PLANETARY SCIENCE

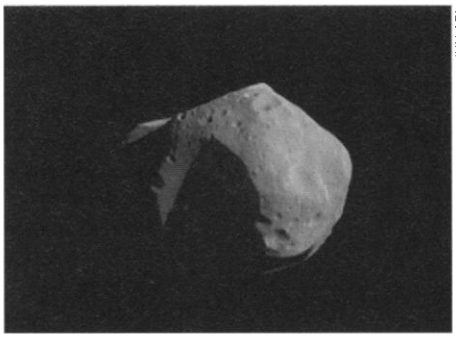
Does Mathilde Have a Broken Heart?

LAUREL, MARYLAND—Seen in the first images from a passing space probe, the asteroid Mathilde was stunning enough, adorned with incredibly deep, shadowed craters. But when the probe radioed back the first clues about the interior of the 52-kilometer asteroid last week, researchers were in for another surprise: They found only a third of the mass they had expected. The discovery supports the claim that most asteroids are heaps of rocks loosely held together only by their own gravity. Eons of banging about in the asteroid belt, it seems, have reduced Mathilde, and perhaps most asteroids, to piles of flying rubble.

Mathilde, the largest asteroid to date to be viewed up close, was imaged by the low-cost, Discovery-class Near Earth Asteroid Rendezvous (NEAR) spacecraft, which is on its way to an encounter with the asteroid Eros in 1999. The spacecraft carries no instrument that could directly probe an asteroid's interior, but NEAR's radio managed to do so indirectly, as researchers reported at a press conference here last week. As the spacecraft passed within 1200 kilometers of Mathilde, the asteroid's feeble gravity slightly deflected NEAR's path. By monitoring the Doppler frequency shift in the spacecraft's radio signal during the flyby, researchers inferred that Mathilde slowed down the spacecraft by 1 millimeter per second—about the speed of a sluggish ant, said NEAR team member Donald Yeomans of the Jet Propulsion Laboratory (JPL) in Pasadena, California.

From that minuscule slowing, Yeomans calculated a mass for Mathilde of 10^{17} kilograms, or a millionth the mass of Earth's moon. Assuming an average diameter of 52 kilometers (a preliminary value determined from NEAR images), Mathilde has a density of just 1.3 grams per cubic centimeter—not much more than water. But meteorites thought to have been chipped off this type of common asteroid are typically twice as dense, or 2.6 grams per cubic centimeter. "We've got an object considerably lighter than we thought," says celestial mechanicist Yeomans. "If it were any lighter, it could float."

Although Mathilde's apparent low density may rise somewhat as researchers take better account of its irregular shape, it's unlikely that the final estimate will approach the density of solid rock, notes asteroid specialist Alan Harris of JPL. The most likely explanation, he says, is that


JHU APL

Not as solid as she looks. Gravity data suggest Mathilde's interior is disrupted.

Mathilde is a conglomeration of blocks, boulders, and loosely compacted debris. There have been earlier signs that asteroids are rubble piles (*Science*, 1 January 1993, p. 28; 26 April 1996, p. 485), but this is the most direct evidence yet, says Harris. Mathilde's apparent density bears on problems such as the collision history of asteroids and strategies for protecting Earth from future asteroid collisions.

The finding could also have implications for NEAR's future if Eros, too, is a low-density body with unexpectedly weak gravity. In January 1999, when controllers aim to put NEAR into orbit around Eros, they will have to keep Mathilde's broken heart in mind.

–Richard A. Kerr

PARTICLE PHYSICS

Case for Neutrino Mass Gathers Weight

"Neutrinos, they are very small / They have no charge they have no mass / And do not interact at all," runs the poem by John Updike. Physicists have known for decades that Updike is mistaken on one count at least: Neutrinos do interact with matter, albeit very feebly. Many are now convinced, however, that he is also wrong about the mass. Three new experimental results, announced last week at a meeting on the Italian island of Capri near Naples, add to hints that neutrinos might indeed have a very small mass.

The three experimental groups approached the question from different directions, two of them by using massive underground detectors to capture neutrinos streaming from the upper atmosphere, and one by studying neutrinos made with an accelerator. But all three believe they may be seeing signs of "neutrino oscillations," in which neutrinos—which come in three "flavors" called electron, muon, and tau—spontaneously switch from one flavor to another. Oscillations can take place only if neutrinos have mass. "We have evidence, in fact, I believe strong evidence, that oscillations are occurring," says Bill Louis, spokesperson for the accelerator experiment—the Liquid Scintillator Neutrino Detector (LSND) at Los Alamos National Laboratory in New Mexico.


SOUDAN 2

Mining for mass. The 1000 tons of corrugated iron at the heart of the Soudan 2 detector in northern Minnesota.

Whether the humble neutrino has a mass is a weighty matter for physicists. Massive neutrinos could help account for the universe's "missing mass," the extra heft astronomers believe must be out there but have not been able to find; neutrino oscillations might also explain why the sun appears to produce fewer neutrinos than theorists expect; and neutrinos with mass would offer a first step outside the Standard Model—the tried-and-tested description of nature's fundamental particles and forces. "The Standard Model, as it stands, doesn't have room for massive neutrinos," says Oxford University physicist Hugh Gallagher, a member of the Soudan 2 experiment in the Soudan iron mine in northern Minnesota, one of the two groups studying atmospheric neutrinos.

Hints of oscillations had already emerged from a previous LSND experiment (*Science*, 10 May 1996, p. 812) and from earlier atmospheric neutrino studies. But the trio of new results may be more compelling. The two atmospheric neutrino experiments offer better statistics and rely on two different detector technologies, and the LSND group has devised new ways to produce and detect their neutrinos. Even so, theorists are scrutinizing the new results very carefully before rushing to rewrite their models. One reason for the skepticism is that the two sets of results seem to deliver different messages about how neutrinos oscillate. "The LSND results are apparently not consistent with atmospheric