SOLAR SYSTEM

Comet Chasers Get Serious

Comets, once considered bad omens, might hold the secret of where Earth's water, and even life, came from. Researchers should soon know much more about these visitors from the outer solar system

Three years from now, on Independence Day 2005, a NASA spacecraft will attack another body in the solar system. No, this is not the plot of the latest summer movie about interplanetary warfare. Researchers hope that by firing a projectile at comet Tempel 1 and studying the resulting crater and debris, they will learn what it is made of.

It won't be the only intense encounter with a comet in the next few years. Scientists are in the process of launching an unprecedented clutch of missions to understand these spectacular visitors from the outer solar system. By the time Tempel 1 comes under attack, a spacecraft scheduled for launch earlier this week, called Contour, should be in the midst of a solar-system-wide tour of two or three other comets; dust captured from yet another comet should be on its way back to Earth for analysis; and the first comet lander in history should be headed for its target. "We're about to enter into a golden era" of cometary research, says Colleen Hartman, director of NASA's Solar System Exploration Division.

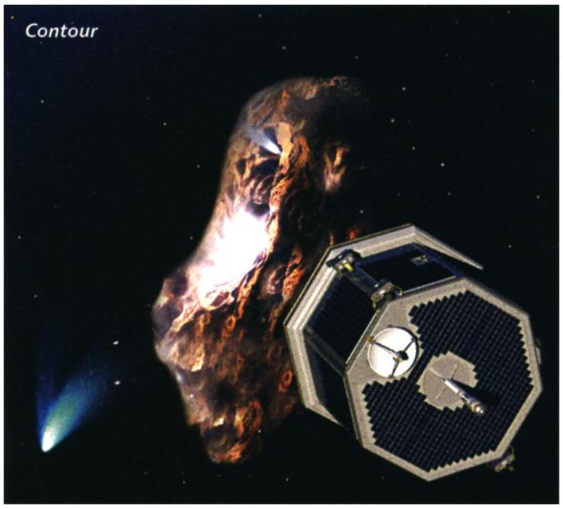
Comets are the afterbirth of the solar system: fluffy aggregates of ice and rock just a few kilometers across that were never swept up by forming planets. Normally, they orbit the sun at extremely large distances, far beyond the outermost planets, but once in a while a comet gets knocked into a highly elliptical orbit that brings it swooping into the inner solar system, where it can be captured in a much smaller orbit.

Once it is exposed to the heat of the sun, the comet's icy nucleus begins to evaporate, and Earth-bound observers can be treated to a spectacular light show of glowing and fluorescent tails of gas and dust. After many centuries, the comet ends up as a dark, porous cinder that resembles a rocky asteroid.

In the past, the sudden appearance of a bright comet was generally regarded as a bad omen, but for present-day astronomers, these capricious objects are time capsules that may shed light on the formation of the planets and on the origin of life.

"We want to know how comets work and what they are made of," says Joseph Veverka of Cornell University in Ithaca, New York. "They may have brought water and organic molecules to Earth. We may really be the progeny of comets."

Astronomers got their first close-up view of a comet in 1986, when the European Space Agency's (ESA's) Giotto spacecraft sped past Halley's Comet (named after 18th century English astronomer Edmund Halley, who first calculated a comet's orbit and predicted that it would reappear at regular intervals). Giotto flew to within 500 kilometers of the comet's nucleus with a relative speed of 68 kilometers per second.



Despite being bombarded and sandblasted by dust and grains from the comet, Giotto managed to take the first-ever pictures of a comet's nucleus. Halley turned out to be a very dark, irregular body, dotted with patches of geyserlike activity. Last September, NASA's Deep Space 1 obtained comparable results for comet Borrelly (*Science*, 5 October 2001, p. 27).

These brief flybys have only whetted astronomers' appetites. They would love to study comet dust in the lab, learn about the difference between old and new comets, peer into their interiors, take surface samples, and witness a comet heating up as it gets closer and closer to the sun.

All these goals should be fulfilled in the next few years by a remarkably diverse suite of American and European spacecraft. "We really want to go down to the key issues of the formation of the solar system," says Gerhard Schwehm of ESA's technology center in Noordwijk, the Netherlands. "Our main science goal is to understand how planetary systems evolve."

Those hopes rest on four spacecraft: Contour, Stardust, and Deep Impact—all from NASA—and the Rolls-Royce of the bunch, ESA's Rosetta. According to Deep Impact principal investigator Michael A'Hearn of the University of Maryland, College Park, there is "a fair bit of collaboration" among the four projects. "Some researchers are in the science teams of two or even three missions," he says.

Contour, short for Comet Nucleus Tour, is going for the big picture. As this issue went to press, the spacecraft was set for launch 3 July on a sightseeing trip around the solar system. Contour is scheduled to visit three comets in 5 years, provided it gets a hoped-for extension beyond its core 4-year mission. The first planned stop, in November 2003, is an encounter with Encke, an old comet in a 3.3-year orbit that has been observed since 1786. Two and a half years later, in June 2006—after repeated flybys of Earth to change trajectory—Contour should swing past the much more active comet Schwassmann-Wachmann 3 (its nucleus broke into at least three pieces in 1995). "These are two

7 February 1999
Launch of Stardust

3 July 2002
Launch of Contour

13 January 2003
Launch of Rosetta

November 2003
Contour encounters comet Encke

2 January 2004
Launch of Deep Impact

2 January 2004
Stardust encounters comet Wild 2

January 2005
Deep Impact flyby of Earth

4 July 2005
Deep Impact impactor slams into comet Tempel 1

26 August 2005
Rosetta flyby of Mars

28 November 2005
Rosetta flyby of Earth

15 January 2006
Stardust returns comet dust to Earth

June 2006
Contour encounters comet Schwassmann-Wachmann 3

11 July 2006
Rosetta encounters asteroid Otawara

28 November 2007
Rosetta flyby of Earth

24 July 2008
Rosetta encounters asteroid Siwa

August 2008
Contour encounters comet d'Arrest

29 November 2011
Rosetta enters orbit around comet Wirtanen

July 2012
Rosetta lander touches down on surface of comet Wirtanen

comets that could not be more diverse," says Donald Yeomans of NASA's Jet Propulsion Laboratory in Pasadena.

Learning about cometary diversity is "an essential next step in the exploration of comets," says Veverka, Contour's principal investigator. Because Schwassmann-Wachmann 3 broke up very recently, the spacecraft might have a rare chance to peek into the interior of a comet nucleus. Contour will fly much closer to the comet, and at slower speeds, than Giotto did in 1986. This should give astronomers their best-ever images of cometary nuclei, with details as small as a few meters and more data on the composition of their extended "atmospheres."


Stardust

If fuel supply and budget permit, a third comet will be added to Contour's itinerary. This could be comet d'Arrest (pencilled in for August 2008), or maybe an as-yet-unknown comet that enters our planetary system for the first time. A third option, according to mission director Robert Farquhar of Johns Hopkins University in Baltimore, is to send Contour to Wilson-Harrington, an essentially "dead" comet that now resembles an asteroid.

As Contour sets off on its tour, another NASA craft is already well on its way. Stardust, launched in February 1999, is on track for an encounter with comet Wild 2 in 18 months. Wild 2 used to roam the outer parts of the solar system, says principal investigator Donald Brownlee of the University of Washington, Seattle, but it was deflected by a close encounter with Jupiter in 1973 and now orbits much closer to the sun. This gives astronomers a chance to study its surface before it gets blasted too much by the sun's heat. "It's actually very exciting. It may be covered with craters" that have not yet been obliterated by cometary activity, says Brownlee.

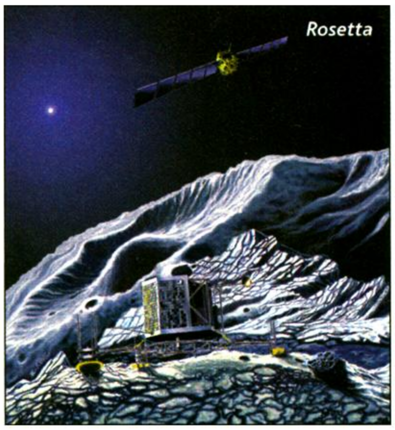
On 2 January 2004, Stardust will pass through Wild 2's coma: the cloud of gas and dust surrounding the solid nucleus. Using paddle-shaped dust collectors made of lightweight aerogel, the spacecraft will catch microscopic comet dust that will be returned to Earth 2 years later.

"We need all the analytical techniques available in ground-based laboratories to study these samples," says Brownlee. He hopes Wild 2's sheddings will provide clues to the links between interstellar matter, protoplanetary disks, comets, and interplanetary dust particles.

On the same day that Stardust encounters Wild 2, NASA is scheduled to launch its third comet mission, Deep Impact. The spacecraft will carry a 370-kilogram impactor, made largely of copper, that should slam into the nucleus of comet Tempel 1 on 4 July 2005. "The comet may temporarily become 100 times as bright, so it will be visible in binoculars and maybe even with the naked eye," says principal investigator A'Hearn. "We assume that every ground-based telescope will be pointed at the comet" around the time of impact.

Tempel 1 is a fairly large comet, so it won't be deflected or destroyed by the impact. A'Hearn expects to create a crater the size of a football field and as deep as a seven-story building. However, he says, it all depends on the density and the internal structure of the nucleus. Scientists hope the crater will be deep enough to reveal parts of the comet that have not yet been affected by the sun's onslaught. As the spacecraft continues to fly past Tempel 1, it will study in detail the crater and the debris from the impact, to learn more about the comet's properties and chemical makeup.

Humankind's first assault on a comet is certain to generate a lot of publicity. "The 4th of July was a conscious choice," says A'Hearn. "Celestial mechanics forced us to encounter the comet somewhere between mid-June and mid-July, and then we thought, 'Why not?' " However, he says the name for the mission had been chosen before the release of the Hollywood blockbuster *Deep Impact*, about a comet that hits Earth. "The movie company is now happy to collaborate," says A'Hearn. "They may even rerelease the movie in 2005."

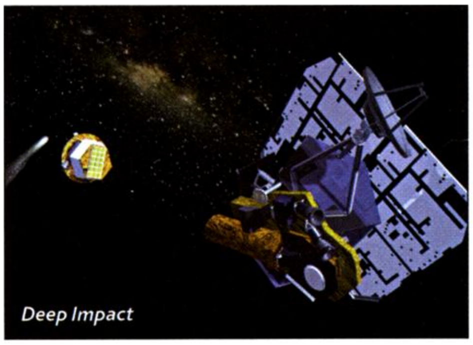

Rosetta

Exciting though these missions are for comet scientists, the true Holy Grail would be to bring a sample of a nucleus back to Earth for analysis. Just such a mission was considered as a NASA-ESA collaboration in the mid-1980s, according to ESA's Schwehm. But some 10 years ago, NASA pulled out of the project, and ESA had to rethink its plans. The result is Rosetta; at nearly $700 million, it costs more than the trio of NASA comet missions put together.

Instead of bringing comet samples back to Earth, Rosetta will fly a laboratory to comet Wirtanen for an extended visit, says Schwehm. The instrument package contains sensitive cameras, mass spectrometers and gas analyzers, and even an atomic force microscope to study dust particles. "It's a wonderful mission," says Brownlee.

Rosetta is scheduled to be lofted by an Ariane 5 launcher on 13 January 2003. After a series of flybys of Mars and Earth (to gain enough speed to reach the distant comet), and encounters with asteroids Otawara and Siwa, Rosetta should rendezvous with Wirtanen in November 2011. For 18 months, the spacecraft will orbit the comet's tiny nucleus as it gets closer and closer to the sun. During this period, Rosetta will deploy a lander to study the surface close up.

"The Rosetta stone was the key to deciphering the origins of the Egyptian hieroglyphs," says Schwehm, Rosetta's project scientist. "Likewise, Rosetta will be the key to deciphering the origins of the solar system." The suite of high-precision instruments on board the spacecraft and the lander might reveal whether most of the water on Earth was delivered by comets, and what role comets played in seeding our planet with prebiotic, organic materials.


Deep Impact

"Ultimately, Rosetta holds the largest promise for comet science," says A'Hearn. "But the nice thing about this whole suite of cometary missions is that each addresses very different problems. They are really very complementary."

With so much expectation hanging on Rosetta and the other missions, Schwehm is acutely aware of all that could go wrong. For the moment, he is focused on overcoming the first hurdle: getting the craft up and deploying its solar panels and communications antenna. "These are the most critical parts [of the mission]," he says. "It's a little bit nerve wracking."

–GOVERT SCHILLING

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