Catching a Volatile Halley Before It's Gone

Although a disappointing sight to many, those with a good view are finding Comet Halley to be bubbling with activity and new insights

As advertised, Comet Halley is not much of a show for most American backyard observers. But the combination of frequent ground- and satellite-based observations and mad dashes through the comet by three spacecraft has revealed that this dirty snowball responds far more dynamically to the sun's heating than was supposed.

Even the best binocular view gives little hint of the fierce sputtering that the tiny chunk of ice at the heart of the comet is undergoing.

From the Southern Hemisphere in early March, Halley was reported to be a lovely sight even with the naked eye, a fine comet sporting a 10°-long tail. That is 20 times the width of the full moon, but in 1910 the tail was more than 90° long. Michael A'Hearn of the University of Maryland compares this apparition of Halley under good conditions with that of Comet Kohoutek in 1975—Halley does not hit you in the face on walking outside but is easily found on looking in the right direction. Casual Northern Hemisphere observers in all but the most southern latitudes have not been so lucky. If near a major city, Americans have usually needed binoculars to see the much heralded visitor.

Even the best binocular view gives little hint of the fierce sputtering that the tiny chunk of ice at the heart of the comet is undergoing. A'Hearn reports that since 9 March, when the International Ultraviolet Explorer was again turned toward the comet, its brightness has been changing from day to day by a factor of 3 or more, due mostly to varying dust expulsion. The production of hydroxyl radical, a short-lived product of the water released by the icy nucleus, varied by a factor of 2 from day to day. A "fantastic outburst" began on 23 March and was still building the next day, A'Hearn says.

All these outbursts make even clearer the fluctuations apparent during the spacecraft encounters and hinted at by studies of historical Halley observations. Dust detectors on the Soviet VEGA 1 spacecraft, the first to penetrate the comet, found several times as much dust as those on VEGA 2, which arrived 3 days later. Most of the extra dust came in a huge spike that struck just after closest approach to the nucleus, according to John Simpson of the University of Chicago, principal investigator of one of the dust instruments.

That the VEGA's encountered a jet of fine, smoke-like dust particles on 6 March but not on 9 March fits the picture of Halley's unseen nucleus developed by Stephen Larson of the University of Arizona and Zdenek Sekanina of the Jet Propulsion Laboratory. They traced the ejection of dust jets in photographs taken in 1910 in order to extrapolate the jets to their sources on the surface of the nucleus. The nucleus, it seemed, was crisscrossed by linear sources but mostly on one hemisphere. Earth-based observations by Larson in the weeks before the encounters showed that VEGA 1 would see the more active face of the nucleus. Apparently that was the case.

VEGA 2, thanks to the 2.2-day rotation of the nucleus first determined by Larson and Sekanina and confirmed by the Japanese Halley probe Suisei, encountered the less active hemisphere, avoided any intense jets, and detected several times less dust. Even so, VEGA 2 lost three instruments at closest approach (about 8000 kilometers) to VEGA 1's two, and its solar panels suffered an 80% power loss to VEGA 1's 45% loss.

A likely explanation offered by Roald Sagdeev, director of the Space Research Institute that runs the VEGA program, is that VEGA 2 collided with more relatively large particles. Because the gases escaping from the nucleus can only drag particles so long before the gas expands and becomes too thin, larger particles never reach the speeds of 400 or 500 meters per second attained by smoke-size particles. Thus, even after the active hemisphere turns away, these slower moving, more dangerous particles could still be lurking in the path of the quarter-million kilometer-per-hour spacecraft. Even so, it is hard to explain reports that two 1- to 2-milligram particles—real boulders by comet standards—hit Suisei during the hour before its closest approach at a distance of 150,000 kilometers, Larson says.

The European Space Agency's Giotto, the last of the three spacecraft to pass close by the nucleus, came within a mere 605 kilometers of the nucleus over its active side. As a result, Giotto encountered every sort of particle, and probably the jets themselves, in the final seconds before closest approach. That knocked out instruments and sent the spacecraft into a wobble that temporarily broke the radio link with Earth.

As dangerous as comet dust proved to be, it is one of the possible keys to the big questions about comets. Do they preserve unaltered primordial ingredients of the solar system?

As dangerous as comet dust proved to be, it is one of the possible keys to the big questions about comets: Do they preserve unaltered primordial ingredients of the solar system? What can they tell us about the origin of the solar system? Turning hundreds or thousands of potentially lethal impacts per second into informative scientific results is no simple matter, but many of the spacecraft instruments seem to have managed it.

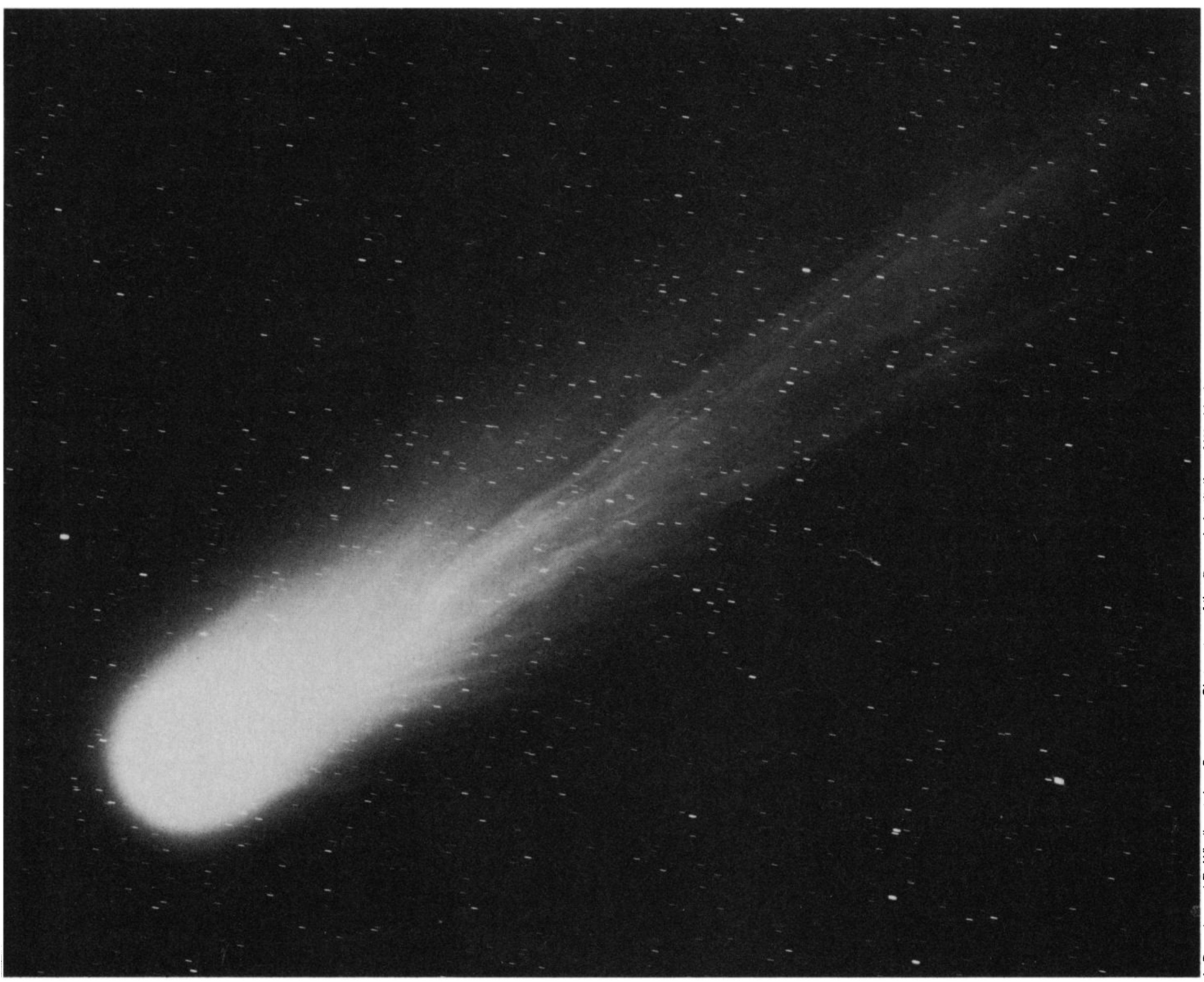
By simply counting particle impacts and measuring the masses of those particles, some of the instruments that detect dust have provided evidence that comets do indeed harbor primordial material. To judge by the visible and infrared radiation scattered to Earth by the dust, the typical particle has a diameter of about 1 micrometer. The abundance of particles larger than that seemed to drop off sharply with increasing size, which is crudely confirmed by the survival of the spacecraft. Particle abundance also seemed to drop off abruptly with decreasing size, the smallest detectable particle being about 0.1 micrometer.

But the VEGA 2 dust counter found that the abundance of particles continued to increase below 1 micrometer almost as fast as it did above that size range. Giotto's dust impact detector system found dust particles smaller than 0.01 micrometer, each a million times less massive than cigarette smoke particles. Such tiny grains are thought to exist in interstellar space and could have accreted to form comets, but they are unknown in meteorites, researchers' principal source of primitive solar system material.

Interpretations of the chemical and isotopic analyses of this dust carried out on the spacecraft are still preliminary. The dust conveniently vaporizes itself on impact, providing the proper samples for mass spectrometers, but the details of the vaporization process—the high energies of which cannot be duplicated in the laboratory—are not well known, which hinders interpretation.

At this point, Jochen Kissel of the Max Planck Institute for Nuclear Physics in Heidelberg is willing to say that his team's particulate impact analyzer on Giotto identified two types of particles. One exhibits a wide mass range (extending toward the broad peak at mass 110 derived from the silver impact target) that is compatible with traditional views of comet dust as silicate minerals dirtied with a bit of organic matter. The second type, constituting a surprising 90% of the total, has only lower mass peaks, principally from 10 to 20 and around 30 mass units. There is evidence of carbon, nitrogen, and oxygen, as well as some indication of low molecular weight compounds of carbon, nitrogen, and hydrogen. A similar instrument on the VEGA's, the dust-impact mass-analyzer, also found evidence of two types of particles, one of which was rich in carbonaceous material.

Unlike those specialists beginning to unravel the mysteries of comet dust, the plasma physicists were taking things in stride. Although tickled with the vast quantities of new information about the behavior of charged particles near an obstacle in the solar wind, they found no startling new phenomena. "The great surprise," says Andrew Nagy of the University of Michigan, a guest VEGA investigator, "is that there are



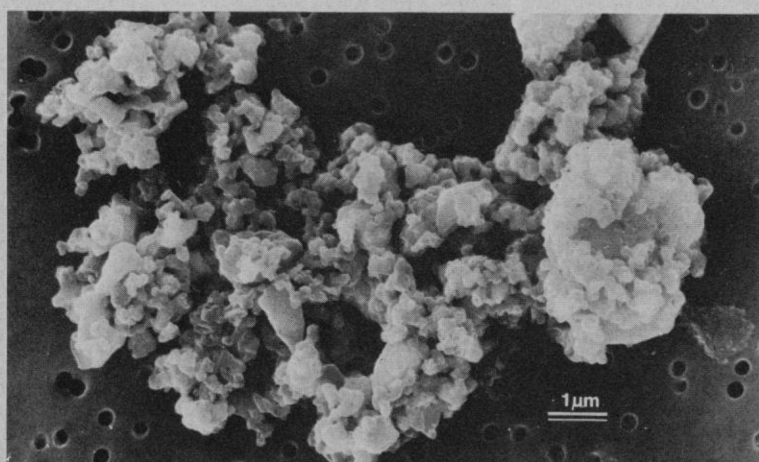
A. Dressler and R. Windhorst, Las Campanas Observatory of the Carnegie Institution of Washington

Comet Halley from Earth. *This is how Halley appeared on 16 March, just days after the armada of spacecraft passed the comet. This is a reproduction from a 50-centimeter-square photographic glass plate exposed for 5 minutes and covering a field of view of about 1°. The full moon covers 0.5° and at the time the visible comet extended 10°. The fine structure of the comet's tail of dust and gas changes over minutes and hours, most likely due to the changing output of the nucleus buried in the head of the comet and to the varying solar wind.*

Comet Dust Closer to Home?

For more than 15 years researchers have been collecting dust in the stratosphere that now appears to be extraterrestrial. Some of it in all likelihood is cometary dust. Although chemical and isotopic analyses have not been reported yet from the Halley encounters, other observations from the Halley armada suggest that comet dust is already in hand.

Cosmic dust is routinely collected at altitudes of 18 to 20 kilometers by U2 aircraft carrying plates covered with a tar-like silicone oil into which particles slam and stick. The micrometeorites among the particles are drifting down from altitudes above 70 kilometers, where the atmosphere is so thin that interplanetary dust arriving at a speed of more than 40,000 kilometers per hour can slow without heating so quickly that it melts. Roughly 10,000 tons of interplanetary dust hit the upper atmosphere every year, but researchers will always be forced to manipulate and analyze, particle by micrometer-sized particle, the tiny store of cosmic dust now housed along with the moon rocks at the Johnson Space Center in Houston.



D. Brownlee

Cometary dust from the stratosphere?
This is an electron micrograph of a cosmic dust particle collected in the stratosphere by a U2 aircraft. Like comet dust, it is black to the eye and highly porous.

The cosmic dust thought to be from comets is like no meteorite that ever fell to Earth. Its bulk chemical composition matches that of chondritic meteorites, the most common type, and it is black, like the rare carbonaceous chondrites, but it is porous and fragile, unlike any meteorite. The dust's extreme porosity, which is greater than 50%, is consistent with the low density of cometary dust inferred from observations of comet-related meteor showers. The composition of the component grains of this dust also matches the bulk chondritic composition, and some mineral crystals appear to have been deposited directly from a vapor, suggesting that the dust has been unaltered by the processes thought to have modified meteorite parent bodies but not comets.

So far, the dust encountered at Halley bears a considerable resemblance to that collected in the stratosphere. The Halley dust and the icy nucleus are also black. All the spacecraft found exceptionally tiny dust as small as 0.01 micrometer, the size of the crystals making up the component grains of some cosmic dust. Jochen Kissel of the Max Planck Institute for Nuclear Physics in Heidelberg, principal investigator of Giotto's particulate impact analyzer, reported that the density of the Halley dust, on first inspection, seemed to be less than 1 gram per cubic centimeter, which would make it porous rock indeed. And there appeared to be two types of particles, one consisting of both light and heavy elements that could be the mineral-organic combination of dust collected in the stratosphere. "The hope," says Donald Brownlee of the University of Washington and a pioneer in the collection and study of stratospheric interplanetary dust, "is that we can make a connection between these particles and those at Halley's." If that can be done, collecting samples for the study of the most primitive material in the solar system will be the easiest part of the job, although the dust from the stratosphere may have been altered by being heated briefly to 500° to 800°C. ■ R.A.K.

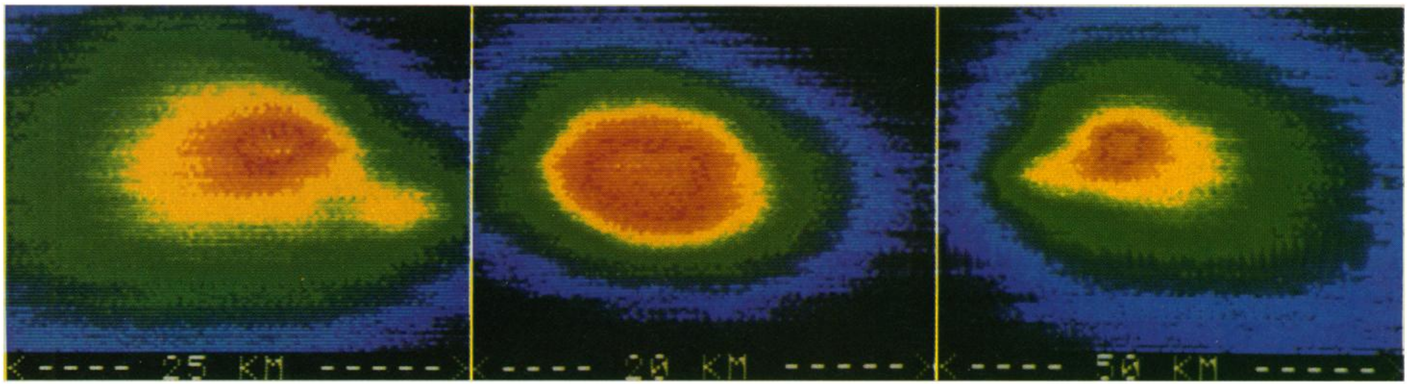
no great surprises. Usually, when we go to a new place for the first time, our predictions are totally wrong. This time our models are consistent with the observations on a gross scale." A. Galeev of the Space Research Institute in Moscow agrees, citing the other solar wind obstacles around the solar system already studied and the relative maturity of the field.

One notable plasma physics achievement of the Halley armada is Suisei's detection of a classical bow shock in front of the comet. Last September the International Cometary Explorer found only a diffuse bow wave region where ions from Comet Giacobini-Zinner began to slow the solar wind. Both VEGA's and Giotto found the same gradual slowing at Halley. Unlike any of these probes, Suisei entered the head of the comet closer to the line between the sun and the comet rather than perpendicular to the sun-comet line.

According to Bruce Tsurutani of the Jet Propulsion Laboratory, an investigator on the second Japanese spacecraft called Sakigake, Suisei encountered sharp changes in the plasma at a distance of 400,000 kilometers from the nucleus; these changes extended over 40,000 kilometers. That thickness is much greater than found at shocks around planets, he notes, but it is consistent with the tendency of the heavy water ions of comets to broaden the shock region. The Suisei results suggest that the classic shock expected at comets does form where cometary material and the solar wind meet head on, but it deteriorates to either side.

Perhaps as big news as any was the international cooperation that instrumented the Halley armada and guided it to its encounters. Soviet researchers, under the guidance of Sagdeev, joined in work with an unprecedented number of colleagues outside Intercosmos, the space research group of Soviet-bloc countries. The VEGA camera was mounted on and pointed by a Czechoslovakian platform, looked through French optics, operated on Hungarian electronics, and recorded its images on Soviet charge-coupled devices. Bradford Smith, an astronomer at the University of Arizona and head of the Voyager imaging team, assisted the Hungarians in image interpretation and reported some results to postencounter science briefings. Groups from France and the German Democratic Republic carried out parallel image analysis.

Other experiments went farther afield, geographically and politically. The VEGA dust-impact mass-analyzer was designed at the Max Planck Institut for Nuclear Physics in the Federal Republic of Germany, but because of a lack of funds, the Space Research Institute had it built in their shop in



VEGA Television System Team

Comet Halley from VEGA 1 in passing. *VEGA 1's view shifted as it approached the nucleus (left, with sun to the left), passed within about 9000 kilometers of it (center), and pulled away (right). After study of Giotto's images, it appears that the nucleus is not visible here, only jetting dust, some of which forms a secondary jet visible on approach and departure. Jetting had recently been detected in photographs of Halley made in 1910.*

Soviet Asia. Late in the process of assembling the VEGA's, word reached Moscow that Simpson had a design for a new type of impact detector. Within 6 months of receiving an invitation, Simpson had two detectors built, tested, and shipped for installation on the already assembled spacecraft. The VEGA neutral gas mass spectrometer was designed by a group at the University of Arizona but built at the Max Planck Institute for Aeronomy. Among the co-investigators for Giotto, itself a European cooperative effort, there are almost 40 Americans.

The capstone of international cooperation was the Pathfinder concept that put Giotto 605 kilometers from the nucleus without risking destruction by straying closer. Engineers navigating Giotto realized that, even at the time of encounter, they would know the location of Halley's nucleus to an accuracy of no better than a few hundred kilometers. The solution, reached under the aegis of the Inter-Agency Consultative Group coordinating Halley encounter activities, required that VEGA experimenters locate the nucleus precisely with respect to their spacecraft using the cameras, that NASA track the VEGA's with great accuracy using very long baseline interferometry, and that everyone inform the European Space Agency promptly enough to keep Giotto out of harm's way. It worked beautifully, reducing the targeting uncertainty to ±25 kilometers instead of the ±100 kilometers hoped for.

If anything about the encounters was more successful than Pathfinder, it was the comet show put on by Soviet scientists. At the Space Research Institute team members and foreign guests watched real-time, large-screen displays of every type of data as well as false-color images of the approaching nucleus, all explained in a simultaneously translated, running commentary. At the invitation of Sagdeev, more than a half-dozen American print journalists took advantage of access to scientists, science team briefings, and work areas unheard of at NASA planetary encounters. Even when problems arose, as when the VEGA 2 camera developed pointing problems, Sagdeev would make impromptu announcements to scientists and journalists, explaining what happened and apologizing for not providing more lucid information in mid-encounter. Looking ahead, Sagdeev spoke of the return to Earth of Mars soil and rocks as the next logical step for international cooperation in space research that could include major U.S. participation.

The future of the Halley armada is only a bit more certain than that of such international space research. Sagdeev said that VEGA 2, battered but still usable, may be directed toward an asteroid for another, presumably less harrowing encounter. Giotto, with half its instruments knocked out or partially damaged, has been redirected so that it will return to the vicinity of Earth on 2 July 1990 when it could be slung past Earth and sent on to an encounter with Comet Grigg-Skjellerup on 14 July 1992. Whether that happens depends on whether Giotto's camera is working well enough. Its status is presently unknown after suffering possible dust damage at the encounter. ■

RICHARD A. KERR

Max Planck Institute for Aeronomy

The view from Giotto. *Taken at a distance of 18,000 kilometers, this false-color image reveals the dark, dirty snowball (upper left), the source of all that is Halley, silhouetted against the brighter dust behind it. Its longest dimension is 15 kilometers. Two bright jets of dust extend from the sunlit side of the nucleus. Dust from such jets probably jolted Giotto at closest approach. The sun shines from the lower right corner of the image.*