An extraordinary feat: NASA probe sent plunging into comet

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8 August 2005

In earlier centuries, the rare arrival of a comet in the heavens was often seen as a portent of doom. Now scientists are able to undertake scientific expeditions to determine the make-up, chemical and geological history of these astronomical phenomena, thought to be relics from the earliest stages of the solar system's formation.

On July 4, the NASA Deep Impact space probe released a copper "impactor" that plunged headlong into the comet Tempel 1 releasing a plume of material from beneath the comet's surface. Scientists believe that an analysis of the comet's emissions will provide insights into the origin of the solar system and possibly of life on earth.

Deep Impact's rendezvous with Tempel 1 near Mars' orbit was an astonishing feat of precision navigation. The comet measures just 14.5 by 4.8 kilometres, was 134 million kilometres from earth and travelling at 106,000 kilometres per hour. The space vehicle to intercept the comet was launched on January 12 (see http://deepimpact.jpl.nasa.gov/gallery/jpg/orbits2a-color.jpg). As Deep Impact approached the comet, it released a module—dubbed the impactor—which then crashed into Tempel 1.

The module, which had its own auto navigation device, made three corrections to its trajectory to enable it to hit the target. Project Manager Rick Grammier commented: "We are really threading the needle with this one. In our quest of a great scientific payoff, we are attempting something never done before at speeds and distances that are truly out of this world."

The impactor had a camera to obtain close-up pictures of the comet's surface as it approached collision. The space probe, 500 kilometres away, had 14 minutes to observe the results, using four data collectors including a camera and infrared spectrometer.

In addition, the collision was observed by three orbital telescopes using various frequencies—the Hubble Space Telescope in the visible light range, Chandra using X-rays and the Spitzer infrared observatory—as well as 60 earth-based telescopes and thousands of amateur astronomers. Many people watched the impact on the NASA homepage, which estimated that 80 million page view requests worldwide on the morning of the collision.

Immediately before collision, the impactor showed the comet's surface as pitted with flat plains, an irregular ridge and circular craters. This is the first time that possible impact craters have been observed on the surface of a comet. The images from the craft stopped abruptly and the comet erupted into a brilliant explosion.

The comet brightened to six times its original level. NASA scientist Donald Yeomans explained: "We've had a far bigger explosion than we anticipated... and there was considerably more matter coming off than I had thought."

So extensive was the blast that it has not been possible to determine the exact size of the resulting crater, estimated at 50 to 250 metres and larger than originally expected. "How a washing-machine sized impactor could produce such a large disturbance is going to take some explanation," Yeomans declared. (Images at http://www.nasa.gov/mission_pages/deepimpact/main/)

Scientists are anticipating important findings. Professor Peter Schultz from Brown University said: "The ice inside comets has been in the deep freeze since the creation of the solar system. Now we are finally going to see what this stuff looks like and what it is made of... Comets may have been the messengers that carried the ingredients of life to Earth."

Previous analysis of Tempel 1's corona, the stream of gases forming the comet's tail, already revealed the presence of water vapour, carbon monoxide, carbon dioxide and complex organic compounds.

While data from the collision is yet to be processed, scientists believe that the impactor may have ploughed into a powdery layer before hitting more solid rock and ice below. Initial spectral examination shows the comet contains new unidentified materials, indicating that its interior composition may differ from the outer layer. Ground-based telescopes observed a large increase in gases making up the comet's corona, including water vapour.

Project leader Michael F. A'Hearn from the University of

Maryland speculated that “the opacity of the plume the impactor created and the light it gave off... suggests the dust excavated from the comet’s surface was extremely fine, more like talcum powder than beach sand. And the surface is definitely not what most people think of when they think of comets... an ice cube.”

The Deep Impact mission brought into play centuries of scientific endeavour to understand comets and more broadly the origin of the solar system.

Isaac Newton’s masterpiece *Philosophiae Naturalis Principia Mathematica* in 1687 identified the laws of motion and gravity that govern the orbits of the planets and other objects such as comets. In 1680, Newton’s friend Edmond Halley observed a comet while travelling in Europe and in 1705, by an analysis of the comet’s trajectory, successfully predicted its return in 1758. Halley’s Comet is the only visible comet to reappear within a human lifetime and it has been observed over 22 centuries.

Newton’s analysis explained the motion of planets, but not how the solar system had formed. The German philosopher Immanuel Kant (1724-1804) was the first to propose a scientific model—known as the nebular theory—for the origins of the planetary system. In 1755, he suggested that it had formed from a cloud of dispersed particles drawn together by gravitational attraction to form the planets and various other objects.

The French mathematician Pierre-Simon Laplace (1749-1827) fleshed out the theory forty years later by proposing that the outer regions of the rotating sun developed into concentric rings of matter that coalesced to form the planets. This model successfully explained why most planets are contained in one plane and rotate around the sun in the same direction.

Comets, however, are more unpredictable. Each century new comets appear without warning and most are never seen again. Some have extremely long periods before they return. For example, comet Bennett, first observed in 1970, is not due to return for 17 centuries. There are also approximately 100 comets with relatively short periods, between 3 and 200 years. Tempel 1, discovered in 1867 by Ernst Tempel, is one of them.

Most short-term comets are thought to originate in what is known as the Kuiper belt, a region beyond Neptune containing a few billion comets. Pluto and its satellite Charon are part of the belt. Astronomers postulate that disturbances, such as a movement in a nearby star or even fluctuations in the enormous gas clouds beyond the solar system, may destabilise a comet in this belt sending it towards the sun.

A bigger repository of comets, known as the Oort cloud, is believed to be located even further out—as far as one third of the distance to the nearest star. It is theorised that the Oort cloud formed at the same time as the giant gas planets, about 4.6 billion years ago, through the aggregation of interstellar particles. Being so far from the sun, this material would have been frozen intact.

In the 1970s, two astronomers Victor S. Safronov in the Soviet Union and A.G.W. Cameron in the US proposed that cometary nuclei were the building blocks for the formation of the planets. Cameron postulated that these developed from a giant protostar nebula that extended 1,000 Astronomical Units (1 AU equals 149,598,000 kilometres) from the sun.

Spectrographic analysis during the twentieth century has consistently shown that comets are rich in organic compounds. In fact, they contain so many carbon-based chemicals that they are black in colour. In 1986, analysis of dust particles from Halley’s Comet by the European Space Agency’s Giotto probe and the Russian Vega probe found it to be one of the richest sources of organic material in the solar system.

In 1988, the scientist L.J. Allamandola performed a laboratory experiment that involved warming organic chemicals known to exist in comets to room temperature in water. He found that insoluble lipid droplets with membrane forming behaviour were produced. Such substances may have been the primitive precursors to the first living organisms.

With the exception of the earth, the inner planets and inner part of the solar system are very poor in organic material. So how did life on earth originate? Some scientists believe that comets may have played a vital part in delivering water and organic chemicals essential for the formation of life.

Director of the NASA Goddard Center for Astrobiology, Michael Mumma, explained: “The key question is: Were water and organic molecules delivered to Earth by cometary impact and does (that process) extend to planets elsewhere?” The results from the Deep Impact mission may provide some of the clues needed to provide an answer.