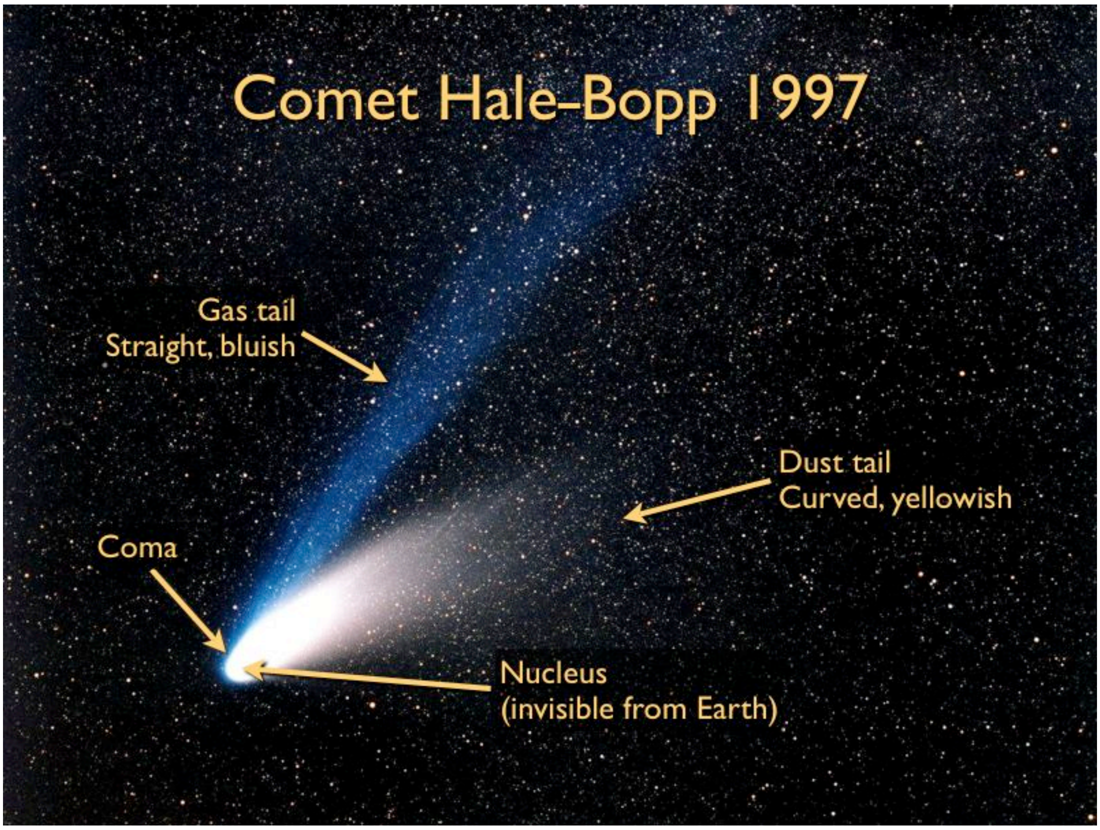
# COMETS – GHOSTLY WANDERERS IN SPACE

Ian Ridpath

Bright comets come along every decade or so. They used to be seen as omens – over the centuries they've been blamed for all manner of ills from plagues to the death of kings and the destruction of cities. And it's easy to understand how a bright comet hanging over the Earth like a ghostly apparition must have looked pretty alarming if you didn't know what it was.

## Main features of a comet

Let's start by looking at the main features of a comet. This example is comet Hale–Bopp of 1997:




*Comet Hale–Bopp, which appeared in 1997, had two beautiful tails. It was one of the brightest comets of recent years. (Credit: ESO)*

It's got two rather different-looking tails: the gas tail, which is straight and bluish, and the dust tail, which is curved and yellowish.

The head of the comet is known as the coma, a huge cloud of gas and dust that can be up to ten times larger than the Earth. At the heart of the coma is the nucleus, a lump of ice and dust only a few miles across. The nucleus is the only solid part of the comet, and it's only when the nucleus comes close to the Sun and warms up that it releases gas and dust to produce the coma and tail, or tails.

Although this whole display looks very impressive, the tails are transparent – stars are visible right through them. Even the head of the comet, which is overexposed here, is also completely transparent – it's less dense than the Earth's atmosphere. So comets are far more show than substance.

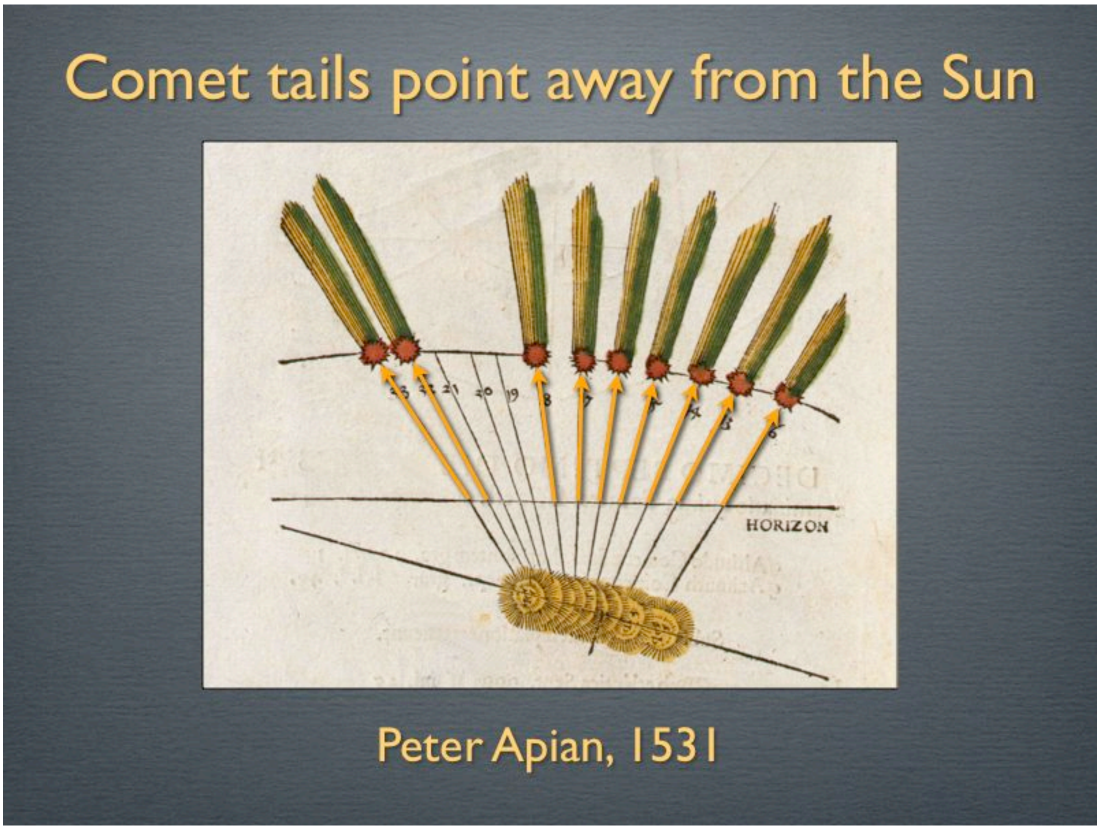
## Comet statistics

Currently around 3,000 comets are known. Most of these are far too faint to be seen without a telescope – you only get one that's bright enough to be seen with the naked eye every few years.

Of those 3,000 comets that we've seen, around 250 have come around more than once and they're termed periodic comets. The others will probably come back as well, although you might have to wait thousands or millions of years.

## Early discoveries

An important discovery was made in 1531 by a German astronomer called Peter Apian. He noted that the tail of a bright comet that appeared that year always pointed away from the Sun. In other words, the tail doesn't indicate the direction of movement of the comet – it indicates the direction of the Sun. This was evidence that the Sun was somehow responsible for the formation of comet tails, but it wasn't until the 20th century that science was finally able to explain why this happens.




*Apian's diagram of the comet of 1531, showing that its tail pointed away from the Sun. (Credit: Royal Astronomical Society library)*

Another major advance was made later that century by Tycho Brahe, a Danish astronomer who's generally reckoned to have been the greatest observer in the days before the telescope. When a bright comet came along in 1577 he attempted to measure how far away it was.

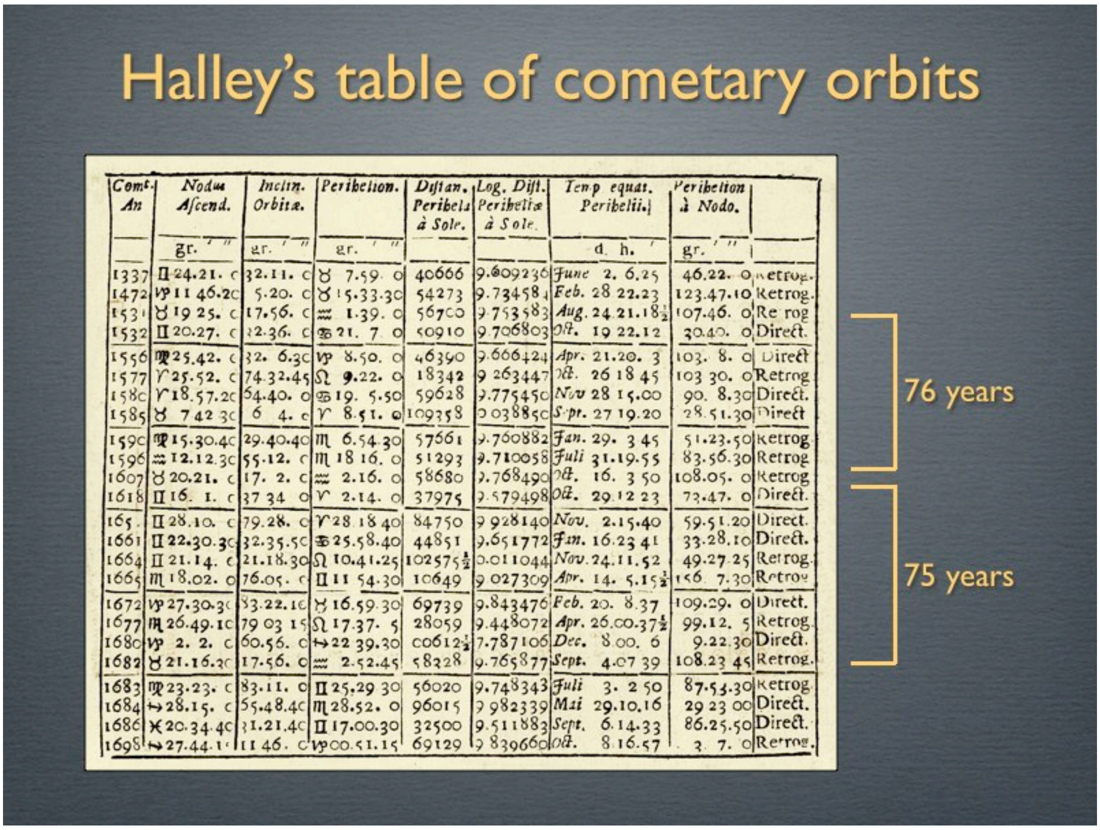
At that time most astronomers still accepted the word of the ancient Greek philosopher Aristotle who had said that comets weren't astronomical objects at all but phenomena of the upper atmosphere. Tycho's observations, though, showed that the comet lay well beyond the orbit of the Moon.

## Comet orbits

Over a century later, two of the finest scientific minds of the era, Isaac Newton and Edmond Halley, finally explained how comets move through space. Newton, having formulated the laws of gravitation, used them to calculate the orbit of a comet that had appeared in 1680. It turned out to be a long and narrow, like a hairpin, looping around the Sun before heading off into the distance again. This showed that cometary orbits were very elongated versions of the orbits of the planets.

Newton's slightly younger contemporary Edmond Halley set about collecting reliable observations of as many comets as he could so that he could work out their orbits, and he published his results in a little book called the *Synopsis of Cometary Astronomy* in 1705.

The core of the book is this table with the orbital statistics of 24 comets:




| Comet. An | Nodus Ascend. | Inclin. Orbitæ. | Perihelion. | Distan. Perihelii à Sole. | Log. Dist. Perihelii à Sole. | Temp. equat. Perihelii. | Perihelion à Nodo. | |
|---|---|---|---|---|---|---|---|---|
| | gr. ′ ″ | gr. ′ ″ | gr. ′ ″ | | | d. h. ′ | gr. ′ ″ | |
| 1337 | ♊ 24.21. 0 | 32.11. 0 | ♉ 7.59. 0 | 40666 | 9.609236 | June 2. 6.25 | 46.22. 0 | Retrog. |
| 1472 | ♑ 11 46.20 | 5.20. 0 | ♉ 15.33.30 | 54273 | 9.734584 | Feb. 28 22.23 | 123.47.10 | Retrog. |
| 1531 | ♉ 19 25. 0 | 17.56. 0 | ♒ 1.39. 0 | 56700 | 9.753583 | Aug. 24.21.18½ | 107.46. 0 | Retrog. |
| 1532 | ♊ 20.27. 0 | 32.36. 0 | ♋ 21. 7. 0 | 50910 | 9.706803 | Oct. 19 22.12 | 30.40. 0 | Direct. |
| 1556 | ♍ 25.42. 0 | 32. 6.30 | ♑ 8.50. 0 | 46390 | 9.666424 | Apr. 21.20. 3 | 103. 8. 0 | Direct. |
| 1577 | ♈ 25.52. 0 | 74.32.45 | ♌ 9.22. 0 | 18342 | 9.263447 | Oct. 26 18 45 | 103 30. 0 | Retrog. |
| 1580 | ♈ 18.57.20 | 64.40. 0 | ♋ 19. 5.50 | 59628 | 9.775450 | Nov 28 15.00 | 90. 8.30 | Direct. |
| 1585 | ♉ 7 42 30 | 6 4. 0 | ♈ 8.51. 0 | 109358 | 0.038850 | Sept. 27 19.20 | 28.51.30 | Direct. |
| 1590 | ♍ 15.30.40 | 29.40.40 | ♏ 6.54.30 | 57661 | 9.760882 | Jan. 29. 3 45 | 51.23.50 | Retrog. |
| 1596 | ♒ 12.12.30 | 55.12. 0 | ♏ 18 16. 0 | 51293 | 9.710058 | Juli 31.19.55 | 83.56.30 | Retrog. |
| 1607 | ♉ 20.21. 0 | 17. 2. 0 | ♒ 2.16. 0 | 58680 | 9.768490 | Oct. 16. 3 50 | 108.05. 0 | Retrog. |
| 1618 | ♊ 16. 1. 0 | 37 34 0 | ♈ 2.14. 0 | 37975 | 9.579498 | Oct. 29.12 23 | 73.47. 0 | Direct. |
| 1652 | ♊ 28.10. 0 | 79.28. 0 | ♈ 28 18 40 | 84750 | 9.928140 | Nov. 2.15.40 | 59.51.20 | Direct. |
| 1661 | ♊ 22.30.30 | 32.35.50 | ♋ 25.58.40 | 44851 | 9.651772 | Jan. 16.23 41 | 33.28.10 | Direct. |
| 1664 | ♊ 21.14. 0 | 21.18.30 | ♌ 10.41.25 | 102575½ | 0.011044 | Nov. 24.11.52 | 49.27.25 | Retrog. |
| 1665 | ♏ 18.02. 0 | 76.05. 0 | ♊ 11 54.30 | 10649 | 9.027309 | Apr. 14. 5.15½ | 156 7.30 | Retrog. |
| 1672 | ♑ 27.30.30 | 83.22.10 | ♉ 16.59.30 | 69739 | 9.843476 | Feb. 20. 8.37 | 109.29. 0 | Direct. |
| 1677 | ♏ 26.49.10 | 79 03 15 | ♌ 17.37. 5 | 28059 | 9.448072 | Apr. 26.00.37½ | 99.12. 5 | Retrog. |
| 1680 | ♑ 2. 2. 0 | 60.56. 0 | ♐ 22 39.30 | 00612½ | 7.787106 | Dec. 8.00. 6 | 9.22.30 | Direct. |
| 1682 | ♉ 21.16.30 | 17.56. 0 | ♒ 2.52.45 | 58328 | 9.765877 | Sept. 4.07 39 | 108.23 45 | Retrog. |
| 1683 | ♍ 23.23. 0 | 83.11. 0 | ♊ 25.29 30 | 56020 | 9.748343 | Juli 3. 2 50 | 87.53.30 | Retrog. |
| 1684 | ♐ 28.15. 0 | 65.48.40 | ♏ 28.52. 0 | 96015 | 9.982339 | Mai 29.10.16 | 29 23 00 | Direct. |
| 1686 | ♓ 20.34.40 | 31.21.40 | ♊ 17.00.30 | 32500 | 9.511883 | Sept. 6.14.33 | 86.25.50 | Direct. |
| 1698 | ♐ 27.44.15 | 11 46. 0 | ♑ 00.51.15 | 69129 | 9.839660 | Oct. 8.16.57 | 3. 7. 0 | Retrog. |

*Table of comets from Halley's Synopsis of Cometary Astronomy published in 1705. (Credit: Royal Astronomical Society library.)*

Halley found that the orbital data for three of them were quite similar: the comet of 1531 (the one that Peter Apian saw); the comet of 1607; and the comet of 1682 which Halley himself saw.

## Halley's comet

The interval between the first two was 76 years and between the last two was 75 years. Halley suggested that these were not three separate comets but the same comet orbiting the Sun every 75 or 76 years – the slight time difference between appearances could be accounted for by the gravitational attractions of the planets.

Halley's masterstroke was to stick his neck out and predict that the comet would return in or about 1758, which it duly did. The return of the comet not only confirmed that comets go around the Sun on predictable paths, it was also a stunning vindication of Newton's laws of gravity, which had made the calculations possible. Since then we've called this comet Halley's Comet. It comes back to its closest point to the Sun in 2061. (See also my pages on A Brief History of Halley's Comet.)

Astronomers continued to discover new comets, work out their orbits and study their tails, but there wasn't any real progress in understanding their physical nature until the middle of the 20th century.

## The Oort cloud and dirty snowballs

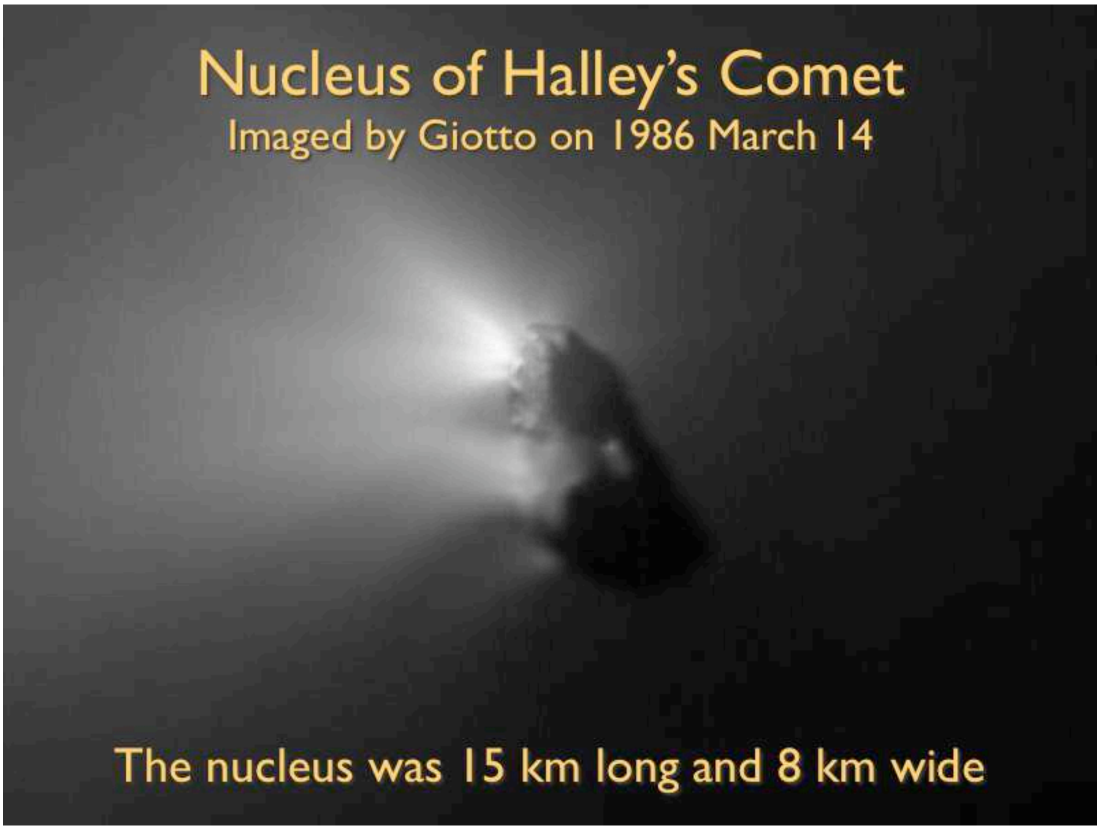
The first big name in our modern understanding of comets was Jan Oort, a very distinguished Dutch astronomer who in 1950 published a paper which proposed that there's a vast cloud of comets surrounding the Solar System. We call it the Oort cloud. It's thought that the gravitational pulls of passing stars nudge the comets out of the cloud onto new orbits that bring them in towards the Sun. Hence we get a continual supply of comets appearing from all directions on very elongated orbits.

Also in 1950, an American astronomer named Fred Whipple proposed that the nucleus of comets is like a dirty snowball. When this snowball comes close to the Sun it warms up and releases gas and dust that forms the head and the flowing tails.

Gas tails are blown away from the comet's head by the solar wind, a stream of atomic particles from the Sun. They appear blue-green because they fluoresce like the gas in an advertising sign. Dust tails, on the other hand, are pushed away by the pressure of sunlight. We're not normally aware of it, but light does exert a slight force and it's enough to push away the tiny dust particles in comets, which are similar in size to the particles in cigarette smoke. Dust tails appear yellowish because they simply reflect light from the Sun. A comet with an astounding fan-shaped dust tail was Comet McNaught of January 2007.

## Space probe exploration of comets

Exploration of comets by space probe started in 1986 at the last return of Halley's Comet. Japan, Russia and the European Space Agency all sent probes. By far the most successful was the European probe, Giotto, which plunged into the head of Halley's Comet on the night of 1986 March 13, and this is what it saw – the first detailed view of the nucleus of a comet:



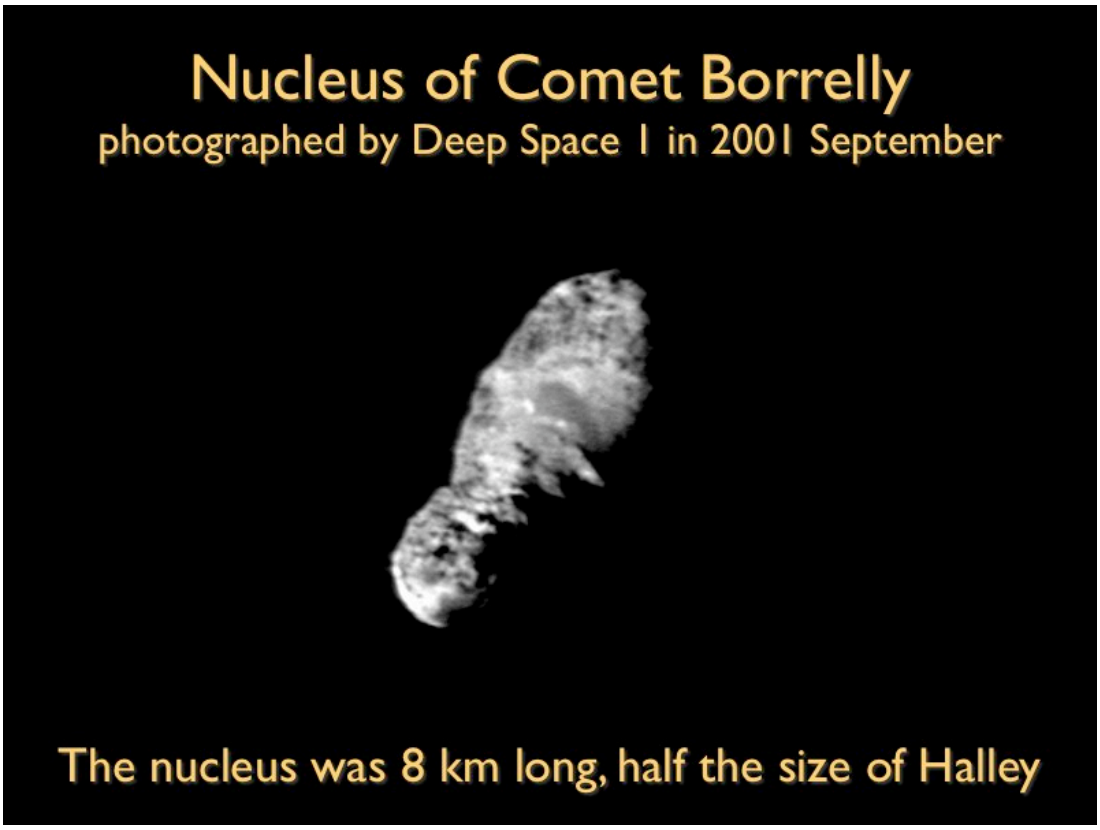

*Nucleus of Halley's Comet, photographed by the European space probe Giotto in 1986. Gas and dust spews into space through cracks on the sunward-facing side, at left in this picture. (Credit: ESA)*

It turned out to be pretty elongated, about 15 km long by 8 km wide. But the most unexpected thing of all was how dark it was – it's black, blacker even than coal, because it's coated with a crust of dust. Another unexpected discovery was that the gas and dust that creates the comet's coma and tail was coming not from all over the nucleus but from only a few cracks in the crust on the side facing the Sun.

## Another nucleus

But is this a typical nucleus? To get a look at another nucleus, NASA flew a probe called Deep Space 1 past the nucleus of Comet Borrelly in September 2001. The nucleus turned out to be half the size of Halley's and very elongated – it looks a bit like the sole of an old shoe.

The picture below has been processed so that the nucleus appears fairly bright, but it's actually as black as soot, just like Halley's nucleus. There's no ice at the surface at all - it's all hidden underneath a dark crust. As a result, instead of referring to nuclei as "dirty snowballs", some cometary scientists have turned the phrase around and now talk about "icy dirtballs".




*Elongated nucleus of Comet Borrelly, photographed by NASA's Deep Space 1 in 2001. (Credit: NASA)*

## Sampling a comet

The next step was to capture some samples from a comet and bring them back to Earth, and that was done by a NASA probe called Stardust. Stardust flew past the nucleus of Comet Wild at the start of 2004, collecting dust with a panel consisting of an extremely low-density glass foam called *aerogel*. Even though the dust particles were hitting this at speeds six times faster than a rifle bullet the aerogel is so good at cushioning the force it was able to capture the particles without damaging them.

Two years after its encounter with comet Wild, Stardust skimmed past the Earth and ejected this collector panel inside a protective capsule which was picked up and taken to the same lab at NASA in Houston where the Apollo Moon rocks are stored.

Stardust collected thousands of particles – they're absolutely microscopic, only a millimetre across or smaller. Scientists are still working on them. One exciting finding is that some of the particles might have drifted across space from other stars, so it may be that Stardust has sampled the environments of other solar systems too.


*Scientists examining the aerogel collector from Stardust, containing samples of dust from Comet Wild. (Credit: NASA)*

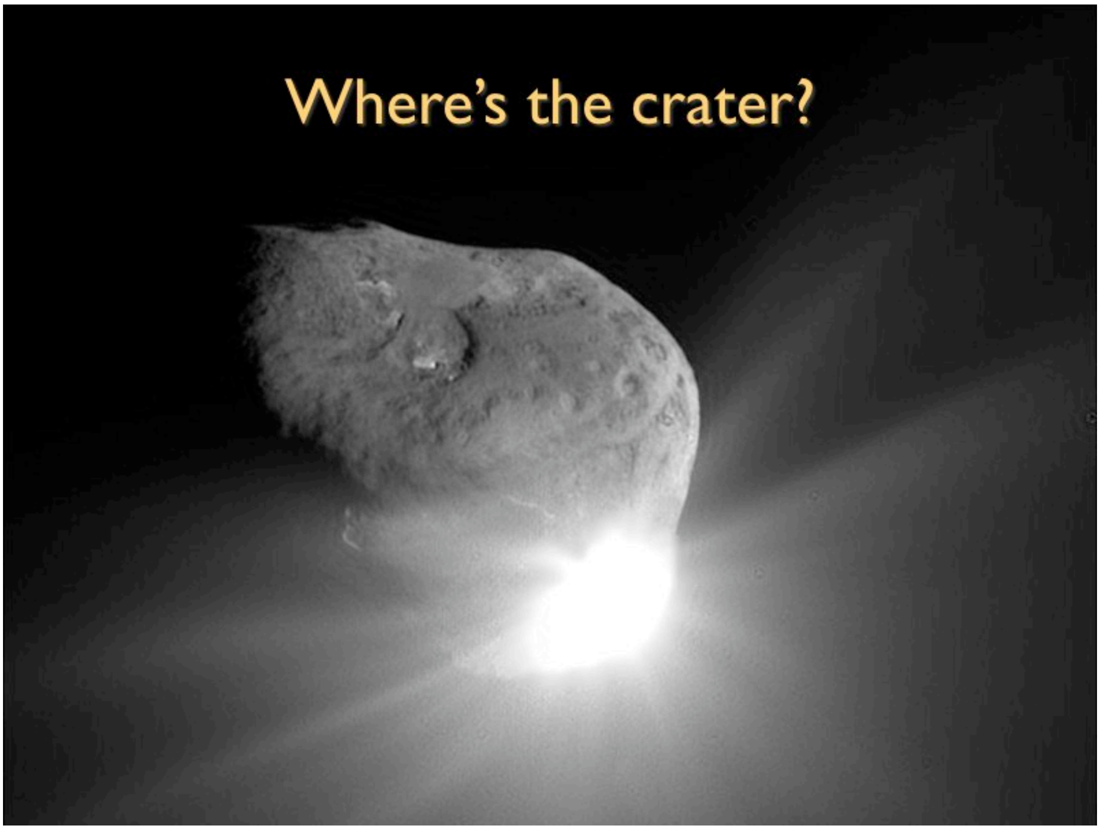
## Hitting a comet

But what's under that dusty crust – the ice that's supposedly lain unchanged inside the comet since it was formed billions of years ago? To get at that meant punching a hole through the surface, and that was the purpose of a mission called Deep Impact which reached Comet Tempel 1 in July 2005. The main spacecraft dropped off a smaller probe called the Impactor which hit the nucleus at very high speed, digging a crater in it.

Comet Tempel's nucleus is one the most fascinating seen so far, marked by craters, ridges and smooth areas that are thought to be caused by flowing ice. The features of each nucleus are a record of the comet's history, and astronomers are still learning how to interpret that history.

## Looking for the crater

Deep Impact was a great success, but it failed in one important respect. It never managed to photograph the crater it made in the nucleus of Comet Tempel, and you can see why on the image below – far more dust came off than expected, obscuring the view.

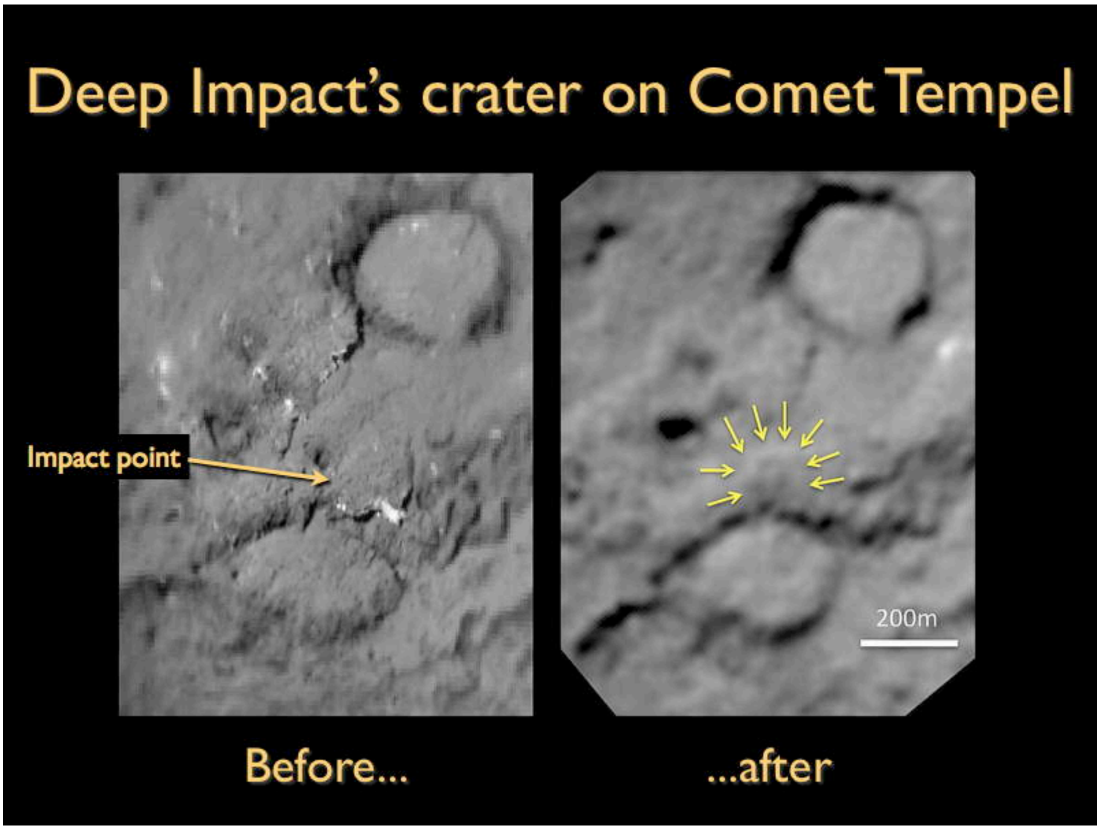



*Deep Impact's view of its Impactor hitting the nucleus of Comet Tempel 1. So much dust came off that it obscured the view of the crater. (Credit: NASA)*

However, help was at hand in the form of Stardust, the probe that collected dust samples from comet Wild. It was put onto a new course that took it past the nucleus of comet Tempel-1 in February 2011. The mission was renamed Stardust-NExT, the NExT part being short for New Exploration of Tempel.

The results were disappointing, though. The image on the next page shows the area of the comet's nucleus as seen by Deep Impact just before the impactor rammed into it, and the same area seen by Stardust five and a half years later.

The two pictures are not exactly comparable because they were taken from slightly different angles and under different lighting conditions, but it's clear that the crater is not like the bright young impact craters we see on the Moon and Mercury. The crater looks as though it has been smoothed out, presumably because much of the dust thrown out by the impact simply came back down again and filled it in.

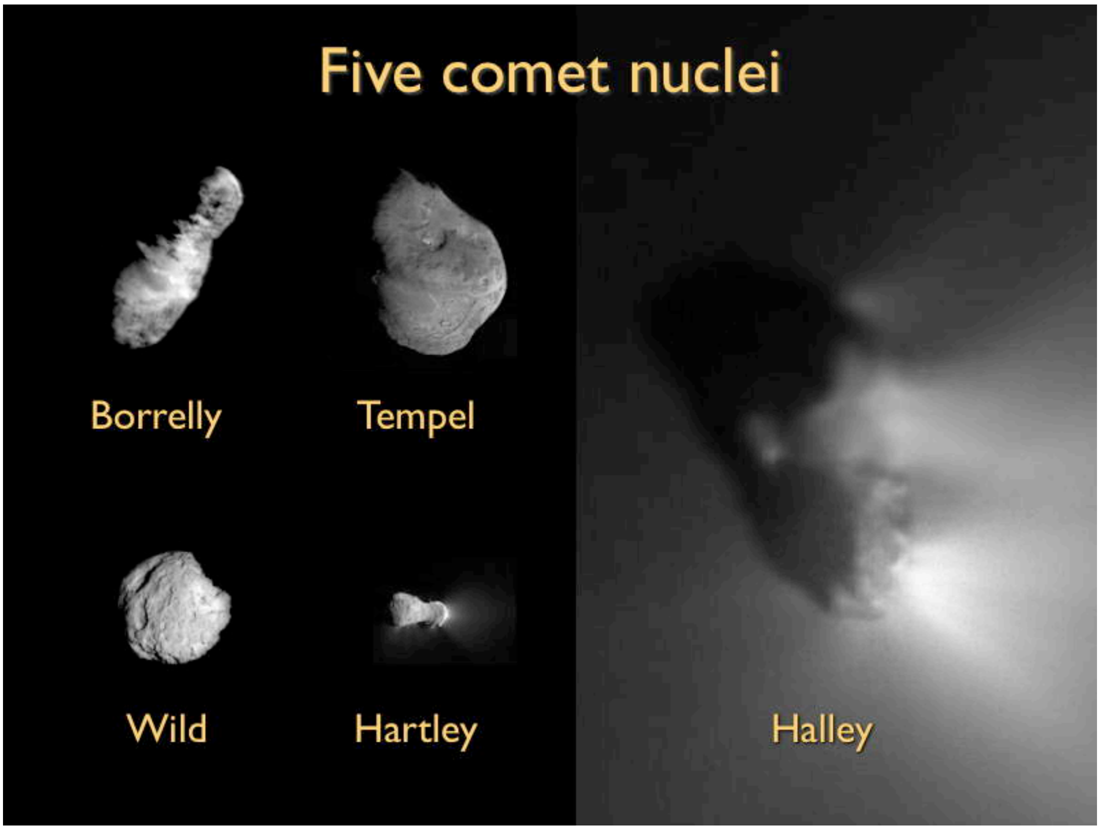



*The surface of Comet Tempel before the impactor hit it (left, photographed by Deep Impact) and afterwards (right, photographed by Stardust). What is thought to be the crater produced by the Impactor is outlined by arrows, but is not prominent. (Credit: NASA)*

## Another comet for Deep Impact

Like Stardust, the Deep Impact probe was also still working well after its initial mission was finished so its controllers decided to send it to another comet. The target this time was comet Hartley, which it reached in November 2010. There was to be no hitting the nucleus this time because there wasn't a spare impactor – it just photographed the nucleus as it flew past. Hartley's nucleus turned out to be the smallest of those seen so far, only 2 km long, and is shaped like a peanut with jets of gas shooting off the ends.

So we now have close-up views of five comet nuclei. These are shown below to the same scale and all are oriented so they are illuminated from the same side (the right):




*The nuclei of five comets photographed by space probes, all to the same scale and with the light from the same direction, i.e. to the right.*

## Kamikaze comets

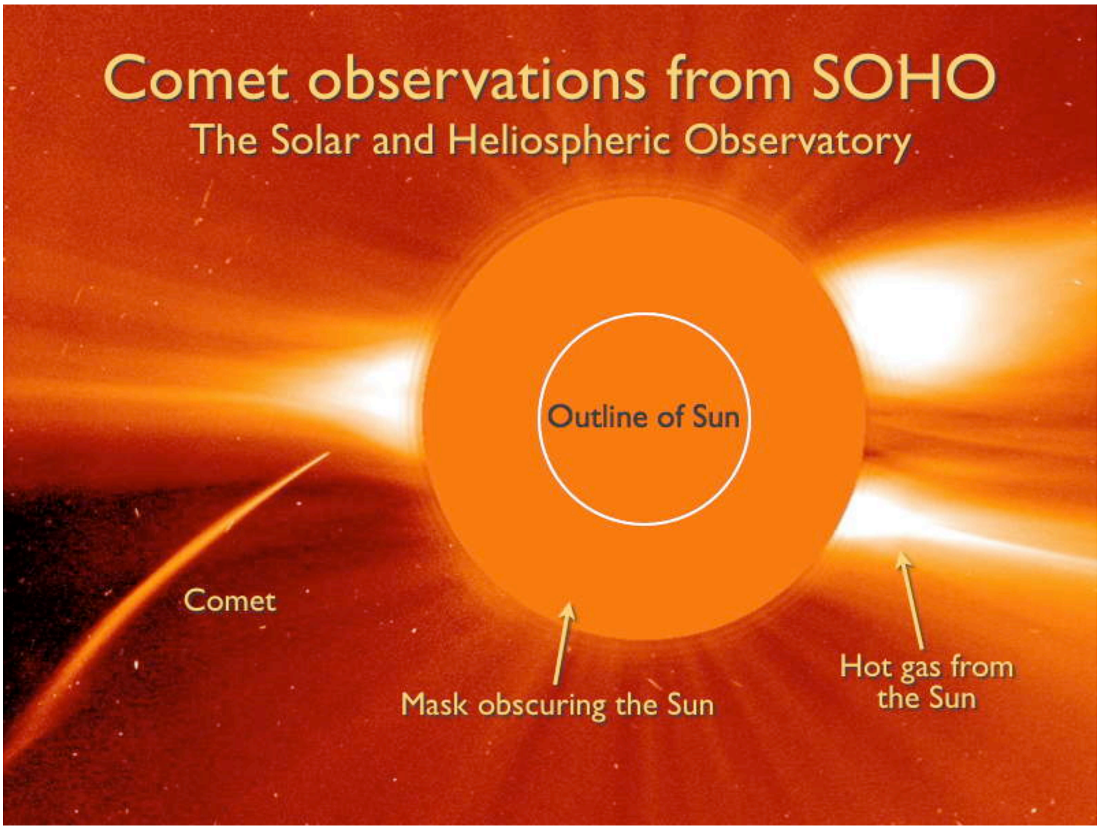
As well as the results from these space probes we also have some interesting observations of comets from an observatory in space called SOHO, designed to study the Sun. SOHO has special telescopes with a mask that blocks out the Sun's brilliant surface so we can see the area around it – the big orange circle in the picture below isn't the Sun but the disk masking it. The outline of the Sun itself is the smaller white circle at the centre. The orange colour is artificial.

At either side of the Sun are bright streamers of hot gas, the solar wind, which is what SOHO is designed to look at. But at lower left is a comet with a long tail heading towards the Sun. This is the type of comet known as a sungrazer.

Sungrazing comets are so-called because they graze past the surface of the Sun at their closest. They usually disintegrate as they do so, and many of them actually crash into the Sun. They're thought to be the remnants of one or more super-comets that broke up thousands of years ago and the bits are still moving along the same orbit.

In December 2011 a sungrazer called Comet Lovejoy actually survived its encounter and emerged to become a magnificent object in southern skies, as well as from space.

Over two thousand sungrazers have now been spotted by SOHO and other spacecraft, and we're still finding them.




*A sungrazing comet that hit the Sun in December 1996, seen by a telescope aboard the SOHO solar observatory. (Credit: NASA/ESA)*

## Rosetta – the future

What of the future? A European probe called Rosetta is currently on its way to carry out the most ambitious comet exploration of all. In 2014 it's due to go into orbit around a comet called Churyumov–Gerasimenko (popularly abbreviated to C-G), and it will also drop a probe called Philae to land on its nucleus, as depicted in the artist's impression on the next page. The lander will drill into the comet's crust to find out what it's made of. If this all works it should be an absolutely huge advance.

## Why comets are important

Are comets really important enough to be worth all this attention we're giving them? I think the answer is yes, for a number of reasons. One of them is because comets are now thought to have been responsible for delivering at least some of the water and the molecules of life to Earth.

There's also a bad side to comets because if one of them ran into us today it would be absolutely lethal.

The popular theory is that the death of the dinosaurs 65 million years ago was caused by a massive impact. It could have been an asteroid rather than a comet, but frankly it doesn't matter – something that big hitting the Earth would cause destruction on a global scale.


*Artist's impression of Rosetta's lander called Philae on the nucleus of Comet Churyumov–Gerasimenko. It is due to touch down in late 2014. (Credit: ESA)*

If such an impact happened today then we'd go the same way as the dinosaurs did. I'm sure you'll be reassured to know that NASA has got observing teams constantly on the lookout for objects that might be headed our way.

So while on the one hand comets might have delivered to Earth the raw materials for the origin of life, on the other, should one of them run into us, they have the power to snuff it out again.



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## Useful links

- Deep Space 1
- Deep Impact
- Deep Impact extended mission
- Stardust
- Stardust-NExT
- Rosetta