Galileo's Frustrating Asteroid Pursuit

Astronomers' first closeup of an asteroid probably won't answer their most burning question—what is it made of?

ARE MOST ASTEROIDS CLUMPS OF PRIMORdial material left over from the formation of the solar system, or are they metal-rich bodies forged in some ancient blast of heat? That's the most contentious question in asteroid science (*Science*, 2 February 1990, p. 527). For two decades it had little prospect of resolution, until the Galileo mission to Jupiter came along.

In early 1986, the small band of planetary scientists who had been trying to divine the true nature of asteroids was eagerly awaiting a May space shuttle launch, which would hurl the Galileo spacecraft toward Jupiter. On its way through the asteroid belt, Galileo was slated to swing by Amphitrite, one of the largest of the S-type asteroids—the most abundant class. At last scientists might resolve the debate. But then *Challenger* blew up, and even though NASA has doggedly maintained the plan for an asteroid flyby, it's been downhill ever since for scientists' hopes of unraveling the mysteries of the asteroids.

On 29 October, Galileo will make the first-ever asteroid flyby. Because of course changes made necessary by the shuttle disaster, the target now is a pipsqueak S asteroid, 12.5-kilometer Gaspra, instead of 200-kilometer-wide Amphitrite. And if that weren't disappointing enough, a later misfortune—the snagging of Galileo's main antenna—has prevented controllers from snapping pictures from as close range as they had planned. As a result, planetary scientists hoping to learn the secrets of S asteroids have lowered their sights a bit. "It will be very interesting," says meteoriticist Michael Gaffey of Rensselaer Polytechnic Institute, "but I don't think it will settle the issue. It's going to be like a classic striptease: tantalizing, but you don't get to see much."

At that rate, the encounter might even end up fueling the great asteroid debate, which has been built on just such tantalizing but unconvincing glimpses. One view of the S-types was developed in the 1970s from studies of chondrites, the most abundant kind of meteorites. The trajectories of meteorites seemed to indicate a birthplace in the inner asteroid belt, which is dominated by S-asteroids; many researchers went on to conclude that chondrites had to be samples of S-asteroids. And since chondrites seemed to represent primitive solar system material, unaltered by heating, that had to be true of their parent bodies as well. Indeed, spectral measurements of some S asteroids seemed to bear out the meteorite link, suggesting the presence of metal and the minerals olivine and pyroxene in the same proportions found in ordinary chondrites.

But in recent years new spectral observations have suggested to some researchers that S-types are metal-rich, too rich to be the source of ordinary chondrites. Instead of being unaltered, some astronomers argued, the S-types were once heated until their metal concentrated toward the center, forming metal-rich cores that were later exposed by collisions among asteroids. If so, chondrites must have some other source—nobody knows where—and some unknown heating process must have roasted the inner asteroid belt early in solar system history.

With a target as large as Amphitrite, Galileo had a fair chance of resolving this quandary. A large asteroid would offer more opportunities for detecting the variations in spectral color expected of an altered body. It would also bear more large impact craters, which might expose telltale glimpses of subsurface metal. And the more massive the asteroid, the more precise an estimate of its density could be made. The relatively strong gravitational pull of Amphitrite might have altered Galileo's path enough to show whether the asteroid has the lower density that is typical of ordinary chondrites or the higher density expected of a metal-rich altered body.

Galileo's encounter with Gaspra is "going to be a classic striptease: tantalizing, but you don't get to see much."

—Michael Gaffey

Gaspra, in contrast, won't have much of a gravitational effect on the spacecraft, leaving Galileo able to probe the nature of its target only by recording spectra and taking color and black and white pictures as it speeds by at 29,000 kilometers per hour. Astronomer Jeffrey Bell of the University of Hawaii, for one, doesn't expect anything conclusive to come of those observations. He points out that the spectra Galileo will record are the same kind of data that meteoriticists and astronomers pondering the nature of S-types have been arguing over for decades. "There's already been an immense amount of work done on these objects from the ground," says Bell. "You just can't take enough data in [a flyby] to resolve anything."

That's especially true when your target is so tiny. In that regard, prospects for the encounter got even worse this spring. As asteroid specialist and Galileo team member Clark Chapman of the Planetary Science Institute in Tucson recalls it: "Gaspra shrank on us." Galileo team members had been quoting a diameter of 16 kilometers for Gaspra based on measurements made by the Infrared Astronomical Satellite (IRAS) during a survey of the infrared sky. "But that turns out to be a bogus measurement," says Chapman. The computer analysis of IRAS data mistook some errant infrared source as Gaspra, which was actually just outside the field of view. After suspicions were raised about the IRAS diameter, new telescopic observations of Gaspra at infrared and visible wavelengths yielded a diameter of 12.5 kilometers, a 40% reduction in the visible disk that Gaspra will present to

The long-awaited goal. *Astronomers are wondering if Gaspra will be as intriguingly shaped as the small asteroid in this speculative rendition.*


William Hartmann

Galileo. That's "just a little disappointing," says Chapman. "Gaspra is still interesting, but it's harder to observe."

Even if it were easier to study, Gaspra might not be the best test case for resolving the great asteroid debate, for it's an odd sort of S asteroid. Gaspra's spectral characteristics show it to be composed of metal and the minerals olivine and pyroxene, as all S-types are, but it is so rich in olivine that it borders on being unclassifiable, according to Chapman. Even though Chapman thinks the S class in general is primordial, he suspects this peculiar specimen could turn out to be altered.

On top of the limitations of the target, there is Galileo's own handicap: its jammed main communications antenna (*Science*, 23 August, p. 846). Luckily, the failure of the large antenna won't hamper the recovery of data. Encounter observations will be stored on-board until Galileo makes its final swing by Earth in December 1992, when the data can be dumped at close range through a smaller antenna. But the main antenna would have transmitted the "navigation" images—photographs taken well before the flyby to help controllers aim the camera once Galileo was within range. In the absence of the main antenna, these navigation images have to trickle to Earth through the backup antenna. So, instead of a final navigation image made 24 hours before the flyby, controllers have to rely on one taken a week ahead, making the targeting of Galileo's camera during the actual flyby a cruder business.

To compensate, controllers will direct the camera to plaster the sky with 51 overlapping images. That, they figure, will give them a 95% chance of catching Gaspra in one of them. But allowing time for all that photography means it will have to start earlier in the flyby than had been planned. At that greater distance, Gaspra will be about 20% smaller than in the images that would have been possible with better camera targeting.

But even though asteroid researchers mourn the encounter that might have been, they're not giving up on the possibility of some unexpected insight. Firsts in planetary exploration are renowned for producing surprises. Perhaps Gaspra will be clearly recognizable as half metal and half rock, or marked by an impact with streaks of metal frozen in mid-splatter—a giveaway that it is altered. But even without a sudden payoff, researchers are eager to see what Galileo can turn up. "Amphitrite would have been a larger, perhaps more spectacular object," says astronomer Richard Binzel of the Massachusetts Institute of Technology. "But I wouldn't discount these small objects. They may be incredibly interesting." ■ RICHARD A. KERR

Concocting a Cosmic Recipe for Matter

Taking their cues from accepted physics, two groups of researchers try to solve the mystery of the non-empty universe

WHY IS THERE MATTER? IT MAY SOUND LIKE a question from a Philosophy 101 final, but physicists have been scratching their heads over that one for the three decades since the emergence of the Big Bang account of the universe's birth. The Big Bang elegantly explained a host of puzzles, but it created a new one: According to existing physics, it should have spawned matter and antimatter in exactly equal quantities. But since matter and antimatter always annihilate each other on contact, a balanced soup would have quickly blasted itself into pure energy, leaving an empty universe and no intelligent creatures to ponder the issue. And yet here we humans are, able to contemplate the conundrum precisely because somewhere along the way matter got slightly ahead of antimatter. But how?

Don Harris, UC Santa Cruz

Taking matter in hand. *Michael Dine.*

Now some of that excess matter—in the form of separate groups of physicists at the University of California, Santa Cruz, and the University of Minnesota—has taken a stab at explaining its own existence. If the new scenario independently developed by these groups stands up, physicists and cosmologists will breathe a sigh of relief. Their inability to nail down the source of the excess matter has left an embarrassing gap in our view of cosmology—a gap that researchers have often tried to fill by enlisting such highly speculative models as grand unified theories, which provide a single description of all of the forces of nature except gravity. In contrast, Santa Cruz physicist Michael Dine, Minnesota physicist Larry McLerran, and their colleagues would fill the Great Cosmology Gap with less exotic ingredients than grand unified theories. McLerran and Dine would be satisfied by mere inflationary cosmology, a few extensions of conventional particle physics, and a well-established (though admittedly obscure) quantum-mechanical effect that enables matter and antimatter to change places.

And that's the beauty of the Dine-McLerran model. "The exciting thing is that these scenarios are dependent on physics that should be accessible at the Super Conducting Supercollider (SSC)"—or at least so says Peter Arnold, a physicist at Argonne National Laboratory who is acquainted with the new notions.

But what exactly are these notions? The essentials of the problem were first laid out in 1967 by Soviet physicist Andrei Sakharov. He noted that skewing the universe toward matter required two things: some means of converting matter to antimatter and vice versa (known as "baryon-number-conservation violation") and some matter-antimatter asymmetry that would make this process favor the direction of matter (known as "charge-parity symmetry violation"). But having proposed these conditions, Sakharov conceded there were few clues as to how they might have been met.

One type of charge-parity (CP) violation had already been observed 3 years earlier. Princeton physicists Val Fitch and James Cronin had noticed a tiny quirk in the decay of the particle called the kaon (see *Science*, 4 October, p. 36)—a quirk that would have tilted the scales in favor of matter over antimatter. Nevertheless, the quirk was too weak by at least ten orders of magnitude to meet Sakharov's conditions.

Meanwhile, grand unified theories provided baryon-number violating processes, but such theories could only be tested at hopelessly unattainable energies. The rock-solid standard model, which provides our current view of particle physics, seemed to slam the door on baryon-number violation.

But then came Gerard 't Hooft, a Dutch