How Many Ways Can Halley Spin?

As astronomers await a prolonged view of Halley's bare nucleus, new evidence supports its rapid rotation and slow wobble as an explanation of its odd behavior

IRONICALLY, ASTRONOMERS ARE WAITING for Comet Halley's demise, its dying away to a lifeless, inactive hunk of ice and dust, in order to take its pulse and solve once and for all a lingering mystery—why does Halley have two heartbeats while it streams past the sun? The light reflected from the active comet's cloud of dust and gas pulsates with a regular cycle about a week long, while the distinct jets of dust spewing from the unseen nucleus spiral outward as if the nucleus were rotating once every 2 days. One explanation, that the nucleus rotates with a 2-day period but wobbles with a 7-day period, recently gained new support.

It might seem that three spacecraft visits to the vicinity of the nucleus over the course of a week, however brief, would settle the question. They have not. Part of the problem is that there are so many possible ways for an object as irregular as Halley's nucleus to rotate. The nucleus has been compared with everything from a potato to a peanut, but it might be idealized as a slightly squashed football. Theoretically, it could rotate around its longest axis, which runs through the ends of the football, or its shortest axis, which runs in the direction that it is squashed.

In order to explain the 7.4-day period of Halley's brightness variations as well as the 2.2-day period of its jet shapes, theoreticians usually complicate a simple rotation with a wobble (*Science*, 5 December 1986, p. 1196). That way the sun's heat would not necessarily turn on a given jet once each rotation; a jet's behavior could become more complicated when it occasionally shuts down as it falls in shadow created by the wobble. Such behavior would repeat itself only once each wobble, not each rotation.

The wobble proposed for Halley is of the same sort as Earth's Chandler wobble, a 430-day meandering of the pole about a rough circle measuring 5 to 10 meters in diameter. Such a minuscule wobble would begin anytime something, possibly a great earthquake, shifts Earth's rotation axis out of line with the axis around which rotation would give the greatest rotational inertia. In the case of Halley, its jets of gas and dust would presumably take thousands of years to offset the axes significantly.

Given two possible axes of rotation, a wobble, and at least two possible periods of rotation, the choices have been numerous. Bradford Smith of the University of Arizona and some of his colleagues on the Soviet Vega spacecraft imaging team believe that they can eliminate two possibilities, those involving a 7.4-day rotation. On the basis of the nucleus's irregular shape—it has one larger, lopsided end and a cleft in the middle—they decided which end of the nucleus each of the three spacecraft was viewing at their encounters, which were 3.0 and 4.7 days apart. These Vega researchers concluded that the nucleus could not be rotating with a 7.4-day period around either the long or the short axis. They were sticking with the 2.2-day rotation determined earlier from the two Vega encounters alone.

With that constraint in hand, much the same group, this time headed by Karoly Szegö of the Central Research Institute for Physics in Budapest, calculated how an object with Halley's dimensions of about 16 by 8 by 7.5 kilometers would rotate. At the July meeting of the Committee on Space Research in Espoo, Finland, the group reported that the nucleus should rotate with the shorter period around the short axis while it gently wobbles about 14° at the longer period. That agrees well with calculations made last year by William Julian of New Mexico State University.

Now Stanton Peale of the University of California at Santa Barbara and Jack J. Lissauer of the State University of New York at Stony Brook have created a computer simulation of the behavior of Halley's nucleus. Their mathematical creation has a jet that responds to the varying heat of the sun as day and night pass around the rotating and wobbling nucleus.

Peale and Lissauer found it easy enough to generate light variations having both periodicities, whether the shorter period was that of rotation or the wobble. But marked changes in the way the brightness pulsated as the simulated nucleus swung around the sun only occurred when the nucleus was wobbling about the short axis.

The nucleus of Halley *was caught in this snapshot by Giotto and on other days by Vega 1 and Vega 2, but exactly how it rotates and thus how the bright, sun-activated jets behave remains uncertain. Photo courtesy of Harold Reitsema, Ball Aerospace.*

Such changes due to the change of "seasons" on the nucleus, as one hemisphere sees more of the sun than the other, have been observed.

Getting the model nucleus to begin wobbling about the long axis proved difficult unless the two shorter axes were nearly identical in length. One look at the images returned by Giotto suggests such symmetry is unlikely. Even exciting a wobble about the shortest axis proved a slow and difficult process, one that would require many passes of the comet by the sun. Conversely, the behavior of such a nucleus would be stable over many appearances, as Halley has been for many centuries.

"We certainly seem to be agreeing with the apparent spacecraft constraints for independent reasons," says Lissauer. "I think the modeling results are fairly convincing."

Although evidence may be mounting in favor of a reasonably conventional rotation with an added wobble, the question remains unsettled. Stephen Larson of the University of Arizona, a member of the Vega imaging group, notes that the current processed versions of the spacecraft images provide some strong constraints but not a unique solution. Hints in the images of a slight wobble are still being analyzed.

Larson has also found another mystery that needs explaining. Using his observations from South Africa, he confirmed the 7.4-day cycle in Halley's brightness, but he also found a 7.4-day cycle in the changing fanned structure of the jets. That would seem to require a 7.4-day rotation, he says. At the same time, the sharp curvature of the jets would require that they are being spun around about once every 2 days. "So there's this conflict within the same data set," Larson says. "I think we won't have a definite answer until we can do some detailed modeling of the jets that we saw."

Halley's motions may become less mysterious before then. Once Halley is so far from the sun that none of its jets is turned on, only brightness variations due to reflection from the rotating nucleus itself will occur. Richard West of the European Southern Observatory in Garching, West Germany, reported at the International Astronomical Union in August that he has detected a periodicity in brightness that is "not inconsistent with a 2.2-day period." That is a first, suggesting that the nucleus may be beginning to peek through its cloud of dust. Within the next year Halley will surely bare itself for good. ■ RICHARD A. KERR

ADDITIONAL READING

B. A. Smith *et al.*, "Rejection of a proposed 7.4-day rotation period of the comet Halley nucleus," *Nature* **326**, 575 (1987).

Another Asteroid Has Turned Comet

It's getting so you can't tell who's who in the solar system. First it was the suggestion that some seemingly ordinary asteroids are comets that have burned themselves out (*Science*, 2 January 1987, p. 29; 22 February 1985, p. 930). Now Chiron, the oddball of asteroids by virtue of its distant orbit between Saturn and Uranus, is acting like a comet. Meanwhile, some asteroids near Earth are revealing cometary inclinations. Clearly, astronomers' renewed attention to the solar system's small bodies is paying off.

Other than its lonely orbit in the outer solar system, nothing set Chiron apart from the asteroids when it was discovered in 1977. Subsequent studies showed that it is large for an asteroid, perhaps about 200 kilometers or more in diameter, has a neutral gray-black color, and reflects roughly 10% of incident sunlight, which is on the dark side for the rocky asteroids. Its brightness fluctuated by 9% every 6 hours as it rotated. Brightness measurements over longer periods were not always consistent, but spectroscopic studies failed to detect any release of cometary gas or dust. If there was no comet-like activity, it was an asteroid and it was cataloged as such.

Still, the brightness variations were intriguing, intriguing enough that some astronomers kept an eye on Chiron. Last February David Tholen of the University of Hawaii, William Hartmann of the Planetary Science Institute in Tucson, and Dale Cruikshank of Ames Research Center at Moffett Field, California, squeezed Chiron into an observing run. This time there was no question about minor inconsistencies. Chiron was twice as bright as expected.

Presumably, Chiron has brightened itself by expelling gas and dust at a distance from the sun about 12 times that of Earth, or 12 astronomical units. What little solar heat reaches that far might vaporize highly volatile ices such as methane and carbon dioxide. The large surface area of the resulting coma of dust could then reflect more light back to Earth.

Sporadic activity on Chiron, assuming it has the requisite ices, would not be all that surprising. A coma has been detected around Comet Bowell as far as 13.6 astronomical units from the sun. And Comet Schwassmann-Wachmann 1, which was also initially misidentified as an asteroid, brightens sporadically by a factor of 100 even though it never comes closer to the sun than 5.5 astronomical units. Chiron itself is now moving in a 51-year orbit toward its 1995 closest approach to the sun at 8.5 astronomical units, so increased cometary activity would be reasonable.

Like other comets, Chiron would be a temporary visitor from the reservoir of comets far beyond Pluto. It is now in an unstable orbit. If a few thousand years from now Chiron's orbit swings inward, inhabitants of Earth may be treated to some spectacular cometary activity.

While one "asteroid" seems to be firing up, further evidence has appeared that some asteroids have at least one comet-like characteristic. Duncan Olsson-Steel of the University of Adelaide reported recently that nine asteroids produce streams of particles that create meteor showers. Comets produce streams of meteoroids in space from the dust that they expel, so asteroidal meteoroid streams have been taken as supporting evidence of an underlying cometary nature. Olsson-Steel had compared the orbits of meteor trails detected in the 1960s by radar from Australia with the orbits of asteroids that cross Earth's orbit. Nine of the asteroids were closely associated enough with meteor showers to conclude that one produced the other.

Three of Olsson-Steel's asteroids—Oljato, Adonis, and Phaethon—had already been associated with meteoroid streams and, short of cometary activity, bore some resemblance to comet nuclei. Four of the nine asteroids—Oljato, 1984 KB, 1982 TA, and 5025 P-L—are closely associated with the Taurid meteoroid stream, which produces a complex, drawn-out shower. Before, Comet Encke alone had been assumed to be responsible, raising the possibility that a single large comet split to form the five objects.

Allowing for all the reasons that the Adelaide radar survey might have missed particular meteoroid streams, Olsson-Steel found that "meteoroid streams associated with Apollo asteroids are the rule rather than the exception." That would be consistent with the best, although still uncertain, theoretical calculations of the number of current Earth-crossing asteroids that could have originated in the asteroid belt. Those calculations have always failed to account for the bulk of Earth-crossing asteroids. But there are other ways to make streams of meteoroids, such as collisions, so other comet characteristics, including color and reflectivity, will have to be considered. ■ RICHARD A. KERR

ADDITIONAL READING

D. Olsson-Steel, "Identification of meteoroid streams from Apollo asteroids in the Adelaide radar orbit surveys," *Icarus* **75**, 64 (1988).