Rocky Relics

Getting the lowdown on near-Earth asteroids

By RON COWEN

Earth shares the inner solar system with a swarm of objects — some of which pass closer to us than the moon. Astronomers know relatively little about these roughly 200 odd-shaped bodies, called near-Earth asteroids (NEAs), which range from 40 kilometers to 10 meters in length. A few thousand more of these NEAs — some with the potential to crash into our planet — may await discovery. But scientists have only recently begun efforts to obtain close-up images of these rocky bodies. Indeed, even their origin remains a matter of debate.

"I'm interested in them just out of natural curiosity; they're nearby and we really don't know much about them," says Lucy A. McFadden, an astronomer at the University of Maryland at College Park. "Every time we study NEAs, we're constantly surprised. The more we look, the more we find and the more we see things like [possible evidence of] new types of asteroid populations."

Indeed, the proximity of NEAs affords a unique opportunity to study the general properties of asteroids. Astronomers believe these chunks of rocky material are leftover rubble from the formation of the solar system — planetary wanna-bes that lacked the gravitational glue to stick together to form another Mercury, Venus, Earth, or Mars.

The composition, shape, and surface appearance of asteroids may harbor important clues to conditions in the early solar system, says planetary scientist Richard P. Binzel of the Massachusetts Institute of Technology. And new evidence provides further hints that asteroids — NEAs in particular — may be closely related to two other relics from the solar system's infancy — comets and meteorites.

"These bodies [NEAs] may provide the missing links between meteorites, comets, and main-belt asteroids," Binzel says.

NEAs represent only a tiny fraction of the million or so asteroids 1 km or larger in diameter thought to orbit the inner solar system. Most asteroids reside in a belt-shaped region that lies between the orbits of Mars and Jupiter. However, astronomers have discovered some 200 asteroids that periodically roam much closer to our planet. Some of these have orbits that intersect that of Earth (see sidebar).

The NEAs so far detected may represent just the tip of the iceberg. Astronomers estimate that there exist 5,000 to 10,000 near-Earth objects with diameters of 0.5 kilometers or larger. These objects come in three classes: Amors, Apollos, and Atens. Amors cross the orbit of Mars and approach that of Earth, and 10 percent of them cross Earth's path over the course of a few hundred to a few thousand years. Apollos cross Earth's orbit, and a few even come closer than the moon. Atens, for most of their orbit, lie closer to the sun than Earth does, but may intersect Earth's path at their farthest point from the sun.

Astronomers have found about half the known NEAs in the past five years and discover two or three new ones each month, thanks in part to improved search techniques, more sensitive photographic films, and the use of sensitive electronic light detectors, known as charged-coupled devices. In addition, astronomers are now using several telescopes — mostly small instruments — for the sole purpose of searching for these small bodies.

One of these telescopes, the 0.9-meter Spacewatch, sits atop Arizona's Kitt Peak and automatically scans the sky each night for near-Earth objects. In 1991, Tom Gehrels, David L. Rabinowitz, James V. Scotti, and their colleagues at the University of Arizona in Tucson used the 72-year-old telescope to detect the closest known approach of an asteroid (SN: 11/30/91, p.358). Dubbed 1991 BA, this NEA came within 171,000 km of Earth — less than half the distance to the moon. Moreover, at 10 m in diameter, the asteroid ranks as the smallest near-Earth object ever detected.

Last February, after analyzing the properties of several NEAs found by Spacewatch, Rabinowitz announced that his team may have found a new class of asteroid (SN: 2/20/93, p.117). They now count 17 near-Earth asteroids with diameters of 50 m or less, six of which move about the sun in nearly circular paths. According to Rabinowitz, current theories can't adequately explain why so many of these small bodies should follow such circular routes. Moreover, he notes, there appears to be an excess of Earth-approaching asteroids with diameters of less than 50 m, compared to what some astronomers predicted on the basis of the number of larger Earth-approachers.

In the June 24, 1993 NATURE, Rabinowitz and his colleagues suggest that the unexpectedly large number of small NEAs argues for the existence of another asteroid belt — this one near Earth. Gehrels proposes two sources: debris gouged out of the moon when other, larger asteroids slam into it; or further breakup of main-belt asteroids already fragmented by collisions within the belt.

Earthlings need not worry about the larger-than-expected number of small NEAs, writes Christopher F. Chyba of NASA's Goddard Space Flight Center in Greenbelt, Md., in the same issue of NATURE. The chances appear slim that any of the objects might strike our planet, he says, because they would most likely burn up in Earth's upper atmosphere.

Whether or not a near-Earth belt exists, the origin of NEAs remains a puzzle. The moon's pock-marked surface and some craters on our own planet indicate that NEAs do slam into Earth and its satellite. At the same time, the influence of Earth's gravity, as well as that of other planets, can sometimes hurl bodies out of the inner solar system. Both effects — collisions and gravitational ejections — suggest that some source must replenish the supply of NEAs.

The asteroids between Mars and Jupiter provide a likely reservoir. But because most asteroids seem to have highly stable orbits, it didn't seem possible for objects in the belt to depart rapidly enough to replenish the supply of NEAs.

However, Jack L. Wisdom of MIT calculated a decade ago that the gravitational influence of Jupiter may remove some asteroids from the main belt and place them in orbits that ultimately bring them near Earth over time scales of about 500,000 years. Likely places where such activity might occur include the Kirkwood gaps, regions in the main belt where the supply of asteroids is much lower than in other areas.

The Kirkwood gaps have a unique feature: The orbital motion of any asteroid at one of these locations has a special relationship, called a resonance, with Jupiter. Resonance means that the relationship between the orbital period of Jupiter and that of an asteroid in one of the Kirkwood gaps is always a simple fraction. For example, an asteroid in a

The NEAR spacecraft is scheduled to rendezvous with the near-Earth asteroid 433 Eros in Dec. 1998. In this composite illustration, NEAR is positioned beside the asteroid 951 Gaspra, photographed by the Galileo spacecraft in 1991.

Johns Hopkins Univ. Applied Physics Laboratory

Kirkwood gap with a 3:1 resonance circles around the sun exactly three times for every one revolution of Jupiter.

Due to the giant planet's gravitational tug, objects in a Kirkwood gap may experience sudden, large changes in their orbit. For a million or more years, asteroids in a gap may have the standard, near-circular orbit typical of objects elsewhere in the asteroid belt. But under Jupiter's influence, these asteroids may undergo chaotic gyrations that change their orbit to a highly elliptical path.

Indeed, Wisdom's calculations show that for asteroids originally placed at the belt's 3:1 resonance, about 2.5 times farther from the sun than Earth, Jupiter's gravity may induce them to move closer to the sun. Eventually the asteroids cross the orbit of Mars, the inner boundary of the main belt. From there, they may venture toward Earth.

The evidence that the 3:1 resonance is the main route for channeling asteroids toward Earth is far from clearcut. But the orbits of many NEAs suggest that they originated somewhere in the belt. And visible-light spectra taken by Binzel and his colleagues indicate that these NEAs have a composition similar to that of residents of the main belt.

Another source of NEAs may be the mixtures of ice, dust, and frozen organic goo known as comets. Typically, the sun's warming radiation evaporates some of the volatile compounds in comets whenever they visit the inner solar system. The expelled gas drags dust out with it, forming the fuzzy coma around the nucleus of the comet as well as its familiar tail. Such an object would seem to bear little resemblance to the rocky body of an asteroid.

But near the end of its lifetime — after passing through the inner solar system hundreds or thousands of times — a comet may have little gas to expel and thus lack the raw material to form a coma or tail.

Evidence also suggests that over time, a crust of inert dust forms over a comet's frozen nucleus. Its volatile compounds trapped beneath this crust, the comet would appear dormant. And since scientists classify as NEAs all near-Earth objects that lack a coma and a tail, a "dead" comet would indeed fit the description.

According to Binzel and others, several bodies classified as asteroids may once have been comets. One candidate is the asteroid 3200 Phaethon. It follows the path of the small bodies that produce the Geminid meteor shower, the flashes of light visible each December. Meteor showers are typically associated with comets. Tracks of dust expelled by active comets as they pass near Earth's orbit produce the flashes as the dust burns up in the atmosphere. Following this line of reasoning, Phaethon may be a comet masquerading in its old age as an asteroid.

Then there's the strange case of an Apollo asteroid known as 1979 VA. Two years ago, astronomer Edward L.G. Bowell of Lowell Observatory in Flagstaff, Ariz., began examining old photographic plates from the Hale telescope atop California's Palomar Mountain. Bowell hoped to trace back in time the paths of some recently discovered asteroids. On a plate exposed Nov. 19, 1949, he found an object at the same place that calculations indicated 1979 VA should lie. However, the object had a faint, but definite, tail. Indeed, in 1949, astronomers identified the object as a comet and dubbed it Wilson-Harrington.

Researchers now say that the comet and the asteroid are one and the same.

Despite such tantalizing evidence, McFadden remains unpersuaded that a strong link exists between comets and asteroids — at least not for an enigmatic object known as 2201 Oljato.

In the late 1970s, McFadden and her colleagues showed that Oljato, classified as an NEA, reflected ultraviolet light unusually well. That might indicate that Oljato is actually a dying comet that has not quite finished expelling its frozen volatile compounds. Another clue: This near-Earth object has a highly elliptical orbit reminiscent of a comet's path.

To determine Oljato's identity, McFadden and her colleagues searched for telltale fingerprints — the presence of even small amounts of cyanogen or hydroxyl, gases that a comet might vent even when its activity sank too low to form a visible coma or tail. Her team looked for traces of hydroxyl with the International Ultraviolet Explorer satellite in October 1992. One week later, using the 1.8-meter visible-light telescope at Lowell Observatory, they looked for traces of cyanogen.

The observations, reported last summer at a meeting in Belgirate, Italy, show no compelling evidence for significant amounts of either compound, McFadden says. When she and her colleagues studied other asteroids suspected of having a cometary heritage, they found equally discouraging results.

McFadden says she finds it hard to fathom how a comet could lose enough energy to shrink its orbit to that of an NEA. A comet could give up energy through gravitational interactions with the planets, she notes. But in the outer reaches of the solar system, where comets are thought to originate, such gravitational perturbations are few and far between. It might take the better part of the solar system's lifetime for a comet to transform into an asteroid, she speculates.

Asteroids and meteorites may also share a common heritage. Meteorites are natural, extraterrestrial objects that survive a fiery passage through the atmosphere to strike Earth. Some studies suggest that meteorites follow a path similar to the one asteroids apparently take as they venture from the main belt to a near-Earth orbit. However, in comparing the composition of meteorites with observations of asteroids, astronomers find both similarities and differences.

Consider the most common type of meteorite, known as an "ordinary chondrite." It would be tempting to think that the most common type of asteroid, known as an S asteroid, is the parent of the most common meteorites. But although S asteroids and ordinary chondrites contain the same minerals and metals, they contain them in different proportions.

It appears that S asteroids more

closely resemble a less common type of meteorite known as stony-iron. These meteorites have been subjected to high heat during their lifetime; ordinary chondrites seem to have escaped the heating, melting, and subsequent chemical alterations that other ancient bodies have undergone since the solar system formed some 4.6 billion years ago.

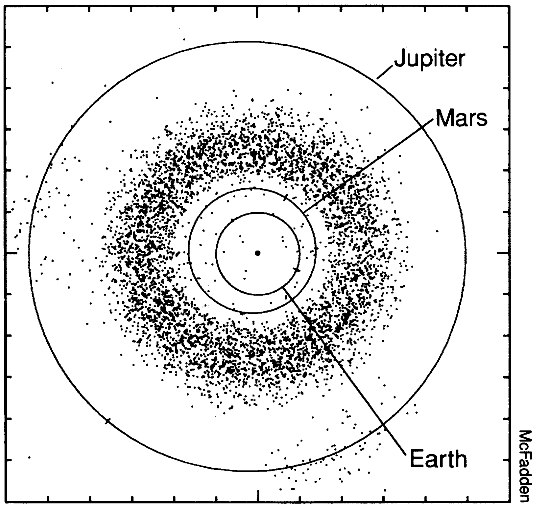
But recently, astronomers reported identifying the first main-belt asteroid to have the same reddish tint and other spectral characteristics of an ordinary chondrite. Known as 3628 Božněmcová, this body also has the right location within the main belt to qualify as a source of ordinary chondrite meteorites.

The asteroid resides in the inner part of the main belt, in the vicinity of the 3:1 resonance where Jupiter's tug might well endow it with a chaotic orbit that could direct it toward Earth. Binzel and his colleagues, including MIT collaborators Shui Xu and Schelte J. Bus, describe their work in the Dec. 3 SCIENCE.

Measuring just 7 km across, Božněmcová is a relatively small parent body. But small may be just the ticket. Small asteroids may soak up less heat in the inner solar system, avoiding the chemical changes accompanying melting, just as ordinary chondrites do.

It seems unlikely that Božněmcová can account for all the chunks of ordinary chondrites that have peppered Earth over tens of millions of years. Some astronomers suggest that the mismatch between the objects on the ground and those in the sky stems from solar heating of asteroids or collisions in space that melt the surface of asteroids. Such "space weathering" might somehow alter the spectra of many asteroids so they no longer resemble ordinary chondrites.

Spacecraft may soon test such speculation with the first voyages to NEAs. On Aug. 31, if all goes according to plan, a spacecraft called Clementine — launched last week — will fly by a tiny, rocky member of the inner solar system (SN: 1/15/94, p.40). That body, a 20-km-



Drawing shows the position of 5,531 asteroids on Aug. 31, 1994. The main asteroid belt lies between the orbits of Mars and Jupiter; some near-Earth asteroids lie inside the orbit of Mars.

wide asteroid known as 1620 Geographos, lies only twice as far from Earth as the moon. And if the craft succeeds in obtaining infrared, visible-light, and ultraviolet images, Clementine will capture the first close-up pictures of a near-Earth asteroid.

Even if Clementine fails to image Geographos, a more ambitious NEA visit is in the works.

Last month, NASA announced plans to send a spacecraft to orbit the near-Earth object 433 Eros, an irregularly shaped body measuring about 35 km across. The unmanned craft, set for launch in February 1996, will first journey through the asteroid belt, flying by the main-belt asteroid Iliya in August 1996. It will then swing back toward Earth for a gravity boost in early 1998. The mission — known as NEAR, for Near Earth Asteroid Rendezvous — will encounter 433 Eros in December 1998.

Developed by the Johns Hopkins University's Applied Physics Laboratory in Laurel, Md., NEAR will orbit Eros for a year, passing within 24 km of the body and resolving surface features as small as 1 m across. In contrast, the Galileo spacecraft could only resolve features measuring some 50 m or larger when it flew by the main-belt asteroids 951 Gaspra in 1991 and 243 Ida in 1993.

In opening a new window on the NEAs, Clementine and NEAR should begin answering some key questions about our nearest solar system neighbors. □

Doomsday Asteroids

An estimated 2,000 asteroids larger than 1 kilometer follow orbits that cross that of Earth. Are any of these rocky missiles headed on a collision course with our planet?

The impact, equivalent to the destructive power of 10,000 megatons of TNT, would dramatically disrupt life on our planet. Some scientists calculate that a 1-km-wide asteroid would deposit enough dust in the atmosphere to create a "nuclear winter," blocking sunlight and triggering widespread crop failure and starvation. The climate might be altered for years.

In the Jan. 6 NATURE, Clark R. Chapman of the Planetary Science Institute in Tucson, Ariz., and David Morrison of NASA's Ames Research Center in Mountain View, Calif., calculate that there is a 1-in-10,000 chance that a 2-km-wide asteroid or comet will collide with Earth during the next century. Collisions with larger objects, like the 10-km object thought to have wiped out the last remaining dinosaurs and many other life forms some 65 million years ago, occur much less frequently.

A NASA study suggested that an early warning system, using sensitive electronic detectors and telescopes around the world, could in 25 years identify 90 percent of the kilometer-wide (and larger) objects threatening Earth. The system, dubbed Spaceguard, carries a start-up cost of $50 million.

But for some, the slim odds that any large object will hit Earth over the next few centuries makes such plans seem less than urgent. Instead, argue Peter J.T. Leonard, now at the University of Maryland at College Park, and Jack G. Hills of the Los Alamos (N.M.) National Laboratory, astronomers should concentrate on predicting the far more frequent collisions between Earth and smaller asteroids, those measuring 100 meters or so across.

New calculations by David Rabinowitz of the Spacewatch telescope team suggest that these small asteroids pass near Earth 10 to 100 times more frequently than anyone had thought. And Leonard and Hills calculate that a rocky body measuring 100 meters across could hit home about once every 100 to 200 years.

"There's a decent chance during anyone's lifetime for the Earth to get nailed by one of these small asteroids, 100 meters or so in size," Leonard says. He adds that because most of Earth's surface is uninhabited, most of these impacts would have gone unwitnessed in the past.

Chapman and Morrison note that the hazard from small asteroids "is much less than the hazard of other natural catastrophes that can and do kill just as many people much more often; moreover, it would be extremely difficult to discover and inventory all of the countless potential colliding objects down to tens of meters in size." The researchers argue that "maintenenance of expensive, active surveillance and inherently risky 'space defenses' against small impacts seems to be out of proportion to their threat."

Richard P. Binzel of MIT agrees. Until a threatening body is found, he says, it's premature to devise a system to divert it from Earth. Some have proposed such controversial strategies as launching a nuclear bomb on an unmanned spacecraft to destroy an asteroid or comet that appears to be on a collision course with our planet. "Right now, we're just trying to learn what's out there," Binzel says. — *R. Cowen*