Halley's Confounding Fireworks

Observations of unprecedented frequency have revealed sudden outbursts and mysterious pulsations in brightness, prompting peripatetic analyses across Europe

Paris

SERENDIPITOUS discovery in science so often comes as a surprise, even when it might reasonably be expected. Such was the case with Comet Halley in the wake of an observation program that dwarfed all preceding efforts. The surprises included sudden outbursts in the presumably steady vaporization of its icy nucleus and a periodic, complex pulsation of the comet's brightness. Whether this pulsation reflects the rotation of the nucleus, wobbling of the nucleus, or some still unimagined phenomenon became a controversial focus of the recent meeting on the Exploration of Halley's Comet* in Heidelberg. The unforeseen variability prompted on-the-spot reanalyses that carried the controversy right through the Division of Planetary Sciences meeting† the following week here in Paris.

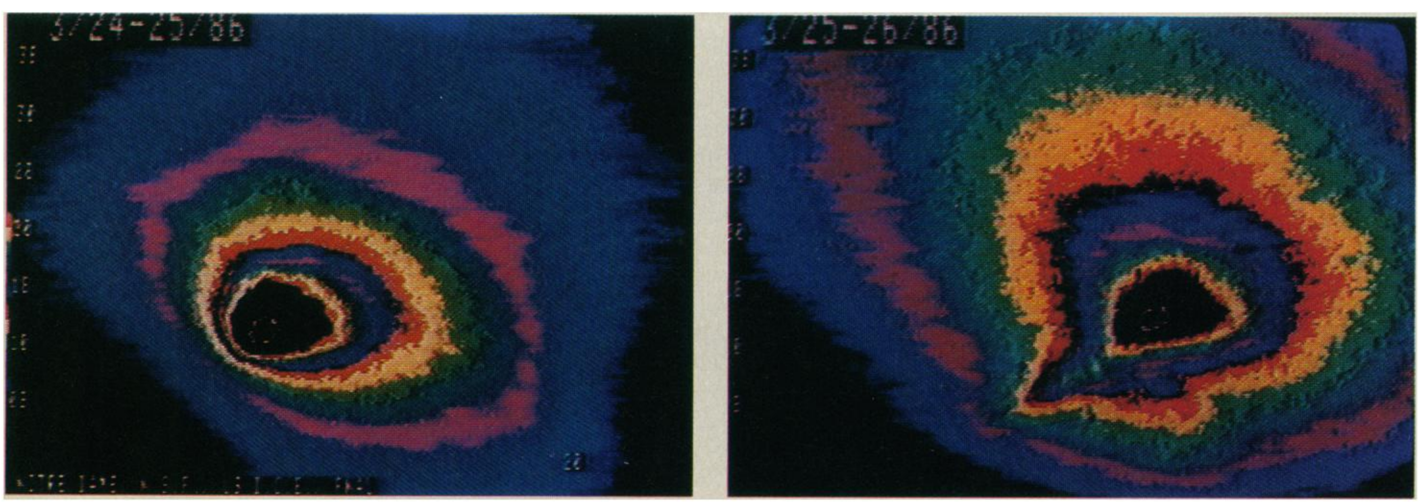
That Halley's behavior was highly variable, even erratic, was clear to anyone attending the Heidelberg meeting, whatever his specialty. One of the most abrupt changes was serendipitously recorded by Paul Feldman of Johns Hopkins University and his colleagues on the International Ultraviolet Explorer (IUE) satellite team observing Halley. Their intent was to record the ultraviolet emission of particular molecules driven off the icy nucleus by solar heating. These measurements would allow them to determine rates of dust and gas production over the months as Halley neared and withdrew from the sun. Hour-by-hour monitoring of the comet's brightness was not so much a part of the program's objectives as an inevitable by-product of periodic checks of the satellite's target tracking. And besides, there seemed to be little change on such time scales, the comet's brightness remaining quite steady during an 8- or 16-hour observing run.

But last Christmas Eve, Halley began acting up, the brightness in the central coma varying by a factor of 2 to 3 during 1 or 2 days. A most revealing fluctuation came the night of 18–19 March, when the IUE tracker recorded a peak in brightness lasting only a few hours. Only 2.5 hours after the outburst, IUE happened to detect a surge in the abundance of singly ionized carbon dioxide 150,000 kilometers down the tail. If it had traveled at the speed of other ions, the carbon dioxide would have left the nucleus at about the time of the peak in brightness measured there. Ground-based observers also reported a burst of carbon monoxide and one of dust, both of which could have originated at the nucleus at about the same time as the carbon dioxide apparently did. Curiously, IUE detected no increase in hydroxyl during the outburst, although hydroxyl's source, water, makes up 80% of the nucleus.

Feldman concluded that some sort of pocket of frozen gas, whose size was on the order of 10 by 10 by 30 meters, must have warmed to the point of bursting through the surface as gas, become rapidly ionized, and streamed down the tail. How that much gas became ionized that quickly presents a problem for those studying the chemistry of comet comas.

IUE caught another sort of Halley variation, a larger although more gradual one. There had been hints of steady increases or decreases in brightness during earlier observing runs, but on 23 March members of the U.S. IUE team caught Halley hitting a

*Twentieth ESLAB Symposium on the Exploration of Halley's Comet, 27–31 October in Heidelberg, West Germany. Abstracts are contained in European Space Agency (Paris) publication SP-250. The proceedings will be published at the end of this year.
†Eighteenth annual meeting of the American Astronomical Society's Division for Planetary Sciences, 4–7 November, Paris, France. Abstracts are part of *Bull. Am. Astron. Soc.*, vol. 18, no. 3 (1986).



University of Notre Dame/Fermilab

Comet Halley in a quiet moment (left) and during a flare-up (right). *Astronomer Terrence Rettig of the University of Notre Dame and his colleagues at Fermi National Laboratory and Siding Spring Observatory in Australia recorded the image on the left on the night of 23–24 March (universal time). By the next night (right), the comet had brightened (enlarged areas of color-coded brightness levels) and a jet of dust and gas had extended about 20,000 kilometers to the lower left (sun is to the upper right). This is the same flare-up recorded by the IUE satellite that may have resulted from the rotation of the nucleus, wobbling of the nucleus, or some unknown phenomenon. Using the same ultrafast digitizing and recording equipment that records high-energy particle events at Fermilab's Tevatron accelerator, Rettig also recorded flickers of the comet lasting only a few tens of seconds.*

distinct minimum in brightness during one observing run and then a distinct maximum during their next run, which was scheduled by sheer chance 8 to 16 hours later. Visual brightness had increased by 3.2 times during 24 hours, and, following the same general trend, dust and various gaseous components had increased by 2.5 to 6 times. At the same time that most components reached relatively modest peaks in abundance, carbon dioxide ion increased sharply.

IUE team member Lucy-Ann McFadden of the University of Maryland concluded that the 24-hour minimum-to-maximum rise reflects an equally gradual increase in vaporization from an exceptionally active spot on the nucleus as its rotation brought the spot from the night side into increasingly intense sunlight. Giotto images of the nucleus, as well as backtracking of dust jets in VEGA images, show that most if not all of Halley's dust and gas escape from small active areas. The outburst superimposed on the broader peak would be of the more abrupt sort seen a week earlier.

Robert Millis and David Schleicher of Lowell Observatory might have predicted the sharp pulsation of Halley that IUE recorded on 23–24 March. On 18 March they completed the first of two observing runs during which they precisely measured the brightness of the central coma at various wavelengths corresponding to light reflected from dust and to the emissions of different components of the coma gas. As they tantalizingly hinted in their abstract for the Heidelberg meeting, the short-term variations were clearly periodic. What the period was they were not saying until their talk.

The period most often associated with Halley has been one of about 2.2 days. Zdenek Sekanina of the Jet Propulsion Laboratory and Stephen Larson of the University of Arizona first proposed in 1984 that the rotation period was roughly 2.2 days. They arrived at that figure by tracing the jets of dust spewed by the nucleus as it spun, first in photographs of the 1910 apparition and then in images made during this apparition. Once the spacecraft fleet had passed by Halley, the 2.2-day period quickly became the canonical rotation period. Images in the ultraviolet made by the Japanese Suisei spacecraft of the waxing and waning of the comet's hydrogen cloud supposedly confirmed the 2.2-day period, as did analyses of the orientation of the nucleus as imaged by VEGA 1 and VEGA 2. During the first session of the first day of the Heidelberg meeting, Monday, 27 October, there was yet another confirmation of the 2.2-day period, a rhythmic production of irregularities in the tail.

On Wednesday, however, Millis and Schleicher said it wasn't so. To prove it they showed a plot of the "noise" in what they had intended as a record of the month-by-month waning of the comet. The first part consisted of a stunning string of almost 3 weeks of nightly observations from Chile in April uninterrupted by clouds or poor seeing conditions. To the eye a week-long set of wiggles in the plot of dust and gas production early in the run seemed to repeat itself in the second half of the period. The 2-week run in March was less impressive but showed similar undulations.

The rotation period of Halley's nucleus was the talk of hallways, Heidelberg-to-Paris trains, and cafés.

The most natural interpretation of their data, they said, was that the nucleus rotates once every 7.4 days. Shorter term variations—evident in their records as two minima, one single-peaked maximum, and one usually double-peaked maximum per complete cycle—must be due to the distribution of active areas on the oblong nucleus. Periodic heating of one active area after another produced changes by a factor of 4 over a few days, variations that presumably had misled earlier workers into finding a shorter period. Searching for a periodicity by using a method that makes the best fit in phase from cycle to cycle, Millis and Schleicher found the 7.4-day period but no 2.2-day period. Only if, instead of using the entire light curve to make a match, they used the times of the maxima alone could they produce a 2- to 3-day period of any sort.

The long-period rotation bandwagon was getting going. The next speaker, Ian Stewart of the University of Colorado, reported that production rates measured by Pioneer Venus, which is still orbiting that planet, showed a 7- to 8-day periodicity including double-peaked maxima. He had not felt confident enough to mention it, he noted, until he saw the data of Millis and Schleicher. After the coffee break, Michel Festou of the Observatory of Besançon, France, claimed that photometric data from January 1985 to March 1986 had failed to produce a recognizable period because no one had bothered to search for periods longer than 2.5 days. Now that he knew the period was more like 7 days, he could fit that data to a 7.4-day period.

The next speaker, Michael Belton of the National Optical Astronomy Observatories in Tucson, begged to differ. He had assembled the available photometric observations made before 1985, when the nucleus was presumably still too far from the sun and thus too cold to produce the jets that modulate later light curves. Using his own statistical method of choice, he searched for a period and found 2.2 days. Under questioning by Festou, Belton conceded that, having taken his cue from the VEGA results, he had not searched for a period much longer than the canonical value; there may well be a 7-day variability in the data as well, he noted.

For the next week the rotation period of Halley's nucleus was the talk of hallways, Heidelberg-to-Paris trains, and cafés. No one ever questioned the validity of Millis and Schleicher's beautiful light curves; something produced them, critics allowed, but it was not rotation of the nucleus. Before leaving Heidelberg, both the VEGA and Giotto imaging teams weighed in on the side of a 2.2-day rotation on the basis of the apparent orientation of the nucleus on the three different encounter days. On 6 March VEGA 1 saw the larger end illuminated, the team spokesmen argued, and Giotto clearly saw the small end in sunlight on 14 March. With a 7.4-day rotation, the two orientations should have been similar, not 180° apart. Fred Whipple of the Smithsonian Astrophysical Observatory in Cambridge, who launched the modern study of comets in 1950 with his hypothesis that the nucleus is a dirty snowball, summed up the confidence felt by many when he told the Friday morning session that he would bet even money on the 2.2-day rotation, and "I never bet except on sure things."

A middle ground appeared before the day was out that the spacecraft people were willing to allow but the photometrists found an unnecessary complication. Perhaps the nucleus rotates once every 2.2 days, it was suggested, but wobbles once every 7.4 days. It was Jack Lissauer of the University of California at Santa Barbara who took up the idea in a serious fashion. A solar system dynamicist catching the highlights of the meeting and the old city of Heidelberg on his way to his serious professional interests at the Paris meeting, Lissauer checked the shelves of a local textbook store, visited the local fruit market, and set about giving demonstrations of possible nuclear wobble, technically called nutation. In an added talk, he laid out the theory of nutation and then tossed a yellow, football-shaped melon in the air to demonstrate. (The nucleus had already been compared to a potato, a peanut, and an avocado.) The bounds were quite broad, he noted, but the nucleus could possibly be nutating with a period as long as 7.4 days.

On Thursday of the following week the existence, at least, of a longer period got a boost from Belton. Prompted by the light curves of Millis and Schleicher, he had extended his search for periodicity to longer intervals. Sure enough, a 7.4-day period was there, along with the 2.2-day period. Now he favored the rotation plus nutation idea.

The final exchanges on the subject came on Friday, the last day of the Paris meeting. In response to an overview talk on the encounters, Bradford Smith, an astronomer at the University of Arizona and Voyager imaging team leader through encounters with three planets and several dozen satellites, made his position clear. "I want to emphasize something because the word doesn't seem to be getting across. Even if we use the VEGA images alone, it is impossible to get the 7.5-day rotation. It is absolutely ruled out."

Smith's argument was difficult to illustrate for a large audience, but by holding slides against the light at the appropriate orientations, as he did for this reporter, he made an impressive show. It impressed Jean-Loup Bertaux of the National Center for Space Research in Verrières-le-Buisson, France, so much that he dropped his bet against the shorter period that he was about to make with Smith. Bertaux had been the one holdout among those with ready access to spacecraft images.

In his review of ground-based observations of Halley that afternoon, Festou forged ahead in the face of Smith's advice. In another case of data analysis on the road, a colleague of Festou's had spent the previous night compiling all 129 brightness measurements in six data sets spanning the period from September 1984 to February 1985. The 7.4-day period was there but no 2.2-day period, Festou reported.

In the last session, after the second presentation of his talk, Millis, unconvinced that the possibility of a 7.4-day rotation period had been eliminated, made an appeal. "Many of these people were looking for a 2.2-day period. We're now asking for them to look at a broader range of periods and see if it's there." Certainly, the observations in hand merit more thoughtful attention. And the spacecraft images need to be presented in a more visually persuasive format. And observational astronomers must win enough time on enough large telescopes to gather new photometric observations that could settle the argument to their satisfaction. Whether that is possible in competition with stellar astronomers in the post-Halley era remains to be seen. ■ Richard A. Kerr

New Drug Counters Alcohol Intoxication

The experimental drug makes drunk animals sober and may reveal the biochemical basis for alcohol's effects

A few years ago, chemists at the Swiss headquarters of the drug company Hoffmann–La Roche found a remarkable compound that initially sounded almost too good to be true. The compound antagonizes the behavioral effects of alcohol in animals and seems to work at doses of alcohol that produce drunkenness but that are not life-threatening. But now, as investigators examine the full implications of such a drug, there is some question about whether it will be developed at all for clinical use and, if so, by whom.

On page 1243 of this issue of *Science*, Steven Paul and his colleagues at the National Institute of Mental Health report on further studies with this drug, confirming that it makes drunk animals behave as though they were sober and suggesting a biochemical basis for its actions.

The use of the drug, which goes by the name Ro15-4513, is controversial. Although it clearly can be a tool to probe how alcohol produces its behavioral effects, it may not be marketable. After considering the legal and ethical drawbacks of an anti-alcohol drug, Hoffmann–La Roche decided not to develop it for clinical use. On the other hand, several researchers in this country think it could be clinically useful and Paul, for one, hopes to develop it. The idea is to make long-acting derivatives of Ro15-4513 that antagonize alcohol but have no adverse effects. Once it is known that Ro15-4513 blocks the behavioral effects of alcohol, chemists can try to alter its structure slightly to eliminate any undesirable qualities.

"The reason this drug is important is that it is safe," says George Koob of the Scripps Clinic and Research Foundation. Other drugs antagonize alcohol, but they are so dangerous that there can be only a small difference between a dose that prevents drunkenness and a dose that produces convulsions or even death. Ro15-4513, in contrast, is a derivative of the benzodiazepines—drugs such as the Hoffmann–La Roche products Valium and Librium. Benzodiazepines are considered to be much less risky than any previously discovered alcohol antagonist. "You can't kill yourself with an overdose of benzodiazepines," says Koob, who is studying the behavioral effects of Ro15-4513 on rats. He agrees with Paul that a derivative of the drug may be worth developing.

The story of Ro15-4513, begins several years ago when Hoffmann–La Roche chemists synthesized it as a research tool. Their aim was to better understand the receptor for benzodiazepines on brain cells. Ro15-4513 is a photoaffinity label for the benzodiazepine receptor cells and so can serve as a probe of the structure and function of the receptor.

The benzodiazepine receptor is part of the receptor for γ-aminobutyric acid, or GABA—the brain's major inhibitory neurotransmitter. The barbiturate receptor is at another site on the GABA receptor. According to Solomon Snyder of the Johns Hopkins University School of Medicine, "there is a good deal of evidence that alcohol acts on the GABA receptor." In addition to suggestive biochemical evidence linking alcohol, barbiturates, and benzodiazepines to the GABA receptor, there is the clinical observation that the three drugs produce cross-dependence and cross-tolerance. As a consequence, an individual who is addicted to alcohol, for example, and suffers withdrawal symptoms when he does not take the drug can be relieved of his symptoms by taking either benzodiazepines or barbiturates.

Because of this relationship between benzodiazepines, barbiturates, and alcohol, Hoffmann–La Roche investigators routinely test any drug that binds to the benzodiazepine receptor by looking for behavioral effects related to all three drugs. As part of this standard battery of tests, the company investigators looked for effects of Ro15-4513 on animals that received alcohol.

They were astonished to find that it blocked the behavioral effects of alcohol intoxication, according to Willy Haefely of Hoffmann–La Roche in Basel, because other benzodiazepine derivatives do not. "A number of my colleagues were extremely excited," Haefely adds. So they next decided to see whether Ro15-4513 could prevent the lethal effect of very high doses of alcohol. It could not. Ro15-4513 appears to act