Frozen Relics of the Early Solar System

By RON COWEN

Some 5 billion years ago, a cold disk of dust encircling the sun grew lumpy. As gravity gathered together more of the dust particles and violent collisions ensued, the rock-sized lumps grew ever larger. Eventually, some began to form planets – first heavy Jupiter and the other orbs nearer the sun, then the more distant, chilly spheres of Uranus, Neptune and Pluto.

But in this scenario of how the solar system formed, not all the dusty debris merged into planets. Some chunks in the outer portions of the disk apparently remained apart, preserved through the eons as frozen fossils of the solar system's birth. These ancient amalgams of ice and dust are the orbiting bodies we know as comets.

"Comets are the dregs of the solar system, the leftover stuff from which the planets were made," says Harold Levison of the U.S. Naval Observatory's Flagstaff (Ariz.) Station. "The only way to tell what the early solar system was like is to study the material that hasn't changed."

For centuries, astronomers have tried to do just that, recording information about the size, orbit and glowing tails of comets as they streak past Earth. But investigations of nearby comets face a stumbling block. The same source that makes them visible – the sun – alters their primordial chemistry by melting their icy surfaces as they pass within a few hundred million kilometers of it. In addition, the gravitational pull of Jupiter invariably distorts their orbits, complicating scientific efforts to reconstruct a comet's original path through the solar system.

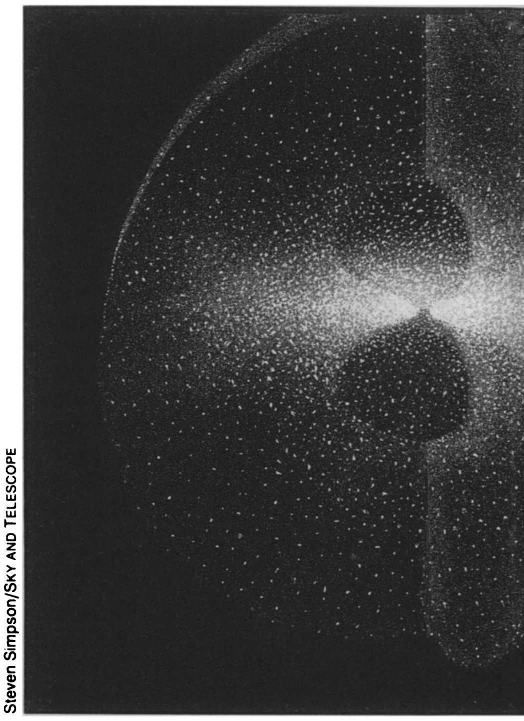
"If comets have really been in the deep freeze, they may have preceded everything else in the solar system," says David Jewitt of the University of Hawaii at Manoa. "But we want to study these comets in the quiescent state, before the sun's heat melts them and changes their composition and before their orbit becomes radically changed."

To capture comets in their unadulterated state, Jewitt and others are now looking far beyond Earth to regions where iceballs could exist free from the threat of solar melting and Jupiter's gravitational influence. Several of the new surveys will involve not just ground-based observations but also the careful tracking of two NASA spacecraft about to hurtle through the proposed Kuiper belt – a region lying just beyond Neptune's orbit and believed to contain as many as 100 million comets.

Attempts to view such distant comets have become possible only in the last several years with the emergence of new technologies for detecting relatively tiny, ultrafaint objects. Comets, like planets, do not glow from within but instead shine only in the light they reflect from the sun. Vastly smaller and more distant than the planets, the faraway comets would appear much fainter than even Pluto or Uranus. Those thought to originate in the Oort cloud – a huge spherical region postulated to exist near the edge of the solar system – would be too dim for detection while still inside the cloud, which may lie about 100,000 astronomical units (AU) from the sun, or 100,000 times farther than the distance from the sun to Earth. But comets believed to originate in the Kuiper belt – about 40 AU from the sun, or about 4,000 times closer to Earth than the Oort cloud – have a better chance of discovery at their home base. These comets represent prime targets for several groups of astronomers who have begun to survey distant skies with high-resolution telescopes and the newest generation of highly sensitive light detectors.

A simple but nagging question sparked Jewitt's survey. Why, he wondered, should the solar system appear so empty beyond the planets? He began his comet search in 1987, one year before evidence emerged to support astronomer Gerard P. Kuiper's 1951 proposal that a belt of comets should lie in an orbit near Neptune, tantalizingly close enough to Earth that it might be visible with long-term observations.

Jewitt, who now makes his observations using the University of Hawaii's 2.24-meter telescope atop Mauna Kea, says he can detect objects as small as 50 kilometers in diameter (comets may run as large as 200 km) and about 1.5 billion times fainter than the stars in the Big Dipper. He and MIT graduate student Jane X. Luu use images taken with a charge-coupled device (CCD), which can detect faint optical light with 100 times the sensitivity of photographic film. They compare CCD images, taken hours apart, for evidence of objects that seem to move at a snail's pace relative to the stars. Such an object might turn out to be a deep-space comet, they say.



Steven Simpson/SKY AND TELESCOPE

Jewitt and Luu have spotted several rocky asteroids and other tiny objects, but they have yet to find any distant comets. Comet hunts require long periods of observation, Jewitt stresses, because likely candidates are rare and might show up in any region of the distant sky. "We need to look for a long time at one spot to search for very faint objects; at the same time, we also want to cover much of the sky," he says.

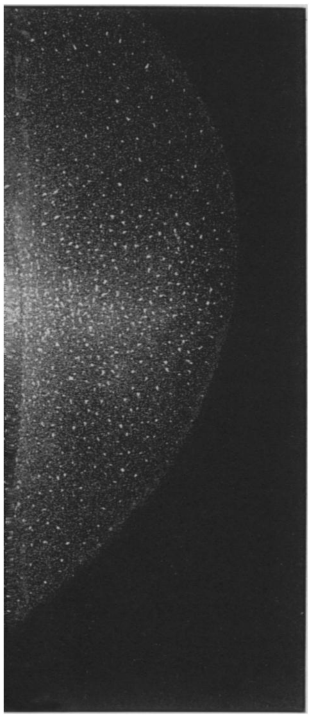
Though the search is far from over, the team expects to have surveyed enough of the sky within the next two years to test recent estimates of the Kuiper belt's comet population. Those estimates were calculated in the late 1980s by Scott Tremaine of the University of Toronto, Martin Duncan of Queen's University in Kingston, Ontario, Thomas Quinn of Oxford University in England, and their colleagues.

Another comet-hunting team relies on high-quality photographic plates at the UK Schmidt telescope at Siding Springs Observatory, New South Wales, Australia. These researchers, including Tremaine, Rachel Webster of the University of Toronto and Anna Zitkow of the University of Cambridge in England, compare sequential images spanning three consecutive nights, looking for slow-moving objects that display a distant comet's telltale path, or trajectory.

Webster told SCIENCE NEWS she and her colleagues have yet to find evidence of a

Science Service, Inc. is collaborating with JSTOR to digitize, preserve, and extend access to *Science News*. www.jstor.org

Astronomers search for distant comets



The proposed home base for an estimated 7 trillion comets, the Oort cloud may appear elliptical at its outer edge — about 200,000 AU from the sun — due to the tug of mass in the galactic plane. Most of its comets may orbit the sun at distances of about 10,000 to 20,000 AU (high-density area of dots in middle), roughly in the ecliptic plane.

comet that might reside in the Kuiper belt. "We're disappointed because we thought it [observing a distant comet] would be much more straightforward," she says. "But there's no reason to say there's something madly wrong with [comet] theory; with a little fine-tuning, our work fits with current models." She adds that the group still faces the painstaking task of completing the analysis of its 1988 sky survey. With each night's plate containing about 250,000 images, analysis is no simple matter.

Webster says she and her co-workers plan to apply for time on the 4-meter telescope at Kitt Peak National Observatory near Tucson, Ariz. That telescope's sensitive CCD detectors can discern far fainter bodies, she notes, but they also feature a narrower field of view, requiring several images a night to cover the same region of sky examined by the UK Schmidt in a single exposure.

Another method for seeking distant comets emerged in January at the American Astronomical Society meeting in Arlington, Va. Developed by Charles Alcock of the Lawrence Livermore (Calif.) National Laboratory and his colleagues, the technique relies on a well-known phenomenon called stellar occultation: When comets of large enough size pass in front of a star, they momentarily block the starlight from astronomers' view. Although an Earth-based observer would not directly glimpse a comet during such an event, the star would appear to blink out for about one-tenth of a second — long enough for a camera to record the happening and for researchers to infer the comet's likely presence.

Alcock and his colleagues propose to use cameras mounted on a trio of telescopes spaced a few kilometers apart to distinguish stellar occultations from mere twinklings due to atmospheric turbulence. The experiment, which may begin next year at the Nevada nuclear test site, should detect comets 3 km or larger in diameter at distances of up to 100 AU from the sun, he says.

While Alcock will focus on relatively small comets, others have stalked bigger game. At the meeting, Levison reported on his recent search for deep-space comets with diameters of about 200 km — the estimated size of Chiron, a proposed comet that may have originated in the Kuiper belt (see story, p.244). The survey revealed no likely candidates. However, Levison adds, "we didn't cover a big patch of the sky."

He and his colleagues used a 40-inch telescope at Flagstaff Station for their 30 nights of observations. Levison says the negative results suggest that Chiron-sized comets may not be common in the Kuiper belt, though the experiment did not address the abundance of smaller iceballs.

One of the most dramatic quests for distant comets won't require a telescope at all. Two NASA spacecraft, launched in the early 1970s, are now heading straight for the postulated Kuiper belt. Pioneers 10 and 11 will enter the densest part of the thin belt — if it exists — by early 1992, says John Anderson of NASA's Jet Propulsion Laboratory in Pasadena, Calif. The gravitational tug from the belt's combined mass, he says, should slightly increase the velocity of the two craft, an effect detectable as a small frequency shift in the radio signals they send back to Earth.

Pioneers 10 and 11 are now more than 30 AU from the sun, and so far they have not changed their velocity, Jewitt notes. This indicates that the proposed belt must weigh less than five times Earth's mass — a value within the predicted range.

Modern comet theory dates back to 1950, when two highly significant models — the "dirty snowball" and the Oort cloud — emerged to enliven the field. U.S. astronomer Fred L. Whipple proposed that cometary interiors contain ice embedded with dust; his model was the first to successfully account for both the gas tails and the dust tails associated with comets. That same year, Dutch scientist Jan Oort postulated a spherical cloud of comets orbiting about 100,000 AU from the sun.

Oort formulated his theory in order to explain an observation that had puzzled astronomers for years: Many comets passing near Earth showed a narrow range of large orbital energies rather than a widely varying distribution. Since large energies correspond to large orbits, Oort suggested that the comets followed long, looping orbits originating in a cloud-like region trillions of kilometers beyond the outer planets — a netherworld so remote that the sun's gravitational tug could barely hold it in the solar system.

In the early 1980s, researchers began to modify Oort's theory. Their models indicated that the Oort cloud, sitting precariously near the edge of the solar system, would be easily influenced by the gravitational pull of nearby stars, giant molecular clouds and galactic tidal forces from the disk of the Milky Way. According to their calculations, these phenomena would sometimes pluck comets out of the Oort cloud and hurl them into interstellar space. Other comets would get pushed closer to the sun, where Jupiter's gravity would either lure them into smaller orbits or kick them out of the solar system, depending on their positions and velocities relative to the large planet. With only about 5 percent of the comets ever returning to their home base, the Oort cloud's comet supply would decline rapidly.

But the notion of a dwindling comet population was at odds with the steady stream of "dirty snowballs" seen whizzing past Earth each year. To resolve the contradiction, theorists in 1981 added another wrinkle to the Oort theory: an inner Oort cloud within the larger sphere, 10,000 to 20,000 AU from the sun, that would act as a reservoir, slowly feeding new comets into the main, outer cloud.

In the November 1987 ASTRONOMICAL JOURNAL, Duncan, Quinn and Tremaine demonstrated that the Oort cloud could indeed exist, and described a possible evolutionary history for it. By feeding into a computer program the initial velocity and position values for comet-sized bodies located at various points in the young solar system, the researchers

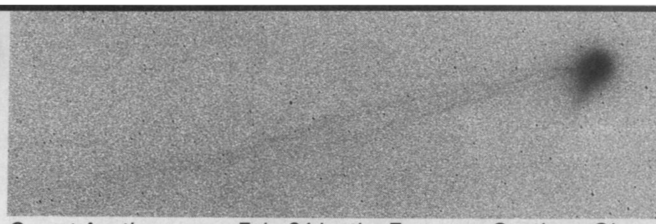
Visitor from the Oort cloud?

First spotted from New Zealand on Dec. 6, 1989, speeding toward the sun about 116 million kilometers from Earth, Comet Austin's initial brightness indicated it could be the most brilliant comet in more than a decade. But as it debuts in the Northern Hemisphere's predawn sky this week, Austin may not put on quite the dazzling light show that some had predicted.

Although some astronomers originally touted the comet as the most luminous since Comet West in 1976 (see cover photo), its rate of brightening took an unexpected nosedive in February and March. Astronomer David Jewitt of the University of Hawaii at Manoa notes that predicting comet luminosity is a tricky business. "We won't know how bright the comet will be [this month and next] until we see it," he says.

Adds astronomer Brian G. Marsden of the Harvard-Smithsonian Center for Astrophysics, "We may never be able to accurately predict comet luminosity." Such variables as the rate of melting by the sun and uncertainty in determining a comet's origin make brightness calculations nearly pure guesswork, Marsden says.

But even if Austin proves a fizzle to naked-eye observers, opportunities for studying it appear bright for scientists. The comet has already ejected enough dust from its icy nucleus to produce a tail oriented about 90° away from the sun — a characteristic associated with comets from the proposed Oort cloud, says astronomer Zdenek Sekanina of the Jet Propulsion Laboratory in Pasadena, Calif. In the past 50 years, Marsden notes, most comets that appeared to come from the Oort region have not been particularly bright as they streaked past Earth; witness 1973's highly publicized but ultimately disappointing Comet Kohoutek.



European Southern Observatory

Comet Austin as seen Feb. 24 by the European Southern Observatory's Schmidt telescope in La Silla, Chile. The comet has a short, stubby dust tail reflecting sunlight and a long, winding gas tail containing carbon dioxide and cyanide, among other molecules.

Jewitt plans to observe Austin at millimeter wavelengths, analyzing chemical properties such as the amount of carbon monoxide and carbon dioxide in its gaseous halo, or coma, for clues to the comet's origin in the solar system. Analysis of the tail may reveal whether Austin has swept along with it dust from interstellar space or the outer reaches of the solar system.

Although this comet may be difficult to view without an optical aid, amateur astronomers equipped with binoculars or telescopes and accurate star charts to track its position might glimpse Austin about 15° to 20° above the northeastern horizon in the hours before dawn in the coming weeks. Austin, which had dawdled since January in the western portion of the twilight sky, began to appear in the morning sky last week as it continued its orbit around the sun. The comet will rise earlier each day, although its brightness should fade slightly in May. The most promising viewing times will likely be this week and the second half of May, when the comet can show off its tail in relative darkness, rising in a moonless sky before the sun appears. By June, Austin will recede from both the sun and Earth, fading rapidly out of view. *— R. Cowen*

tracked the trajectories that could have evolved over several million orbits. Their feat relied on sophisticated software that dramatically reduced computing time by enabling them to account for the constantly changing gravitational interactions just once in each orbit.

The model indicated that comet-like material originally residing between Uranus and Neptune was gravitationally ejected into roughly the same region Oort had proposed for his comet cloud nearly four decades earlier. This both affirmed Oort's theory and suggested that the cloud arose from material that at one time was closer to the sun than the Kuiper belt is.

Scientists continue to refine the Oort cloud concept. Computer modeling by Julia Heisler of the University of Arizona in Tucson now indicates the cloud may have a mass density three to four times lower than previously thought, due to the unexpected ease with which galactic forces can hurl comets into the inner solar system, Heisler told SCIENCE NEWS. And Paul R. Weissman of the Jet Propulsion Laboratory estimates the cloud has a total mass about 50 times that of Earth and contains about 7 trillion comets. His review of current comet theory, including Heisler's new estimates, will appear in a forthcoming NATURE, he says.

However, notes Duncan, these and other modeling triumphs of the past decade account only for the longer-period, "new" comets — those that take about 4 million to 10 million years to reach the inner solar system on their first visit. Astronomers have observed that most shorter-period comets, which streak past Earth at least once every 200 years, seem to lie in the same ecliptic plane as the solar system and orbit the sun in the same direction as the planets. Such a specialized distribution would not likely come from the spherical Oort cloud, whose comets are believed to have scattered in all directions rather than clustering in one particular plane.

To reconcile theory with observation, Duncan and his co-workers borrowed from the concept of the Kuiper belt, which is essentially a flat, or planar, distribution of comets. Again, the team used its computer model to track various orbits of comet-like particles. Pushed and pulled, hurled and tugged by the gravitational forces of the four heaviest planets, the cluster of simulated particles could retain its distribution only if it were arranged in a disk among or just beyond the outer planets, the researchers reported in the May 1988 ASTROPHYSICAL JOURNAL LETTERS. Thus, they reasoned, a belt of material located at 50 AU — just beyond Neptune and about one-thousandth the average distance to the Oort cloud — could survive through the solar system's 4.5 billion years of evolution.

Moreover, Duncan says, this belt would give rise to the nearly flat distribution of short-period comets seen in the inner solar system. Many researchers credit the group's computer models with sparking new interest in the search for distant comets. Through modeling, Levison says, "we're learning about new [observing] possibilities."

Amid the enthusiasm, some researchers remain skeptical of current models for comet origins. Mark E. Bailey of the University of Manchester in England suggests an intriguing alternative: Not all comets now in the solar system necessarily originated there; instead, some might well have come from a source in the interstellar medium. If so, Bailey notes, gravitational capture of interstellar comets by the planets could still explain the number and frequency of comets observed near Earth.

Whether or not they provide ultimate answers, comet theories raise questions that captivate astronomers. "There's something there beyond the outer planets," Jewitt says. "Space is not really so empty; we just have to keep looking long enough. The really exciting thing is that some of this stuff might have been created with the birth of the solar system." □