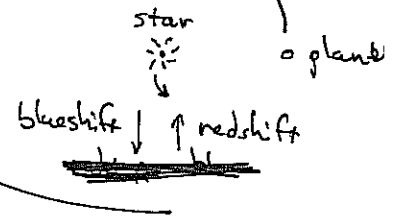
## Discovery techniques

- Direct imaging - very hard, as planets MUCH fainter than their stars
- Astrometric method - note wobbling of a star's path across the sky due to the gravitational influence of its planet

- Doppler method - detects wobbling in edge-on systems via the Doppler effect



- Transit method - note dimming of star as planet passes in front of it.

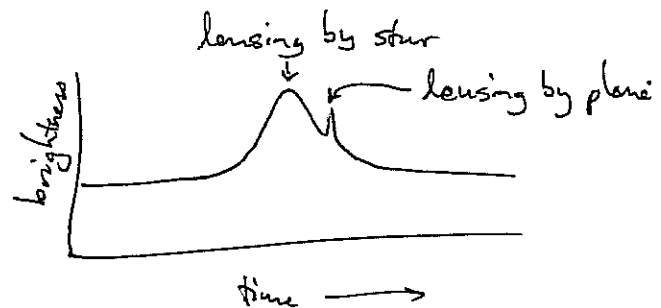


- Gravitational lensing - a star with a planet passes directly in front of a background star. Light bending by the gravity of the star & the planet temporarily brighten the background star.

background star \*

star with planet →

observer ↙



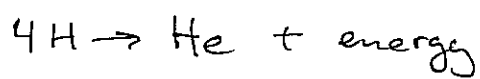
# The sun

The sun is a fairly ordinary star

> 99.8% of the mass of the solar system resides in the sun.

In state of hydrostatic equilibrium -

inward force of gravity balanced by outward pressure generated by fusion



$$\text{energy} = \epsilon mc^2$$

$$\epsilon = 0.7\% = 0.007$$

P-P chain

