NASA

▲ **Deep Impact reaches its most dramatic stage in this artist's impression, as the probe prepares to launch its impactor at Comet Tempel 1**

Prepare for **Deep Impact**

[04.07.05]

Mark Kidger takes us on a journey to the interior of a cometary nucleus

Some time in the early morning of 4 July one of the most remarkable NASA space missions of all time will reach its climax. The Deep Impact mission, one of NASA's new generation of Discovery missions – simple, low-cost operations limited to a maximum budget of $299 million and three years' development before launch – aims to pass extremely close to the nucleus of Comet Tempel 1. It will also send back very high quality images and crash a small sub-probe into the comet's surface to study its reactions.

Comets are the most numerous and, to many, the most fascinating bodies in the Solar System. Some estimates suggest that there may be as many ▸

▸ as 10 billion beyond the orbit of Neptune. That far away from the light of the Sun, they are totally invisible to us, until they fall closer in to the Solar centre and the frozen gases from which they are formed start to vaporise.

Born from the remnants of the protoplanetary nebula that gave birth to the Sun and the planets, they represent material that was left over after the planets were formed. This is what makes them so interesting and valuable to scientists: they offer a way of studying the composition and conditions of the nebula in which the planets originated.

Close encounters

Deep Impact is not the first mission to a comet; that honour went to the International Cometary Explorer probe, which passed through the tail of Comet Giacobini-Zinner in November 1985. In fact, there have been no less than nine previous comet encounter missions launched, resulting in successful encounters with five different comets. One mission – the NASA Contour probe – apparently exploded on leaving Earth orbit and was lost. A further mission, ESA's Rosetta spacecraft, is on its way to an eventual encounter in 2014.

What Deep Impact will do at Comet Tempel 1, though, is unique. The mission was first proposed in 1996, the idea back then being to crash a probe into the asteroid Phaethon at very high speed – 38km/s (85,000mph) – and study the crater formed. In the impact, material from the comet's nucleus would be revealed.

The idea was rejected at the time but revived two years later with the aim of going to an active, but old, comet. This would allow scientists to test the current conception that a comet becomes less active as the vaporising ice leaves behind a suffocating layer of dust that prevents the rest of the icy core from being warmed.

Comet of choice

Comet Tempel 1 was selected because it had been in the inner Solar System for tens of thousands of years and was thus very old and hardly active. Its orbital period of 5.5 years was well known and it had been observed at every return since 1967. The comet would also be very well positioned in summer 2005 – well outside the Earth's orbit but close enough to the Sun to heat any ice that was revealed. It would also be close to the celestial equator and thus visible to most of the planet. The mission was approved in 1999 and launched on 12 January 2005.

Deep Impact consists of a mother probe containing a 30cm telescope fitted with a CCD camera and an infrared spectrograph, plus an impactor that will be released 24 hours beforehand. After release, the main probe will slow slightly to allow it to pass by the comet's nucleus at a distance of 500km, taking images with a resolution of up to 1.4 metres.

The impactor probe, made principally from copper (chosen because it produces fewer spectral lines than aluminium and will interfere less with the observations of the comet's material), has a 12cm telescope also fitted with a CCD camera. It has a mass of 373kg and will hit the comet at 10.2km/s (22,800 mph). Like the 1960s Ranger probes to the Moon, it will send images continuously until the very last frame is interrupted by the impact. The probe will use these images to guide itself to the target, its aim being to hit the nucleus in the daylight hemisphere so that the formation of the crater can be observed by the mother probe.

This leads to some huge challenges as Alan Delamere, one of the original proposers of Deep Impact, points out.

"The biggest challenge of the mission is making sure we have a very stable flyby spacecraft that is able to track the event as the impactor reaches the comet. We'll have 800 seconds or so to gather high fidelity images and data. All this makes the flyby spacecraft critical because it will be travelling through a hazardous area filled with cometary material," he explains.

Structural survey

By observing the formation of the crater, scientists will get the chance to work out the exact details of the comet's structure. Because they know everything about the impactor, including its mass, composition, shape and velocity, the crater that it forms will reveal details such as the comet's strength, structure and density.

What scientists do know is that comets are mainly icy bodies, made out of gases that freeze far from the Sun. As the comet approaches the inner Solar System these ices warm and begin to vaporise, forming a temporary atmosphere or 'coma'. The solar wind pushes these gases away to form the tail of the comet.

Although water ice is a comet's main constituent, it is not advisable to put a cube of the stuff in your drink: it also contains frozen carbon dioxide, carbon monoxide, ammonia, methane and ▸

[DATA]

Mission name	Deep Impact
Launch date	12 January 2005
Impact date	4 July 2005
Mass of impactor	373kg
Impact velocity	10.2km/s
Camera resolution	20cm (2 seconds before impact)
Energy of impact	Equivalent to 5 tonnes of TNT

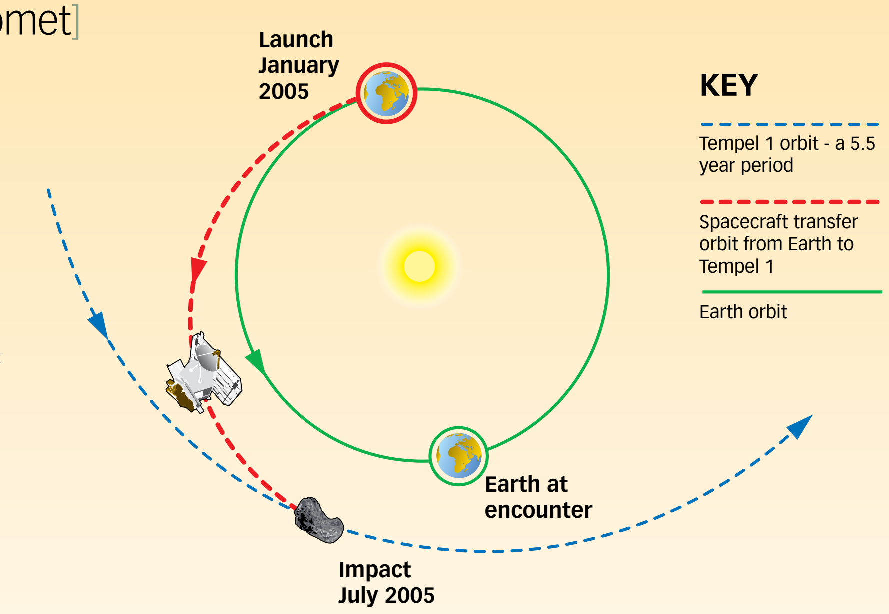
LAUNCH & TRAJECTORY

[Journey to a comet]

Deep Impact was originally intended to launch in January 2004 and carry out an initial orbit of the Sun. An Earth encounter in January 2005 would have redirected the probe to the comet.

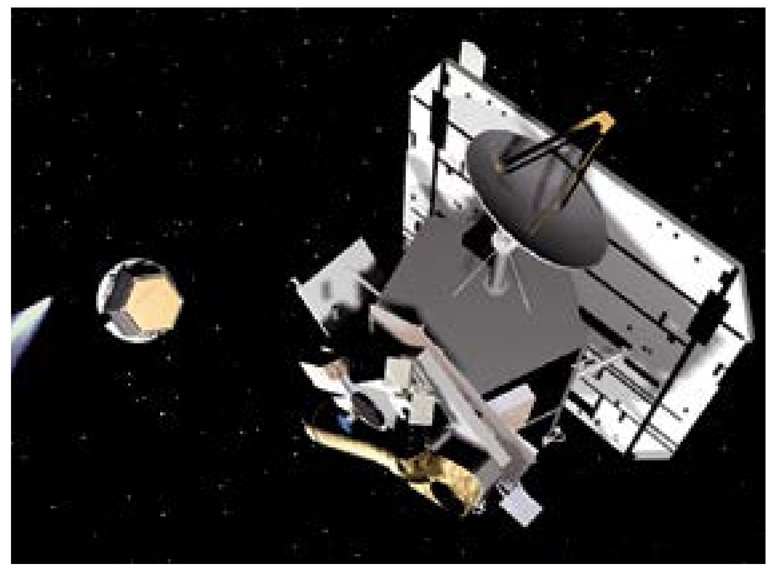
In the end, though, it was decided to go for the quicker option of a high-energy trajectory with a simple direct transfer orbit. This shorter trajectory means Deep Impact has taken just six months to reach the comet rather than 18, as was originally intended.

The probe's orbit takes it into a tail chase similar to a Mars mission, so it will encounter Comet Tempel 1 from behind at perihelion, overtaking at a relatively modest velocity of 10km/s.



◂ Deep Impact blasts off from Kennedy Space Flight Center, Florida, in a Delta II rocket on 12 January 2005

In this rendition ▸ 24 hours before impact, Deep Impact's 3.2-metre-long flyby spacecraft has just released the impactor on its collision course



[The NASA investigator]

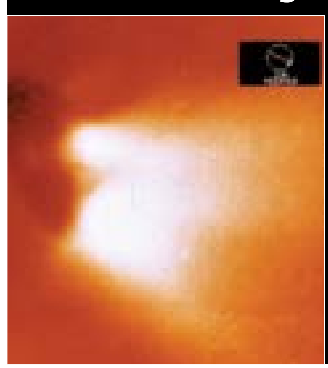
Karen Meech is co-ordinating all ground observations on 4 July

What will happen on 4 July?
From Earth, I think we'll see a sudden flash that will bring something that wasn't previously visible to the naked eye to possibly a magnitude three object. At the same time, dust should move into the tail, making it much more prominent. As far as my predictions of the crater... something on the order of a football field in size, perhaps 25 metres deep.

Will the impactor hit its target?
The navigation engineers have done thousands of simulations with all sorts of extreme cases of nucleus shape and roughness. The impactor is 'smart' too: it has sophisticated computer algorithms on board for navigating to the comet.

What will happen after impact?
Comets are dirty snowballs and it will probably take some time for the heat to penetrate into the interior. The comet probably has layers of different types of ices on its surface from past orbital evolutions. As the heat slowly penetrates inside, I think there will be a lot of new activity from the comet. How long this will last depends on how well the heat is transported into the interior. Because we really don't know for sure, it will be a very interesting experiment. Even if all our predictions are wrong, we will still learn something new about cometary physics.

A history of comet chasers



[1986: Giotto]

Although not the first mission to a comet, ESA's Giotto was the most spectacular of the six probes launched to Comet Halley. Its encounter on 13 March 1986, passing 605km (375 miles) from the nucleus, gave the first clear view of the nucleus of a comet and provided spectacular images and much information about the comet's dust and gas. The probe was seriously damaged, although it continued on to a later encounter with Comet Grigg-Skjellerup.

[2001: Deep Space 1]

Designed as a mission to test new space technology, Deep Space 1 was targeted at the asteroid Braille and Comet Borrelly, although its primary mission was not scientific. Despite relatively low expectations, the probe sent remarkable images of the surface of Comet Borrelly's nucleus, showing it to be extremely dark with some areas reflecting under 1 per cent of the Sun's light. The probe also showed unexpected images of prominent gas jets emerging from the nucleus.

[2004: Stardust]

On 2 January 2004 the Stardust mission passed 236km (145 miles) from the nucleus of Comet Wild 2 at 6km/s (13,420mph). Images showed the nucleus to be very heavily cratered. Before encounter it unfurled a 'butterfly net' made of silica aerogel – a material made up of 99.8 per cent air – to trap particles released from the comet. On 15 January 2006 it will pass by the Earth, jettisoning the container with the aerogel inside to parachute down to the Utah desert.

[2014: Rosetta]

The most ambitious cometary probe yet launched, this ESA mission will encounter Comet Churyumov-Gerasimenko in 2014 after nine years in space. The probe will go into orbit around the nucleus and will then detach a lander to the surface, which will make measurements of its strength and composition. The mission will encounter the comet about 18 months before perihelion and will follow the comet through to perihelion, although an extension is not being ruled out.

NASA X2; PAUL WOOTTON; KENNEDY SPACE CENTER/ELIZABETH WARNER; NSSDC; NASA/JPL; NASA/JPL-CALTECH; ESA/MPGH/H UWE KELLER

Planetary science

▸ hydrogen cyanide, plus considerable quantities of dust and significant amounts of other gases.

Within the frozen ices of the interior of the comet's nucleus is material that has not changed since the earliest days of our Solar System; by studying it we find out more about how our Earth was formed. Comets may also hold the key to resolving two great mysteries about the early Earth: where did the water in the oceans come from, and how did life start? It is strongly suspected that the Earth's oceans were filled by water that fell from the sky in the form of comets.

There is also an increasing feeling that the appearance of life on Earth may have received a very large helping hand from organic material brought to Earth by comets.

Mysterious travellers

There are many aspects of comets that are not understood at all. In 1950, Fred Whipple proposed what is now known as the 'dirty snowball' model of comet anatomy. He suggested that the interior of a comet was a ball a few kilometres in diameter made up of a mixture of ice, snow and dirt. This was confirmed by the Giotto mission in 1986, which passed only 605km (375 miles) from the nucleus of Comet Halley, sending back spectacular images.

In recent years, though, Whipple's ideas have been modified and it is now thought that a comet's nucleus is not a solid body, but rather a cluster of smaller icy snowballs. They may only be very weakly held together, perhaps by an icy glue, or maybe even by the very weak gravity of the nucleus itself.

We do not know how strong a cometary nucleus is, nor how dense; estimates range from about 0.1-0.8g/cm3, so it may be very porous. We do not even know what the composition is inside. We can measure the gases released when the comet is close to the Sun, but that does not necessarily mean that the interior has this same composition as the gas.

Suffocating dust

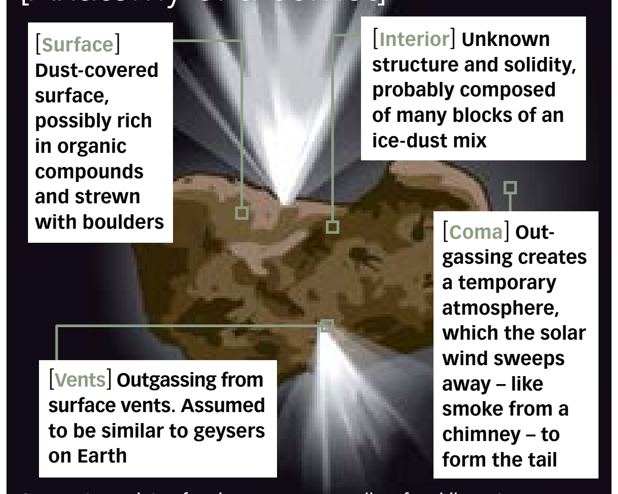
Crucially, we don't know how comets die. There is strong evidence that some asteroids in eccentric orbits that cross the Earth's – like Phaethon, the source of the Geminid meteor shower – are dead comets, but if they are, how and why did they die? The idea that comets change into asteroids by losing all their ice slowly over time has largely been discarded. It is now thought more likely that comets die because the vaporising ice leaves behind much of the dust that it contains. The dust blanket that is formed in the process gradually thickens until the Sun's warmth cannot reach the ice below, suffocating the comet's activity.

Probing for answers

Scientists at NASA hope that the crater caused by Deep Impact will provide them with the answers to these mysteries. But they are not 100 per cent sure what will happen when the impactor reaches its target. There are many possibilities depending on just how strong the comet is. They range from the two nightmare scenarios – a complete miss, or the impactor simply being absorbed gently by the comet – to the possibility of a large crater being formed or even a fragment breaking off the nucleus. If the former happens we will see nothing from Earth. If it turns out to be the latter, the comet may suddenly become a bright naked-eye object of around magnitude 0 - 1 that will stay visible for several weeks. ✪

ILLUSTRATIONS BY PAUL WOOTTON X5; BALL AEROSPACE & TECHNOLOGIES CORP; T FARNHAM/ M KNIGHT/ UNIVERSITY OF MARYLAND; NASA/JPL/UMD

[Anatomy of a comet]



[Surface] Dust-covered surface, possibly rich in organic compounds and strewn with boulders

[Interior] Unknown structure and solidity, probably composed of many blocks of an ice-dust mix

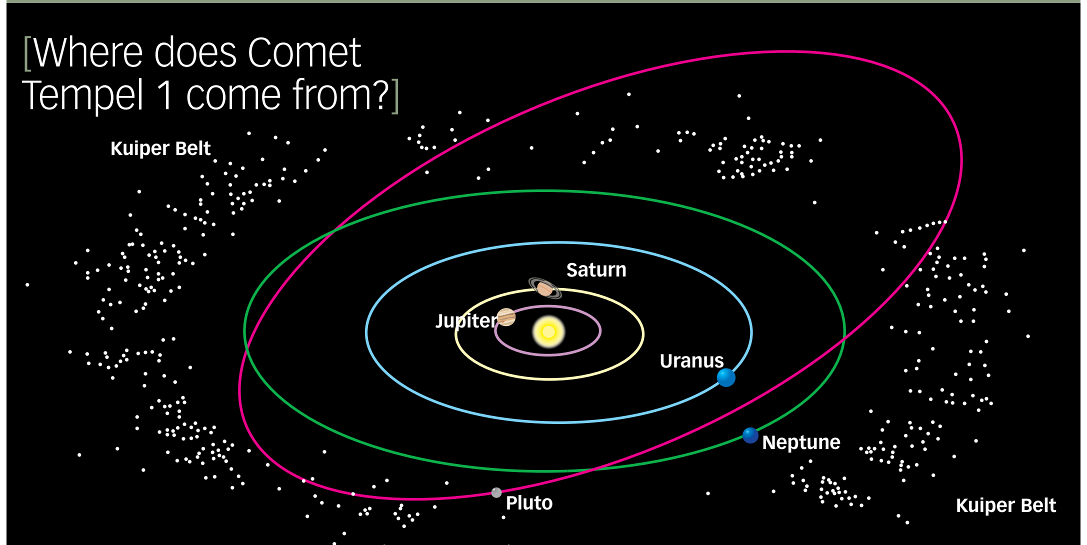
[Coma] Out-gassing creates a temporary atmosphere, which the solar wind sweeps away – like smoke from a chimney – to form the tail

[Vents] Outgassing from surface vents. Assumed to be similar to geysers on Earth

A comet consists of an icy nucleus, which holds almost all the mass, and a tenuous atmosphere around it. Giotto found that Comet Halley's atmosphere was composed of dust and gas. Most of the latter was water, with elements of carbon monoxide, formaldehyde, carbon dioxide and methane. The nucleus is usually a few kilometres across, but can be much larger, and is thought to be composed of loosely bound blocks. It is not known what unites them: one theory suggests the nucleus is a pile of rubble held together only by its own gravity. Another possibility is that loose ice and dust act as a glue to bind the blocks together.

ORIGIN OF A COMET

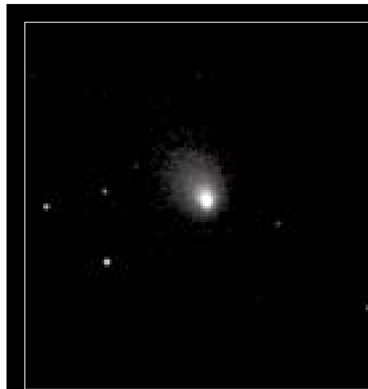
[Where does Comet Tempel 1 come from?]



One of the reasons why Comet Tempel 1 has been selected is that we know that it has been in the inner Solar System, with perihelion closer than Saturn, for at least 300,000 years, so it is a very highly evolved object. Short period comets like Tempel 1 are thought to have come from the Kuiper Belt and to have been slowly deflected into the inner Solar System by repeated planetary perturbations. What is not known, however, is when Tempel 1 passed from having its aphelion out beyond the orbit of Neptune to the much shorter period orbit that it has now.

▲ Engineers at the Ball Aerospace plant in Boulder, Colorado, pictured here in the process of joining the Deep Impact flyby spacecraft to the impactor

Deep Impact's ▸ quarry, Comet Tempel 1 pictured through a 2.1-metre telescope in April 2005 about 140 million miles from Earth. At that distance it is near perihelion, its closest approach to our planet

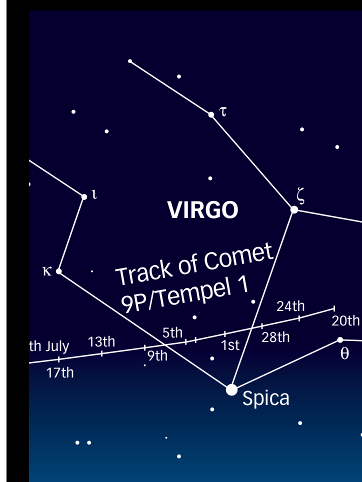


Comet Tempel 1 pictured by Deep Impact at a distance of 64 million km

[Where to watch for Comet Tempel 1]

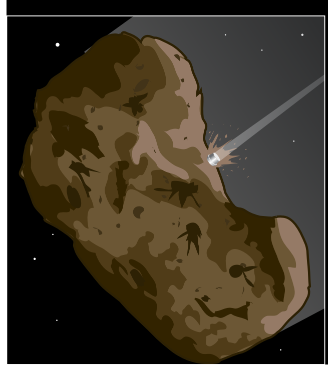
Before impact, Comet Tempel 1 will be quite a faint object peaking at around magnitude 11 in the constellation of Virgo, and requiring at least a 15cm telescope to see. Impact will be visible from the Pacific but will occur during daytime in the UK; if a large crater forms the comet could be an easy naked-eye object of magnitude 0 - 1 by nightfall.

Tempel 1 will be easy to find low in the west, close to the star Spica. Observers in southern England will be far better placed than those in northern Scotland, where twilight lasts longer and the comet will be lower and probably very difficult to see.



What will happen on **impact**

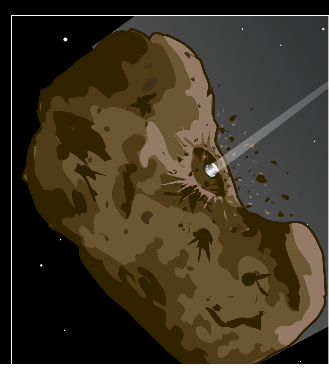
[Squelch]



The nightmare scenario for the project, apart from a clear miss, is if the nucleus turns out to be so porous that it behaves like an aerogel.

If this is the case, rather than a solid impact there will be a dull squelch and the impactor will bore down into the nucleus, slowly coming to a stop with little or no visible result. The probe's signal will stop suddenly to show that it has made impact, but the comet will not react.

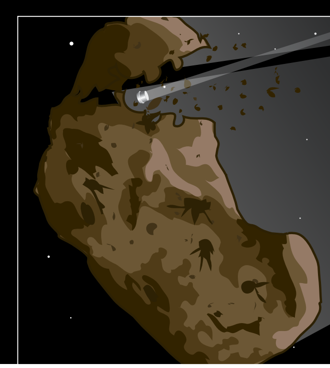
[Crater]



The most likely scenario is that the comet will be strong enough to stop the probe abruptly and make a crater around 100 metres across and 25 metres deep.

The impact will cause a flash from an explosion at 10,000°C and a crater will form over two to three minutes from the material thrown out. A more solid nucleus would make a smaller and deeper crater. As much material may be thrown out as in a week of normal activity.

[Splitting]



Although it is very unlikely that the nucleus will be destroyed, if the impact is near an edge there is a possibility that a large fragment may be broken off.

If this happens it would be even more spectacular than the formation of a large crater and would lead to a huge amount of fresh ice from the interior being exposed. Depending on the size of the fragment that breaks off, splitting could turn Tempel 1 into a double comet.

ON THE CD Turn to the coverdisc for video and animation of Deep Impact

[FIND OUT MORE]

See Deep Impact! See the results of the Deep Impact collision by visiting our website at **www.skyatnightmagazine.com** on the morning of 4 July 2005. We'll be carrying pictures from the Faulkes Telescope North in Hawaii, which is likely to be the first telescope to release images of the event. The impact is scheduled to occur at 05:52 UT (6:52am).

http://deepimpact.jpl.nasa.gov/index.html

www.aerith.net

http://astrosurf.com/somyce/noticias_y_observaciones_de_cometas.html