The Solar System

An Overview

Sun

Planets: terrestrial - Mercury, Venus, Earth, Mars

gas giants - Jupiter, Saturn, Uranus, Neptune

Pluto?

Moons: ~ 61 known, only 3 orbit terrestrial planets

Asteroids (also meteoroids)

Comets

Rings: around all four gas giants

Interplanetary gas, dust

Key Features of the Solar System

• The Sun dominates the mass; all other components = 0.0014 M_{sun}

• Jupiter's orbit contains nearly all the angular momentum of the System; collectively, planets hold > 99% of SS angular momentum

• The Sun dominates energy output; small contributions from Jupiter, Saturn, Uranus, and Neptune

• All planetary orbit planes close to ecliptic, i.e., nearly coplanar. Mercury 7^0 inclination, Pluto 17^0, all others < 3.4^0

• Nearly circular orbits, i.e., small eccentricities. Mercury 0.206, Pluto 0.249, all others < 0.1

• "Direct orbits" (planetary rotation in same sense as orbit) in most cases. Exceptions: Venus $i = 177^0$ (retrograde rotation), Uranus $i = 98^0$ (rotates on side)

Planetary Interiors

Masses: from (1) Kepler's 3rd Law applied to satellite orbits or (2) gravitational perturbations to orbits of passing objects.

Radii: from (1) apparent optical size, (2) timing occultations of stars, moons, space probes, and (3) timing radar pulses from various parts of nearby planets

Mean density $\langle \rho \rangle = \dfrac{M}{4/3\pi R^3}$.

Terrestrial: <ρ> in range 3400-5500 kg/m^3 (vs. water 1000 kg/m^3)
- heavy elements such as iron, silicon, magnesium

Gas giants: <ρ> in range 700-1700 kg/m^3 , mainly H and He, like Sun, but probably do have a rocky core resembling the terrestrial planets

Planetary Surfaces

Albedo A = fraction of incident solar energy that is reflected.

Power emitted by Sun $P_{Sun} = 4\pi R_{Sun}^2 \sigma T_{Sun}^4.$

Flux received at planet $F_p = P_{Sun} / (4\pi r_p^2).$

Power absorbed by planet $P_{p,abs} = (1 - A)\pi R_p^2 F_p.$

Power emitted by planet $P_{p,em} = 4\pi R_p^2 \sigma T_p^4.$

Equate power absorbed and emitted by planet to find equilibrium

$$T_p = (1 - A)^{1/4} (R_{Sun} / 2r_p)^{1/2} T_{Sun}$$

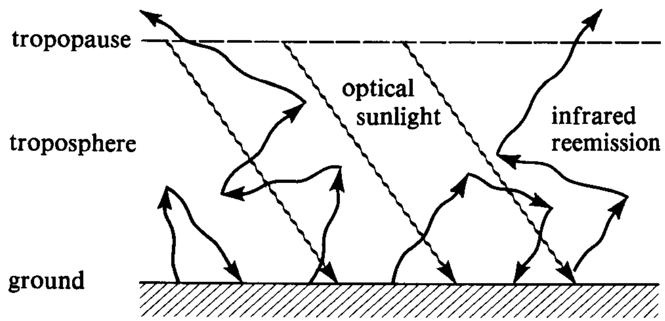
$$\approx 279(1 - A)^{1/4} r_p^{-1/2}, \text{ where } r_p \text{ is in AU.}$$

For Earth (r_p=1, A=0.35) find T_p = 250 K. Compare to actual average 290 K at Earth's surface.

Planetary Atmospheres

Mercury: essentially no atmosphere. Venus, Mars: CO_2 atmosphere, Earth: primarily N_2 and O_2. Jovian: mainly H and He.

<u>Greenhouse effect</u>: Earth absorbs visual light. Reradiates primarily in infrared. Infrared photons absorbed by atmospheric CO_2 and H_2O => thermal energy concentrated near surface.



<u>Stratification:</u> $\frac{dP}{dz} = -r g_z$, and $P = nkT$.

If T = const.,

$$r(z) = r_0 \exp(-z/H), \text{ where } H = \frac{kT}{m m_H}\frac{1}{g_z} = \text{scale height.}$$

At large heights, solar UV and x-rays => <u>ionosphere</u>.

Planetary Atmospheres

Maxwellian distribution of atomic/molecular speeds

$$F(v) \propto v^2 \exp(-1/2mv^2/kT) \quad \Rightarrow v_{rms} = (3kT/m)^{1/2}.$$

Compare with escape speed

$$v_{esc} = (2GM/R)^{1/2}.$$

A gas can be maintained for billions of years if

$$v_{esc} \geq 10 v_{rms} \quad \Rightarrow \quad T \leq \frac{GMm}{150kR}.$$

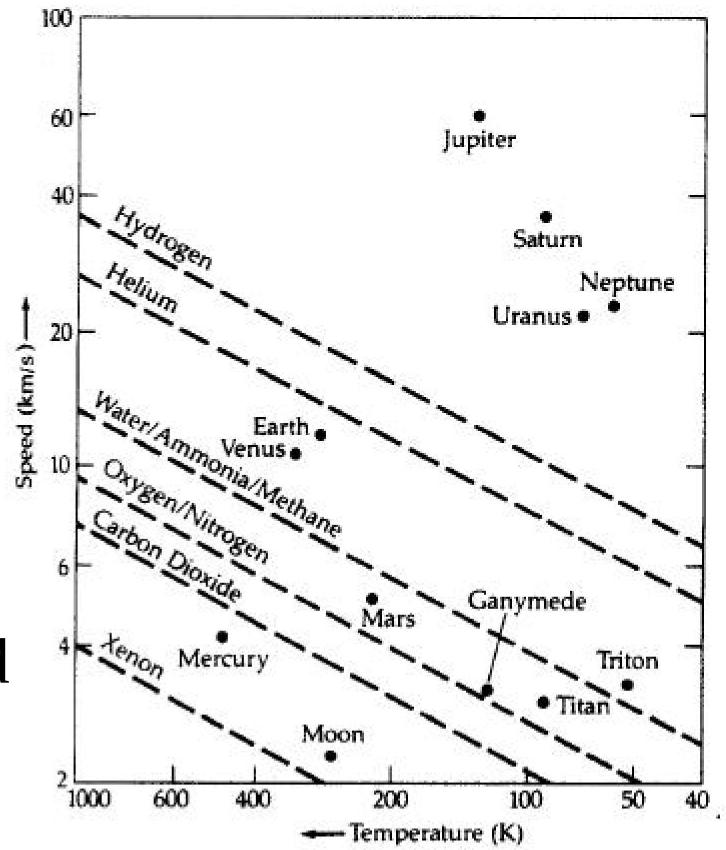


Figure: dots at position of temperature and v_{esc} for each planet, dashed lines represent $v = 10\, v_{rms}$ for each element.

Moons

61 known

Earth	-	Moon (almost a double system)
Mars	-	two captured asteroids (Phobos and Deimos)
Jupiter -	≥ 16	moons. Four largest: Io - volcanic activity. Europa - ice surface (+ocean below?). Ganymede - largest moon in SS. Callisto.
Saturn -	≥ 19	moons. Titan - atmosphere, N_2 (+ocean of N_2 on surface?)
Uranus -	≥ 15	moons. Most move in planet's equatorial plane, perpendicular to ecliptic
Neptune -	≥ 8	moons. Triton - atmosphere, N_2, CH_4

Asteroids

• First observed in 1801 – Ceres

• Found in asteroid belt, 2.3 - 3.3 AU, ~3000 known

• Size 1 km - 1000 km (Ceres). Irregular shapes.

• No atmospheres

• Depleted regions (Kirkwood gaps) at radii where *P* is a simple fraction (e.g., 1/2, 1/3, 1/4, 2/5, 3/7) of Jupiter's orbital period

Meteoroids

• Pieces from asteroid collisions and disintegrated comets

• Size ~1 mm - 10 km.

• Terminology: <u>Meteor</u> - a meteoroid which enters the Earth's atmosphere (a "shooting star"). <u>Meteorite</u> - a piece of a meteor which reaches the Earth's surface; <u>stones</u> (including <u>carbonaceous chondrites</u>), <u>stony irons</u>, and <u>irons</u>.

Comets

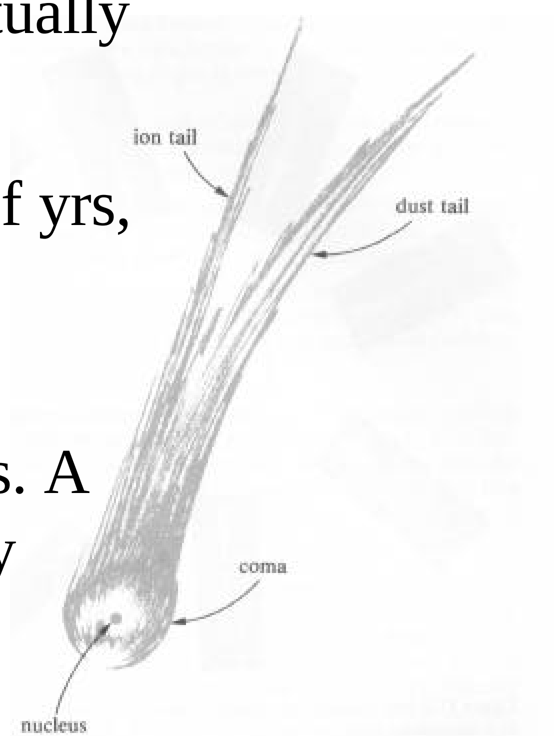
• Nucleus (1-10 km) + coma ($\sim 10^5$ km) + tail ($> 10^6$ km).

• Nucleus: dust + frozen H_2O, CH_4, NH_3, CO_2, a "dirty snowball"

• Tail: vaporized gases, <u>ion tail</u> and <u>dust tail</u>. Typically point away from Sun. The comet eventually evaporates after many encounters.

• Two groups: (1) long period, P up to millions of yrs, $e \sim 1$, seen only once. (2) short period, $P > 3$ yrs, return regularly, e.g., Halley's comet, $P = 76$ yr.

• Oort cloud, size $\sim 10^4$- 10^5 AU, supplies comets. A spherical volume, i.e., comet orbits have arbitrary inclination to ecliptic.



Rings

- Found around all four Jovian planets. All lie within Roche limit. Remains of tidal disruption?

Dust

- Size 1-100 μm
- From dust tails of comets. Also, gas from solar wind and escape from planetary atmospheres.
- Responsible for zodiacal light emission.
- Dust must be continually replenished, as small (< 1 μm) dust blown out of SS by solar wind, and larger (> 1 μm) dust spirals into the Sun.
- 10^6 kg (dust + meteoroids) deposited to Earth every day