Giotto Finds a Big Black Snowball at Halley

Halley's dust took its toll on Giotto but not before the spacecraft revealed that the comet's nucleus is larger, darker, and more encrusted with debris than expected

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THE catastrophic end of the European Space Agency's Giotto mission to Comet Halley came as no surprise to the scientists here at the European Space Operations Center awaiting the high point of the most daring and potentially most rewarding comet visit. In fact, the sudden disappearance of camera images from monitoring screens seconds before the closest approach to the comet's icy nucleus marked one of the more successful predictions in cometary science. As expected, dust particles hitting the spacecraft set it wobbling out of control.

Expectations about the nucleus—the chunk of ice that is the source of all that is Halley's—were not so accurately fulfilled. It is about twice as large and twice as dark as thought, and even a comet that blazes as Halley does apparently clothes itself in its own coal-black debris.

A few days earlier, the Soviet spacecraft VEGA-2 had given some clues as to what Giotto would reveal. Passing about 9000 kilometers sunward of the nucleus on 9 March, VEGA-2 returned an image of two bright spots side by side. At first, debate concerned whether they were a 6-kilometer nucleus and a smaller jet of dust recently released from it or two separate nuclei formed by splitting. But on 11 March the VEGA television team announced a new interpretation—the bright spots were on one nucleus. There might be parts of a darker, unseen nucleus outside the bright spots, but the sharpness of the bright edges showed that it was one object at least 11 kilometers long and 7.5 kilometers across its greatest width.

This peanut-shaped nucleus was not what some astronomers had expected. It was a bit on the large side, a diameter of 5 kilometers being a typical prediction. And with a reflectivity or albedo of about 7 percent, it was also distinctly darker than the 10 to 15 percent albedo (somewhat less than that of the moon) often presumed for comets. Most recently, the Halley Environment Working Group of the international Interagency Consultative Group that was coordinating the Halley missions summed up its best estimates of the nature of an object normally shrouded from view. Halley's nucleus had a diameter of 6 kilometers, largish but not huge, and an albedo of 6 percent, dark but not the coal-blackness of some asteroids and low-activity comets.

Then Giotto approached Halley to cast the deciding vote. But first it had to traverse, at a relative speed of a quarter million kilometers per hour, the cometary debris spewing from the nucleus. The sequence of events was now familiar from the VEGA's and last September's International Cometary Explorer flyby of Comet Giacobini-Zinner: first the ionized gas appeared, beginning almost 8 million kilometers out; at a distance of about 1.1 million kilometers, the gas had thickened enough to slow the solar wind markedly and create a broad "bow wave" in the charged particles of the plasma.

Then at 287,000 kilometers, the first dust particle hit at 50 times the speed of a bullet, harmlessly vaporizing itself on Giotto's dust shield. Surprisingly, the rate of impact here reached only a tenth of that predicted by the working group's model of Halley's surroundings. That was a promising omen as the camera began returning images every 4 seconds. A central bright spot stood out in false color at the narrow end of a gaudily tinted fan—the dust and gas streaming toward the sun. Almost unnoticed by the press and many scientists, a dark splotch was biting into the small end of the fan. That would turn out to be the nucleus silhouetted against the brighter background dust.

The impact rate was continuing to increase gradually when at a distance of about 8000 kilometers the first dust particle remained intact after piercing the leading layer of the dust shield and slammed into the second and last barrier. This intensifying rain of particles was all the time eroding the camera's polished aluminum mirror, threatening to blind it. At a distance of 5000 kilometers, a surge of fine dust suddenly decreased the image contrast.

Despite the pummeling Giotto was taking, things looked a lot better than had been feared as Giotto sailed through uncharted territory inside 8000 kilometers. It passed the point at about 4500 kilometers where purely cometary ions hold off the solar wind and then headed inward in pursuit of unaltered cometary debris. That was when the camera's troubles began. Its automatic tracking of the brightest spot in view began to push the nucleus off the screen as the bright jetting dust loomed larger and larger.

Then 1350 kilometers from the nucleus, short of closest approach at 605 kilometers, the camera took its last picture of anything. Something, presumably a dust impact, created a power supply anomaly that caused the camera to search for the comet as if the encounter were only just beginning. A few seconds later, a sudden surge of dust sent

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Giotto's Halley

Taken at a distance of 18,000 kilometers, this image of the nucleus of Comet Halley reveals two major bright jets of dust from the sunlit side of the nucleus and the dark, largely unlit nucleus to the left with a darker region in its upper left corner. Its longest dimension is 15 kilometers. The sun shines from the lower right corner of the image.

about 150 particles as large as 1 milligram through the first layer of the shield, ending the mission if not the life of the spacecraft. After the monitoring screen went blank, a ripple of applause in the press room recognized a job well done to the bitter end. As anticipated by the working group, that blast of hypervelocity dust carried enough momentum to slow noticeably the half-ton spacecraft and start it wobbling. That knocked its narrow radio beam off the receivers and prevented the reception of usable data from most of the instruments.

Before its demise, Giotto's camera showed that what had been the focus of attention since VEGA-2's encounter—the bright spots—were jets of dust streaming from the nucleus, not bright spots on its surface. The nucleus itself remained cloaked in darkness. In the best Giotto image released to the public, taken at 18,000 kilometers, two major jets from the sunlit side of the nucleus mask one of its edges, but its longest dimension is 15 kilometers and its width is at least 8 kilometers. Although the running commentary provided during the encounter included talk of craters and hills, the only obvious feature in this picture is a dark, mottled feature near the silhouetted edge of the nucleus.

Uwe Keller of the Max Planck Institute of Aeronomy in Katlenburg-Lindau, West Germany, the head of the camera team, again described the nucleus as a peanut or a potato, albeit a larger one. A lump of coal may be more accurate, its color being "absolutely black," according to Keller, "very similar to the lowest albedo in the solar system."

By observing them at different wavelengths of light, astronomers had deduced that the nuclei of some low-activity, nearly burned out comets are indeed big black lumps. But many researchers assumed that Halley, unlike these nearly defunct comets, would be active enough when near the sun to blow off any dark, non-icy debris that might have accumulated on its surface and show lighter, if not bright, dirty ice all over. "I had thought some comets were covered with a dark, nonvolatile mantle," said Martha Hanner of the Jet Propulsion Laboratory, "but I still thought very active comets would have ice at the surface. It seems even Halley may have a predominantly nonvolatile surface." The mantle of nonvolatile debris—presumably rock and dark organic material—would protect the underlying ice and lead to outgassing and dust jetting from only a small part of the surface.

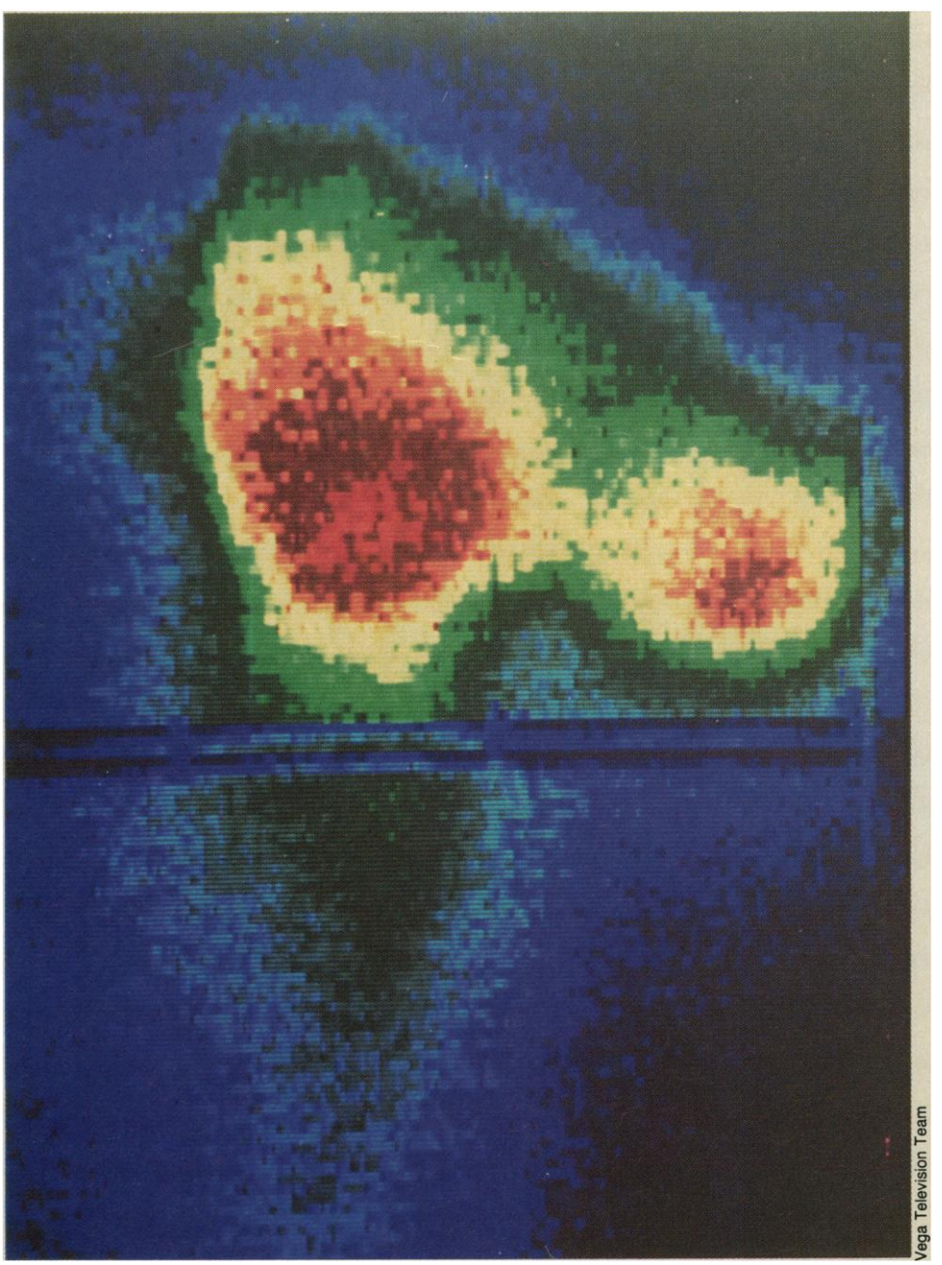
It was this jetting that probably affected the camera and then ended the mission. Jets were known from computer enhancement of 1910 photographs of Halley analyzed by Stephen Larson of the University of Arizona and Zdenek Sekanina of JPL. But no one suspected that they produced more than a minor portion of the total gas and dust released by the sun's heat. Now it appears that most of it escapes that way. The models predicting the dust that Giotto would encounter did not include jets, so that they overestimated the dust hazard early in his encounter and underestimated it later, close to the nucleus. The end result would seem to have been the same.

Thirty-four minutes after dust knocked Giotto out of kilter, an onboard damping device reduced the wobble enough to reestablish good data reception. Six of the 10 instruments suffered some damage, but none is dead. As evaluation of damage continued, the European Space Agency made plans to nudge Giotto into an orbit that would bring it by Earth in July 1990 for a slingshot redirection to another comet or an asteroid. Even then its Halley observations will probably be central to the study of comets. ■ **RICHARD A. KERR**

ADDITIONAL READING

R. A. Kerr, "A comet's heart may be big but black," *Science* **229**, 372 (1985).

——— *ibid.*, "Heading for a dusty death at comet halley?" p. 541.



VEGA-2's best view of Comet Halley

This false-color image contains two bright spots spanning 11 kilometers that now appear to have been two jets of dust spewing from the dirty snowball that is Halley's nucleus. Dust streams downward in this view from the larger jet.