A Comet's Heart May Be Big but Black

Astronomers straining to catch a glimpse of the "dirty snowball" of Comet Halley are finding that it may be bigger and dirtier than thought

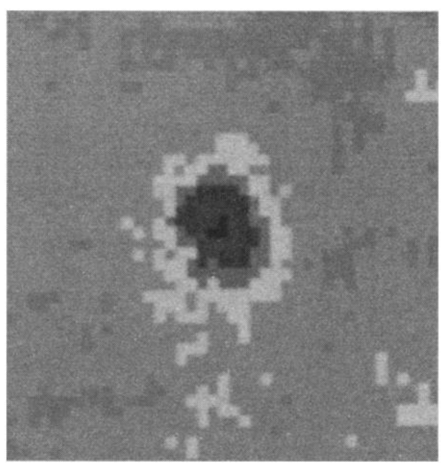
There is a mystery at the heart of every comet. Appearing at best as a star-like point of light in the largest telescopes, the tiny solid nucleus within the head of every comet is usually shrouded by an impenetrable haze. But the nucleus, through the dust and glowing gas that streams away from it to form a misty tail millions of kilometers long, has been the ultimate source of the awe, wonder, and excitement for which comets are renowned. Yet the visible comet is the merest wisp, next to nothing really, compared with the mass of frozen gases and primordial dust and dirt still locked up in the nucleus. Hidden there as well are perhaps the best clues to how the solar system formed.

Although something of the nature of the nucleus beyond its being a "dirty snowball" has been learned in this century by studying the visible comet, the age of direct studies of comet nuclei, Halley's in particular, has just begun. A flotilla of five spacecraft will intercept Comet Halley next March. One of the five, the European Space Agency's Giotto, will attempt a death-defying, quarter-million-kilometer-per-hour swoop within 500 kilometers of the nucleus in order to sample unaltered dust and gas spewing from the nucleus and to photograph the nucleus close up.

In the meantime, more mundane Earth-based comet observations of the past year or two are beginning to reveal what the spacecraft may find, if the dust is not so thick as to destroy them or obstruct their view of the nucleus. In what one astronomer has termed a "nuclear confrontation," Earth-based observers are debating whether close inspection by spacecraft will reveal a nucleus several times larger than once thought that is darkened by an organic-rich "dirt." The outcome will reflect on the interpretation of some of the basic types of observations made of comets.

For decades, most astronomers have thought of the dust of a dirty snowball as not being all that dirty. Until recently, the 40 percent dust apparently mixed with the ice was not thought to darken the nucleus all that much. Early guesses that a nucleus would reflect as much as 60 percent of the sunlight falling on it, almost as much as fresh ice, have been lowered to about 20 percent on the basis of some indirect determinations of nucleus reflectivity or albedo. That is about the albedo of the moon. Given that albedo, the observed brightness of most comets would imply nucleus diameters of about 2 to 5 kilometers.

At the recent annual meeting of the Astronomical Society of the Pacific (*1*), Michael Belton of Kitt Peak National Observatory reported his latest estimate of the albedo and size of Comet Halley. Belton started with a method developed in 1971 by Armand Delsemme and D. A. Rud of the University of Toledo that depends on two observed properties of the nucleus. One is the brightness of the nucleus before the increasing heat of the sun began to sublimate its ices and form an obscuring coma of dust and glowing gas. The brightness of such a bare nucleus depends on both the fraction of sunlight reflected by its surface, the albedo, and the total surface area doing the reflecting. The other characteristic is the amount of solar energy absorbed by the nucleus. This also depends on the area as well as the fraction of solar energy absorbed rather than reflected. The latter is determined from an estimation of the production of coma gases observed spectroscopically. Belton added another constraint, the observed rocket-like effect of gases released by the nucleus on its orbit about the sun.



Last view of Halley until August

Last April 18, just before it became lost in the glare of the sun, Comet Halley was displaying a coma 10,000 kilometers across that bulged toward the sun (bottom). Image by Wyckoff et al. *(ASU) and C. Heller and K. Hege (MMT Observatory).*

Using the brightness of Halley's bare nucleus last year, a gas production rate estimated from 1910 observations, and orbital changes over recent returns to the inner solar system, Belton determined a nuclear albedo of 26 percent and a diameter of about 5 kilometers. That would make the size of Halley's nucleus fairly typical by traditional standards. Delsemme predicted a similar size for Halley's during his talk at the ASP meeting.

Two kinds of observations are leading a growing number of astronomers to expect to find a larger, darker nucleus at the heart of Comet Halley than this conventional method would suggest. One approach combines observations at visible wavelengths of a bare or nearly bare nucleus with simultaneous observations at infrared wavelengths. By directly measuring the amount of solar energy reflected from the nucleus (the visible light) and absorbed and reemitted from it (infrared radiation), both of which depend on the size of the nucleus, the albedo and size can be calculated without assumptions about either. An accuracy of about 15 percent has been achieved when applying the method to size determinations of asteroids.

A group of astronomers reported at the meeting that they had applied the visible-infrared method to Comet Arend-Rigaux, a relatively inactive comet that appears to be nearly extinct. That low activity apparently allowed the group, consisting of Michael A'Hearn of the University of Maryland, Humberto Campins of the Planetary Science Institute, and Robert Millis of Lowell Observatory, to view the bare nucleus during its most recent swing by the sun last year. Filters helped eliminate light emitted from the gas in the meager coma and the variation of brightness in the visible range with varying aperture size allowed an adjustment for the half of the brightness due to coma dust. At least 90 percent of the dominant infrared emissions were from the nucleus.

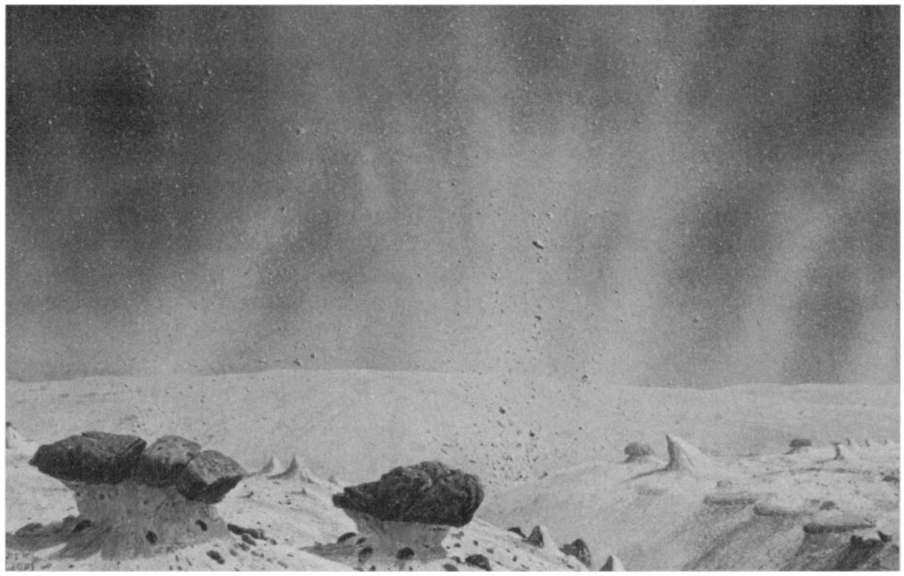
A'Hearn's group determined a diameter of about 10 kilometers for Arend-Rigaux, making it a relative giant among comets if sizes determined earlier are any guide. From the same observations, Arend-Rigaux has an albedo of roughly 2 percent. That is as dark as charcoal. Similar observations of Comet Neujmin 1, another nearly extinct comet, yield a whopping 19-kilometer diameter and an equally low albedo of about 2 percent. Dale Cruikshank and his colleagues at the University of Hawaii have reported visible-infrared observations of Halley that yield a diameter of 15 to 20 kilometers and an albedo of 3 to 5 percent (2). But at the meeting Cruikshank conceded that interference by coma dust was a distinct possibility, one for which they had no adjustments.

Belton sees a way to reconcile the large and dark nuclei of nearly extinct comets with a small and relatively bright nucleus for Halley's. A nearly extinct comet probably has so little activity because an insulating layer of dust has covered most of its surface, he notes. Comet Halley, on the other hand, is 100 to 1000 times more active and probably blows away any mantling dust each time it approaches the sun, exposing fresher, brighter ice, he argues.

William Hartmann of the Planetary Science Institute, Cruikshank, and Johan Degewij of the Jet Propulsion Laboratory argue in turn that there is no getting away from the brownish black, primordial organic sludge that apparently colors comet nuclei (*3*). Even freshly exposed comet ice will be black, they say. They see the same color—that of "a very dark Hershey bar"—in comets whether they are active and near the sun or nearly inactive in the cold outer reaches of the solar system. They see it in the outer asteroid belt. They see it in the small outer satellites of Jupiter and Saturn thought to be captured from the debris of the solar system.

The reddish tint of these bodies stands in sharp contrast to the bluish tint of the icy major satellites of Jupiter and Saturn. And laboratory experiments show that mixing a bright, clean ice with even 1 percent of opaque dark material produces a very dark dirty ice having an albedo of only a few percent. Thus, knowing that the dust mantling Arend-Rigaux is nearly black, Halley's dirty snowball must be black as well, they reason. If Giotto only determines a size for Halley's nucleus, it should resolve whether comets are large and dirtied with this black goo or small and not such dirty snowballs after all.

Whatever the size and reflectivity of Halley's nucleus, its shape could be odd indeed. A possible clue involves the period of rotation of the nucleus. Halley's rate of rotation became a matter of considerable interest and some controversy last year when observers began reporting brightness variations in the comet that some thought to be periodic. The nucleus was still more than six times Earth's distance from the sun and thus too cold to release its frozen water and dust to form an observable coma. Even so, everyone now agrees that the brightness of light reflected from Halley's nucleus was varying by about one magnitude or a factor of 2.5.



A not so dirty "dirty snowball"

Planetary scientist William Hartmann painted this comet nucleus landscape in early 1981 just before he concluded that cometary ice must be dirtied to the point of being black. Dust and debris ejection would still occur, leaving remnants of an old crust.

If the brightness variations were periodic, as suggested by some observers, rotation of the nucleus must be responsible. As reported by several groups at the ASP meeting, the rotation of Comet Arend-Rigaux, at least, does cause brightness variations. All three groups of observers—whose results were reported by Theodore Fay of McDonald Observatory, A'Hearn, and Timothy Brooke of the State University of New York at Stony Brook—agree that the brightness varies with a period of about 13.5 hours.

A'Hearn observed Arend-Rigaux at both visible and infrared wavelengths, which allowed his group to show that it is the nucleus's shape that is responsible for the brightness variations. And an odd shape it is. If the simplest possible shape is assumed, like a blunt cigar, and it is spinning end over end, it is at least twice as long as it is thick.

If a periodicity cannot be confidently found in the Halley observations, as many astronomers now believe, then some sort of sporadic activity on the nucleus might be responsible for the brightness variations, possibly the sublimation of some minor ice more volatile than water ice. A possible alternative, some believe, is that the sparseness of the observations might conceal sporadic outbursts of sublimation and the effects of rotation.

Whatever Comet Halley is up to in the outer solar system, there is every reason to expect that it will flare to its celebrated brilliance this fall as it nears the sun. Unfortunately, it will be a bit of a bust for casual observers in the middle latitudes of the Northern Hemisphere. The dramatic display of 1910 depended on both the comet's innate brilliance when nearest the sun and Earth's being in a position to provide a view at that time.

This time, Earth is in one of the worst positions of the past 2000 years. Halley will be lost to view behind the sun when the comet is brightest in early February. Astronomers are reluctant to predict comet brightness after being burned by the poor performance of Comet Kohoutek in 1974, but most agree that Halley's will be visible to the naked eye in early January, if the observer is far from city haze and lights and knows where to look. In late March, the comet will be brighter, but it will barely peek above the horizon for observers in the middle latitudes of the Northern Hemisphere. At 40°N, the latitude of Philadelphia, it will just reach an elevation of 10° above the horizon, which is the apparent height of a four-story building viewed from a distance of 70 meters. As Brian Marsden of the Smithsonian's Center for Astrophysics has been quoted, "If you didn't see Kohoutek in 1974, you won't see Halley in 1986."—**Richard A. Kerr**

References

1. Annual meeting of the Astronomical Society of the Pacific, held 25 to 27 June 1985, in Flagstaff, Ariz.
2. D. P. Cruikshank, W. K. Hartmann, D. J. Tholen, *Nature (London)* **315**, 122 (1985).
3. W. K. Hartmann, D. P. Cruikshank, J. Degewij, *Icarus* **52**, 377 (1982).