Heading for a Dusty Death at Comet Halley?

Researchers are betting the success of the Giotto mission on their understanding of the debris shed by the comet—big uncertainties remain

No one will be surprised next March if a speck of dust smashes into the Giotto spacecraft at 250,000 kilometers per hour, knocks it completely out of kilter, and ends its mission to explore Comet Halley just as it is reaping some of its most valuable results. Things could well be much worse. If astronomers' admittedly crude guesses about how much dust surrounds the ice ball at the heart of Comet Halley are very far off, the European Space Agency's Giotto mission could end even earlier, before the spacecraft is able to take its best pictures of the icy nucleus or collect unique samples of the surrounding gas cloud.

Giotto's possible fates are varied. More dust than expected could erode the optics of Giotto's camera before its closest approach to the nucleus, leaving it blind. A larger than expected dust particle could rip through the guts of the spacecraft and disable it. Collision with a monster, centimeter-sized particle of the sort recently found in a swarm about Comet IRAS-Araki-Alcock would surely obliterate Giotto. The first check on predictions of Giotto's ultimate end will come on 11 September when the International Comet Explorer, the only American comet probe, will pass through the tail of Comet Giacobinni-Zinner, which should be a relatively safe but still potentially informative scurry through the dust of a comet.

To look at it, the typical cometary dust particle would not strike fear into the hearts of spacecraft designers. Judging from the visible light scattered by comet dust, which accounts for part of the brightness of comets, and the infrared radiation that the dust emits, the typical particle measures about 1 micrometer in diameter. That is hardly larger than the wavelength of visible light and roughly the size of smoke or smog particles. Comet dust particles span a range of sizes, but their numbers drop drastically with increasing size, so that few are larger than 10 micrometers in diameter.

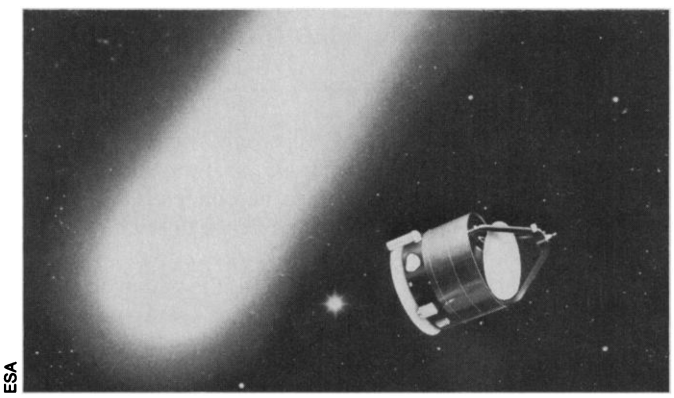
Comet dust is dark, as dark as soot, presumably from a primordial organic sludge that apparently darkens comet nuclei as well (*1*). If the porous cosmic dust that drifts into Earth's stratosphere originates in comets, as suspected, the smallest comet dust consists of individual silicate mineral grains and larger dust particles are fluffy aggregates of grains that are more empty space than rock.

What makes these seemingly inconsequential specks so intimidating is the speed with which they will smash into Giotto. Because Comet Halley orbits in the direction opposite to that of Earth, the only practicable way of encountering Halley as it swings around the sun is to meet it nearly head on. Consequently, the speeds of dust and spacecraft add to each other, reaching the uncomfortably high speed of a quarter million kilometers per hour or 70 times the speed of a bullet. A 100-milligram particle (about 1 millimeter in diameter) at that speed has the kinetic energy of a subcompact car doing 80 kilometers per hour, which is enough energy to drive the particle through 8 centimeters of solid aluminum.

Giotto cannot carry that much aluminum, but it will protect itself with a shield that ingeniously foils impacting dust. It has two parts, the leading component consisting of a 1-millimeter-thick aluminum sheet. That cannot stop a 100-milligram particle, but it will vaporize it. By the time the vapor crosses the 23-centimeter space behind the front shield, it has expanded so that its energy is dispersed over a larger area of the rear shield, a sandwich of foam and Kevlar, the bulletproof vest material.

Being blasted through by a particle is not the only hazard at Halley. Every dust impact on the angled mirror that lets Giotto's camera peek around the shield at the nucleus will erode the mirror. Eventually the dust could blind the camera. A 10-milligram dust particle, one about 3 millimeters in diameter, may not breach the shield, but an off-center hit would transfer enough momentum to the spacecraft to reorient it by more than 1°—not that much of a jolt but enough to knock Giotto's narrow-beam radio transmission off its target, Earth, and end the mission.

Giotto scientists now consider loss of radio contact within seconds of Giotto's closest approach to the nucleus as the most likely end to their mission. The spacecraft, it is calculated, has a better than 90 percent chance of surviving, but there is a 50 percent chance that a hit will break radio contact, according to Rüdeger Reinhard, the Giotto project scientist. Still, the 50:50 chances for this mission may be too optimistic or too pessimistic by a factor of at least 4.



ESA

Homing in on Halley

The Giotto mission has a 50 percent chance of ending abruptly after colliding with a dust particle at its closest approach to Halley's nucleus, which is hidden at the center of the 100,000-kilometer-wide coma. The spacecraft may also complete its mission unscathed, or meet an untimely end before closest approach.

Much of that uncertainty resides in estimates of how fast a comet produces dust. There are two fairly direct methods to estimate dust production. One depends on watching how the feeble push of sunlight drives away dust particles to form a curving tail. The dust is first launched into space from the icy nucleus by the ice vaporizing under the sun's heat. Within a few tens of kilometers from the nucleus, the particles are no longer being dragged by the gas, and the smaller ones begin coasting at perhaps 2000 kilometers per hour until the solar pressure turns them back some 100,000 kilometers from the nucleus. The other method depends on infrared observations of the dust. Opinions vary, but the accuracy of these methods for determining the production rate of comet dust may be no greater than a factor of 2 to 3.

Giotto planners wish they could be that precise. The only pertinent modern observations of Comet Halley are photographs in visible light made in 1910. There were no infrared observations and the view of the tail then did not reveal its true curvature, eliminating use of the dust tail method.

That leaves the even more indirect method of measuring, from old photographic plates and magnitude estimates, the visible light emitted by gaseous carbon. The rate of gas production is then estimated from recently observed correlations between carbon emissions and gas production measurements of other comets. Unfortunately, the observed correlation is not a strong one. Through theoretical calculations the gas production gives the velocity of ejection from the nucleus, and the reasonable assumption that five times as much gas is produced as dust leads to a dust production for Halley of 5 tons per second during the encounter. The Halley Environment Working Group, a subcommittee of the international Inter-Agency Consultative Group, came up with this best guess as one part of the input to a computer model of the behavior of dust around Halley that was developed by Neil Divine and Ray Newburn of the Jet Propulsion Laboratory (*2*).

The Halley dust model suggests that things will get pretty rough when Giotto is 500 kilometers from the nucleus, its intended point of closest approach. There will be only 30 particles per cubic meter of the typical 1-micrometer size or smaller, but at a quarter million kilometers per hour that means more than 3 million hypervelocity impacts per second on the shield. In the 1- to 10-milligram size range of direct danger to Giotto, there are liable to be several hits. Fortunately for Giotto, most of those hits would come within 10 seconds of closest encounter as a result of the rapid thinning of the dust with distance from the nucleus.

Still, some of the most crucial analyses of the comet's gas will be made within seconds and minutes of closest approach. And although the camera will first resolve the nucleus 15 minutes earlier, it must survive up to at least a minute before closest approach in order to improve on images returned by the Soviet Vega 1 spacecraft 10,000 kilometers away. If Vega 1 succeeds, Vega 2's target will move in to 3000 kilometers, placing further demands on Giotto. This is all predicated on Giotto's hitting its 500-kilometer target point without straying even closer, a feat spacecraft controllers intend to achieve with Soviet cooperation.

As if these uncertainties were not great enough, Halley may harbor additional hazards not included in the dust model. One other hazard is certainly dust jets. Stephen Larson of the University of Arizona and Zdenek Sekanina of JPL have enhanced the contrast of 1910 photographs of Halley in order to bring out details in dusty jets streaming from the nucleus (*3*). They found at least three areas on the nucleus, one of them strung along one-quarter of the circumference of the nucleus, that had ordinary gas production rates but were ejecting at least 30 times as much dust as less active areas. Sekanina and Larson concluded that Giotto's approach from the south on the morning side of the nucleus—the sources seem to be concentrated in the northern hemisphere—will tend to fortuitously protect the spacecraft from encountering a jet until it is within seconds of closest approach. That assumes, of course, that only those jets active in 1910 are active in 1986. There is also the problem of larger, more dangerous particles that move far more slowly than smaller ones and thus lag days behind the visible jets.

Being blasted through by dust is not the only hazard at Halley.

Another highly uncertain hazard is a possible swarm of golf ball–sized debris ejected from the nucleus. Richard Goldstein, Raymond Jurgens, and Sekanina at JPL detected such a debris swarm around Comet IRAS-Araki-Alcock in 1983 using the 64-meter Goldstone antenna as a radar (*4*), as did Donald Campbell of the National Astronomy and Ionosphere Center, Arecibo, Puerto Rico, and Irwin Shapiro and Brian Marsden of the Harvard-Smithsonian Center for Astrophysics, using the giant 300-meter dish at Arecibo. The debris must be at least a centimeter or two in diameter or it would never reflect the 3.5- and 13-centimeter-wavelength signals of the radars. There must be many such particles because they returned about 25 percent of the total radar power. And huge particles are well within the lifting ability of gases vaporizing off Halley's nucleus.

Assuming that Halley has a debris swarm like that of IRAS-Araki-Alcock—a big assumption indeed—and that the swarm has specific properties that cannot be pinned down by radar, the Arecibo observers have calculated that Giotto would have a few percent chance of being obliterated by a swarm particle. That is disconcertingly high compared to the infinitesimal probability of such a collision determined by the dust model. It assumes that, as observed for submillimeter dust particles, a particle twice as large as another will be 16 times as scarce. So, perhaps the swarm debris does not obey that general rule, or there could be a different rule for particles larger than the largest ever seen in visible light, which are millimeter size.

The first narrowing of the range of these uncertainties concerning the Halley encounter will come 11 September when the International Cometary Explorer (ICE), a U. S. satellite appropriated from Earth orbit, encounters Comet Giacobinni-Zinner. ICE will penetrate the dust tail 10,000 kilometers from the nucleus, far from the densest of the dust, and is equipped only with instruments designed to study the magnetic and plasma properties of the solar wind.

But one type of instrument on board, the plasma wave instrument, has already proved itself a competent dust detector. One of these was on Voyager 2 when it brushed the edge of the minor G ring of Saturn. Without prior planning, the instrument detected the impacts of particles in the size range typical of comet dust. In fact, notes Frederick Scarf of TRW in Redondo Beach, the principal investigator of the plasma wave instrument, the Giacobinni-Zinner encounter should produce impacts similar to that of the uneventful Voyager ring crossing if Divine's application of the dust model to Giacobinni-Zinner is any guide. That should provide some test of the model as well as the spacecraft. Other tests will come this fall as astronomers make measurements of Halley's gas and dust production. Closer to the encounter, mapping of dust jets and reports from the Soviet Vega spacecraft may help target Giotto more safely. Even so, the final test of the understanding of cometary dust will fall to Giotto.

—Richard A. Kerr

References

1. R. A. Kerr, *Science* **229**, 372 (1985).
2. N. Divine and R. L. Newburn, in *Cometary Exploration*, T. I. Gombosi, Ed. (Hungarian Academy of Science, Budapest, 1983), vol. 2, pp 81–98.
3. Z. Sekanina and S. M. Larson, *Astron. J.* **89** 1408 (1984).
4. R. M. Goldstein, R. F. Jurgens, Z. Sekanina *ibid.*, p. 1745.