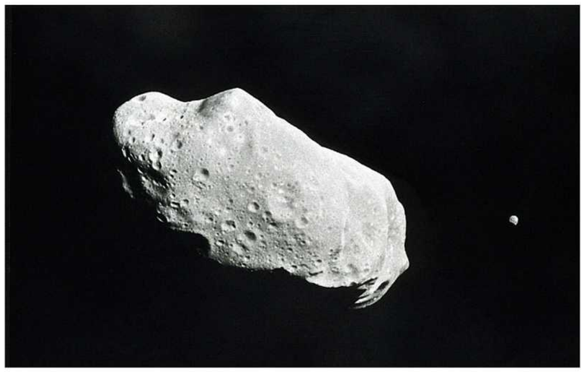
ASTEROIDS

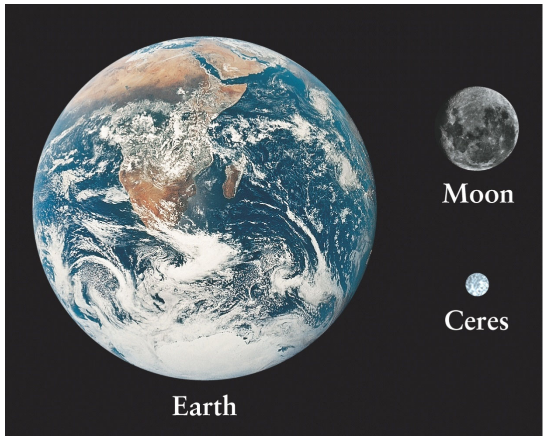


Discovery of the Asteroids

Most of the asteroids are located between the orbits of Mars and Jupiter. From the time of Kepler, it was recognized that this region of the Solar System represented a gap in the spacing of planetary orbits. The Titius-Bode Law predicted a planet at 2.8 AU. After the discovery of Uranus seemed to confirm this "law", many astronomers felt there should be a concerted effort to locate this missing planet.

Ceres	January 1, 1801	1000 km
Pallas	March 1802	540
Juno	1804	265
Vesta	1807	510
Moon		3476 km

Size Scale



Naming an Asteroid

Today, more than 50,000 asteroids are known, and tens or hundreds more are discovered every month.

After the discoverer reports a new object to the Minor Planet Center of the Smithsonian Astrophysical Observatory, the new asteroid is given a provisional designation. If the asteroid is located again on at least four successive oppositions, it is assigned an official sequential number.

Then the discoverer is given the privilege of suggesting a name.

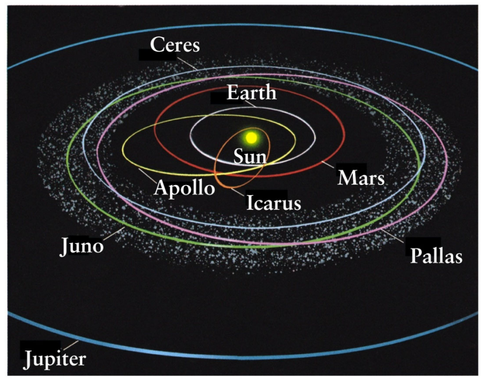
The name must be approved by the International Astronomical Union.

Orbits of Asteroids

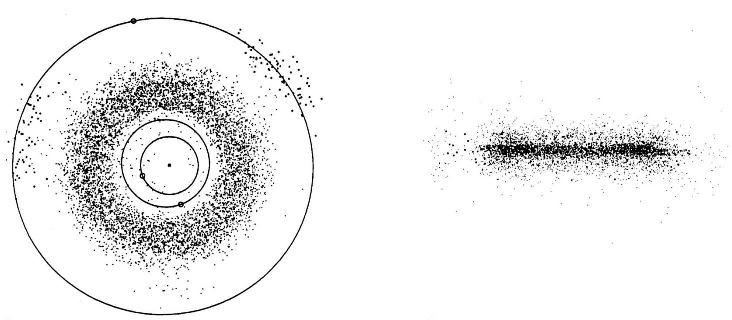
The asteroids all revolve about the Sun in the same direction as the planets, and most have orbits that lie in the plane of the Earth's orbit.

The main belt contains objects with semi-major axes in the range of 2.2 to 3.3 AU, with corresponding periods of orbital revolutions about the Sun from 3.3 to 6 years.

The spacing between asteroids is approximately 5 million km or 12 times the Earth-Moon distance.



Asteroid Belt



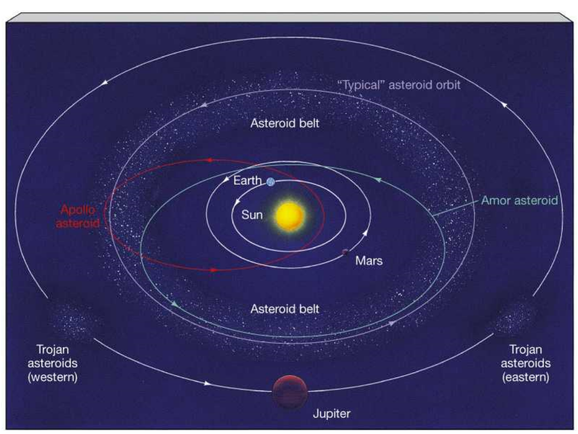
Families of Asteroids

In 1917 the Japanese astronomer K. Hirayama found that a number of the asteroids fall into families – groups with similar orbital characteristics.

He hypothesized that each family may have resulted from the breakup of a larger body or from the collision of two bodies. Slight differences in the initial velocities of the fragments account for the small spread in orbital characteristics now observed for the different asteroids in a given family.

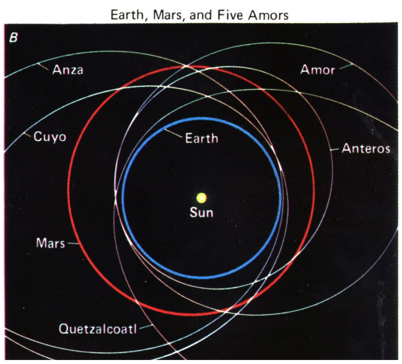
There are several such families.

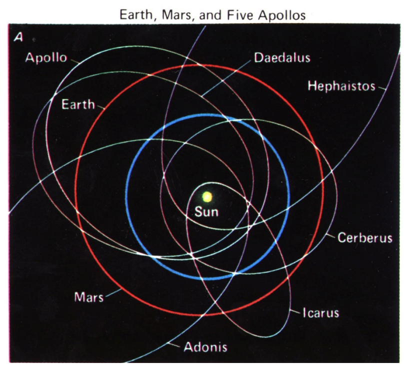
Orbits of Families



Earth Approaching Asteroids

Three groups: **Atens** (orbits completely inside the Earth's), **Apollos** (orbits cross the Earth's), and **Amors** (orbits cross Mars' orbit). About 100 are known, but could be as many as 2000 objects down to 0.5 km diameter size.

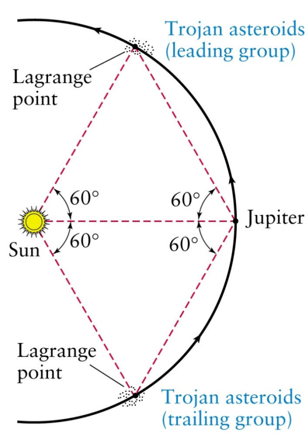




The Trojans

The **Trojan asteroids** are objects located far beyond the main belt, orbiting the Sun at about the same distance as Jupiter. Lagrangian points L4 and L5 are the two points that with Jupiter and the Sun make equilateral triangles.

The Trojans are all very dark, primitive objects like those in the outer part of the asteroid belt. The total mass of the Trojan asteroids is about equal to that of the asteroid belt.

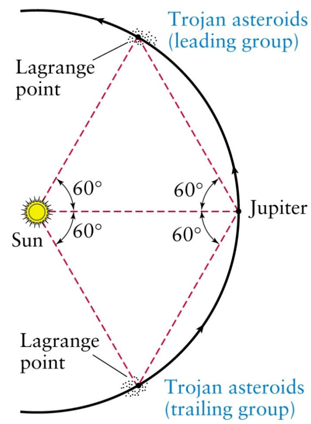


The Trojans

There are currently over 1,800 Trojan asteroids associated with Jupiter. About 60% of these belong to the preceding group (L4), while the other 40% cluster around the L5 point and trail 60^o behind.

The term *Trojan asteroid* was coined when it was decided to name all asteroids discovered at the L4 and L5 points after warriors in the Trojan war, Greek and Trojan, respectively.

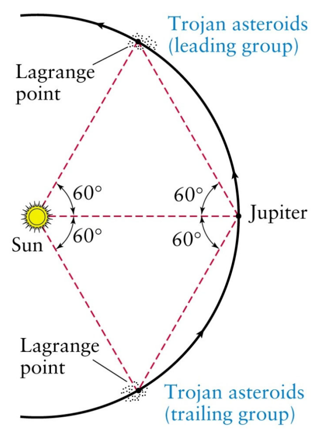
The exceptions are Hector (a Trojan spy in the Greek camp) and Patroclus (a Greek spy in the Trojan camp).



The Trojans

Although their orbits are stabilized at the Lagrangian points by gravitational interactions with Jupiter and the Sun, their actual distribution is elongated along the orbit.

Perturbations by the other planets (primarily Saturn) cause the Trojans to oscillate around L4 and L5 by 15 - 20^o and at inclinations of up to 40^o to the orbital plane. These oscillations take between 150 and 200 years to complete.

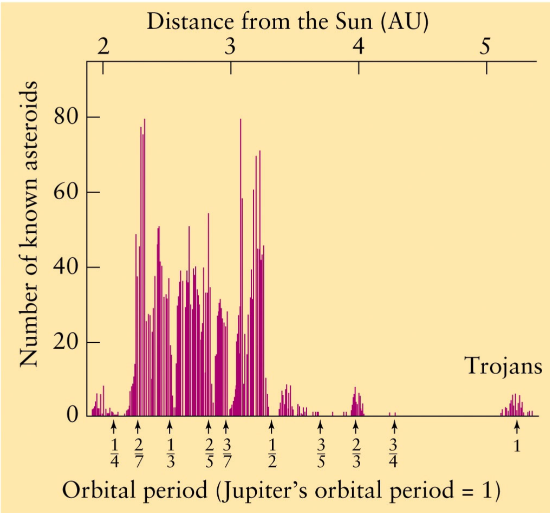


Orbits of Asteroids

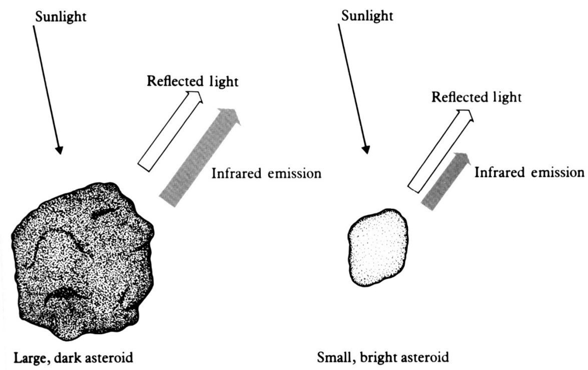
An interesting characteristic in the distribution of asteroid orbits is the existence of several gaps, corresponding to orbital periods that the asteroids seem to avoid. These unoccupied periods were interpreted in 1866 by the American astronomer Daniel Kirkwood as a **resonance** phenomenon caused by the **gravitational perturbations from Jupiter**.

For example, an asteroid at about 5/8 of Jupiter's distance from the Sun (3.3 AU) would have a period exactly half that of Jupiter. Every two times around the Sun it would find itself relatively near the planet. The repeated attractions toward Jupiter, always in the same direction, would eventually perturb the orbit of such an asteroid, just as **resonances** with moons produce gaps in the rings of Saturn.

Kirkwood Gaps

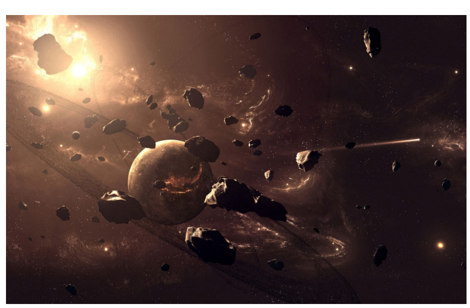


Differential Photometry



Composition and Classification

When the **reflectivities** of many asteroids are compared, a great diversity is seen. (1) The majority are very dark, with reflectivities of only 3 to 5%, about as dark as a lump of coal. (2) However, there is another group with typical reflectivities of about 15%, a little brighter than the Moon. (3) Still others have reflectivities as high as 60%. From these reflectivity measurements we can see that there are different kinds of asteroids.



(1) Composition and Classification

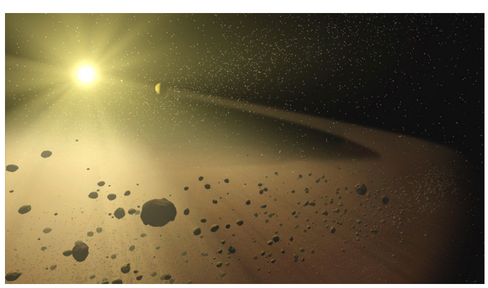
The majority of the asteroids are seen to be **primitive bodies**, composed of silicates mixed with dark organic carbon compounds. The presence of these dark materials reduces the reflectivities of the asteroids to the 3% to 5% level observed. Many of these objects also include some water chemically bonded to the silicates.

Two of the largest asteroids, **Ceres** and **Pallas**, are primitive, as are almost all of the objects in the outer third of the belt. Most of the primitive asteroids are classed as **C** asteroids, where the **C** stands for Carbonaceous.

However, beyond 3 AU, the **C** asteroids thin out and are replaced by other primitive forms with different spectra. These appear to be composed of other mixtures of silicates and carbon compounds.

(2) Composition and Classification

The second most populous asteroid group comprises the **S** asteroids, where the **S** stands for "silicaceous". In these, the dark carbon compounds are missing, resulting in higher reflectivities and clearer spectral signatures of silicate minerals. The minerals present are common ones, similar to those in many meteorites, but the exact compositions of the **S** asteroids remain in dispute. Scientists do not know if they are primitive or differentiated.



(3) Composition and Classification

Spectral observations have identified a few asteroids, not more than 5% of the total, that are clearly **differentiated** objects. These include the **M** class asteroids, which are made largely of **Metals** (presumably the cores of differentiated parent bodies that were shattered in collisions).

Other differentiated asteroids have **basaltic** surfaces like the volcanic plains of the Moon and Mars. The large asteroid **Vesta** is in this category.

Statistical Studies of Sizes

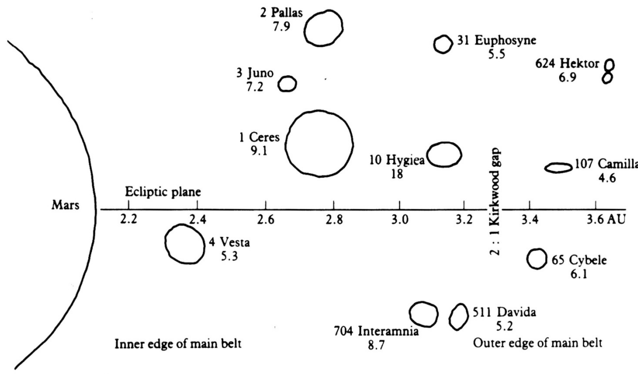
The largest asteroid is **Ceres**, with a diameter of just under 1000 km. Two asteroids have diameters near 500 km, and about 30 are larger than 200 km. The number of asteroids increases rapidly with decreasing size; the number that are 10 km across is more than 100 times greater than the number of objects 100 km across.

Our census of asteroids is ~ 99% complete for objects down to 100 km in diameter, and at least 50% complete for those down to 10 km.

It is possible to estimate the total mass of the asteroids, which is about 1/20 the mass of the Moon. **Ceres** accounts for nearly half of the total mass.

Asteroid Sizes

FIGURE 5.3 This scale drawing shows the relative sizes of some of the larger asteroids compared with that of the planet Mars. The numbers next to the names give the rotation periods in hours. The horizontal scale gives the mean distance from the Sun in astronomical units (AU).



Masses and Densities

Measurements of reflected sunlight provide only surface information − not masses and densities. Only for the largest asteroids have the masses been measured, which is by the perturbations they produce on other asteroids.

The densities of **Ceres** and **Pallas** (2.4 and 2.6 g/cm^3) are about what one would expect for primitive bodies with little or no water ice.

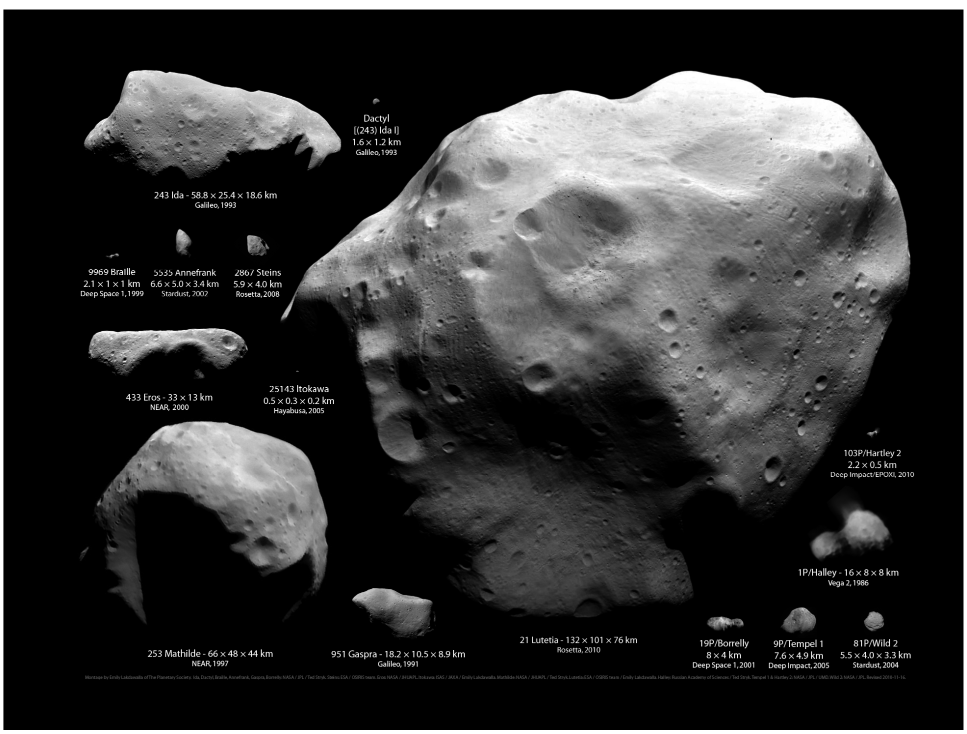
Vesta apparently has a higher density, presumably the result of loss of volatiles when it differentiated.

Asteroid Statistics

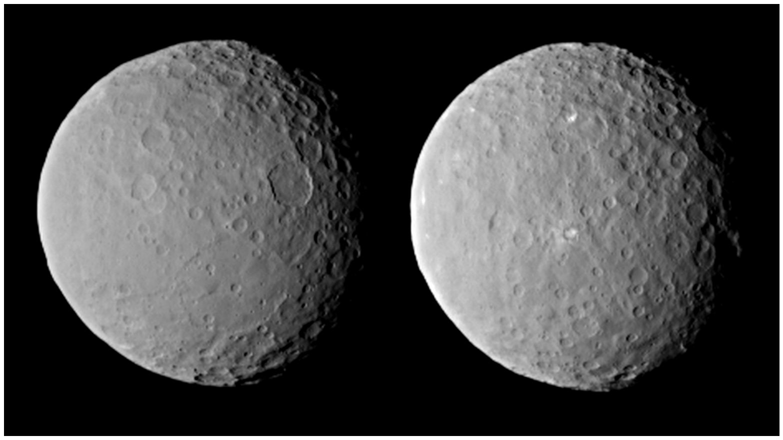
TABLE 5.1 The 20 largest asteroids

Name	Discovery	Semimajor Axis (AU)	Diameter (km)	Class
1 Ceres	1801	2.77	940	C
2 Pallas	1802	2.77	540	C
4 Vesta	1807	2.36	510	*
10 Hygeia	1849	3.14	410	C
704 Interamnia	1910	3.06	310	C
511 Davida	1903	3.18	310	C
65 Cybele	1861	3.43	280	C
52 Europa	1868	3.10	280	C
87 Sylvia	1866	3.48	275	C
3 Juno	1804	2.67	265	S
16 Psyche	1852	2.92	265	M
451 Patientia	1899	3.07	260	C
31 Euphrosyne	1854	3.15	250	C
15 Eunomia	1851	2.64	245	S
324 Bamberga	1892	2.68	235	C
107 Camilla	1868	3.49	230	C
532 Herculina	1904	2.77	230	S
48 Doris	1857	3.11	225	C
29 Amphitrite	1854	2.55	225	S
19 Fortuna	1852	2.44	220	C

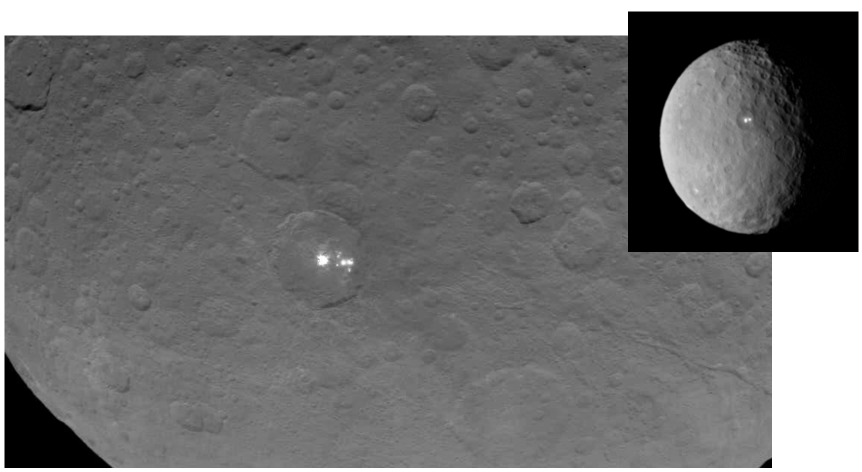
*Vesta has a very unusual (once thought unique) basaltic surface.



Dawn Spacecraft Orbits Ceres

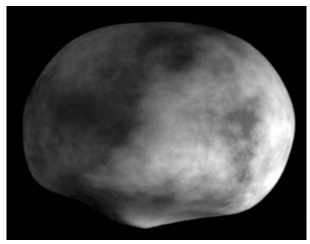


Ceres: Unexplained Bright Spots



Vesta

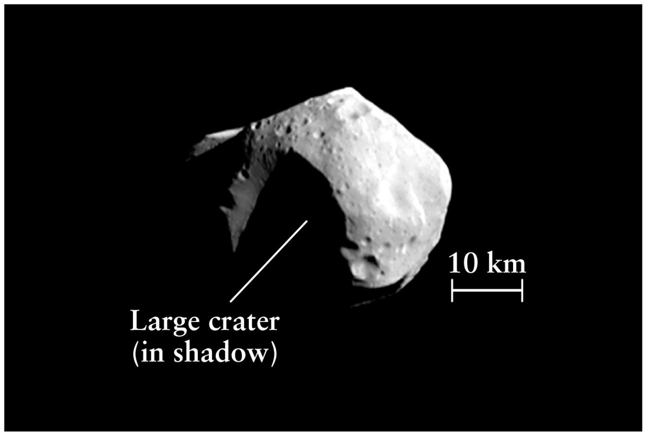
Vesta's surface is covered with **basalt**, indicating it was once volcanically active in spite of its small size (500 km). Vesta is the only large asteroid with a basaltic surface, although several very small objects composed of basalt have been recently discovered.



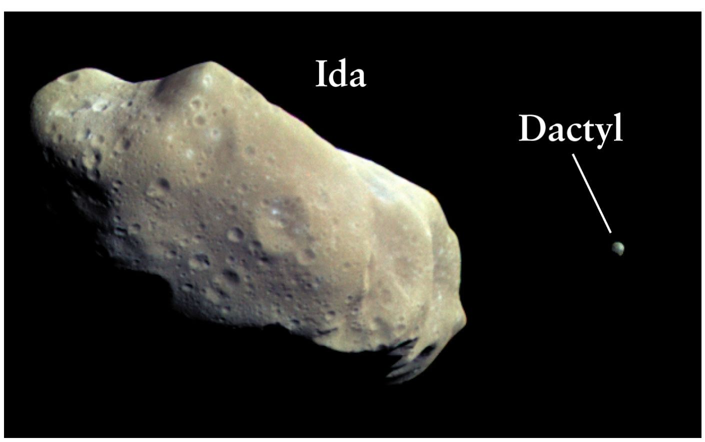
Gaspra

(16 x 11 x 10 km)

Mathilde

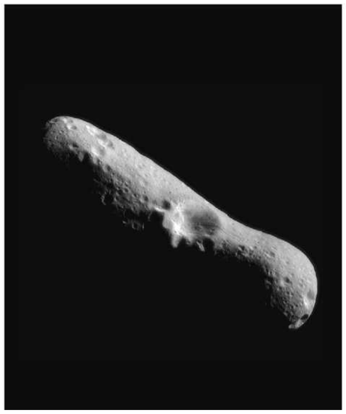


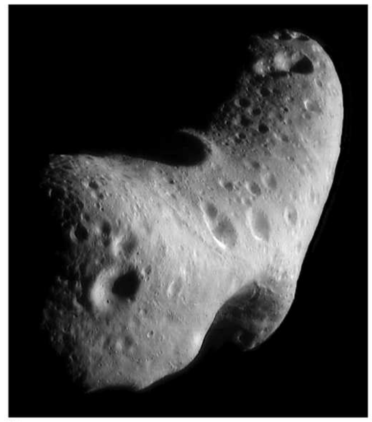
Ida and Dactyl



(Ida: 56 km; Dactyl: 1.5 km; Distance: 100 km)

Eros

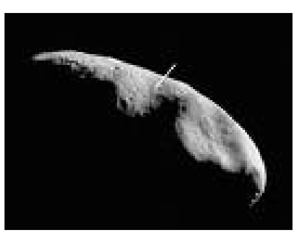


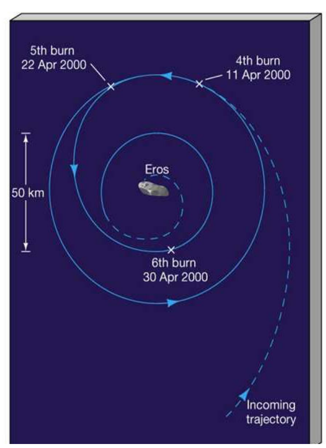


(33 x 13 km)

Eros Landing

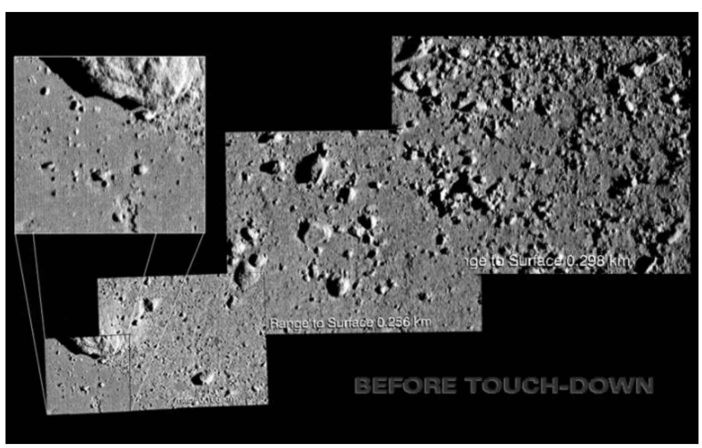
On 12 February 2001, the NEAR spacecraft touched down on asteroid Eros, after transmitting 69 close-up images of the surface during its final descent.



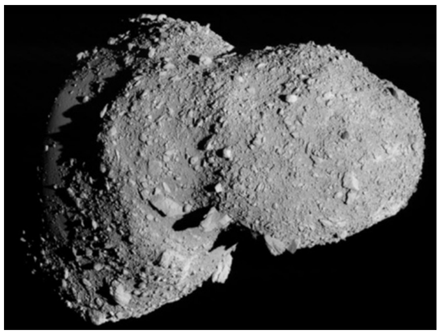


Eros' Surface

Landing on Eros



Itokawa



The ***Hayabusa*** spacecraft images of **Itokawa** show a lack of impact craters, and a very rough surface studded with boulders.

This would mean that Itokawa is not a monolith but rather a 'rubble pile' formed from fragments that gravi-tated toward each other and stuck together.

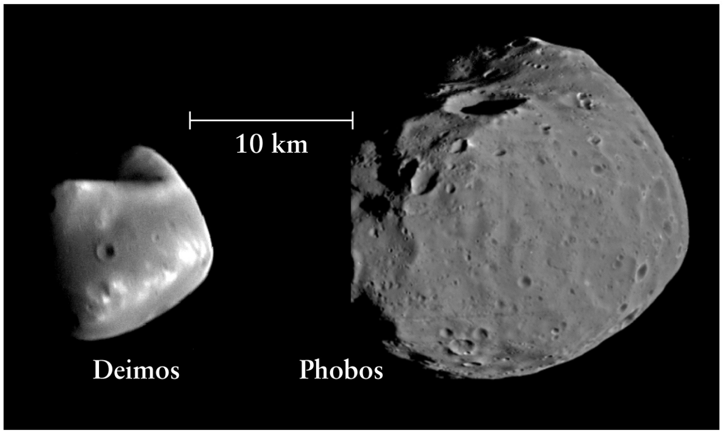
Phobos and Deimos

These two moons of Mars are probably captured asteroids.

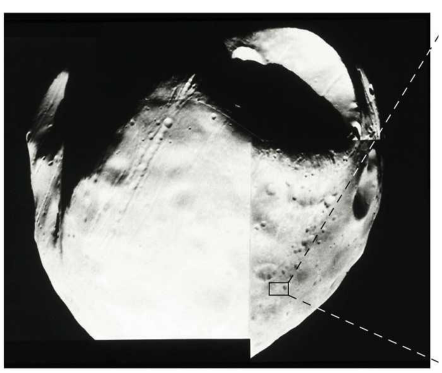
Both have an irregular, somewhat elongated shape, are heavily cratered, and are chemically primitive.

Each one has a density of about 2.0 g/cm^3. This density is low for rocky objects, since the temperature is such that water ice should not be present. But the composition is still a mystery.

Phobos and Deimos



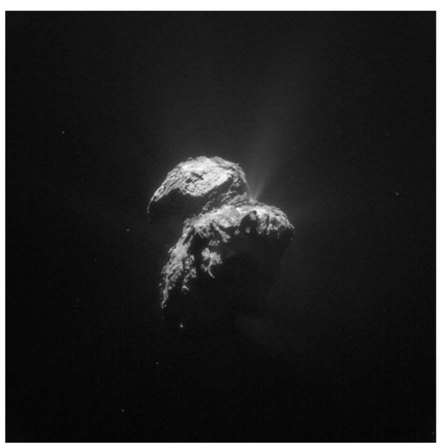
Phobos



Interstellar (?) Asteroid Ouamuamua

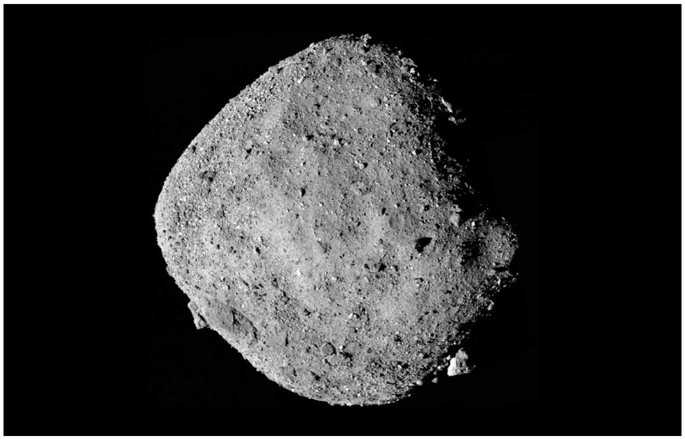
Description

Rosetta (Philae) Lands on a Comet



Philae Lands on a Comet

Osiris-Rex Lands on an Asteroid



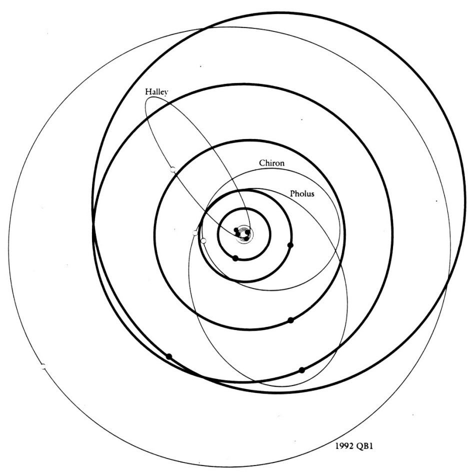
Osiris-Rex Lands on Asteroid Bennu

Hidalgo and Chiron

These two go far beyond Jupiter's orbit. Ever since their discoveries, astronomers have wondered about the relationship between such distant asteroids and the comets.

If they were the latter, they should have volatiles and should develop an atmosphere.

This did happen for **Chiron** ("Ki-ron").

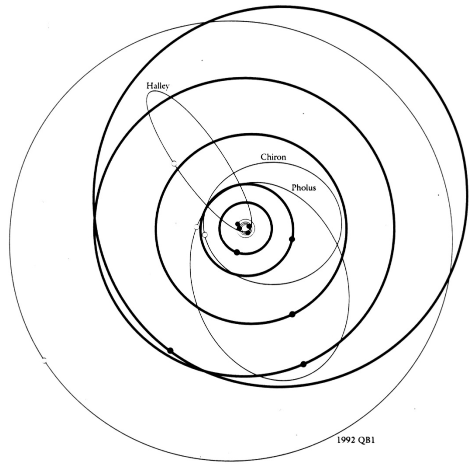


Hidalgo and Chiron

In February 1988, at 12 AU from the Sun, **Chiron** brightened by 75 percent. This is behavior typical of comets but not asteroids.

Further observations in April 1989 showed that Chiron had developed a cometary coma, and a tail was detected in 1993.

Chiron differs from other comets in that water is not a major component of its coma, because it is too far from the Sun for water to sublimate.



Hidalgo and Chiron

At the time of its discovery, **Chiron** was close to aphelion, whereas the observations showing a coma were done closer to perihelion, perhaps explaining why no cometary behavior had been seen earlier. The fact that Chiron is still active likely means it has not been in this orbit that long.

Chiron is officially designated as both a comet and an asteroid. The term proto-comet has also been used. Being at least 130 km in diameter, it is unusually large for a comet nucleus.

Since the discovery of Chiron, other **centaurs** have been discovered, and nearly all are currently classified as asteroids but are being observed for possible cometary behavior.