Could an Asteroid Be a Comet in Disguise?

Two asteroids of the inner solar system are strong candidates for once-active comets that now masquerade as inert hunks of rock

Most everything has its place in the solar system and has been there from the beginning. The major planets formed in the same set of orbits they hold today, and even the minor planets, the asteroids orbiting in the wide gap between Mars and Jupiter, seem to be where they are because they first formed there as versions of true planets.

A major exception to the order and stability of the solar system is the existence of planet-crossing asteroids. How they came to share the inner solar system with Earth, Venus, and Mars is a mystery. Celestial mechanicians can show that the planets will collide with these asteroids or gravitationally hurl them from the solar system in only a few hundred million years. Thus, planet-crossers formed 4.5 billion years ago could not linger until today. The leading candidates for the newcomers that resupply the planet-crossers are errant asteroids from the main belt between Mars and Jupiter and comets, which swing in from the far more distant comet cloud well beyond Pluto.

But neither celestial mechanicians or astronomers have been able to build strong cases for either comets or main-belt asteroids as the major source of planet-crossing asteroids. In fact, until recently, there was little evidence that even one comet had ever had its ices burned off by the sun's searing heat and had its orbit swung inward, thus allowing it to impersonate an asteroid as one of the 82 known planet-crossers. Now several possible ex-comets have been identified that look like good prospects.

One new candidate is Oljato, an asteroid discovered in 1947 that follows a highly elliptical orbit that swings it inside the orbit of Venus and out almost as far as Jupiter's orbit. Oljato's highly eccentric orbit hints of a cometary origin, since such orbits are more typical of comets than asteroids. However, Jack Drummond of the University of Arizona has linked Oljato's orbit to a more distinctive characteristic of comets, their association with meteor showers. About 16 comets have been associated with dust particles orbiting the sun in tenuous rings, called meteoroid streams, that Earth passes through at the same time each year. During each passage, some of the dust burns up in the atmosphere, producing a meteor shower.

To see which, if any, asteroids might conceivably be associated with meteoroid streams, Drummond compared the orbits of asteroids and meteoroid streams using an objective technique. Only two asteroids seemed associated with meteor showers. One was Oljato, which had been seen in 1979 for the first time since its discovery, and the other was Adonis. Their orbits did not fit those of meteoroid streams as well as the orbits of many comets do, but they provided the best fits of any asteroids and met Drummond's criterion for an acceptable orbit match.

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Unaware of Drummond's identification of Oljato as a possible ex-comet, Chris Russell of the University of California at Los Angeles and his colleagues were homing in on Oljato as a likely cause of a newly discovered, comet-like phenomenon. Russell was not looking for comets or anything to do with them. He was just routinely reviewing the record of the magnetometer aboard the Pioneer spacecraft orbiting Venus when he came across a temporary intensification of the interplanetary magnetic field of a sort that he had never noticed before. The field strengthened at an increasing rate, peaked, and declined much as it had risen, all during a few hours. Russell has now identified 13 events in the record like this one and 15 others that are weaker or masked by noise but are probably of the same type.

At least one magnetic field disturbance, the strongest recorded, may well have been caused by the spacecraft passing through the wake of an unidentified comet. Comets near the sun spew gas as well as dust, gas that becomes ionized and thus susceptible to the magnetic field of the solar wind blowing outward from the sun. Like an earthly wind blowing through a tree, the solar wind tends to slow where it encounters an obstacle such as a ball of slow-moving ionized gas. Thus the solar wind's magnetic field drapes around the obstacle, compresses against it, and thus intensifies. That could produce the typical disturbance identified by Russell. If the comet were active enough, its ionized gases would actually deflect the solar wind and create a bow shock, as Russell observed in the case of the strongest event.

None of the 27 magnetic disturbances is associated with known comets, but 7 of them do seem to be associated with Oljato. Five of these disturbances occurred during the 5 days in June 1983 before the spacecraft and Venus passed within only 1.3 million kilometers of Oljato's outbound orbit. The asteroid had been at that spot 22 days before in the course of its 5.2-Venus-year circuit about the sun. The chance of observing five events clustered there as happened in 1983 is only 4 in 10,000, Russell says. In 1980 a pair of events 5 days apart occurred at the same near-intersection of orbits about 70 days after Oljato's passage. The remainder of the events seem to be randomly distributed around Venus's orbit, Russell says. If the seven disturbances result from the solar wind's encounter with outgassed material, the gas cannot have come from Oljato itself, Russell notes, but rather from unseen material broken from and trailing behind the asteroid by up to 70 days.

Oljato's apparent association with interplanetary field disturbances and meteor showers suggests it has a masked or perhaps weak comet-like nature, but direct observations of the asteroid give no hint of a classic enveloping haze, called a coma, or the sunlight-stimulated emissions typical of a comet. There are, however, observations to suggest that Oljato is peculiar, even unique, among the planet-crossing asteroids. Lucy McFadden (now at the University of Maryland) and her colleagues at the University of Hawaii measured the amount of sunlight at wavelengths between 0.3 and 1.0 micrometer reflected from 17 near-Earth asteroids in order to determine their compositions. Sixteen of the 17 seem to be made of common rockforming minerals. The exception is Oljato. Its distinctive spectrum resembles no other, and McFadden cannot interpret it in terms of any material studied so far in the laboratory.

Oljato is also an exceptional reflector of radar. Steven Ostrow of the Jet Propulsion Laboratory has studied radar signals reflected from 19 main-belt asteroids and a half-dozen near-Earth asteroids. The character of the 13-centimeter signal of the Arecibo antenna after reflection from an asteroid depends on the asteroid's shape, its rotation, and the roughness and composition of its surface. Once again, Oljato and Adonis stand out from all others studied.

On one night, Oljato's reflected radar signal had a double-peak structure when plotted against wavelength, a feature unique among the asteroids studied so far. The only similar radar signature was a triple-peak signal returned from a comet, comet IRAS-Araki-Alcock. The odd signal from Oljato could result from an extreme shape, such as two separate bodies in contact with each other, extreme variations in reflectivity around one body, or an intermediate combination of shape and reflectivity. And Adonis, the other asteroid apparently associated with a meteor shower, is "one of the weirdest objects I have ever looked at," says Ostrow. The way it depolarizes a polarized signal makes it a unique radar target.

On the strength of only one characteristic, astronomers now regard another planet-crossing asteroid as the most likely candidate for being the product of comet-to-asteroid evolution. Asteroid 1983TB, discovered in 1983 by the Infrared Astronomical Satellite, clearly orbits in the midst of the dust and debris that produces the Geminid meteor shower each 14 December (*Science*, 25 November 1983, p. 916). "It is moving right smack-dab in the middle of the meteoroid stream," says Drummond. "Not just any meteoroid stream but the best of the year. In my opinion it is a dead comet." Drummond says that the fit of 1983TB's orbit to the orbit of the Geminid meteoroid stream is better than that of 14 of the 16 previously accepted comet-meteor shower associations. The closeness of the fit impresses everyone, and recent searches have failed to find even the slightest sign of cometary emissions from 1983TB, but everyone is not quite as impressed as Drummond. A collision between two asteroids could produce, albeit only briefly, such a meteoroid stream.

Exactly what would constitute convincing proof that the ices of a comet could no longer be vaporized is not clear. To some astronomers, an apparent comet-turned-asteroid that eventually showed the slightest cometary activity would simply be a misclassified comet. The most productive approach may be to determine what the nucleus of a comet is really like when it is unadorned by its obscuring coma of dust and glowing gas.

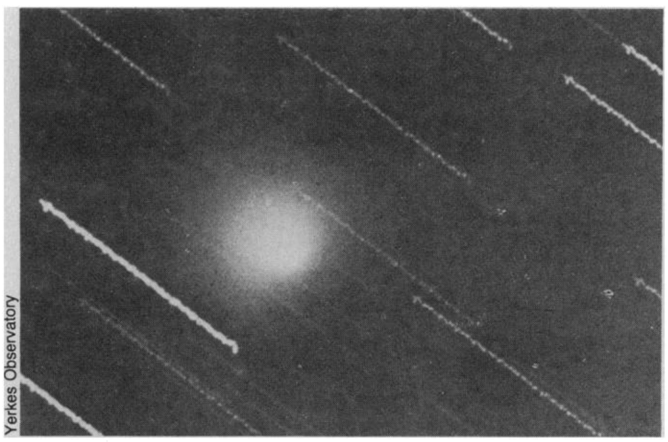
Michael A'Hearn, Humberto Campins, and McFadden of the University of Maryland and Robert Millis of Lowell Observatory have recently observed two low-activity comets, Arend-Rigaux and Neujmin 1, that seem to be barely sputtering under the sun's blaze. A'Hearn believes that in the case of Neujmin 1 they are detecting the bare nucleus or possibly millimeter-size particles held just above the surface by escaping gas. In either case, the color revealed in the comet's visible spectrum is "consistent with" the color of S-type (metal-rich silicate) asteroids, the most common type among the near-Earth asteroids. Neujmin 1's reflectivity or albedo is about 25 percent, which is at the bright end of the S-type range. Anita Cochran and Edwin Barker of the University of Texas have reported that the color and albedo of 1983TB is also similar to that of an S-type.

A superficial resemblance to S-type asteroids is odd because the non-ice component of comets has been presumed to resemble the dark, reddish material of C- or D-type asteroids and organic-rich meteorites. Based on this assumption, only 6 of the 82 Earth-crossing asteroids had seemed to be possible ex-comets on the basis of their colors and orbits.

Preliminary reflectance observations aside, most astronomers expect that there are only a few burned-out comet interlopers among the near-Earth asteroids. George Wetherill of the Carnegie Institution of Washington would disagree. For years he has argued that most Earth-crossing asteroids were once comets, in part because no one can find a way to bring into the inner solar system the 15 main-belt asteroids needed every million years to replace those lost to impacts and ejection from the solar system. The best anyone has done using mathematical modeling is to transfer about one per million years through the gravitational interactions of Jupiter, Saturn, and Mars.

Comets are not easy to corral within the inner solar system either. Jupiter's gravity can redirect a comet that would otherwise not return for tens of thousands of years into an orbit having a period of only a few years. But if the farthest point of the comet's orbit is to be brought in from outside Jupiter's orbit, the comet must do the work itself. The uneven ejection or jetting of gases around the nucleus could push it into the smaller orbit the way a rocket motor would. How often that happens is not clear. Wetherill notes that the orbit of comet Encke is already well inside that of Jupiter, and the comet trails dust that produces a typical meteor shower. In a few hundred years, he notes, Encke could be another Earth-crossing asteroid.

Opportunities for deciphering what comet nuclei and planet-crossing asteroids are really like should be numerous although difficult to capitalize on. Earth-based observations of asteroids and low-activity comets are proceeding apace. Even now astronomers are debating what, if anything, they saw before Halley's comet turned on its coma. And spacecraft will take a close look at Halley's next March.—**Richard A. Kerr**



Yerkes Observatory

Soon to be asteroid Encke?

Comet Encke circles the sun every 3.3 years as it loses more and more of its ices to vaporization. Eventually it will disappear or its inert remains could possibly linger as an asteroid.

Additional Reading

1. A. L. Cochran and E. S. Barker, *Icarus* **59**, 296 (1984).
2. J. D. Drummond, *ibid.* **49**, 143 (1982).
3. L. A. McFadden, M. J. Gaffey, T. B. McCord, *ibid.* **59**, 25 (1984).
4. C. T. Russell, M. R. Arghavani, J. G. Luhmann, *ibid.* **60**, 332 (1984).