PHY2003 ASTROPHYSICS I

Lecture 12. Asteroids and comets

The Asteroid Belt

First asteroid was discovered on 1st Jan 1801 - (1) Ceres. Largest asteroid (and also a Dwarf Planet), diameter $D = 933$km, $a = 2.77$ au.

Currently $> 700,000$ catalogued, extrapolation predicts $\sim 10^6$ in total with diameters $D \geq 1$km

99.9% have orbital semimajor axis 2.0au$< a < 4.0$au, with mean eccentricities $< e > \simeq 0.1$ and mean inclinations $< i > \simeq 5^\circ$. Hence they form a belt known as the main asteroid belt.

Almost no asteroids optically resolved from Earth, so need to separate albedo and size.

$$F_\odot = \frac{L_\odot}{4\pi R_h^2}$$

Total flux reflected by asteroid and received at Earth:

$$f_{opt} = \frac{1}{4\pi\Delta^2} A\pi r_a^2 \frac{L_\odot}{4\pi R_h^2}$$

Everything is known apart from Ar_a^2.

Absorbed flux heats asteroid - re-emitted thermally.

$$f_{IR} = \frac{1}{4\pi\Delta^2}(1-A)\pi r_a^2 \frac{L_\odot}{4\pi R_h^2}$$

$$\frac{f_{opt}}{f_{IR}} = \frac{A}{1-A}$$

$$\boxed{A = \frac{f_{opt}}{(f_{opt} + f_{IR})}}$$

Hence by measuring optical and infrared radiation from an asteroid, can measure the albedo. Then can combine with optical brightness to determine size.

Masses are generally unknown except for largest asteroids, but asteroid densities generally expected to be around 2000–3500 kg/m^3.

Asteroid collisions

Asteroid belt is collisionally dominated - all observed asteroids are likely fragments.

There are approximately 10^6 asteroids with a diameter of 1 km or larger, and any random asteroid of this size will hit anpother one once every $\sim 10^{11}$ years.

Thus with 10^6 asteroids, collisions between asteroids of this size or larger should occur once every $\sim 10^5$ years on average.

Evidence of collisions can be seen in *asteroid families* - groups of asteroids with very similar orbits. The first collision between two small asteroids ($D \simeq 100$m) was seen in 2010, and others have been seen since.

Comet Orbits

Almost all comets have highly elliptical orbits ($e > 0.4$). *e.g.* Halley's comet: $a = 17.9$au, $P = 76$ years, $e = 0.967$, so perihelion distance $= 0.59$au. Observed perihelion distances range from < 0.1 au to > 5 au.

Can split comets into roughly two groups based on their orbits.

Long-Period Comets: $P > 20$ years, many comets only seen once due to their long orbital periods ($P > 300 - 400$ years).

Short-Period Comets: $P \leq 20$ years, comets seen regularly.

Physically, a comet can be split into three connected parts; the nucleus, the coma and the tails.

Nucleus

Almost all the mass of observed comets is contained within central body called the nucleus. The nucleus is composed of about 50% ices and 50% small solid particles (dust). Although it contains large amounts of ice, the nucleus albedo is very low ($A = 0.04$), because of a crust of dark dust particles.

Largest nucleus known is Comet Hale-Bopp ($D = 70$km), most are 1–2 km across.

At large distances, nucleus is an inert frozen body. Water ice sublimates when $T \simeq 200$ K (solid $\Rightarrow$ gas directly), so surface ices will escape as a gas when the nucleus is close enough to the Sun.

$$T = (1 - A)^{1/4} \frac{279}{\sqrt{R_h}} \,\mathrm{K}$$

$$R_h \leq (1 - A)^{1/2} \left(\frac{279}{T} \right)^2 \simeq 2.0 \,\mathrm{au}$$

Coma

Gas expands away from the nucleus, also pushing out the freed dust grains. The gas and dust flows outwards to form a temporary atmosphere as long as the nucleus is near the Sun called the coma, $\sim 10^5$km across.

The gas is optically thin, and hence shows emission lines. We see the dust particles from the sunlight they reflect - so comets also show a reflected solar spectrum as well as gas emission lines.

Tails

Some molecules are ionised, and are then caught up in magnetic fields carried by the solar wind travelling past at ~ 500 km/s. As the orbital velocity of the comet is $\sim 30 - 60$km/s, then resultant velocity vector is pointing almost directly away from the Sun.

The ions are swept away from comet to form straight ion tail, pointing almost directly away from the Sun.

Large dust particles with $d \geq 10^{-3}$m will have a very slow velocity relative to the nucleus, so will remain close to the orbit of the comet. Slowly spread along comets orbit, If Earth passes close to the comet orbit, dust particles enter Earth's atmosphere, we see a meteor shower.

Much smaller dust particle are affected by solar radiation pressure, and are blown back from the coma at small velocities to form the dust tail.

Because the solar wind and sunlight are pushing the comet tails, a comet's two tails will point in the direction away from the Sun, no matter which part of its orbit the comet is currently on. Thus, after perihelion passage, you will find a comet's two tails pointed in front of the comet.

The origin of comets

Comet mass lost by sublimation near perihelion does not return. This means comets have a finite lifetime.

This finite lifetime must mean that the population of solar system comets is replenished over time. Astronomers have now identified two sources of new comets.

Example: In 1986, Comet Halley emitted 4×10^4kg of water per second near perihelion. If outgassing lasts for ~ 4 months near perihelion and the nucleus has a radius of ~ 7 km, how many more orbits can Comet Halley survive?

The Oort Cloud: Long-period comets have essentially random inclinations i.e. they can come from any direction towards the Sun, with equal numbers orbiting prograde (orbit the same way as the planets) and retrograde (the opposite direction),

Mean distance is $a \simeq 50,000$ au, $P \simeq 10^7$ years. Importantly, the distribution of semi-major axes (where known) is very strongly peaked towards 10^4-10^5 au.

This shows the Sun is surrounded by a spherically symmetric cloud of comets 10^5 au in radius - the Oort Cloud - from which a fraction are occasionally perturbed by passing stars into long-period comet orbits. Current models predict a total population of $\sim 10^{12}$ comets.

The Kuiper-Belt

Short-period comets cannot come from the Oort Cloud, as they (a) have low-inclination orbits, (b) are all prograde.

The easiest way to produce a low-inclination short-period comet is to start in a low-inclination orbit beyond Neptune; gravitational perturbations change its orbit until it reaches the inner solar system.

First objects found beyond Neptune in 1992–1993, said to lie in the Kuiper-belt, named after American astronomer Gerard Kuiper.

Over 1600 Trans-Neptunian Objects (TNOs) now discovered, most lie in in belt between $42 - 48$ au from Sun. But $\sim 30\%$ have same type of orbit as Pluto.

Pluto

Discovered in 1930: $a = 39.4$ au, $P = 248.6$ years, $e = 0.249$

First and only spacecraft flyby: New Horizons in July 2015.

Radius $R_P = 0.18 R_E$, mass $M_P = 0.002 M_E$, $\rho_P = 1830$ kg/m^3.

5 moons - Charon is 50% as large as Pluto, orbital period 6.4 days, plus 4 small moons with radius $R_M < 80$km.

Orbit brings Pluto within Neptune's orbit - last occurred between 1980 and 1999. Planets will never collide, as Pluto is in a 2:3 orbital resonance with Neptune - so are 30% of known TNOs. Conclusion - Pluto is a very large TNO as well as a dwarf planet.