The Great Asteroid Roast: Was It Rare or Well-Done?

Many astronomers now believe most of the asteroids were cooked early on rather than being largely unaltered primordial stuff

William K. Hartmann

A meteorite's beginnings. *Collisions break open asteroids as well as start bits of them on their trips to Earth.*

IT WOULD BE QUITE A FIELD TRIP, but a grand tour of the asteroid belt would be well worth it to researchers trying to settle a long-simmering controversy that has recently shown signs of coming to the boil. The issue: Are the 4000 or so asteroids that orbit in a 400-million-kilometer-wide belt between Mars and Jupiter mainly unchanged remnants of the cosmic debris that made the planets? Or were many of them radically altered by severe heating shortly after they formed, some even to the point of melting?

The answer is eagerly being sought by two disparate groups of specialists. To meteoriticists—the small coterie of lab workers who study the bits of asteroids that have fallen to Earth as meteorites—a reasonable answer seems obvious. The meteorites that most commonly fall to Earth, called ordinary chondrites, show no evidence of extreme heating. Ergo, the asteroids from which they came have not been reshaped by high temperatures since they agglomerated from hot gases and dust in the early days of the solar system. Asteroids began as unaltered, primitive matter, and, said the meteoriticists, most of them have remained that way ever since.

That has been the conventional wisdom for decades. But now come the revisionist astronomers. While meteoriticists have been peering at asteroid remains through their microscopes, astronomers have been focusing their telescopes on the asteroids themselves—and most of them have come to the opposite conclusion. Many of the asteroids they see appear to have gone through just as much melting as the planets did. If the astronomers are right, this raises an interesting conundrum: Where did the primitive, unaltered material in ordinary chondrites come from?

The astronomers' most provocative summation of their case comes in a publication out late last year entitled "Asteroids: The Big Picture." In it, astronomer Jeffrey Bell of the University of Hawaii and his colleagues cite 20 years of astronomical observations in rejecting the traditional assumption of meteoriticists—that the inner belt's most common type of asteroid, the S type, is the source of the most common type of meteorites, ordinary chondrites. Drawing on observations by his coauthor, Michael Gaffey of Rensselaer Polytechnic Institute in Troy, New York, Bell argues that analysis of the light reflected by S asteroids indicates that they are too rich in metal to be the ordinary chondrite source (see box on p. 528).

Bell then goes on to rewrite the belt's history. Nobody would argue with his starting assumption—that the asteroids formed from the cosmic debris of the early solar nebula as cold, primitive matter. The controversy is over what happened next.

According to the meteoriticists, very little has changed in the asteroid belt over the 4.5 billion years since it was first formed. The odd asteroid or two might have been altered to yield the variety of meteorites seen on Earth, but on the whole the asteroids remain much as they were in the early days of the solar system.

Not in Bell's scheme. He proposes that early on the asteroids of the inner and middle belt underwent a great heating, so intense that many of them melted. He does not specify how the heating might have occurred, but one possibility is that the powerful solar wind thrown off by the young sun induced heating within asteroids electromagnetically.

Whatever the heat source, the molten metal in the asteroids would have sunk to their interiors and frozen there. The metallic cores could then have become exposed over the eons as collisions between asteroids chipped away the more fragile surface rock. That could account, Bell suggests, for the metal-rich surfaces of the S asteroids that Gaffey has detected.

Farther out, near the middle of the belt, the heating would have been less extreme and complete melting would have been rare, according to Bell's scenario. The heating there would, however, have been intense enough to have metamorphosed primitive bodies, in part by causing the water they carried to react with their rock. Toward the outermost part of the belt, the relatively cool temperatures would have allowed asteroids rich in organic matter to form, and little has changed there since. Bell indeed finds spectral evidence of metamorphosis in the middle belt and primitive asteroids beyond.

This all makes for a nice, self-consistent picture of the solar system, but meteoriticists and even some astronomers argue that it must be wrong. Their main problem is that it simply does not fit with what is known about meteorites. If ordinary chondrites do not come from the abundant S asteroids, where *do* they come from? "It's hard to understand how we could have so much ordinary chondrite raining down on us without [obvious] sources out there," says Clark Chapman of the Planetary Science Institute in Tucson.

The first line of attack on Bell and Gaffey's theories focuses on their conclusion that the S asteroids are rich in metals. "People who are far removed from spectroscopy [of asteroids] put greater emphasis on what they know about meteorites," says Chapman, who is one of the rare astronomers who has doubts about the identification of S types as being metal-rich.

Bell and Gaffey may have been deceived, some skeptics propose, by ordinary chondrites traveling incognito in the inner asteroid belt. It might not take much to mask an ordinary chondrite and make it look metal-rich, the way Bell and Gaffey say S asteroids look. The reflected light used in spectroscopy passes through only the outer millimeter or less of an asteroid. A superficial alteration of an asteroid's surface by solar radiation or micrometeorite impacts, for example, might give the erroneous impression that the asteroid has an abundance of metal.

"Virtually everything in the solar system is altered one way or another," says astronomer Carle Pieters of Brown University. "I strongly believe that alteration must occur. My bias comes from looking at lunar samples," in which several processes lumped together under the term "space weathering" have altered surface material. "Which of these processes are occurring on the asteroids, I can't pinpoint," she says.

So far, however, none of Bell's critics has been able to come up with a specific space weathering process that would make an asteroid of ordinary chondrite look metal-rich. But Daniel Britt of Brown and Pieters are pursuing another possibility. Impacts are known to turn black some of the ordinary chondrites arriving at Earth. If impacts can also turn the entire surface of an ordinary chondrite asteroid black, black asteroids could be the masked, unrecognized source. As it happens, there are plenty of dark C type asteroids in the middle of the belt that could fill the bill.

Bell, however, has an alternative suggestion: the ordinary chondrites seen on Earth may have come from smaller, poorly studied asteroids, known as Q type asteroids. "The Q's do better resemble ordinary chondrites," concedes George Wetherill of the Carnegie Institution in Washington, D.C., "but unfortunately we don't find them in the asteroid belt." There is only one certain member of the Q class, and it has been nudged into an orbit as close to the sun as Earth's. Bell is not fazed by this. He argues that small asteroids in the inner belt will turn out to be Q types once improved telescope technology provides better spectra of very small bodies that allow them to be classified.

Wetherill, who specializes in the orbital and collisional behavior of solar system bodies, puts little stock in small asteroids as a solution to the mystery of the origin of the ordinary chondrites. He argues that Bell's small Q types cannot be the only ordinary chondrite bodies in the belt. Large ones must be there too because only large bodies could survive eons of battering by collisions. Wetherill also ticks off another problem with Bell's hypothesis—there is a distinct shortage of the rocky asteroidal debris that ought to be left over if S types were formed by chipping away their exteriors.

Wetherill has his own alternative. "I don't think any of the proposed solutions make sense. They're all wrong. My guess is that there's something wrong with the spectroscopy."

With luck, the astronomers and meteoriticists will get a chance to check the spectroscopy during some actual fieldwork in August of 1991 when the Galileo spacecraft is scheduled to make a close pass by S asteroid Gaspra. At that range, researchers should be able to see some of the actual geologic features of the asteroid—boulders gouged from beneath the surface, or perhaps bodies of metallic "ore"—that every one agrees could be crucial to proving Bell right—or wrong. ■ RICHARD A. KERR

S Asteroids at Controversy's Core

"It's like going to trial with some circumstantial evidence and a collection of mediocre witnesses," says astronomer/geologist Michael Gaffey, "but it all points the same way"—the S type asteroids are not guilty of littering Earth with tons of ordinary chondrite meteorites. These most common of meteorites must come from some other, as yet unidentified, type of asteroid, he contends. This verdict has engendered an even greater mystery—and controversy—about the fundamental nature of asteroids (see main story).

Although the controversy continues, Gaffey, who works at Rensselaer Polytechnic Institute in Troy, New York, has cleared two of the 144 known S type asteroids of any involvement with ordinary chondrites. No one can claim anymore that ordinary chondrite meteorites were ever chipped off asteroids 8 Flora and 15 Eunomia by random collisions. Gaffey proved this by recording the visible and near-infrared spectra of the two asteroids as they rotated. The color of light reflected from a rotating ordinary chondrite body should change little with time. This is true because lab analysis has shown that not enough has happened to ordinary chondrite meteorites, and therefore their parent asteroids, to concentrate their various minerals and metals into separate masses big enough to show different colors when observed from Earth.

But the various sides of Flora and Eunomia showed too much variation in color to consist of ordinary chondrite material. Elongated Eunomia in particular seems to have surfaces of several different kinds of rock, including crustal rock, deeper mantle rock, and metal-rich rock, such as might be found near a metal core. Something must have heated and melted these two asteroids, Gaffey says, so that their finely dispersed components separated, or differentiated, into layers that collisions later exposed by knocking off chunks of the asteroids.

Astronomers and meteorite mavens generally accept Gaffey's characterization of Flora and Eunomia, but many part company with him when he extends his findings to other S type asteroids, claiming that most of them have differentiated. Many researchers find this hard to swallow. "We all think S types are a mixture of [the minerals] olivine and pyroxene and metal," says astronomer Clark Chapman of the Planetary Science Institute in Tucson. "Unfortunately, many meteorites are made out of these same components. To tell the difference between differentiated and undifferentiated requires getting down to a second level of detail. Gaffey believes he can do that. I'm not so sure that we aren't being fooled. The error bars are large. The differences aren't very great; the implications are."

But Gaffey is optimistic that he is right. Flora is solidly in the S class, he notes, and some astronomers, including Chapman, had suggested that Flora in particular bore a strong resemblance to ordinary chondrites. So Gaffey was not choosing an easy target for his test by rotation.

In addition, Gaffey finds a whole suite of remotely determined characteristics indicating that most S type asteroids, not just Flora and Eunomia, have differentiated. The evidence includes their visible and near-infrared spectra, the amount of their infrared emission, and the way radar reflects from them.

"I can't find any plausible way to make S asteroids ordinary chondrites," says Gaffey. "I may be wrong. Each of us works in our own area and weights that evidence more than evidence from outside. But where the evidence allows you to decide, it is unanimous. The majority of observers feel that most S asteroids were melted."

■ R.A.K.

ADDITIONAL READING

J. Bell, D. Davis, W. Hartmann, M. Gaffey, "Asteroids: The big picture," in *Asteroids II*, R. Binzel, T. Gehrels, M. Matthews, Eds. (University of Arizona Press, Tucson, AZ, 1989), pp. 921–945.

M. Gaffey, J. Bell, D. Cruikshank, "Reflectance spectroscopy and asteroid surface mineralogy," *ibid.*, pp. 98–127.