Lecture

Asteroids and Comets

Objectives

- Asteroids: Asteroid Belt, Kirkwood gaps, orbital resonance, orbital evolution, main belt asteroids, NEAs, PHAs, taxonomic class
- Comets: nucleus, coma, tail, Kuiper Belt, Kuiper Belt objects, Centaurs, Oort cloud, short-period comets, long-period comets

Notes

**Asteroids: Where are they located and what are they made of?**

Asteroids are by far the most abundant named objects in the solar system. Many asteroids have non-spherical, irregular shapes. Over one hundred thousand \( \left(10^5\right) \) asteroids have been detected. Most asteroids reside in the Asteroid Belt, between Mars and Jupiter. These are known as the main belt asteroids. There are about 2000 known Near Earth Asteroids (NEAs), of which around 400 are Potentially Hazardous Asteroids (PHAs). PHAs are likely to collide with the Earth in the future.

The total mass of the main belt asteroids is about one-thousandth (0.001) of an Earth mass. Most of the mass in the Asteroid Belt is concentrated in the few largest asteroids. The numerous small ones only accounts for a small fraction of the total Asteroid Belt mass. The size distribution of impact craters seen on planetary bodies bears close resemblance to the size distribution of asteroids, suggesting that many impacts are made by asteroids.

When we plot the number of asteroids with a given semimajor axis interval against semimajor axis, there are gaps where very few asteroids with a particular value of semimajor axis are found. These gaps are known as Kirkwood gaps. They occur when the orbital period associated with a given value of semimajor axis is a simple fraction of the orbital period of Jupiter. This is known as orbital resonance. If during the same time period, an asteroid orbits the Sun twice while Jupiter orbits the Sun once, it is a 2:1 resonance. When a small body orbits the Sun, and is in orbital resonance with a large body, it may be kicked out of the orbit (hence producing Kirkwood gaps) or locked into the orbit (stable resonance). Note that Kirkwood gaps are not physical gaps in the Asteroid Belt. This is due to the elliptical orbits according to Kepler’s First Law.

As minor bodies of the solar system, the orbital parameters (eccentricity, semimajor axis, or orbital inclination) of asteroids may change significantly with time. This is called orbital evolution. As a result of orbital evolution of inner asteroid belt, the NEA population is being continuously replenished. Understanding the orbital evolution of NEAs and PHAs is critical because of their potential impacts on the Earth.

Asteroids are sorted into taxonomic classes, based on observational astronomy. These classes are due to compositional differences. One useful parameter for classification is albedo. A more precise indicator is how the albedo changes with the wavelength of incident light, as described by a reflectance spectrum. Important types include:

- **C-type**: “C” stands for “carbonaceous”. They are relatively dark, with low albedo and neutral reflectance spectra (albedo does not change much with wavelength of incident light). C-type asteroids contain carbon-rich rocky material.
- **S-type**: “S” comes from “S”-shaped reflectance spectra. They are more reflective and somewhat red. S-type asteroids are generally stony or stony-metallic.
E-type: “E” stands for “enstatite”. They are often highly reflective and appear to be predominantly composed of the mineral enstatite.

Asteroids are now thought to represent fragments of many small planetary bodies that never managed to accrete into one single body.

**Comets: What are they made of and where are they from?**
Comets are minor bodies composed mainly of water-ice and rocky (silicate) material. The ices (water ice plus ammonia ice, dry ice, etc.) are mixed with dust particles (mainly silicate minerals) to form a fluffy dirty snow-like structure. Their bulk densities might be as low as one-tenth that of compact ice.

An active comet consists of nucleus (the cometary body), coma (the bright head, a tenuous envelope of streaming gases, surrounding a comet nucleus and emitted by it), and tail (a stream of dust particles or ionized gas extending outward from a comet nucleus in a direction away from the Sun). The orbit of an active comet is difficult to predict. As the comet approaches its perihelion, it will degas. The emission of gas and dust alters the comet’s orbit.

There are two distinct groups of comets.
Short-period comets generally have semimajor axes less than that of Neptune, which corresponds to an orbital period of less than 200 years (Kepler’s Third Law). Their orbital inclinations are relatively low (mostly prograde orbits). Most of the short-period comets are thought to come from the Kuiper Belt, a zone between ~ 30 and ~ 50 AU which contains $10^7$ to $10^9$ bodies including icy planetesimals and cometary nuclei. The total mass of the Kuiper belt is about 0.1 Earth’s mass. Under the influence of Jupiter and Saturn, some Kuiper Belt objects may evolve into Centaurs (a class of minor bodies whose orbits cross one or more of the giant planets), then become short-period comets.
Long-period comets have very large semimajor axes, hence very long orbital periods (Kepler’s Third Law). Their orbital inclinations can take any value between 0 and 180° (both prograde and retrograde orbits). The long-period comets come from the Oort cloud, a spherical cloud of possibly $10^{12}$ cometary nuclei, extending to tens of thousands of AU from the Sun. The total mass of the Oort cloud is about 25 times that of the Earth.

Comets are considered leftovers from planetary formation process. Details of their origin will be discussed in next week’s lectures.