Chapter 14 Solar System Debris
Part a Asteroids & Comets

Properties

Orbits:
Kirkwood Gaps

Classification
Ceres, Vesta

Asteroids Visited by Spacecraft

Appearance

Properties

Long and Short period Comets

Source

Discovery

Father Giuseppe Piazzi
In 1801, Giuseppe Piazzi discovered an object which he first thought was a new comet.

After its orbit was better determined it was clear that it was not a comet but more like a small planet.

Three other small bodies were discovered in the next few years (Pallas(1802), Vesta, and Juno(1804)).

By the end of the 19th century there were several hundred.

Largest Asteroid

Ceres (largest): 940 km diameter
1/10,000 Earth’s mass contains about 25% of the mass of all the asteroids combined.
The next largest are Pallas and Vesta which are about 530 km or so in diameter.

About 30 others are between 200 and 300 km across
About 200 larger than 100 km
Most less than 1 km across

Total mass of all asteroids is about 4% of Moon’s Mass

Asteroid Location

Belt:
- The asteroid belt extends between the orbits of Mars and Jupiter,
  - 75% of known asteroids in the main belt.
  - semi-major axes 2.2 to 3.3 Au.
  - Periods: 3.3 to 6 years.

Trojans: located near Jupiter’s Lagrange points (60 degrees ahead and behind Jupiter in its orbit).

Father Giuseppe Piazzi

Asteroids are also called minor planets or planetoids.

Piazzi named it Ceres, after the Sicilian goddess of grain.
Jupiter’s gravity continuously disturbs these chunks of matter, preventing them from accumulating into a planet. They have been modified by internal heating, impact melting, and space weathering. The asteroid belt can be considered a relic of the primitive Solar System.

As of April 14, 2006, there are a total of 330,795 registered minor planets.

These gaps are located at orbital resonances with Jupiter. Thus, any asteroids in the gaps receive regular, repeated tugs from Jupiter and are disturbed, clearing out the gaps.

Kirkwood Gaps

There are small gaps in the asteroid belt known as the Kirkwood Gaps. These gaps are located at orbital resonances with Jupiter. Thus, any asteroids in the gaps receive regular, repeated tugs from Jupiter and are disturbed, clearing out the gaps.

Types of Asteroids

M-type: Brighter, less reddish asteroids, probably made out of metal rich materials; probably iron cores of fragmented asteroids—inner belt.

C-type: Dark asteroids, probably made out of carbon-rich materials (carbonaceous chondrites)—in outer belt

S-type: Brighter, redder asteroids, probably made out of rocky materials—inner belt.

DAWN Spacecraft on its way to Ceres and Vesta: (Launched 2007)

Vesta: arrival 2011 departure 2012
Ceres: arrival 2015 end 2015
Vesta
Diam = 525 km, rotation 5.34 hours.
The most geologically diverse asteroid
A basin so deep that it exposes the mantle beneath Vesta's outer crust.
seems to have been differentiated into layers like the terrestrial planets.
Heat for existence of lava flows probably from radioactive decay of $^{26}\text{Al}$.
In 1960, a small chunk rock believed to have originated on Vesta fell to Earth and in Australia.

Ceres:
a dwarf planet
1/4th the diameter of the Moon
Orbits Sun every 4.6 years

Asteroids Visted by Galileo
Gaspra and Ida and Dactyl(Moon)
Gaspra (S type) is in false color; it is really gray.
Note that Ida (S-type) has a small moon, Dactyl:

Asteroids visited by Near
NEAR; Visited Mathilde(C type), on its way to its main target, Eros (S type).
NEAR orbited Eros for a year and it crash landed on Eros, 2001

HAYABUSA landed on Itokawa
HAYABUSA(MUSES-C), launched 2003, arrived at Itokawa 2005.
It collect samples for about 3 months.
returned to the earth in 2010, June 13

HAYABUSA landed on Itokawa

Eros is (33 km x 13 km x 13 km)
density is 2.7 g/cc
Eros has little gravity---200 pound person would weigh 2 ounces

A"rubble pile" of 4.5-billion-year-old planetary debris that loosely coalesced only about 10 million years ago.
Non-Belt Asteroids

Asteroid orbits can be changed by the gravitational influence of nearby massive Jupiter. The orbits may eventually become interlopers with orbits that cross the Earth’s orbit.

- Atens
- Apollos
- Amors
- Trojan

Atens--Venus Crossing
✓ orbital period less than 1 year.
✓ 300 Atens

Apollos: Earth crossing
✓ orbit periods that are longer than one year.
✓ More than 1,700 Apollos

Amors: Mars crossing
Mars’ orbit but do not quite cross Earth’s orbit.
✓ More than 1,500

Earth-Approaching Asteroids --NEO

- 1992 5-km NEO Toutatis, approached the Earth at less than 3 times the distance to the Moon
- Radar images show it is a double object 3 and 2 km objects squashed together.
- Toutatis is in a 4 year orbit which moves it from the asteroid belt to just inside Earth’s orbit.

- 640 NEOs larger than 1km located by the end of 2002---Actual population more likely to be > millions.
- Fate: Collide with our planet or be ejected from the Solar System
- Impact – once every 100 million years...

Near-Earth Asteroid

In April 2029, an asteroid called Apophis will come within five Earth radii - below the orbits of geosynchronous satellites,

Discovered in 2004, Apophis, 200x 1000 meter, will make a historically close approach to the Earth
Centaur Asteroids: orbit between Jupiter and Neptune
- called "Centaurs" because of their "half-comet, half-asteroid" status,
- many have diameters greater than 100 km
- There are over 100 Centaur asteroids known

Example: Chiron first centaur 1977

Period 50.7 year Rotation: 5.9 hr.

It exhibits a faint dust and gas coma like a comet.

Because of this dual nature it was named after a centaur, one of the mythical half-human horses of ancient Greek mythology

Appearance of Comets

Observed since antiquity
Typical comets appear as rather faint, diffuse spot of light – smaller than the Moon, and many times less brilliant.

Small chunk of icy material that develop an atmosphere as they get closer to the Sun.

As they get “very close” they may develop a faint, nebulous tail extending far from the main body of the comet.

Typically remain visible for periods from a few days to a few months.

Appearance seemingly unpredictable

Comet Census

Records exist for ~1000 comets

Comets are discovered at an average rate of 5-10 per year.

Most visible only on photos made with large telescopes.

Every few years, a comet appears that is bright enough to be seen with the naked eye.

Comets are given a name consisting of the year of perihelion passage followed by a roman numeral in order of perihelion passage.

Often the discoverer’s name precedes the designation; for example, Comet Bennett 1970 II.

If the comet is periodic, the letter P followed by the discoverer’s name, as in comet 1910 II P/Halley.

Comets

In antiquity, comets were thought to be harbingers of doom. Even in recent time, during the Halley appearance in 1910, the detection of various gases in the comet tail gave rise to panic. Newspapers and magazines were full of dreadful stories, showing people poisoned in the streets by e.g. comet Carbon Monoxide and HCN (Cyanic Acid) gases:
Halley's comet is one of the most famous; it has a period of 76 years and has been observed since antiquity.

Edmond Halley pointed out that the parameters of the comets of 1533, 1607 and 1682 were the same and concluded that this was a periodic comet.

(8 November 1656 – 14 January 1742) an English astronomer

He predicted its return in 1758. In that year (Halley had died in 1742) the comet appeared as predicted and has been called Halley's Comet ever since.

Comet Halley
- Observed on every passage at intervals from 74 to 79 years since 239 B.C.
- Period variations caused by Jovian planets
- 1910, Earth was brushed by the comet tail. – causing much public concern...
- Last appearance in our skies – 1986.
- Return of Halley in 2061.

Met by several spacecrafts
In 1986, the European spacecraft Giotto became the first spacecraft to encounter and photograph the nucleus of a comet.

Enhanced image of the potato shaped nucleus that measures roughly 15 kilometers across.

Dark nucleus is on the right, while gas and dust flowing into Halley's coma are on the left.

Spacecraft and Comets
Comet Halley 1984 and 1985:
- ESA mission
- Japan mission, Soviet mission

Comet P/Wild 2:
- Stardust, NASA sample return to P/Wild 2
  - Launch February 7, 1999  Sampled returned 2004

Comet Tempel 1:
- Deep Impact, NASA mission to comet Tempel 1
  - Launch January 12, 2005  Impact on July 4, 2005
  - A bright curtain of hot gas and dust emerged and expanded from the crater—— revealed a complex mix of silicates, water and organic compounds.

Comet Structure
- **nucleus:** mostly ice with a small amount of dust
- **coma:** dense cloud of water, carbon dioxide and other neutral gases sublimed off of the nucleus
- **hydrogen cloud:** huge (millions of km in diameter) but very sparse envelope of neutral hydrogen
- **dust tail:** up to 10 million km long composed of smoke-sized dust particles driven off the nucleus by escaping gases
- **Ion(Plasma) tail:** several hundred million km long composed of plasma and interacts with the solar wind
The nucleus
10 or 20 km across.

Composition: 80% H₂O, 10% CO, 3.5% CO₂, ammonia and other organic compounds.

The ice is mixed with stony and metallic solids, and it is all contained within a dark black crust.

When the comet approaches the Sun, the gases evaporate in jets through vents in the crust.

The material in these jets ultimately forms the coma and tails.

When the comet approaches the Sun, the gases ultimately forms the Hydrogen envelope and coma

Hydrogen envelope 10 million km across

Coma---1,000,000 km

the hydrogen cloud is not visible from the Earth, as it is only detectable in ultraviolet light.

Types of Tails

A dust tail is created as radiation pressure from the Sun pushes dust particles away from the nucleus. The broad, yellowish dust tail curves behind the comet’s head. We see it by the sunlight that it reflects toward us.

The blue tail is made of ions given off by the comet’s nucleus and is blown in the direction opposite to the Sun by the solar wind. We detect this “gas tail” by its own emission.
Short Period Comets periods less than 200 years

Of the two dozen or so comets that are seen each year through telescopes, the majority are short-period comets, with periods of less than 200 years; the most famous of them is Halley's Comet. They closely confined to the ecliptic plane

Source of Short Period Comets

Short-period comets originate in the Kuiper belt. These bodies lie near the plane of the solar system.

The Kuiper belt is a disk-shaped region past the orbit of Neptune roughly 30 to 100 AU from the Sun containing many small icy bodies.

When Kuiper belt objects are gravitationally disturbed and come into contact with the inner solar system, they become short period comets (orbits of 20 to 200 years).

Comet Reservoirs: Kuiper Belt and Oort Cloud

Comets are left over from the formation of the Solar System.

Comets in the Oort cloud can be perturbed by the gravitational influence of passing stars or interstellar clouds and thrown into new, orbits that bring them into the inner Solar System.

Long Period Comets periods greater than 200 years

Dutch astronomer Jan Hendrik Oort first proposed the existence of a comet cloud in 1950 to explain the paths of comets that take more than 200 years to orbit the sun.

Origin

The model suggests that the comets started out near Jupiter and the other gas giants, until gravitational encounters with those planets knocked the primordial bits into the Oort Cloud. The cloud would have taken about a billion years to form.

Barely 5 percent of that original material remains in the Oort cloud; the rest was ejected entirely from the solar system.

Over time, the gravitational pulls of passing stars jostles the orbits of the objects, causing them to approach the inner solar system.

Fate of Comets

- Comets spend nearly all their existence in the Oort cloud or Kuiper belt
- As comet enters the inner Solar System, their “life” changes altogether!
- If they survive the initial passage they may return towards their original location, may impact the Sun or interact with a planet
- Each flyby the Sun reduces the size and mass of the nucleus of the comets.

- Breakups is the ultimate fate of most comets,”
- Evaporation Rate: 10 tons/ second near the Sun
- Lifetime: about 5000 orbits or about 400,000 years for Halley's Comet
Shoemaker-Levy 9: Its last orbit

• SL-9 passed close to Jupiter in July 1992
• Tides pulled the comet apart
• Each fragment on slightly different orbit, headed towards Jupiter
• Impacts on Jupiter over period 16 – 22 July 1994

Comet Shoemaker-Levy 9: Over twenty fragments, each with its own tail, appear in this image taken six months before their collisions with Jupiter.


End of Chapter