
# Bright Comet Poses Puzzles

## Hyakutake's tails of mystery

By RON COWEN

It came, it shone, it undoubtedly conquered. During its sojourn near Earth last March, Comet Hyakutake wowed observers with a ghostly blue-white gas tail stretching a third of the way across dark northern skies. Even in urban areas swamped by light pollution, the newly discovered comet made a memorable apparition as a bright, fuzzy snowball.

On May 1, Hyakutake achieved its closest approach to the sun, its dust tail in full bloom. The comet's orbit then took it south, and astronomers are now catching a few fleeting glimpses of this icy, fragile wayfarer as it leaves the inner solar system. Although Hyakutake won't grace terrestrial skies for at least 10,000 years, it has left behind several mysteries.

Among the puzzles are chemical fingerprints hinting that Hyakutake assembled from a chillier mix of ice and dust than several other comets. The first X-ray emissions ever associated with a comet posed another riddle, one researchers think they have now solved.

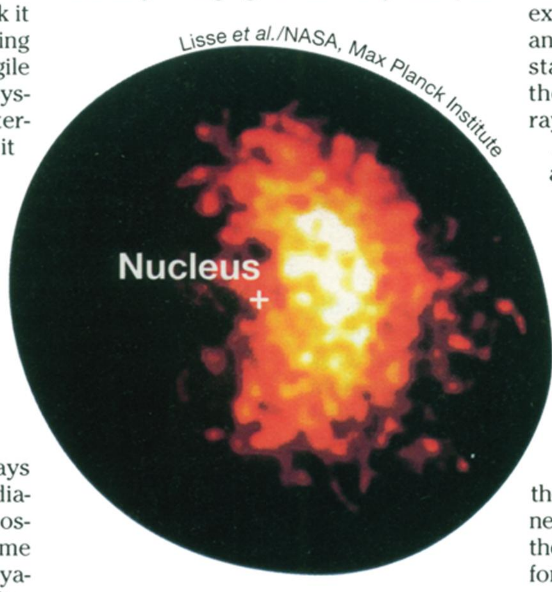
Only spacecraft can detect X rays from comets, because this radiation can't penetrate Earth's atmosphere. Thirteen years ago, the last time a comet came as close to Earth as Hyakutake did, few craft with the capability of recording X rays were in orbit. Soon after the discovery of Hyakutake, astronomers realized that its brightness and proximity to Earth—it came within one-tenth of Earth's distance from the sun—would present a rare target of opportunity for ROSAT, a German-U.S.-British X-ray satellite.

Still, ROSAT scientists didn't expect to see much of a signal. No previous observations or theory suggested that comets emit or are associated with a substantial amount of high-energy radiation.

"It was a thrilling moment when the X rays from the comet appeared on our screen at the ROSAT ground station," recalls Konrad Dennerl of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany.

The X-ray emission was 100 times brighter than predicted, says Carey M. Lisse of the University of Maryland at College Park and NASA's Goddard Space Flight Center in Greenbelt, Md., who led the X-ray investigation.

ROSAT images taken over 30 hours revealed that the puzzling, crescent-shaped area of emission was variable, its intensity changing dramatically over just a few hours. The location of the radiation, says Lisse, provides a clue to its origin. The emission came from a region on the sunward side of the comet, some 20,000 kilometers outside the icy nucleus and well into the outer coma, the low-density shroud of gas and dust surrounding Hyakutake's core.




*The bright, crescent-shaped region in this false-color image taken by ROSAT depicts X rays associated with the comet.*

Lisse and his ROSAT colleagues, including Robert Petre of Goddard, believe that the comet alone doesn't generate the X rays. If it did, at least some of the emission should have come from the innermost dense regions of the coma. Instead, researchers believe, the sun must have somehow played a role.

That would seem to leave open two possibilities, notes Petre. X rays that originate from the sun and scatter off the comet might produce the high-energy glow, in the same way that solar radiation striking the moon's surface generates an X-ray pattern (SN: 9/15/90, p. 167). However, the moon is a solid body, whereas the comet's coma consists of an extremely low density collection of gas and dust particles. It's difficult to understand, says Petre, how light scattering off the coma could produce such a bright X-ray pattern.

A more likely explanation, he and Lisse assert, relies on the interaction between the comet and the solar wind, the breeze of charged particles blowing out from the sun. When this high-speed wind and its associated magnetic field collide with gas at the leading edge of the coma, it creates a shock wave similar to the V-shaped wave that precedes a speedboat.

Ionized gas molecules that peel off from the coma get trapped inside the wind's magnetic field, which has become tangled by the collision. These ions bounce back and forth in the tangled field, accelerating to energies high enough to emit X rays, Petre and Lisse suggest.

Most recently, a review of data taken by ROSAT's extreme-ultraviolet camera has revealed that the X rays form a continuous spectrum over a broad range of energies. John P. Pye of Leicester University in England and his colleagues, including Lisse, reported this finding in a May 9 circular of the International Astronomical Union. The spectrum seems to match that predicted by the solar wind model and appears to rule out the scenario in which solar X rays scatter off the comet.

"The new data make the case for the solar wind model much stronger," says Lisse.

A follow-up ROSAT study, now scheduled for late June, may help to confirm this scenario, though the researchers say they will need more detailed spectra. Observations planned for a Japanese satellite carrying several X-ray spectrometers may give the final word.

Comets rank as invaluable fossils—pristine, frozen relics of a tumultuous past. Traditionally, two theories have addressed the nature of these fossils. In one model, their icy composition reflects conditions in the dense interstellar cloud that later collapsed to form the primitive solar system. In the other model, comets derive directly from the disk of gas and dust that surrounded the infant sun, 4.5 billion years ago.

In the interstellar model, ices form on dust grains in the dense cloud that preceded the sun. This mix of ice and dust then gathers together into a comet without appreciable chemical modification.

In the solar model, the ices that form in the interstellar cloud don't initially gather together but turn to vapor as they become part of the disk of gas and dust around the young sun. The vaporized ices later resolidify and assemble into comets. If these ices underwent chemical changes during their gaseous phase, then the comets formed from these materials would have a different composition from those made directly from interstellar ice.

Most comets are extremely faint, and taking their chemical fingerprints, or spectra, has proven difficult. In this regard, astronomers have had a field day with Hyakutake. The body's close approach to Earth enabled researchers to identify a slew of compounds thought to exist in comets but never before observed. Those detections include ammonia, acetylene, and ethane.

Michael J. Mumma of Goddard and his colleagues found ethane while observing Hyakutake with NASA's Infrared Telescope Facility atop Hawaii's Mauna Kea. The researchers report in the May 31 SCIENCE that they detected it at a high concentration, roughly half that of a more familiar cometary constituent, methane.

"The detection of ethane was a blinding surprise," says Mumma. "This [spectral] line came screaming off the screen."

At first, Mumma proposed that Hyakutake had to have assembled near Jupiter's orbit, where a variety of hydrocarbons, including methane and ethane, are abundant. He now believes that the comet may have gathered its icy material directly from the interstellar cloud. Mumma speculates, however, that the comet assembled from ices that originated in a chillier region of the cloud than did the ices in several other comets, which contain a high abundance of methanol but little or no ethane.

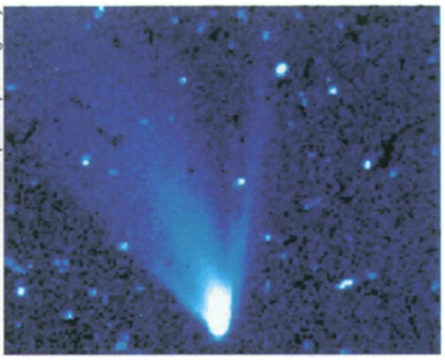
"We have found some real evidence that icy material in comets has a [direct] interstellar origin," says Mumma.

In one scenario proposed by Mumma's team, the hydrocarbon acetylene resides as a gas in the interstellar cloud but then condenses as ice on frigid dust grains that don't exceed 20 kelvins. Later, when the sun formed, the acetylene remained frozen but reacted with hydrogen to make ethane. Hydrogen atoms are most abundant near the sun, where solar radiation can split apart hydrogen-bearing molecules. Thus, before assemling, the comet's icy building blocks may have migrated to a region closer to the sun than Uranus. They could not have come too close, however. Inside Jupiter's orbit, acetylene would have vaporized.

The frigid temperatures required for acetylene to freeze suggest that Hyakutake gathered its ices from the inner part of the cloud, Mumma speculates. Bolstering this model, he notes that other researchers have found acetylene in the comet. In addition, Hyakutake's nucleus appears to emit relatively little carbon monoxide, a finding that makes sense if carbon is tied up in heavier molecules, such as ethane and formaldehyde.

"Hyakutake does indeed seem to have unusual [compounds] present," says Lisse. "But until the astronomical community meets and presents all the evidence . . . it is too soon to start speculating on the possible formation sites."

NASA/European Space Agency



*On May 3, 2 days after Hyakutake made its closest approach to the sun, a coronagraph aboard the SOHO spacecraft blocked out the sun's glare and captured this image of the comet. The image shows three tails (left to right): a dust tail made of large particles, the more common dust tail of smaller particles, and a gas tail.*

Nonetheless, the comet behaves strangely, note Lisse and A'Hearn. Astronomers had expected to see a sharp increase in the amount of water-ice converted into vapor as Hyakutake neared the sun. Instead, measurements showed that the water vapor remained nearly constant from mid-February through mid-March. Observations with the Hubble Space Telescope and the International Ultraviolet Explorer showed that the amount of water vapor increased only slightly in late March and early April.

That behavior, says A'Hearn, is suggestive of a comet on its first visit to the inner solar system. Yet analyses of the comet's orbit have firmly established that Hyakutake has toured the inner solar system many times before.

"This is a real puzzle," says A'Hearn.

Another curiosity stems from the sheer amount of water vapor produced by the comet. One of the detectors aboard the Solar and Heliospheric Observatory (SOHO), designed to study the sun, has periodically cast its eye on the comet. The detector counts hydrogen atoms, an indirect measure of water vapor, by recording the intensity of a particular wavelength of ultraviolet light emitted by the atoms.

Data collected by the instrument in late March indicate that the comet was then expelling 6 tons of water vapor a second, SOHO researcher Jean-Loup Bertaux of the Service d'Aeronomie du CNRS in Verrières-le-Buisson, France, told SCIENCE NEWS. Hubble measured a slightly higher rate a week later, says Michael R. Combi of the University of Michigan in Ann Arbor.

That rate is intriguing, says Bertaux, because radio waves bounced off the comet indicate that its nucleus is small, only about 2 km in diameter, or one-fifth the diameter of Halley. Solar heating must have made Hyakutake's entire surface "active"—turning water-ice into jets of steam—in order to account for all the water vapor, he argues. Bertaux notes that among the handful of comets that scientists have observed closely, usually only a small fraction of the surface is active.

Hyakutake's high abundance of diatomic sulfur also fascinates researchers. Compared to other sulfur molecules, the diatomic form is short-lived. A'Hearn says no existing theory can account for its abundance, but he suggests its presence indicates that observers are directly seeing material from the comet's inner coma or perhaps even its heavily shrouded nucleus.

Comet expert Brian G. Marsden of the Smithsonian Astrophysical Observatory in Cambridge, Mass., marvels at the cooperation among astronomers, who quickly joined forces to observe a comet that was only discovered in late January. "I'm very impressed with how many astronomers got together and made supporting observations . . . even though this comet was unexpected and lasted for a short time."

The myriad observations of Hyakutake bode well for studies of Comet Hale-Bopp, a visitor expected to tour the inner solar system next spring (SN: 12/23&30/95, p. 428). Astronomers will have had more than a year to prepare for the arrival of this icy body, which they predict will be the comet of the century.

Skywatchers, you ain't seen nothin' yet! □