Terrestrial Planet Atmospheres

The thin veil between a planet's solid surface and the hard vacuum of space

Atmospheric Pressure $P = NkT$

- P — Pressure
- N — Number density of air molecules
- k — constant
- T — Temperature

More gas means higher pressure
Higher Temperature means higher pressure

Pressure is a function of altitude, being greatest at the surface where the weight of the atmosphere above presses down, and decreasing to zero upwards as the atmosphere tapers into space.

Planet	Pressure (ATM)	Composition	Temperature
Mercury	—	—	797° F (day) −283° (night)
Venus	90	96% CO_2 3.5% N_2	878°F
Earth	1	78% N_2 21% O_2 + H_2O, CO_2, etc.	~59°F
Moon	—	—	257°F (day) −283° (night)
Mars	0.007	95% CO_2 2.7% N_2	−58°F

The "normal" atmospheric composition appears to be CO_2 & N_2. The Earth is unique in having washed most of its CO_2 out of the atmosphere and sequestering it in rocks. It is also unique

Factors Affecting Atmospheres

Sources of Atmospheric Gas:

- Outgassing by Volcanoes
- Evaporation/Sublimation of Liquid/Ice from surface
- Delivery from comets

Sinks of Atmospheric Gas:

- Thermal Escape to Space
- Condensation onto surface
- Chemical reactions combining with surface materials
- "Bombardment" – splitting of molecules by hard radiation with subsequent escape of lighter components to space.
- Atmospheric cratering – big impact events can eject material into space & take some atmosphere with it.

The Atmosphere of Mars appears to have evolved from one thick & warm enough in the ancient past to permit the presence of liquid water to the thin, cold place it is now through a gradual loss of gas both to space and to condensation on the surface.

Climate

The temperature of a planet is a balance between

↑ heat input from sun

↓ heat lost to space

Sunlight warms the surface by day, which cools by night by radiating into space as a thermal radiator (with λ_p in the infrare

Heat input depends on
- distance from the sun
- albedo of surface

Heat loss to space depends on
- temperature reached during day
- heat trapping by atmosphere

Greenhouse Effect

Gases like CO_2, H_2O, CH_4 have strong absorption lines in the IR

Remember Kirchoff's laws: heat trying to escape into space as InfraRed radiation is partially absorbed and trapped by greenhouse gas.

The final temperature is determined by the balance of heat input and heat outflow. The more trapping of heat by greenhouse gases, the higher the resultant temperature.

Hence Venus, with a thick CO_2 atmosphere, is very hot — hotter even than Mercury, despite its greater distance from the sun.

ASTR 201 Exam III (Final) Notes

Jovian planets

Jupiter, Saturn } gas giants

Uranus, Neptune } ice giants

More massive and larger than the terrestrial planets

but lower density 0.7 – 1.7 g/cm^3

so also a different bulk composition

Jupiter & Saturn : mostly hydrogen & helium

Uranus & Neptune : mostly hydrogen compounds

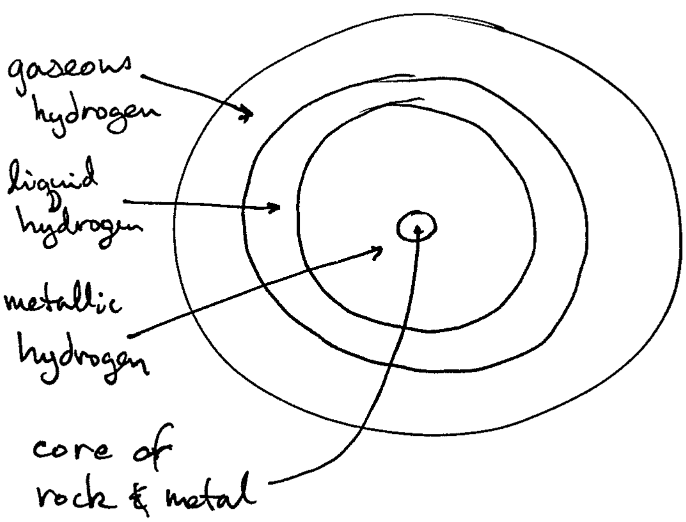
e.g. H_2O water

CH_4 methane

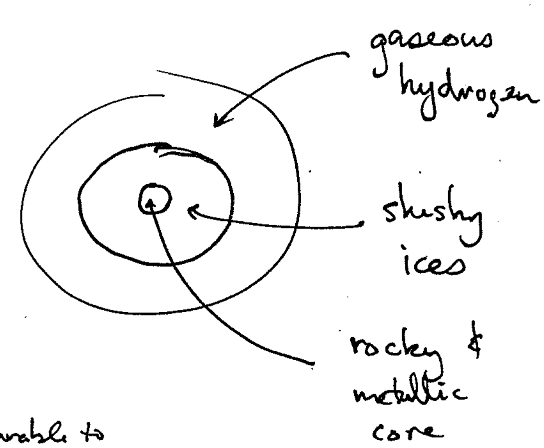
NH_3 ammonia

Interior structure

Gas giants



Ice giants



The cores are themselves comparable to or bigger than terrestrial planets

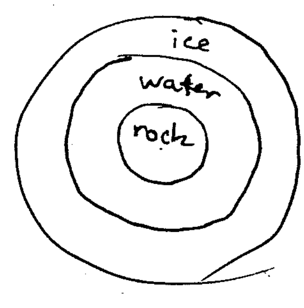
Energy release: with the exception of Uranus, the Jovian planets are emitting more energy (by a factor of ~2) than they receive from the sun. This is powered by gravitational potential energy: Jupiter is still contracting (VERY slowly!); the helium is raining out of Saturn's atmosphere.

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 something rings~~ and also rings.

Moons of Jovian planets are cold and low density (~2 g/cm³) made of ice as well as rock & metal may often have a mantle of liquid water



Asteroids

Small, rocky objects orbiting the sun

- the dregs of planet formation

Irregularly shaped "rubble piles"

densities are lower than that of solid rock, 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 is likely to become a meteor.

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

Meteor showers occur when the Earth moves through the orbit of a comet that has left a debris trail of meteoroids.

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

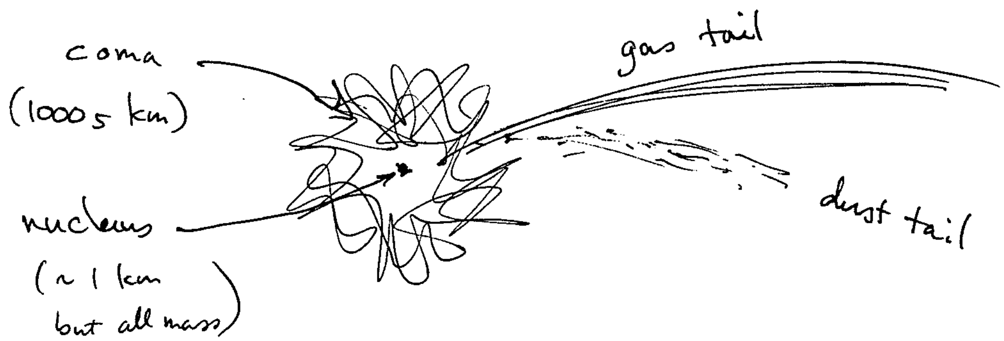
Most comets remain frozen far from the sun.

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.

   etends MUCH further out, to ~ 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.

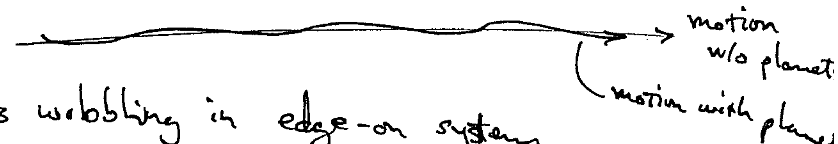
Exoplanets

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

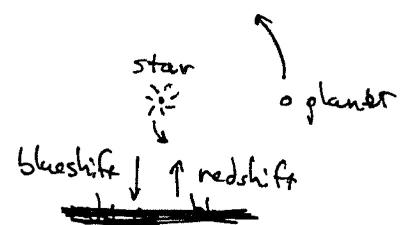
Planets around other stars

Discovery techniques

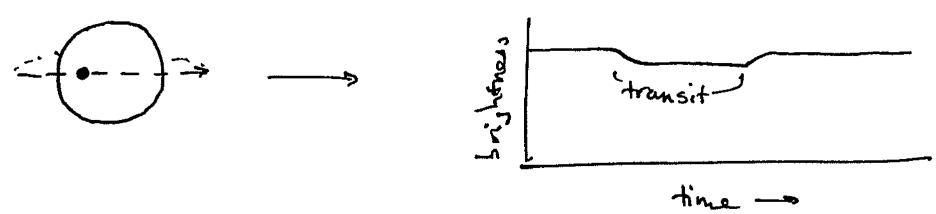
- Direct imaging - very hard, as planets MUCH fainter than their sta[r]
- Astrometric method - note wobbling of a star's path across the sky due to the gravitational influence of its plane[t]



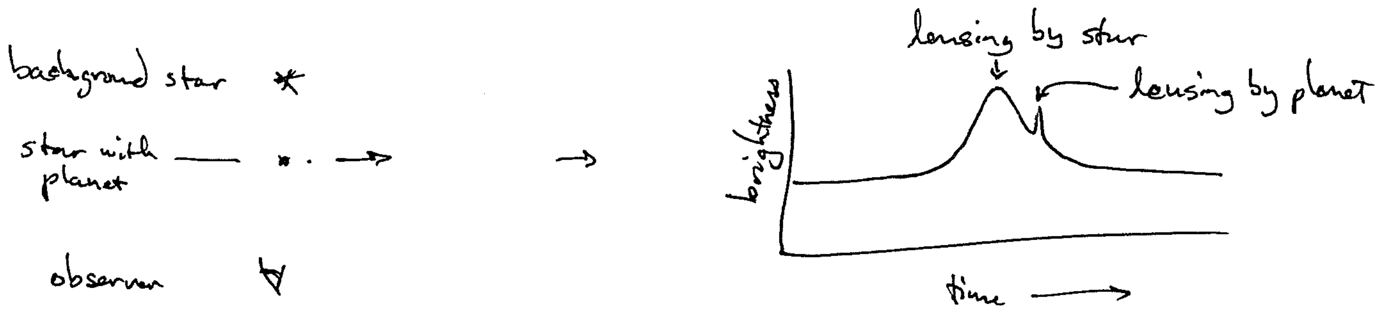
- Doppler method - detects wobbling in edge-on systems via the Doppler effect



- 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.



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 hydronamic equilibrium —

inward force of gravity balanced by outward pressure generated by fusion

$4H \rightarrow He + \text{energy}$ $\text{energy} = \epsilon mc^2$

$\epsilon = 0.7\% = 0.007$

P-P chain

$p + p \rightarrow D + e^{+} + \nu$ $e^{+} + e^{-} \rightarrow 2\gamma$

$D + D \rightarrow {}^{3}He + \gamma$

${}^{3}He + {}^{3}He \rightarrow {}^{4}He + 2p + \gamma$