Comet

Comet Hale-Bopp, as seen on 29 March 1997 in Pazin, Croatia.

For other uses, see Comet (disambiguation).

A **comet** is a Small Solar System Body that orbits the Sun. When close enough to the Sun, a comet exhibits a visible coma (fuzzy "atmosphere"), and sometimes a tail, both because of the effects of solar radiation upon the comet's nucleus. Comet nuclei are themselves loose collections of ice, dust and small rocky particles, ranging from a few kilometers to tens of kilometers across.

1 Background

1.1 Name and symbol

The word ***comet*** came to the English language through the Latin *cometes* from the Greek word *komē*, meaning "hair of the head"; Aristotle first used the derivation *komētēs* to depict comets as "stars with hair." The astronomical symbol for comets (☄) accordingly consists of a disc with a hairlike tail.

1.2 Orbits and origin

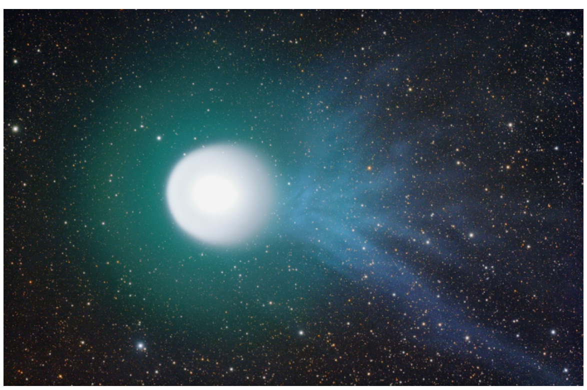
Comets have a variety of different orbital periods, ranging from a few years, to hundreds of thousands of years, while some are believed to pass only once through the inner Solar System before being thrown out into interstellar space. Short-period comets are thought to originate in the Kuiper Belt, or associated scattered disc,[1] which lie beyond the orbit of Neptune. Long-period comets are believed to originate in the Oort cloud, consisting of debris left over from the condensation of the solar nebula, located well-beyond the Kuiper Belt. Comets are thrown from these outer reaches of the Solar System towards the Sun by gravitational perturbations from the outer planets (in the case of Kuiper Belt objects) or nearby stars (in the case of Oort Cloud objects), or as a result of collisions between objects within these regions.

Comets are distinguished from asteroids by the presence of a coma or tail, though very old comets that have lost all their volatile materials may come to resemble asteroids (see extinct comets).[2] Asteroids are also believed to have a different origin from comets, having formed in the inner Solar System rather than the outer Solar System,[3] but recent findings[4] have somewhat blurred the distinction between asteroids and comets (see centaurs and asteroid terminology).

As of May 2009 there are a reported 3,648 known comets[5] of which about 1500 are Kreutz Sungrazers and about 400 are short-period.[6] This number is steadily increasing. However, this represents only a tiny fraction of the total potential comet population: the reservoir of comet-like bodies in the outer solar system may number one trillion.[7] The number of comets visible to the naked-eye averages to roughly one per year, though many of these are faint and unspectacular.[8] When a historically bright or notable naked-eye comet is witnessed by many people, it may be termed a Great Comet.

2 Physical characteristics

2.1 Nucleus



Comet Holmes (17P/Holmes) in 2007 showing blue ion tail on right

Main article: Comet nucleus

Comet nuclei are known to range from about 100 meters to more than 40 kilometers across. They are composed of rock, dust, water ice, and frozen gases such as carbon monoxide, carbon dioxide, methane and ammonia.[9]

They are often popularly described as "dirty snowballs", though recent observations have revealed dry dusty or rocky surfaces, suggesting that the ices are hidden beneath the crust (see Debate over comet composition). Comets also contain a variety of organic compounds; in addition to the gases already mentioned, these may include methanol, hydrogen cyanide, formaldehyde, ethanol and ethane, and perhaps more complex molecules such as long-chain hydrocarbons and amino acids.[10][11][12] Because of their low mass, comets cannot become spherical under their own gravity, and will thus have irregular shapes.

Surprisingly, cometary nuclei are among the darkest objects known to exist in the solar system. The Giotto probe found that Comet Halley's nucleus reflects approximately 4% of the light that falls on it,[13] and Deep Space 1 discovered that Comet Borrelly's surface reflects 2.4–3.0% of the light that falls on it;[13] by comparison, asphalt reflects 7% of the light that falls on it. It is thought that complex organic compounds are the dark surface material. Solar heating drives off volatile compounds leaving behind heavy long-chain organics that tend to be very dark, like tar or crude oil. The very darkness of cometary surfaces allows them to absorb the heat necessary to drive their outgassing.

2.2 Coma and tail

Main article: Coma (cometary)
Main article: Comet tail

In the outer solar system, comets remain frozen and are extremely difficult or impossible to detect from Earth due to their small size. Statistical detections of inactive comet nuclei in the Kuiper belt have been reported from the Hubble Space Telescope observations,[14][15] but these detections have been questioned,[16][17] and have not yet been independently confirmed. As a comet approaches the inner solar system, solar radiation causes the volatile materials within the comet to vaporize and stream out of the nucleus, carrying dust away with them. The streams of dust and gas thus released form a huge, extremely tenuous atmosphere around the comet called the *coma*, and the force exerted on the coma by the Sun's radiation pressure and solar wind cause an enormous *tail* to form, which points away from the sun.

Both the coma and tail are illuminated by the Sun and may become visible from Earth when a comet passes through the inner solar system, the dust reflecting sunlight directly and the gases glowing from ionisation. Most comets are too faint to be visible without the aid of a telescope, but a few each decade become bright enough to be visible to the naked eye. Occasionally a comet may experience a huge and sudden outburst of gas and dust, during which the size of the coma temporarily greatly increases in size. This happened in 2007 to Comet Holmes.

The streams of dust and gas each form their own distinct tail, pointing in slightly different directions. The tail of dust is left behind in the comet's orbit in such a manner that it often forms a curved tail called the antitail. At the same time, the ion tail, made of gases, always points directly away from the Sun, as this gas is more strongly affected by the solar wind than is dust, following magnetic field lines rather than an orbital trajectory. Parallax viewing from the Earth may sometimes mean the tails appear to point in opposite directions.[18]

While the solid nucleus of comets is generally less than 50 km across, the coma may be larger than the Sun, and ion tails have been observed to extend 1 astronomical unit (150 million km) or more.[9] The observation of antitails contributed significantly to the discovery of solar wind.[19] The ion tail is formed as a result of the photoelectric effect of solar ultra-violet radiation acting on particles in the coma. Once the particles have been ionised, they attain a net positive electrical charge which in turn gives rise to an "induced magnetosphere" around the comet. The comet and its induced magnetic field form an obstacle to outward flowing solar wind particles. As the relative orbital speed of the comet and the solar wind is supersonic a bow shock is formed upstream of the comet, in the flow direction of the solar wind. In this bow shock, large concentrations of cometary ions (called "pick-up ions") congregate and act to "load" the solar magnetic field with plasma, such that the field lines "drape" around the comet forming the ion tail.[20]

If the ion tail loading is sufficient, then the magnetic field lines are squeezed together to the point where, at some distance along the ion tail, magnetic reconnection occurs. This leads to a "tail disconnection event".[20] This has been observed on a number of occasions, notable among which was on the 20th. April 2007 when the ion tail of comet Encke was completely severed as the comet passed through a coronal mass ejection. This event was observed by the STEREO spacecraft.[21]

Comets were found to emit X-rays in 1996.[22] This surprised researchers, because X-ray emission is usually associated with very high-temperature bodies. The X-rays are thought to be generated by the interaction between comets and the solar wind: when highly charged ions fly through a cometary atmosphere, they collide with cometary atoms and molecules, "ripping of" one or more electrons from the comet. This ripping off leads to the emission of X-rays and far ultraviolet photons.[23]

2.3 Connection to meteor showers

As a result of outgassing, comets leave a trail of solid debris behind them. If the comet's path crosses Earth's path, then at that point there will likely be meteor showers as Earth passes through the trail of debris. The Perseid meteor shower occurs every year between August 9 and August 13, when Earth passes through the orbit of the Swift–Tuttle comet.[24] Halley's comet is the source of the Orionid shower in October.[24]

3 The fate of comets

3.1 Departure/ejection from Solar System

If a comet is traveling fast enough, it will enter and leave the solar system; such is the case for most non-periodic comets. In addition, comets can be ejected by interacting with another object in the solar system (see Perturbation), such as Jupiter.

3.2 Volatiles exhausted

Main article: Extinct comet

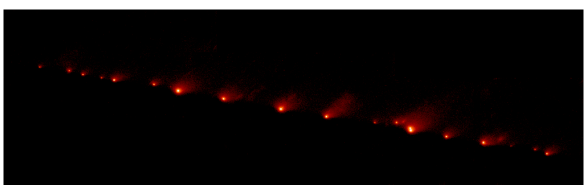
Jupiter family comets (JFC) and long period comets (LPC) (see "Orbital characteristics", below) appear to follow very different fading laws. The JFCs are active over a lifetime of about 10,000 years or ⍰1,000 revolutions while the LPCs disappear much faster. Only 10% of the LPCs survive more than 50 passages to small perihelion, while only 1% of them survives more than 2,000 passages.[25] Eventually most of the volatile material contained in a comet nucleus evaporates away, and the comet becomes a small, dark, inert lump of rock or rubble that can resemble an asteroid.[26]

3.3 Breakups/Disintegration

Comets are also known to break up into fragments, as happened with Comet 73P/Schwassmann-Wachmann 3 starting in 1995.[27]

This breakup may be triggered by tidal gravitational forces from the Sun or a large planet, by an "explosion" of volatile material, or for other reasons not fully explained.

3.4 Collisions



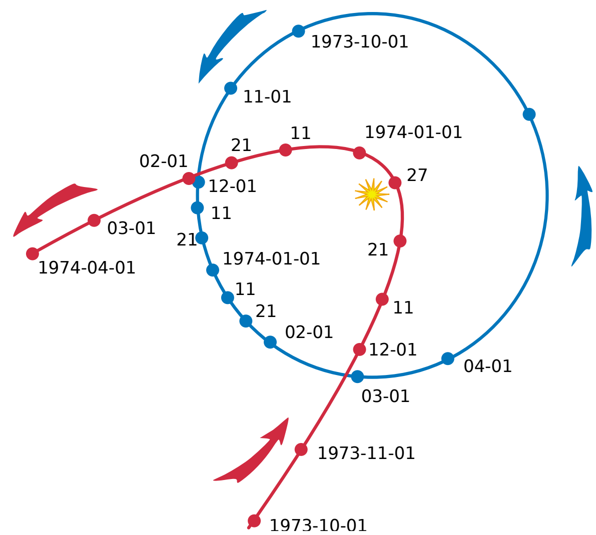
Shoemaker-Levy 9 was broken up by tidal forces shortly before colliding with Jupiter

Some comets meet a more spectacular end—either falling into the Sun,[28] or smashing into a planet or other body. Collisions between comets and planets or moons were common in the early Solar System: some of the many craters on the Earth's Moon, for example, may have been caused by comets. A recent collision of a comet with a planet occurred in 1994 when Comet Shoemaker-Levy 9 broke up into pieces and collided with Jupiter.

Many comets and asteroids collided into Earth in its early stages. Many scientists believe that comets bombarding the young Earth (about 4 billion years ago) brought the vast quantities of water that now fill the Earth's oceans, or at least a significant proportion of it. But other researchers have cast doubt on this theory.[29] The detection of organic molecules in comets has led some to speculate that comets or meteorites may have brought the precursors of life—or even life itself—to Earth.[11] There are still many near-Earth comets, although a collision with an asteroid is more likely than with a comet.

It is suspected that comet impacts have, over long timescales, also delivered significant quantities of water to the Earth's Moon, some of which may have survived as lunar ice.

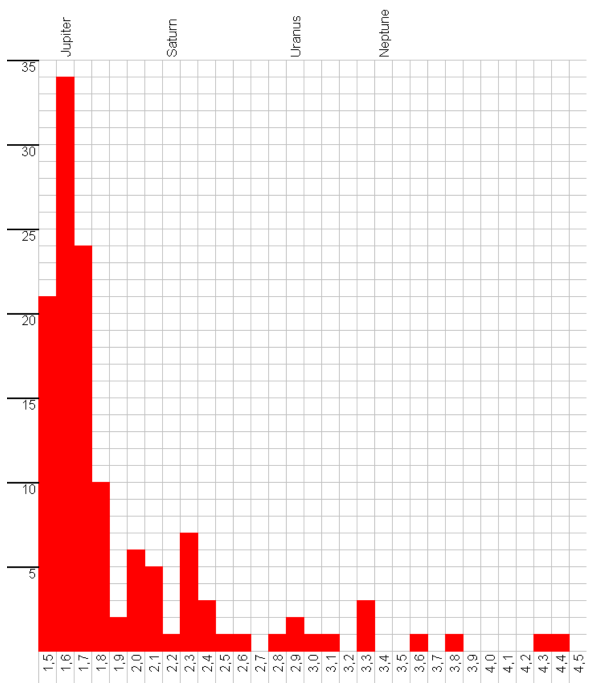
4 Orbital characteristics



Orbits of Comet Kohoutek (red) and Earth (blue), illustrating the high eccentricity of the orbit and more rapid motion when closer to the Sun.

Most comets have elongated elliptical orbits (oval shaped) that take them close to the Sun for a part of their orbit, and then out into the further reaches of the Solar System for the remainder. Comets are often classified according to the length of their orbital period; the longer the period the more elongated the ellipse.

- *Short-period comets* are generally defined as having orbital periods of less than 200 years. They usually orbit more-or-less in the ecliptic plane in the same direction as the planets. Their orbits typically take them out to the region of the outer planets (Jupiter and beyond) at aphelion; for example, Comet Halley's aphelion is a little way beyond the orbit of Neptune. At the shorter extreme, Comet Encke has an orbit which never places it farther from the Sun than Jupiter. Short-period comets



Histogram of the aphelia of the 2005 comets, showing the giant planet comet families. The abscissa is the natural logarithm of the aphelion expressed in AUs.

are further divided into the *Jupiter family* (periods less than 20 years) and *Halley family* (periods between 20 and 200 years).

- *Long-period comets* have highly eccentric (elongated) orbits and periods ranging from 200 years to thousands or even millions of years. (However, by definition they remain gravitationally bound to the Sun; those comets that are ejected from the solar system due to close passes by major planets are no longer properly considered as having "periods".) Their orbits take them far beyond the outer planets at aphelia, and the plane of their orbits need not lie near the ecliptic.

- *Single-apparition comets* are similar to long-period comets, but have parabolic or hyperbolic trajectories which will cause them to permanently exit the solar system after passing the Sun once.[30]

- Some authorities use the term *periodic comet* to refer to any comet with a periodic orbit (that is, all short-period comets plus all long-period comets),[31] while others use it to mean exclusively short-period comets.[30] Similarly, although the literal meaning of *non-periodic comet* is the same as *single-apparition comet*, some use it to mean all comets that are not "periodic" in the second sense (that is, to also include all comets with a period greater than 200 years).

- Recently discovered *main-belt comets* form a distinct class, orbiting in more circular orbits within the asteroid belt.[32][33]

Based on their orbital characteristics, short-period comets are thought to originate from the centaurs and the Kuiper belt/scattered disk[1]—a disk of objects in the transneptunian region—whereas the source of long-period comets is thought to be the far more distant spherical Oort cloud (after the Dutch astronomer Jan Hendrik Oort who hypothesised its existence).[34] Vast swarms of comet-like bodies are believed to orbit the Sun in these distant regions in roughly circular orbits. Occasionally the gravitational influence of the outer planets (in the case of Kuiper Belt objects) or nearby stars (in the case of Oort cloud objects) may throw one of these bodies into an elliptical orbit that takes it inwards towards the Sun, to form a visible comet. Unlike the return of periodic comets whose orbits have been established by previous observations, the appearance of new comets by this mechanism is unpredictable.

Since their elliptical orbits frequently take them close to the giant planets, comets are subject to further gravitational perturbations. Short period comets display a tendency for their aphelia to coincide with a giant planet's orbital radius, with the Jupiter family of comets being the largest, as the histogram shows. It is clear that comets coming in from the Oort cloud often have their orbits strongly influenced by the gravity of giant planets as a result of a close encounter. Jupiter is the source of the greatest perturbations, being more than twice as massive as all the other planets combined, in addition to being the swiftest of the giant planets. These perturbations may sometimes deflect long-period comets into shorter orbital periods (Halley's Comet being a possible example).

Early observations have revealed a few genuinely hyperbolic (i.e. non-periodic) trajectories, but no more than could be accounted for by perturbations from Jupiter. If comets pervaded interstellar space, they would be moving with velocities of the same order as the relative velocities of stars near the Sun (a few tens of kilometres per second). If such objects entered the solar system, they would have positive total energies, and would be observed to have genuinely hyperbolic trajectories. A rough calculation shows that there might be four hyperbolic comets per century,[35] within Jupiter's orbit, give or take one and perhaps two orders of magnitude.

A number of periodic comets discovered in earlier decades or previous centuries are now “lost.” Their orbits were never known well enough to predict future appearances. However, occasionally a “new” comet will be discovered and upon calculation of its orbit it turns out to be an old “lost” comet. An example is Comet 11P/Tempel-Swift-LINEAR, discovered in 1869 but unobservable after 1908 because of perturbations by Jupiter. It was not found again until accidentally rediscovered by LINEAR in 2001.[36]

5 Comet nomenclature

The names given to comets have followed several different conventions over the past two centuries. Before any systematic naming convention was adopted, comets were named in a variety of ways. Prior to the early 20th century, most comets were simply referred to by the year in which they appeared, sometimes with additional adjectives for particularly bright comets; thus, the "Great Comet of 1680" (Kirch's Comet), the "Great September Comet of 1882,” and the "Daylight Comet of 1910" (“Great January Comet of 1910”). After Edmund Halley demonstrated that the comets of 1531, 1607, and 1682 were the same body and successfully predicted its return in 1759, that comet became known as Comet Halley.[37] Similarly, the second and third known periodic comets, Comet Encke[38] and Comet Biela,[39] were named after the astronomers who calculated their orbits rather than their original discoverers. Later, periodic comets were usually named after their discoverers, but comets that had appeared only once continued to be referred to by the year of their apparition.

In the early 20th century, the convention of naming comets after their discoverers became common, and this remains so today. A comet is named after up to three independent discoverers. In recent years, many comets have been discovered by instruments operated by large teams of astronomers, and in this case, comets may be named for the instrument. For example, Comet IRAS-Araki-Alcock was discovered independently by the IRAS satellite and amateur astronomers Genichi Araki and George Alcock. In the past, when multiple comets were discovered by the same individual, group of individuals, or team, the comets' names were distinguished by adding a numeral to the discoverers' names (but only for periodic comets); thus Comets Shoemaker-Levy 1–9. Today, the large numbers of comets discovered by some instruments has rendered this system impractical, and no attempt is made to ensure that each comet has a unique name. Instead, the comets' systematic designations are used to avoid confusion.

Until 1994, comets were first given a provisional designation consisting of the year of their discovery followed by a lowercase letter indicating its order of discovery in that year (for example, Comet 1969i (Bennett) was the 9th comet discovered in 1969). Once the comet had been observed through perihelion and its orbit had been established, the comet was given a permanent designation of the year of its perihelion, followed by a Roman numeral indicating its order of perihelion passage in that year, so that Comet 1969i became Comet 1970 II (it was the second comet to pass perihelion in 1970)[40]

Increasing numbers of comet discoveries made this procedure awkward, and in 1994 the International Astronomical Union approved a new naming system. Comets are now designated by the year of their discovery followed by a letter indicating the half-month of the discovery and a number indicating the order of discovery (a system similar to that already used for asteroids), so that the fourth comet discovered in the second half of February 2006 would be designated 2006 D4. Prefixes are also added to indicate the nature of the comet:

- P/ indicates a periodic comet (defined for these purposes as any comet with an orbital period of less than 200 years or confirmed observations at more than one perihelion passage);
- C/ indicates a non-periodic comet (defined as any comet that is *not* periodic according to the preceding

definition);

- X/ indicates a comet for which no reliable orbit could be calculated (generally, historical comets);
- D/ indicates a comet which has broken up or been lost, referred to as dark comet;[41]
- A/ indicates an object that was mistakenly identified as a comet, but is actually a minor planet.

After their second observed perihelion passage, periodic comets are also assigned a number indicating the order of their discovery.[42] So Halley's Comet, the first comet to be identified as periodic, has the systematic designation 1P/1682 Q1. Comet Hale-Bopp's designation is C/1995 O1. Comets which first received a minor planet designation keep the latter, which leads to some odd names such as P/2004 EW38 (Catalina-LINEAR).

There are only five objects that are cross-listed as both comets and asteroids: 2060 Chiron (95P/Chiron), 4015 Wilson-Harrington (107P/Wilson-Harrington), 7968 Elst-Pizarro (133P/Elst-Pizarro), 60558 Echeclus (174P/Echeclus), and 118401 LINEAR (176P/LINEAR).

6 History of comet study

6.1 Early observations and thought

Before the invention of the telescope, comets seemed to appear out of nowhere in the sky and gradually vanish out of sight. They were usually considered bad omens of deaths of kings or noble men, or coming catastrophes, or even interpreted as attacks by heavenly beings against terrestrial inhabitants.[43] From ancient sources, such as Chinese oracle bones, it is known that their appearances have been noticed by humans for millennia. Some authorities interpret references to "falling stars" in Gilgamesh, the Book of Revelation and the Book of Enoch as references to comets, or possibly bolides.

In the first book of his *Meteorology*, Aristotle propounded the view of comets that would hold sway in Western thought for nearly two thousand years. He rejected the ideas of several earlier philosophers that comets were planets, or at least a phenomenon related to the planets, on the grounds that while the planets confined their motion to the circle of the Zodiac, comets could appear in any part of the sky.[44] Instead, he described comets as a phenomenon of the upper atmosphere, where hot, dry exhalations gathered and occasionally burst into flame. Aristotle held this mechanism responsible for not only comets, but also meteors, the aurora borealis, and even the Milky Way.[45]

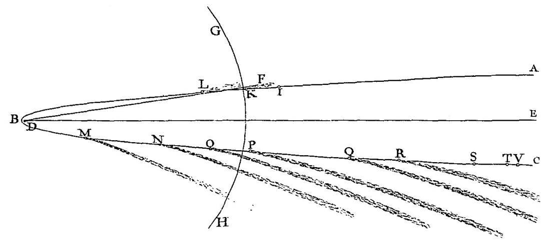
A few later classical philosophers did dispute this view of comets. Seneca the Younger, in his *Natural Questions*, observed that comets moved regularly through the sky and were undisturbed by the wind, behavior more typical of celestial than atmospheric phenomena. While he conceded that the other planets do not appear outside the Zodiac, he saw no reason that a planet-like object could not move through any part of the sky, humanity's knowledge of celestial things being very limited.[46] However, the Aristotelian viewpoint proved more influential, and it was not until the 16th century that it was demonstrated that comets must exist outside the Earth's atmosphere.

In 1577, a bright comet was visible for several months. The Danish astronomer Tycho Brahe used measurements of the comet's position taken by himself and other, geographically separated, observers to determine that the comet had no measurable parallax. Within the precision of the measurements, this implied the comet must be at least four times more distant from the earth than the moon.[47]

One very famous old recording of a comet is the appearance of Halley's Comet on the Bayeux Tapestry, which records the Norman conquest of England in AD 1066.[48]

6.2 Orbital studies

Although comets had now been demonstrated to be in the heavens, the question of how they moved through the heavens would be debated for most of the next century. Even after Johannes Kepler had determined in 1609 that the planets moved about the sun in elliptical orbits, he was reluctant to believe that the laws that governed the motions of the planets should also influence the motion of other bodies—he believed that comets travel among the planets along straight lines. Galileo Galilei, although a staunch Copernicanist, rejected Tycho's parallax measurements and held to the Aristotelian notion of comets moving on straight lines through



The orbit of the comet of 1680, fit to a parabola, as shown in Isaac Newton's Principia

the upper atmosphere.

The first suggestion that Kepler's laws of planetary motion should also apply to the comets was made by William Lower in 1610.[47] In the following decades other astronomers, including Pierre Petit, Giovanni Borelli, Adrien Auzout, Robert Hooke, Johann Baptist Cysat, and Giovanni Domenico Cassini all argued for comets curving about the sun on elliptical or parabolic paths, while others, such as Christian Huygens and Johannes Hevelius, supported comets' linear motion.

The matter was resolved by the bright comet that was discovered by Gottfried Kirch on November 14, 1680. Astronomers throughout Europe tracked its position for several months. In 1681, the Saxon pastor Georg Samuel Doerfel set forth his proofs that comets are heavenly bodies moving in parabolas of which the sun is the focus. Then Isaac Newton, in his *Principia Mathematica* of 1687, proved that an object moving under the influence of his inverse square law of universal gravitation must trace out an orbit shaped like one of the conic sections, and he demonstrated how to fit a comet's path through the sky to a parabolic orbit, using the comet of 1680 as an example.[49]

In 1705, Edmond Halley applied Newton's method to twenty-three cometary apparitions that had occurred between 1337 and 1698. He noted that three of these, the comets of 1531, 1607, and 1682, had very similar orbital elements, and he was further able to account for the slight differences in their orbits in terms of gravitational perturbation by Jupiter and Saturn. Confident that these three apparitions had been three appearances of the same comet, he predicted that it would appear again in 1758–9.[50] (Earlier, Robert Hooke had identified the comet of 1664 with that of 1618,[51] while Jean-Dominique Cassini had suspected the identity of the comets of 1577, 1665, and 1680.[52] Both were incorrect.) Halley's predicted return date was later refined by a team of three French mathematicians: Alexis Clairaut, Joseph Lalande, and Nicole-Reine Lepaute, who predicted the date of the comet's 1759 perihelion to within one month's accuracy.[53] When the comet returned as predicted, it became known as Comet Halley or Halley's Comet (its official designation is **1P/Halley**). Its next appearance will be in 2061.

Among the comets with short enough periods to have been observed several times in the historical record, Comet Halley is unique in consistently being bright enough to be visible to the naked eye. Since the confirmation of Comet Halley's periodicity, many other periodic comets have been discovered through the telescope. The second comet to be discovered to have a periodic orbit was Comet Encke (official designation **2P/Encke**). Over the period 1819–1821 the German mathematician and physicist Johann Franz Encke computed orbits for a series of cometary apparitions observed in 1786, 1795, 1805, and 1818, concluded that they were same comet, and successfully predicted its return in 1822.[38] By 1900, seventeen comets had been observed at more than one perihelion passage and recognized as periodic comets. As of April 2006, 175 comets have achieved this distinction, though several have since been destroyed or lost. In ephemerides, comets are often denoted by the symbol ☄.

6.3 Studies of physical characteristics

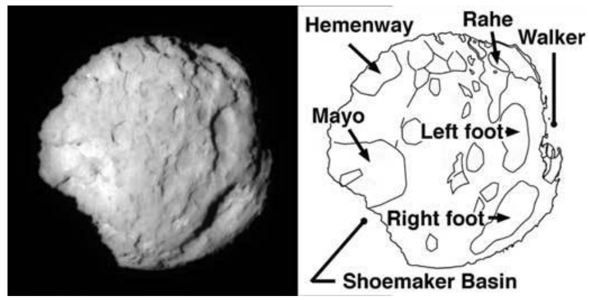
Isaac Newton described comets as compact and durable solid bodies moving in oblique orbits, and their tails as thin streams of vapor emitted by their nuclei, ignited or heated by the sun. Newton suspected that comets were the origin of the life-supporting component of air. Newton also believed that the vapors given off by comets might replenish the planets' supplies of water (which was gradually being converted into soil by the growth and decay of plants), and the sun's supply of fuel.

As early as the 18th century, some scientists had made correct hypotheses as to comets' physical composition. In 1755, Immanuel Kant hypothesized that comets are composed of some volatile substance, whose vaporization gives rise to their brilliant displays near perihelion.[54] In 1836, the German mathematician Friedrich Wilhelm Bessel, after observing streams of vapor in the 1835 apparition of Comet Halley, proposed that the jet forces of evaporating material could be great enough to significantly alter a comet's orbit and argued that the non-gravitational movements of Comet Encke resulted from this mechanism.[55]

However, another comet-related discovery overshadowed these ideas for nearly a century. Over the period 1864–1866 the Italian astronomer Giovanni Schiaparelli computed the orbit of the Perseid meteors, and based on orbital similarities, correctly hypothesized that the Perseids were fragments of Comet Swift-Tuttle. The link between comets and meteor showers was dramatically underscored when in 1872, a major meteor shower occurred from the orbit of Comet Biela, which had been observed to split into two pieces during its 1846 apparition, and was never seen again after 1852.[39] A "gravel bank" model of comet structure arose, according to which comets consist of loose piles of small rocky objects, coated with an icy layer.

By the middle of the twentieth century, this model suffered from a number of shortcomings: in particular, it failed to explain how a body that contained only a little ice could continue to put on a brilliant display of evaporating vapor after several perihelion passages. In 1950, Fred Lawrence Whipple proposed that rather than being rocky objects containing some ice, comets were icy objects containing some dust and rock.[56] This "dirty snowball" model soon became accepted. It was confirmed when an armada of spacecraft (including the European Space Agency's *Giotto* probe and the Soviet Union's *Vega 1* and *Vega 2*) flew through the coma of Halley's comet in 1986 to photograph the nucleus and observed the jets of evaporating material (though see also "Debate over comet composition", below). The American probe *Deep Space 1* flew past the nucleus of Comet Borrelly on September 21, 2001 and confirmed that the characteristics of Comet Halley are common on other comets as well.

Although comets formed in the outer Solar System, radial mixing of material during the early formation of the Solar System is thought to have redistributed material throughout the proto-planetary disk,[57] so comets also contain crystalline grains which were formed in the hot inner Solar System. This is seen in comet spectra as well as in sample return missions.



Comet Wild 2 exhibits jets on light side and dark side, stark relief, and is dry.

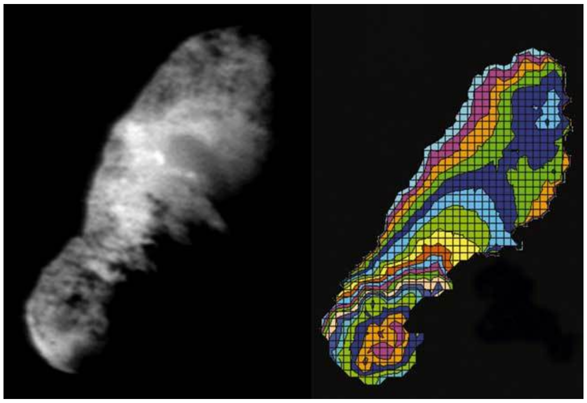
The *Stardust* spacecraft, launched in February 1999, collected particles from the coma of Comet Wild 2 in January 2004, and returned the samples to Earth in a capsule in January 2006. Claudia Alexander, a program scientist for Rosetta from NASA's Jet Propulsion Laboratory who has modeled comets for years, reported to space.com about her astonishment at the number of jets, their appearance on the dark side of the comet as well as on the light side, their ability to lift large chunks of rock from the surface of the comet and the fact that comet Wild 2 is not a loosely cemented rubble pile.[58]

Forthcoming space missions will add greater detail to our understanding of what comets are made of. In July 2005, the *Deep Impact* probe blasted a crater on Comet Tempel 1 to study its interior. And in 2014, the European *Rosetta* probe will orbit Comet Churyumov-Gerasimenko and place a small lander on its surface.

Rosetta observed the Deep Impact event, and with its set of very sensitive instruments for cometary investigations, it used its capabilities to observe Tempel 1 before, during and after the impact. At a distance of about 80 million kilometres from the comet, Rosetta was the only spacecraft other than Deep Impact itself to view the comet.

6.4 Debate over comet composition

Debate continues about how much ice is in a comet. In 2001, NASA's Deep Space 1 team, working at NASA's Jet Propulsion Lab, obtained high-resolution images of the sur-



Comet Borrelly exhibits jets, yet is hot and dry.

face of Comet Borrelly. They announced that comet Borrelly exhibits distinct jets, yet has a hot, dry surface. The assumption that comets contain water and other ices led Dr. Laurence Soderblom of the U.S. Geological Survey to say, "The spectrum suggests that the surface is hot and dry. It is surprising that we saw no traces of water ice." However, he goes on to suggest that the ice is probably hidden below the crust as "either the surface has been dried out by solar heating and maturation or perhaps the very dark soot-like material that covers Borrelly's surface masks any trace of surface ice".[59]

The recent Deep Impact probe has also yielded results suggesting that the majority of a comet's water ice is below the surface, and that these reservoirs feed the jets of vaporised water that form the coma of Tempel 1.[60]

However, more recent data from the Stardust mission show that materials retrieved from the tail of comet Wild 2 were crystalline and could only have been "born in fire."[61][62] More recent still, the materials retrieved demonstrate that the "comet dust resembles asteroid materials."[63] These new results have forced scientists to rethink the nature of comets and their distinction from asteroids.[64]

7 Notable comets

7.1 Great comets

Main article: Great Comet

While hundreds of tiny comets pass through the inner solar system every year, very few are noticed by the general public. About every decade or so, a comet will become bright enough to be noticed by a casual observer—such comets are often designated Great Comets. In times past, bright comets often inspired panic and hysteria in the general population, being thought of as bad omens. More recently, during the passage of Halley's Comet in 1910, the Earth passed through the comet's tail, and erroneous newspaper reports inspired a fear that cyanogen in the tail might poison millions,[65] while the appearance of Comet Hale-Bopp in 1997 triggered the mass suicide of the Heaven's Gate cult. To most people, however, a great comet is simply a beautiful spectacle.

Predicting whether a comet will become a great comet is notoriously difficult, as many factors may cause a comet's brightness to depart drastically from predictions. Broadly speaking, if a comet has a large and active nucleus, will pass close to the Sun, and is not obscured by the Sun as seen from the Earth when at its brightest, it will have a chance of becoming a great comet. However, Comet Kohoutek in 1973 fulfilled all the criteria and was expected to become spectacular, but failed to do so. Comet West, which appeared three years later, had much lower expectations (perhaps because scientists were much warier of glowing predictions after the Kohoutek fiasco), but became an extremely impressive comet.[66]

The late 20th century saw a lengthy gap without the appearance of any great comets, followed by the arrival of two in quick succession—Comet Hyakutake in 1996, followed by Hale-Bopp, which reached maximum brightness in 1997 having been discovered two years earlier. The first great comet of the 21st century was Comet McNaught, which became visible to naked eye observers in January 2007. It was the brightest in over 40 years.

7.2 Sungrazing comets

Main article: Sungrazing comet

A Sungrazing comet is a comet that passes extremely close

The Great Comet of 1882, is a member of the Kreutz group

to the Sun at perihelion, sometimes within a few thousand kilometres of the Sun's surface. While small sungrazers can be completely evaporated during such a close approach to the Sun, larger sungrazers can survive many perihelion passages. However, the strong tidal forces they experience often lead to their fragmentation.

About 90% of the sungrazers observed with SOHO are members of the Kreutz group, which all originate from one giant comet that broke up into many smaller comets during its first passage through the inner solar system.[67] The other 10% contains some sporadic sungrazers, but four other related groups of comets have been identified among them: the Kracht, Kracht 2a, Marsden and Meyer groups. The Marsden and Kracht groups both appear to be related to Comet 96P/Machholz, which is also the parent of two meteor streams, the Quadrantids and the Arietids.[68]

7.3 Unusual comets

Of the thousands of known comets, some are very unusual. Comet Encke orbits from outside the main asteroid belt to inside the orbit of Mercury while Comet 29P/Schwassmann-Wachmann currently travels in a nearly circular orbit entirely between Jupiter and Saturn.[69] 2060 Chiron, whose unstable orbit is between Saturn and Uranus, was originally classified as an asteroid until a faint coma was noticed.[70] Similarly, Comet Shoemaker-Levy 2 was originally designated asteroid 1990 UL3.[71] Roughly six percent of the near-earth asteroids are thought to be extinct nuclei of comets which no longer experience outgassing.[25]

Some comets have been observed to break up during their perihelion passage, including great comets West and Ikeya-Seki. Comet Biela was one significant example, breaking into two during its 1846 perihelion passage. The two comets were seen separately in 1852, but never again afterward. Instead, spectacular meteor showers were seen in 1872 and 1885 when the comet should have been visible. A lesser meteor shower, the Andromedids, occurs annually in November, and is caused by the Earth crossing Biela's orbit.[72]

Another significant cometary disruption was that of Comet Shoemaker-Levy 9, which was discovered in 1993. At the time of its discovery, the comet was in orbit around Jupiter, having been captured by the planet during a very close approach in 1992.[73] This close approach had already broken the comet into hundreds of pieces, and over a period of 6 days in July 1994, these pieces slammed into Jupiter's atmosphere—the first time astronomers had observed a collision between two objects in the solar system.[74] It has also been suggested that the object likely to have been responsible for the Tunguska event in 1908 was a fragment of Comet Encke.[75]

8 Observation

A new comet may be discovered photographically using a wide-field telescope or visually with binoculars. However, even without access to optical equipment, it is still possible for the amateur astronomer to discover a Sun-grazing comet online by downloading images accumulated by some satellite observatories such as SOHO.[76]

Comets visible to the naked eye are fairly infrequent, but comets that put on fine displays in amateur class telescopes (50 mm to 100 cm) occur fairly often—as often as several times a year, occasionally with more than one in the sky at the same time. Commonly available astronomical software will plot the orbits of these known comets. They are fast compared to other objects in the sky, but their movement is usually subtle in the eyepiece of a telescope. However, from night to night, they can move several degrees, which is why observers find it useful to have a sky chart such as the one in the adjoining illustration.

The type of display presented by the comet depends on its composition and how close it comes to the sun. Because the volatility of a comet's material decreases as it gets further from the sun, the comet becomes increasingly difficult to observe as a function of not only distance, but the progressive shrinking and eventual disappearance of its tail and the reflective elements it carries. Comets are most interesting when their nucleus is bright and they display a long tail, which to be seen sometimes requires a large field of view best provided by smaller telescopes. Therefore, large amateur instruments (apertures of 25 cm or larger) that have fainter light grasp do not necessarily confer an advantage in terms of viewing comets. The opportunity to view spectacular comets with relatively small aperture instruments in the 8 cm to 15 cm range is more frequent than might be guessed from the relatively rare attention they get in the mainstream press.

9 In popular culture

See also: Comets in fiction and Category:Impact events in fiction

The depiction of comets in popular culture is firmly rooted in the long Western tradition of seeing comets as harbingers of doom and as omens of world-altering change.[77] Halley's Comet alone has caused a slew of frightful or excited publications of all sorts at each of its reappearances. It was especially noted that the birth and death of some notable persons coincided with separate appearances of the comet, such as with writers Mark Twain (who correctly speculated that he'd "go out with the comet" in 1910)[77] and Eudora Welty, to whose life Mary Chapin Carpenter dedicated the song *Halley Came to Jackson*.[77]

In science fiction, the impact of comets has been depicted as a threat overcome by technology and heroism (*Deep Impact*, 1998), or as a trigger of global apocalypse (*Lucifer's Hammer*, 1979) or of waves of zombies (*Night of the Comet*, 1984).[77] Near impacts have been depicted in Jules Verne's *Off on a Comet* and Tove Jansson's *Comet in Moominland*, while a human expedition visits Halley's Comet in Arthur C. Clarke's *2061: Odyssey Three*.

10 See also

- List of comets

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13 External links

Template:Commons2

- Comets at DMOZ
- Comets Page at NASA's Solar System Exploration
- Source of useful comet-related material on the Web
- How to Make a Model of a Comet audio slideshow - National High Magnetic Field Laboratory

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RexNL, Gurch, OrbitOne, TeaDrinker, Alphachimp, Malhonen, BradBeattie, Benjwong, Chobot, ScottAlanHill, DVdm, Bgwhite, Algebraist, The Rambling Man, YurikBot, Wavelength, TexasAndroid, Spacepotato, Mushin, Huw Powell, RussBot, V Brian Zurita, The Great Zo, The Storm Surfer, Conscious, SnoopY, Epolk, The-Wretched, Bergsten, Stephenb, טרול רפאים, David Woodward, Gaius Cornelius, Pseudomonas, Wimt, Shanel, NawlinWiki, Wiki alf, Arichnad, BlackAndy, LiamE, Nick, Unmake, Raven4x4x, Misza13, Nick C, BOT-Superzerocool, Mysid, Bota47, Elkman, Dna-webmaster, Dv82matt, Wknight94, The Halo, Pegship, FF2010, KateH, Sandstein, 21655, Zzuuzz, Chesnok, Mike Dillon, Ageekgal, Smoggyrob, Theda, Reyk, JQF, Exodio, Alias Flood, Tarawneh, Jaranda, Allens, Junglecat, Mhkay, NeilN, Carlosguitar, Serendipodous, DVD R W, Tsm1128, Yvwv, Sardanaphalus, SmackBot, Curtlindsay, Saravask, Moeron, Anarchist42, TestPilot, DanwWiki, Shoy, Pgk, Bomac, ScaldingHotSoup, Jrockley, Brossow, Canthusus, Kintetsubuffalo, 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