# Chapter 14 Solar System Debris

## Asteroids

Asteroids are mainly small, rocky bodies that orbit the Sun. They are often referred to as *minor planets* or *planetoids*. They differ from the planets in both orbit and size. Their orbits are usually found between Mars and Jupiter. Their orbits are quite eccentric unlike the nearly circular orbits of the major planets. Few are larger than 300 km and the largest, Ceres, is only 940 km across. If you were to put the known asteroids together, it would be less than the mass of our Moon.

## Orbital Properties

The first asteroid discovered was found in 1801 by Giuseppe Piazzi. It was found at a distance of 2.8 AU and within a few years they had found 3 more. By the start of the 20$^{th}$ century several hundred asteroids had their orbits known to a high level of accuracy. By now there are about 75,000 known. The official number of asteroids known now, including those whose orbits are not known, is over 200,000. Most of these are found in the *asteroid belt*. This is found between 2.1 and 3.3 AU. All but one asteroid orbits the Sun in a prograde motion. From all of the available data it appears that the asteroid belt is made up of material that never accreted into a larger body. One piece of evidence is that the asteroids are made up of such different material. It is thought that the gravity of Jupiter keeps the pieces from becoming a larger body.

## Physical Properties

Almost all of the asteroids are too small to be resolved from the Earth. This means that we must find other ways to determine the size, shape and composition of these bodies. Asteroids are classified by their spectroscopic properties. The dark asteroids contain a large amount of carbon so they are called the *C type* asteroids. They are also called *carbonaceous* asteroids. The more reflective are called the *S types* or silicates, also known as the rocky asteroids. The S type asteroids dominate in the inner belt, but as you move outward, the C type asteroids become more dominant. About 15% are S type, 75% are the C type and about 10% are the M type (metals). Measuring the amount of light they reflect and the heat they radiate is one method to determine the size of an asteroid. Over 1000 have been done this way. Another way is when an asteroid occults a star. By timing the time it takes the asteroid to pass in front of the star we can calculate its shape and size. Probably 99% of the asteroids larger than 100 km are known and have been catalogued. The asteroid Vesta is very unique because in spite of its small size it appears to have undergone volcanism. One possibility is that Vesta was once part of a much larger body that underwent volcanic action.

## Asteroid Observations from Space

The first close up view of an asteroid came from the Galileo spacecraft. It passed by Gaspra and Ida. Both of these are S types. They are both irregularly shaped bodies that are about 20 km and 60 km respectively. They are both cratered with Ida being more heavily cratered than Gaspra. Ida is thought to be about 1 billion years old while Gaspra is about 200 million years old. Closer examination of Ida revealed a moon named Dactyl. Dactyl is about 1.5 km across and orbits Ida at a distance of about 90 km. By using Dactyl, we were able to determine the density of Ida at 2200 – 2900 $kg/m^3$. In 1997 the Near Earth Asteroid Rendezvous spacecraft passed by Mathilde. This is a C type asteroid. It is 60 km across and by measuring the gravitational pull the density was calculated to be about 1400 $kg/m^3$. This is extremely low for rocky material. We now believe that Mathilde is a *rubble pile*. A large impactor struck the asteroid and pulverized it. When it went back together the pieces didn't fit nice and neat. Mathilde probably has empty spaces inside it to account for the low density. After passing Mathilde the NEAR spacecraft continued on to Eros. The spacecraft was put into orbit around Eros. High resolution pictures were sent back for a year and measurements were made of the shape, size, gravitational and magnetic fields. The density is about 2700 $kg/m^3$ and it appears to be solid all the way through. All of this points to Eros being a primitive, unevolved piece of the solar system. The spacecraft was landed on Eros (no, it was not a lander) and even though no more pictures were sent back, it broadcast data for another 16 days before it stopped. Other than Ida, Mathilde, and Eros, the masses of the asteroids are unknown. Some have their masses calculated out with reasonable accuracy due to their pull on their neighbors.

Earth Crossing Asteroids

Most asteroids have eccentricities less than about .3. A few have eccentricities greater than .4 and these are interesting to us. This is because their orbits may intersect the orbits of the Earth. They are called *Earth-crossing asteroids*. They have highly elliptical orbits. These asteroids are called *Apollo asteroids* if their semi-major axes exceed 1 Au and if not they are called *Aten asteroids*. Asteroids whose orbit crosses only Mars are called *Amor asteroids*. Right now we know of about 2600 Earth-crossing asteroids. Most have been found since the early 1990's. More than 600 of these are officially classified as *Potentially Hazardous Asteroids*. These are bigger than 150 m and come within 7.5 million km of the Earth. The possibility of a collision with one of these is very real. We have had several come within 100,000 km or a little less. Many of these are going to hit the Earth. Over a million year period the Earth is hit by 3 asteroids. A kilometer sized body hitting the Earth is worth about 1 million megatons of TNT. This is why we are spending more time watching the space around our world; we want to find them before they hit.

Orbital Resonances

There is another group of asteroids called the *Trojans* that orbit at a distance of Jupiter. There are several hundred such asteroids and they are locked in a 1:1 orbital resonance with Jupiter. It was calculated in 1772 that there are 5 places that small bodies can orbit the Sun in synchrony with Jupiter. These 5 places are called the *Lagrangian points*. Three of these points lie on the Jupiter – Sun line. The other 2 lie 60° in front of and behind Jupiter in its orbit. The 3 points on the Jupiter – Sun line are unstable places in the orbit. The other 2 places are very stable and you will find that bodies here will orbit forever. More of the Trojans are found in the leading Lagrangian point than the trailing one. We have now found asteroids at the Lagrangian points of Venus, Earth and Mars. IN the main asteroid belt you will find that there are gaps in the belt. There are some very underpopulated areas in the belt. These areas are called *Kirkwood gaps*. As you can see from the chart the gaps are due to certain resonances with Jupiter. Unlike the rings of

Saturn, there are no physical gaps in the asteroid belt. Due to the eccentric orbits, there are always asteroids found throughout the asteroid belt.

## Comets

Comets are usually faint, fuzzy objects that grow a tail as they near the Sun. They are in very eccentric orbits (.8) and the tail brightens and then diminishes as it goes back out from the Sun.

## Comet Appearance and Structure

When a comet comes close to the Sun it starts to melt and grow in size. This is when we see it. At the center of what we call the comet is the *nucleus*. It is usually quite small (a few kilometers). The material around it that obscures the view of the nucleus as called the *coma*. It may measure 100,000 km across. Around the coma is an invisible *hydrogen envelope* and it is usually distorted by the solar wind. The comets *tail* is material that is sublimating from the nucleus. It is the most prominent part of the comet. The tail may have 2 parts: the *ion tail* which is composed of ionized molecules. It is straight and blue in color. The *dust tail* is curved and yellow in color. It is broad and diffuse and made of microscopic dust particles. Comets tails always point away from the Sun. The shapes or the ion and dust tails are due to the way the dust and gas reacts to the forces of interplanetary space.

## Comet Orbits

Comets that survive their encounter with the Sun's gravity may find themselves traveling out to the edge of the solar system. Their highly elliptical orbit may take them out 50,000 AU from the Sun. Some comets are called *long period comets*, comets whose periods are in the thousands and millions of years. Other comets are called *short period comets* because their periods are 200 years or less. These comets probably don't get past Pluto. Unlike the orbits of the planets, long period comets are found at all inclinations to the plane of the solar system and orbit either prograde of retrograde. The short period comets originate beyond Neptune in an area called the *Kuiper Belt*. This belt is thought to go from about 30 AU to 100 AU. This is where you will find them unless a gravitational encounter happens and a comet is kicked out of its orbit into the inner solar system.
The long period comets originate in an area of space called the Oort Cloud. One theory says that there may be trillions of comets in the cloud. From the orbital properties of long period comets it has been calculated that the cloud may be 100,000 AU across. Since we lie in the middle of this cloud, these comets may come from any direction to circle the Sun.

## A Visit to Halley's Comet

The most famous comet of all is probably Halley's comet. Edmund Halley predicted its return in 1758, the first such prediction ever. It returned after he died, but they honored him with by putting his name on it. Looking back in the written records through time we now believe that the first record of the comet is from about 240 BC. Halley's comet was last here in 1986. Its next approach will be in 2061. IN 1986 when Halley's comet came around the Sun it was met by an armada of spacecraft, just none from the US. The Russians, the Japanese, and the ESA all had spacecraft there to study Halley's. It was found to be very dark and also to be 10 x 15 km in size. They also found jets of material streaming out from the comet. It was spewing 16 tons of material every second from the comet.

Physical Properties of Comets
The mass of a comet can be estimated from the interaction of the comet with other bodies in the solar system. Over time the mass will decrease due to it sublimating. Knowing this we estimate that Halley's comet only has about 5000 more orbits left in it before it is gone. Chemical composition can be determined by looking at reflected light off the tail and coma. From this we have found that the dust comes off along with methane, ammonia, $CO_2$, and water ice. Due to all of this they are often called dirty snowballs. In Feb., 1999 we launched a mission named Stardust whose job was to go out and collect samples from comet Wild. Stardust will return to Earth with samples from a comet.

The Kuiper Belt and Pluto
We have never seen any objects in the Oort Cloud, but in the 1990's we started finding objects in the Kuiper Belt. In early 2004 the count was 710 KBO's. It is thought that the total number of objects bigger than 100 km may be 100,000. The objects range in size from about 50 km to more than 1000 km. The object Quoaor is the largest known. It is about the size of Charon. Looking at the largest KBO's, we now see that Pluto is simply the biggest of the group; the king of the Kuiper Belt. Officially Pluto is still the $9^{th}$ planet. Are there more Pluto sized objects out there? Maybe.

Is Pluto a Planet?
Many astronomers are disturbed by the idea that Pluto is not a planet. It orbits the Sun, it is round due to its own gravity, and it has its own moon. So what is the problem? The answer is that Pluto is still a planet, not just a major one. It is too much like the KBO's and not enough like the major planets of the solar system. The first asteroids were called planets, but after a few decades of study they realized they weren't planets after all and revised their ideas. There are many who feel the same about Pluto.

Meteoroids
If you get away from city lights, you will see several shooting stars in the evening. These are *meteors* entering the atmosphere and burning up. A *meteoroid* is a fragment that is orbiting out in space. If any piece survives its trip through the atmosphere it is a *meteorite*. Most pieces that enter our atmosphere are from an asteroid, comet or a meteoroid.

Cometary Fragments
Smaller meteoroids are usually the fine material from a comet. A large number of these particles are called a *meteoroid swarm* and they move in the same orbit as their parent comet. As time goes on, the swarm is spread out and these *micrometeoroids* as they are called spread out evenly. They are responsible for *meteor showers*. The Earth's motion takes us through the same spot in our orbit each year and we pass through the meteoroids. If you watch a meteor shower you will see that they all appear to come out of a central point in the sky. This is called the *radiant*. Whichever constellation the radiant lies in is

how the meteor shower is named. One of the best year after year is the Perseids which gives you about 50 per hour. It comes from the comet Swift-Tuttle.

## Stray Asteroids

Meteoroids that are not small, fluffy pieces are not from comets. When these objects enter the atmosphere you can have a fireball. The more massive pieces don't burn up or break up in the atmosphere and can make a crater like Barringer Crater in Arizona. There are more than 100 craters larger than .1 km in diameter on the Earth. Fortunately these impacts are very rare. The orbits of the larger objects that enter our atmosphere have been calculated and most come from the asteroid belt. Not all come from the asteroid belt though.

Not all strike the Earth. An example of that is in Tunguska in Siberia where a fragment air burst about 8 km above the Earth. There is only a slight depression and no fragments. Modern calculations show that it was a rocky body about 30 m across which is equivalent to a 10 megaton warhead.

## Meteorite Properties

Large and small meteorites are different in composition. The small meteoroids have a density of about 500 – 1000 $kg/m^3$ while large meteorites are much denser, up to 5000 $kg/m^3$. Most meteorites are rocky in composition, but a few are metallic. The most primitive of all the meteorites are the carbonaceous meteorites. They are high in carbon and very dark. They are most likely related to the C type asteroids.

Finally all meteorites are old. Most have been dated from 4.4 – 4.6 billion years old. These are from the original formation of the solar system.