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Ida and Dactyl: The Double-Asteroid Debate

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The asteroid Ida and its remarkable moon, Dactyl, have many secrets to tell about what's going on in the asteroid belt.

Ida & Company

By J. Kelly Beatty

AUGUST 1993 was the worst and best of times for NASA's planetary-exploration effort. The abrupt loss of Mars Observer that month, just three days shy of reaching its destination, dealt the space agency its worst blow since the loss of *Challenger.* All-out efforts to save the doomed Mars mission overshadowed Galileo's flyby of the asteroid 243 Ida just one week later.

Only now do planetary scientists fully appreciate everything the spacecraft saw and sensed during its August 28th visit to a second asteroid. Because the main antenna on Galileo remains a useless tangle, results from the encounter took many tedious months to transmit home via a smaller antenna. It was during one of these glacial playbacks, in February 1994, that mission scientists learned Ida was not the solitary interplanetary wanderer they had imagined. It had company: a small, round moon.

The little companion turned up both in camera frames and in scans from the Near-Infrared Mapping Spectrometer (NIMS) during what team members term "jailbar" sequences used to preview data stored on the spacecraft's tape recorder. Imaging-team leader Michael J. S. Belton (NOAO) has little doubt the object is a satellite of Ida, since there is only one chance in 10 million trillion (10^{19}) that something of that size chanced to drift slowly into view precisely when Galileo came calling.

Measuring 1.6 by 1.2 kilometers, the egg-shaped body was initially tagged with the unwieldy designation 1993 (243) 1. Then in September the International Astronomical Union approved the permanent name Dactyl, derived from beings in Greek mythology called Dactyli who lived on Mount Ida in the company of Zeus.

The Galileo data offer some clues to the moonlet's origin. Its roundness has been eyed suspiciously by collision specialists, since small bodies in the solar system are notoriously irregular in shape. Perhaps Dactyl has grown fat on bits of debris kicked off Ida, or it may be all that remains of a larger moon long since smashed apart.

Researchers think the histories of Dactyl and Ida are closely intertwined. Ida itself belongs to the Koronis family, a collection of roughly 150 minor planets with similar orbits that are likely the remains of a larger precursor shattered while colliding with another object. The Koronis members have been a favorite target for asteroid specialist Richard P. Binzel (MIT). After a careful study of their spins and shapes, he has concluded that the family cannot be more than a billion years old — though it could be much younger.

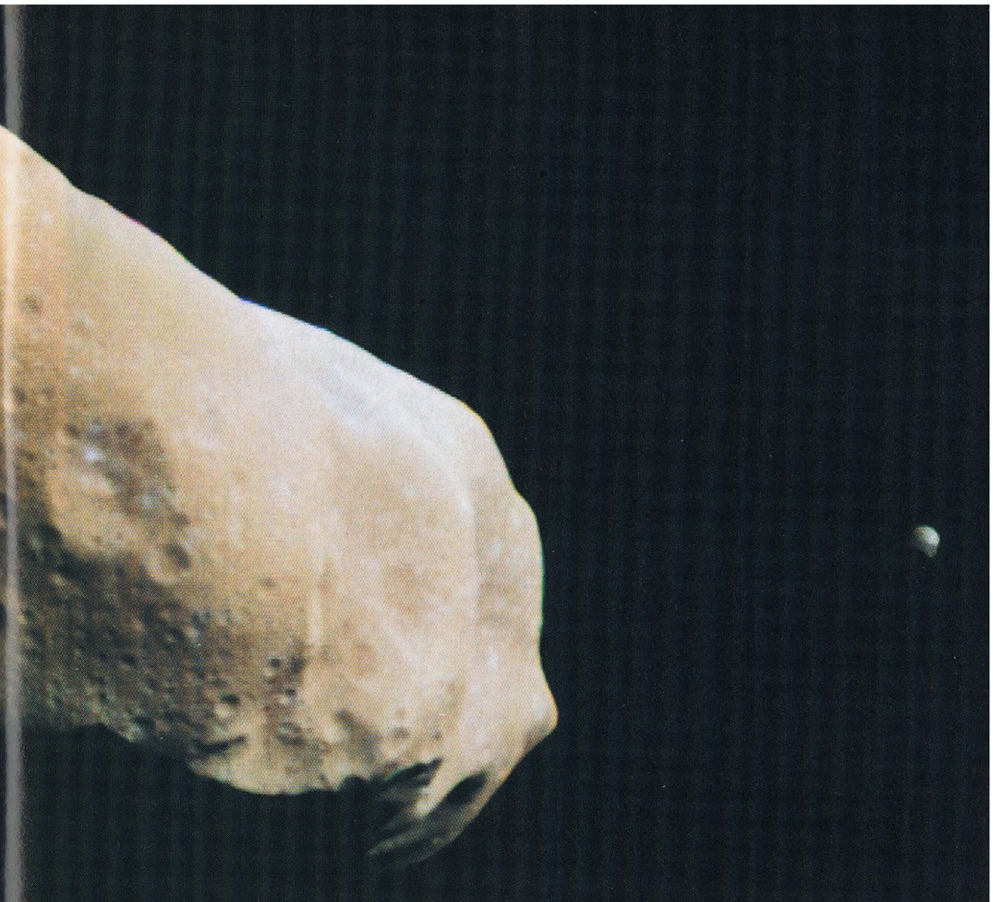
The concept of binary asteroids has been around since early this century. Not until 1979, however, did William K. Hartmann (Planetary Science Institute) suggest that binaries might be a natural consequence of a large asteroid's disruption. Later theoretical and experimental studies have supported Hartmann's idea.

The "B word" has been a touchy subject among planetary scientists since the late 1970s, when a handful of amateur observers reported seeing extra wink-outs during occultations of stars by asteroids (see the box on page 23). Now, with an uncontested double to study, astronomers feel our understanding of asteroids is about to take a quantum leap. In fact, Belton underscores, Dactyl's discovery probably represents "one of the most important results in the past 20 years."

DIVINING AN ORBIT

The Galileo imaging team realized right away that if they could determine the size and period of the little moon's orbit, Kepler's third law of motion would yield the mass of Ida. This value, divided by Ida's volume, would give its overall density — the first clue to composition. Without Dactyl, Ida's density can only be guessed at, since Galileo flew by too fast (12.4 km per second) and too far away (2,400 km) to be affected perceptibly by the asteroid's gravity.

Step one was getting a reliable volume estimate. Based on its light curve, tele-



Months after Galileo's 1993 visit to asteroid 243 Ida, mission engineers received this family portrait of Ida and its newly discovered satellite, Dactyl (right). Taken from a distance of 10,500 kilometers, the false-color view is a composite of images at wavelengths of 4100 (violet), 7560 (infrared), and 9680 (infrared) angstroms. This combination, which accentuates compositional differences, shows that Dactyl does not match any part of Ida's surface seen here. Unless otherwise noted, illustrations with this article were supplied by the Jet Propulsion Laboratory and NASA.

scopic astronomers already knew that Ida rotates in just 4.63 hours and is quite elongated. So Galileo scientists had the spacecraft record 150 snapshots of the craggy, 55-km-long body over a span of 5.7 hours, more than a full rotation's worth. Peter Thomas (Cornell University) and other members of the imaging team then used these views in a painstaking reconstruction of Ida's shape. Thomas feels the resulting volume, 14,100 km^3, is accurate to about 10 percent.

Deducing Dactyl's orbit proved more challenging. Situated about 100 km from Ida and moving in the same retrograde direction as Ida's rotation, the little satellite appears in 47 Galileo images. But the flyby path ended up very nearly in Ida's equatorial plane — a big plus for imaging the asteroid but a handicap for watching the motion of its satellite, whose orbit is inclined only 8½°.

The perspective was so poor, in fact, that a whole range of orbits can fit the observations. At one extreme Dactyl might be just barely within Ida's gravitational grip; its very eccentric orbit would measure roughly 80 by 8,000 km, and Galileo's visit would have coincided with the once-per-year occasion when the two bodies are close together. This scenario requires that Ida have a relatively low mass. At the other extreme, a nearly circular 82-by-95-km orbit implies a third more mass for Ida; in this case, Dactyl completes a revolution every 27 hours. The moonlet's circuit shrinks further as its parent becomes heftier. However, computer simulations done by Jean-Marc Petit (Nice Observatory), Richard Greenberg, and Paul Geissler (both at the University of Arizona) show that still-tighter orbits probably don't work. In most cases they become unstable if the nearest point to Ida's center (periapsis) is under 70 km, and Dactyl either crash-lands or escapes to interplanetary space.

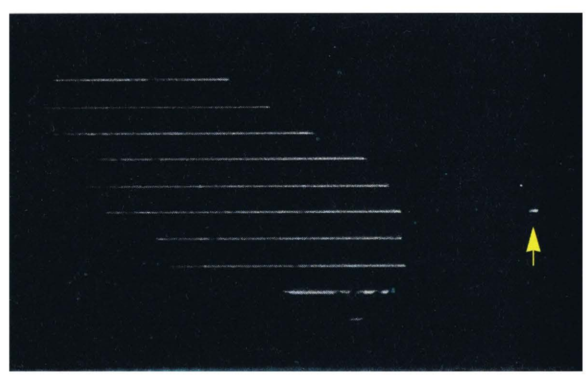
Taken together, these factors dictate that Ida have a density somewhere between 2.2 and 2.9 grams per cubic centimeter (g/cm^3). But there might be some flexibility at the high end. Petit notes that Dactyl almost certainly occupies a resonant orbit whose period is some simple multiple of Ida's spin rate. Stable arrangements probably exist, he says, even if Dactyl's periapsis is under 70 km and Ida's density above 3.0 g/cm^3.

THE S CONUNDRUM

What this density range means in terms of Ida's composition is not completely clear. Because of its slightly reddish color and moderate reflectivity, Ida is classified as an S asteroid, the dominant type in the inner asteroid belt but a breed found less often at Ida's larger heliocentric distance of 2.86 astronomical units (428 million km).

Spectroscopically, S-type asteroids bear some resemblance to the meteorite varieties called ordinary chondrites and stony-irons, both of which contain the silicate minerals pyroxene and olivine as well as iron. Ordinary chondrites are primitive objects that have been altered very little over the eons, while stony-irons were once molten long enough for their minerals to segregate and pool before recrystallizing.

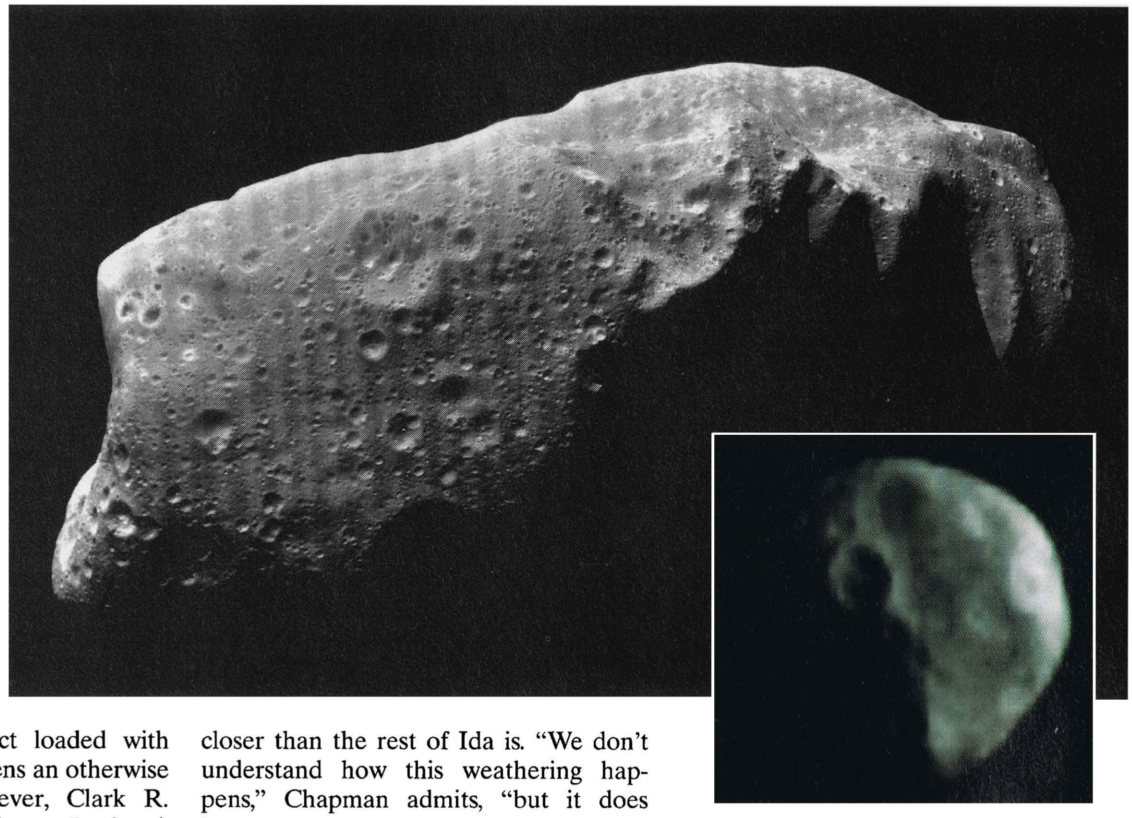
Ordinary chondrites fall to Earth far more often than any other meteorite type, so they should have obvious look-alikes out among the asteroids. The conundrum, as observers discovered in the early 1970s, is that S asteroids are not very good par-



To cope with Galileo's very slow playback rates, mission scientists developed a bit-saving technique that samples stored data and transmits only a few well-spaced lines, dubbed "jailbars," rather than the entire image. The jailbar ploy allowed them to pinpoint Ida's location in this frame — and discover Dactyl (arrow) — when it was relayed to Earth last February 16th.

ent candidates for ordinary chondrites after all. Their colors are too red and their infrared absorptions due to olivine and pyroxene too weak. In fact, to date only one small main-belt asteroid has been found that could be called a close match (*S&T*: November 1993, page 11).

The overall color of Ida most nearly



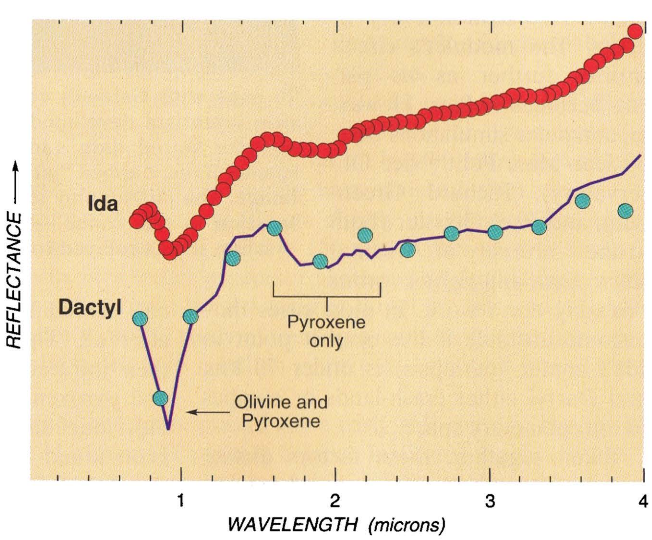
A mosaic of five images shows an exquisitely detailed hemisphere of 55-km-long Ida. The smallest discernible features include hundreds of craters, dozens of huge boulders 30 to 150 meters across, and numerous grooves. Craters cover this half of Ida so completely that impact geologists believe the present surface could be at least a billion years old.

***Inset:* Measuring only 1.6 by 1.2 km, egg-shaped Dactyl still sports dozens of impact craters. The largest, seen astride the terminator, is 300 meters across.**

mimics that of an object loaded with metallic iron (which reddens an otherwise neutral spectrum). However, Clark R. Chapman (Planetary Science Institute) insists that Ida cannot be an overgrown stony-iron meteorite because the latter typically have densities of 5 g/cm^3 or more. Even if Ida were a pile of iron-rich rubble, with empty cavities occupying a third of its interior, the resulting density would still fall outside the range established by Galileo's imaging team.

Instead, Ida may be a huge ordinary chondrite in disguise. Chapman has long contended that some kind of "space weathering" has altered the surfaces of S-type asteroids, and now he may have proof. A few areas of Ida, sometimes near fresh craters, are less red and have stronger absorptions than elsewhere. Spectrally these locations still don't quite match ordinary chondrites, but they're closer than the rest of Ida is. "We don't understand how this weathering happens," Chapman admits, "but it does happen."

The rush to embrace Ida as some kind of ordinary-chondrite derivative bears on the findings of Galileo's magnetometer. Team leader Margaret G. Kivelson (University of California, Los Angeles) reports that as the spacecraft passed Ida it sensed a shift in the direction of the interplanetary magnetic field. Galileo observed a similar field rotation while flying past asteroid 951 Gaspra in 1991, and the team later concluded that Gaspra was probably magnetized (*S&T:* July 1993, page 11). "The situation with Ida is more complex," cautions Kivelson and UCLA colleagues Zhi Wang and Raymond J. Walker. Although other explanations are possible, they still think the asteroid is somehow responsible for the solar-wind disturbance their detector recorded. In that case, Kivelson notes, its interior at least needs to have high electrical conductivity, even if it lacks substantial chunks of nickel-iron metal.



NIMS spectra of Ida and its moon show a distinct absorption near 1 micron, which implies that the iron-rich silicates olivine and pyroxene are abundant on both surfaces. However, Dactyl's spectrum is subtly different, with a deeper and broader absorption near 2 microns. (For Dactyl, filled circles show a "quick-look" spectrum; the line is the average of two higher-resolution observations.) Courtesy R. Carlson and the NIMS team.

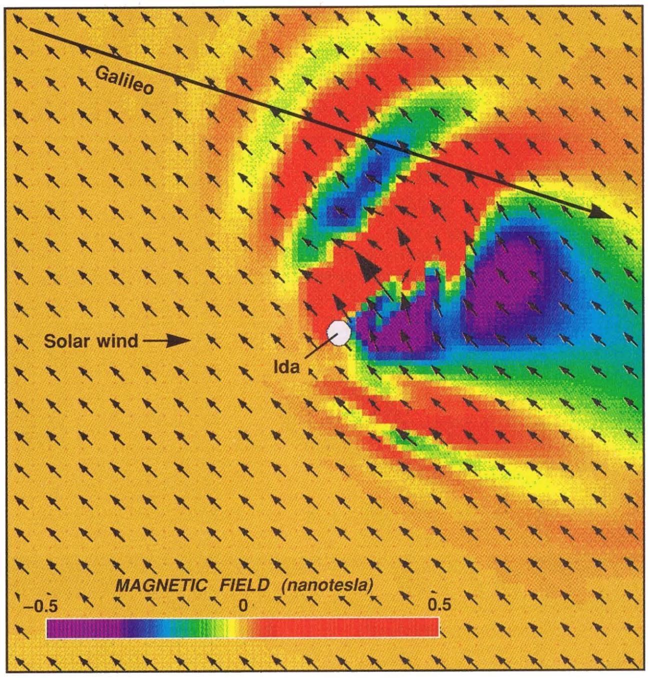
Meanwhile, Dactyl has a spectrum that has no exact complement on Ida, though the differences are subtle. "If you had a hand-size sample of each," observes Torrence V. Johnson (JPL), Galileo's project scientist, "even an expert would have trouble telling them apart." The mineralogical evidence, says NIMS team leader Robert W. Carlson (JPL), suggests that Dactyl is not a chip off Ida but rather its sibling.

All this spectral rumination provides yet another thread linking both bodies to the breakup of a larger object long ago. Binzel has found that members of the Koronis family exhibit subtle color differences not unlike those seen on Ida and Dactyl. These might be due to slightly different compositions, varied exposures to the mysterious weathering process, or both.

DATING DACTYL

The story of Ida and Dactyl has a messy complication. Both objects are so heavily peppered with craters that they look to be at least a billion years old. This ancient terrain is at odds with dynamical evidence from Binzel and others that the Koronis family is young. Moreover, calculations suggest that objects the size of Dactyl last no longer than 100 million

As Galileo raced past Ida at a distance of 2,400 km, its magnetometer detected a twist in the direction of the interplanetary magnetic field (IMF), most likely caused by the solar wind interacting with Ida. This computer model shows the flyby geometry (not to scale). Black arrows indicate the IMF's direction in the plane of the diagram; colors show the field's direction out of (red) and into (blues, yellows) the page. Courtesy Margaret Kivelson, Zhi Wang, and Raymond J. Walker.



years or so before being blasted to smithereens. To survive so much longer would seem out of the question. Something seems amiss.

The answer may lie in deducing what happens when an asteroid family forms. "Just because you see lots of craters," admonishes Binzel, "you shouldn't automatically assume it's old." Perhaps the new Koronis offspring endured a hail of impacts as they flew apart. Or the family members may have showered one another with debris before their orbits became well separated. Or Dactyl may indeed have been smashed to bits sometime in the past.

"We have got to start over from scratch," agrees Chapman. Fortunately, Galileo's reconnoitering of Ida, Dactyl, and Gaspra has given researchers much to work with. And besides, Belton reflects, "God doesn't tell you everything all at once."

The Binary Brouhaha

WHEN WORD first trickled out that a small moon had been found circling Ida, David Dunham felt relief and vindication. Widely known as the heart and soul of the International Occultation Timing Association, Dunham has argued for years that amateur astronomers had already detected satellites around asteroids.

As evidence Dunham cites, for example, the 1977 occultation of Gamma Ceti A by 6 Hebe. Although he was apparently well outside the occultation track, Texas amateur and veteran observer Paul Maley still saw the 3rd-magnitude star disappear for about a half second. Or there's the case of Gerald Ratley and Bill Cooke, who independently witnessed a secondary dropout during an occultation by 216 Kleopatra in October 1980.

Dunham's most persuasive event involved 532 Herculina, which passed in front of a 6th-magnitude star on June 7, 1978. James McMahon, responding to a last-minute call for observers, set up near Boron, California, and saw the occultation as predicted. But he also noted another disappearance, lasting 5 seconds, about 90 seconds before the main event. And 550 kilometers to the east, Lowell Observatory astronomers Edward Bowell and Michael A'Hearn saw it too.

However, to this day Bowell and A'Hearn remain iffy about the implications of their observation, much to Dunham's consternation. Herculina's putative companion, with an estimated diameter of 50 km, failed to materialize when examined later by speckle interferometry and even the Hubble Space Telescope. In fact, no telescopic search for asteroidal binaries has ever turned one up.

On the other hand, roughly one in seven large impacts on Earth involves a double crater. Side-by-side blasts are seen as well on the Moon, Mars, and Venus. Small asteroids pinged by radar as they zip past Earth sometimes show multiple lobes that may once have orbited one another. And now there's the Ida-Dactyl duo.

Astronomer Tom Van Flandern (Meta Research), an outspoken proponent in the binary debate, says, "Those with a good sense of the laws of probability must realize that finding a moon of an asteroid during only the second spacecraft encounter with one implies that these minor satellites are at least not rare." But Brian Marsden (Minor Planet Bureau) counters that the occultation record is not enough. "I don't want to be close-minded about this, but their data aren't convincing."

Still, the discovery of Dactyl has renewed Dunham's enthusiasm and won his case another hearing from the community's cautious onlookers. Dactyl's existence will cause many people to be less skeptical, observes Clark Chapman (Planetary Science Institute), "but any good scientist needs to have confirmation."

J. K. B.

Does asteroid 532 Herculina have a satellite? You be the judge. On June 7, 1978, Herculina occulted a 6th-magnitude star, and astronomers at Lowell Observatory saw the star wink out for 23½ seconds, as their photoelectric record (*right*) clearly shows. However, they also recorded a brief dropout 90 seconds earlier (*left*) — was this second event due to an unseen satellite or to some other cause?