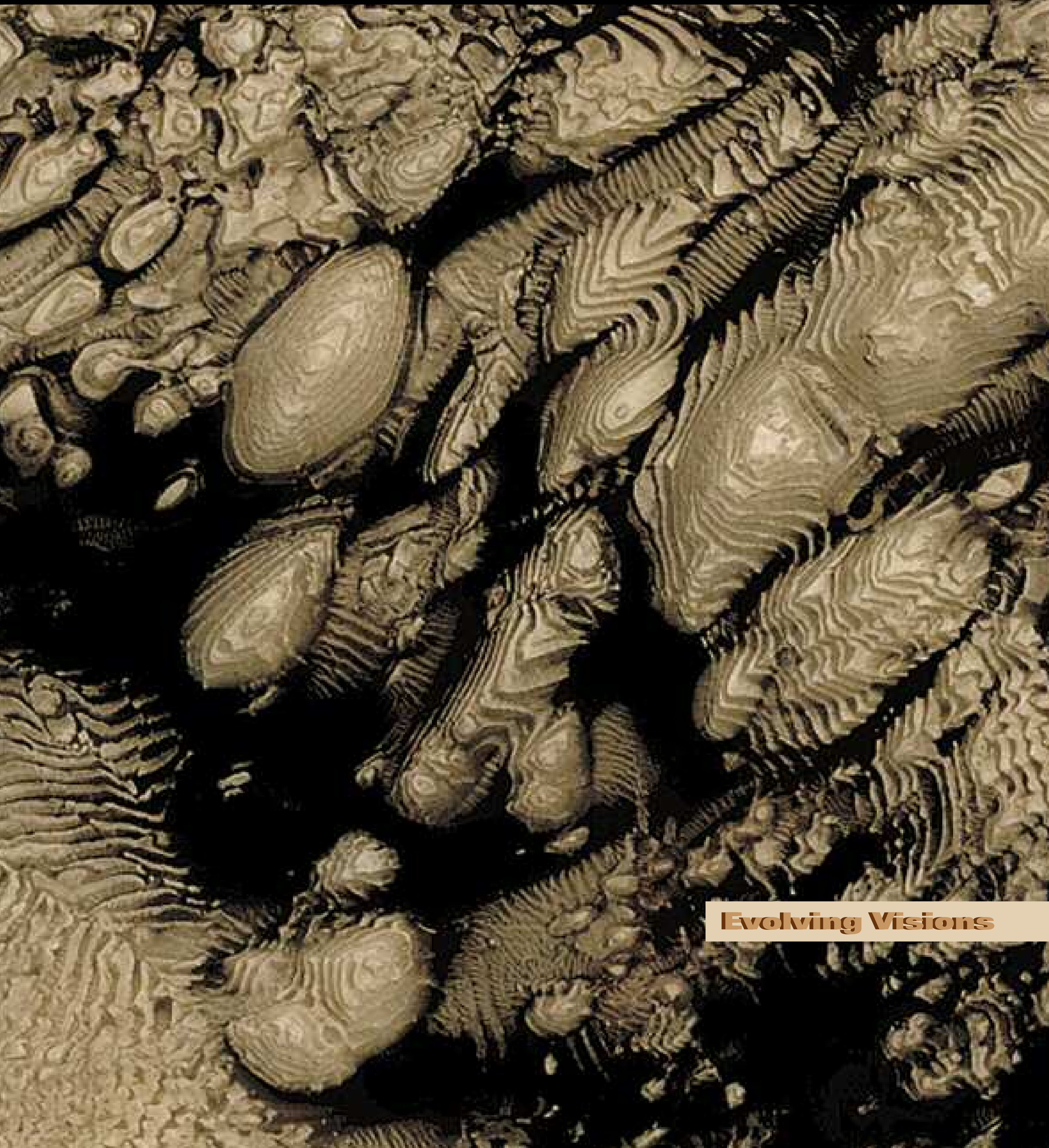
The PLANETARY REPORT

Volume XXI Number 1 January/February 2001



Evolving Visions

On the Cover:

The plucky *Mars Global Surveyor*'s Mars Orbiter Camera (MOC) zoomed in to get a closer look at erosion processes exposing hundreds of layers of similar thickness, texture, and pattern in an impact crater 64 kilometers (40 miles) wide in western Arabia Terra. In this MOC image, dark, windblown sand enhances the appearance of the layers. These layers provide a record of repeated, episodic changes that took place sometime in the Martian past. Layers toward the center of the crater are nearly horizontal, but those closer to or draping over the crater walls are tilted toward the basin center. Such relationships suggest the sediments creating these layers were deposited from above—perhaps settling out of the Martian atmosphere or else out of water that might have occupied the crater as a lake. Image: NASA/JPL/MSSS

From The Editor

Mars has definitely been the planet in the news these past two months, and two events have triggered larger-than-normal reverberations in the Society.

First, on November 22, Gerald Soffen died. He served as project scientist on the epic *Viking* missions to Mars in the late 1970s, and to those of us who remember back that far, Gerry was someone who commanded both respect and affection. In recent years he had undertaken the possibly even more monumental task of nurturing the future generation of space scientists. Through his work with the NASA Academy, he brought young people into Society projects, most memorably at our Planetfest '97. We will miss him greatly.

Then, on December 4, while we were wrapping up this issue, Mike Malin and Ken Edgett announced their latest news-making discovery—this time of sedimentary layers on the Martian surface. While we had no time to prepare a major feature, we were able to insert a few images into our *Mars Express* feature.

As you might remember from last issue, we announced the winners of the Red Rover Goes to Mars Student Scientist Team. Now these nine young people are on their way to work with Mike and Ken to select a landing site for some future Mars mission.

So the symmetry is fixed: one Mars scientist and educator leaves us, and the current generation passes the torch to the next. We at the Society are grateful to have played a role in making that happen.

—Charlene M. Anderson

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Members' Dialogue

Don't Mess With Mars

My wife and I are disappointed with Chris McKay's essay ["A Flower for Mars" in the September/October 2000 issue of *The Planetary Report*]. Flowers for Mars? What is the point? To prove that life can set a foothold on Mars? Life may already be there. We should not be messing around with something as grand, and as delicate, as life. The history of human colonization, invasions, conquests, and introduction and relocation of plant and animal species (not to mention smaller life-forms) on Earth should serve as a warning, not a blueprint.

NASA and other organizations should rethink their strategy for Mars. Instead of sending surface-probing rovers and robots, we should send orbiting probes that can detect, without intrusion, the telltale emissions produced by life as we know it, rather than risk further bio-contamination of a hypothetical Martian biosphere with surface instruments sent from Earth.
—DAVID MORA MARIN,
Albany, New York

Even if a biosphere could be established on the surface of Mars, maintaining and controlling it would be difficult and prohibitively expensive. Complex matters like climate and ecology are notoriously intractable on Earth, so why should Mars be expected to behave in an orderly fashion? Besides, Earth's biosystems are not superficial, nor are they separable from energetic processes active within the planet. What is to sustain a living Mars other than constant, vast inputs of energy and cash?

The case for terraforming is usually predicated on the mid-20th-century sci-fi notion of colonizing alien planets. It is far cheaper, however, to develop living space in orbit than at the bottom of another gravity well, albeit a smaller one than Earth's.

By the time we are able to actually walk on Mars, there will be so much to investigate and so much fundamental knowledge to be gained that to suggest changing conditions there rings like a call to "improve" Antarctica. Already our view of our own planet and what makes a living world is very different from when terraforming was first conceived.

If indigenous Martian life is discovered, it would be doubly misguided to contemplate wrecking an extant world to fulfill an outmoded dream.
—ROB NORMAN,
Edinburgh, Scotland

Patience and Perseverance

On reading "From the Editor" in the November/December 2000 issue, I am reminded of how small I felt when Carl Sagan first described the great distances of space and time in his *Cosmos* series. Is it not fitting that we step back a bit and allow the overwhelming sense of our own insignificance to guide our conception of a timetable for our exploration of the universe?

Perhaps we have imbued our voyage of discovery with a sense of urgency that does not necessarily exist in nature. A task such as this, an undertaking of such great historical significance, perhaps equaled only by unlocking the secrets of the atom or unraveling the human genome, may not be able to satisfy our intellectual appetites as soon as we would like. In fact, it may take generations just to make a cursory exploration of our very own solar system.

Our preoccupation with finding life may be more a reflection of our uncertainties over the question of spirituality than a desire to acquire evidence of the beginnings of carbon-based life. Whether planetary reconnaissance or the elusive search for life, need we prioritize them? I say not; for whatever our purpose, we need only make the supreme effort to persevere. Time and, ultimately, our resources will determine the direction of the journey.
—KENNETH D. LEVY,
Scottsdale, Arizona

Whether we should be exploring Pluto and the Kuiper belt at this juncture or at any other time is perhaps less of an issue than the fickle management of what precious funds are available. The propensity for Congress and/or NASA to start, then cancel or fail to fund programs already under way is irresponsible and wasteful. A greater scientific payoff could be realized through more consistent long-term planning and perseverance.

Value is realized by seeing projects through to completion and by continuing to fund missions that, while outliving their planned life span, are still providing us significant benefits. Canceling projects in which a significant investment has already been made squanders resources. Publicly funded research programs can ill-afford mood swings.
—IAN MERRITT,
Woodland Hills, California

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SYSTEMS ENGINEERING— A Personal Memoir

BY JAMES D. BURKE

Twittering Machine (Zwitscher Maschine), ***Paul Klee, 1922***
Reprinted by permission from The Museum of Modern Art, New York

"If you have to ask what jazz is, you'll never know." If, as believed, Louis Armstrong said these words, he spoke wisely about an art whose whole is greater than the sum of its parts. The same is true of systems engineering, the art that has enabled our robotic exploration of the Moon and planets.

After five decades of working in this flourishing area of the engineering landscape on Jet Propulsion Laboratory (JPL) missions, I have yet to come up with my own satisfying definition of just what we systems people do. Perhaps that is because we seldom do the same thing twice. In assembling each new set of disparate subsystems, we strive for harmonious combinations that will function reliably in the presence of competing criteria and constraints.

As a sideline to my work at JPL, on generously granted leaves of absence, I participated in the development of two human-powered aircraft, the *Gossamer Condor* and *Gossamer Albatross*. Meeting tough goals and overcoming strict limits on time and funding to accomplish this feat brought world renown to innovative project leader Paul MacCready, to pilot Bryan Allen, and to the rest of us on the small and devoted team who won the Kremer Prizes.

Though unique in many ways, this project resembled much bigger ones in its dependence on some primary principles of systems engineering: careful analysis, appropriate documentation, smart compromises among competing constraints, and above all a sense of likely pathways to solutions. Add to these a major cause of its success: the objectives, clearly defined at the outset, did not change.

In space programs and other large, complicated efforts such as building worldwide communications networks, setting and maintaining requirements and standards is itself a task for systems engineering. Given a goal—travel to a planet; land on it; make such-and-such measurements; send the data; receive, file, and distribute the data on Earth—requirements flow downward in a hierarchy from system to subsystems. But there is also an upward stream generated either by the arrival of new subsystem technolo-

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Views expressed in this article are those of the author and do not necessarily represent those of The Planetary Society.

gies or by events such as (usually bad) political or budget news. Keeping everything in harmony under changing external constraints is a task shared by systems engineering and project management. The result: mountains of documents and the growth of an entire profession using computers and software tools to track and maintain requirements. The potential for failure lurks everywhere—not just in-flight failure but failure even to get off the ground, as may happen when a planned project doesn't pass a critical review or a planned launch opportunity is lost. Faster, better, and cheaper projects are indeed possible (see box), but balancing performance and risk is a subtle challenge.

Progress in systems engineering is evident in the way spacecraft are assembled and tested before being sent to the launch site. Previously, subsystem faults would be identified and corrected in their home organizations before hardware delivery, but then inter-subsystem troubles would crop up in the spacecraft assembly facility: misplaced bolt holes, cable connectors wired incorrectly, power supplies sending the wrong voltages to users.

Over the years, most of these problems were reduced through rigorous system documentation and change control. Then a powerful new source of capability—but also of trouble—emerged, namely, software. With the advent of computers and networks both in the spacecraft and in ground tracking and data systems, it became much more difficult to visualize, document, and demonstrate every failure possibility. At the same time, it became possible to build in fault protection. Recent missions have been lost due to failure to understand all the software modes affecting the spacecraft, but other missions have been saved by in-flight reconfiguring with the aid of onboard software.

Prelaunch design and testing now involve more stages: when only parts of the system are ready, those hardware items can be placed in a system test bed and operated with computer mockups of the missing subsystems. Even earlier in the design process, analysts operating a roomful of computers can create virtual subsystems and make instant trade-offs among them, for example, adjusting one subsystem's power demand to the needs of others. Sometimes called *concurrent engineering*, this practice is spreading among space organizations. Yet even with all these aids, deep-space systems engineering depends ultimately on human judgment—the ability to balance risks.

Not to have telemetry during descent of the *Mars Polar Lander* was a systems engineering and management decision. In retrospect it was wrong. Despite the identification of a possible landing-subsystem fault, whichever subsystem, or combination of subsystems, actually failed will not be known until some robot or human visits the crash site, and maybe not even then. Now at JPL we have reverted to an old policy. We have telemetry from our planetary spacecraft whenever it is physically possible.

Recently, a systems design fault has been discovered in the *Cassini* spacecraft en route to Saturn. When the *Huygens* probe separates from the *Cassini* orbiter and descends into Titan's atmosphere in 2004, *Cassini*'s radio relay receivers may have difficulty maintaining lock with the probe's uplink. This is because of the Doppler shift in frequency due to the relative motions of the orbiter and probe. Solutions are being worked out—possible only because *Cassini*'s system is capable of being reconfigured in flight. The problem itself was found only because of rigorous and skeptical systems analysis plus continuing ground testing.

Can systems engineering be taught? Yes, it is a popular course at the International Space University. The Profession is recognized worldwide via its journal, *Systems Engineering*. Tools and methods are rapidly advancing, but even in very complex systems it is sometimes still possible to discern the hand of a master who knows from the outset what is likely to look good and work well, reliably doing what is intended and no more, while meeting constraints on people, technology, time, and money.

On my recent retirement from JPL, I realized that one of my happiest memories is being a member of a family of devoted systems people who seek harmony, deal with changing limits, accept risk, power on past failures, bring us new knowledge of the cosmos, and make the whole thing seem as exquisite as jazz.

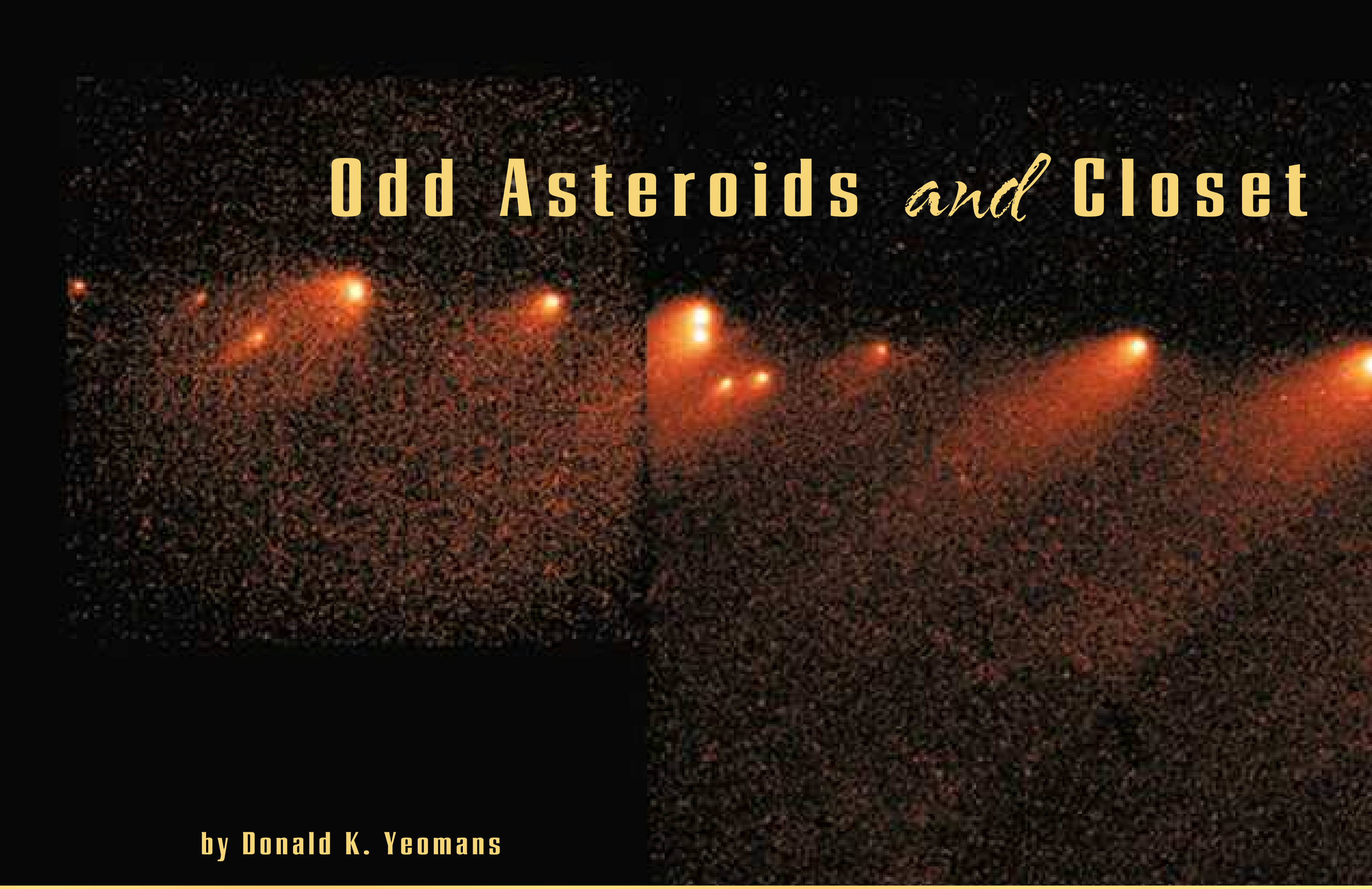
James D. Burke is Technical Editor of The Planetary Report.

There's no such thing as a free launch, but lower cost is possible.

Changes in system requirements are often driven by bad news. However, they can also result from new opportunities. A good example is the recent discovery that lunar and interplanetary trajectories can start from a geosynchronous transfer orbit (GTO). This opens the possibility that small deep-space craft, carried at low cost as auxiliary payloads, may piggyback on the big rockets used to send large commercial communications satellites on their way to geostationary equatorial orbit (GEO).

The trick depends on being able to wait in GTO (an eccentric orbit whose apogee is at the GEO altitude of 35,786 kilometers, or 22,282 miles), perhaps for many months, until Earth's motion around the Sun brings the axis of the GTO in line with a departure path to the Moon or a target planet. Of course, the deep-space craft must be small enough to ride piggyback, and the cost of monitoring and controlling it during the wait must be balanced against the lower price of the launch—a typical systems engineering problem. As microspacecraft technology advances, we are seeing more and more use of auxiliary payload opportunities for Earth-orbit missions. Deep-space missions (smaller, better, and cheaper but perhaps not faster because of the wait) may soon follow.
—*JDB*

Odd Asteroids *and* Closet



by Donald K. Yeomans

Scientists have a strong urge to place Mother Nature's objects neatly into boxes. For most of the past half-century, the comets and asteroids of our solar system did seem to represent two distinct populations—each belonging to its own separate box.

Comets, with their wide range of orbits, were defined as solid, dirty ice balls originating in the Oort cloud at the edge of the solar system. Asteroids, meanwhile, were bits of rock confined mostly to a region between Mars and Jupiter and traveling roughly in the same plane and in the same direction as the planets about the Sun. From time to time over the past 50 years, astronomers found objects that did not really fit either definition. These objects they considered occasional exceptions to the rule.

Within the past few years, however, Mother Nature has kicked over the boxes labeled respectively *comets* and *asteroids*, forever mixing their contents. Consequently scientists are having to recognize crossover objects—asteroids that behave as comets and comets that behave as asteroids. As a result, the line between comets and asteroids is no longer clearly drawn.

Crossover Objects

The modern model for the nucleus of a comet was introduced in 1950 to 1951 by Fred Whipple. Whipple's "dirty ice ball" model proposed a solid nucleus a few kilometers across made up of various ices (frozen water, methane, ammonia, carbon dioxide, and hydrogen cyanide) embedded with dust.

This model can explain the impressive dust tails we associate with comets passing the Sun. As the comet approaches the Sun, the ices vaporize, liberating the embedded dust particles. These particles get blasted away by solar radiation pressure, often forming impressive, gently curved dust tails.

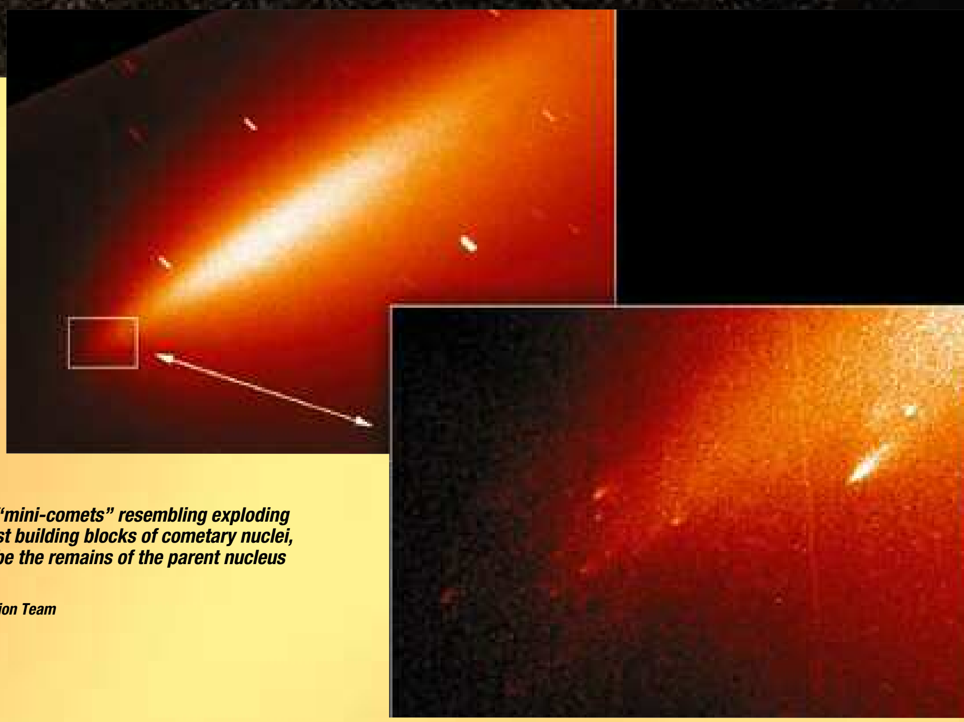
As the comet ages, dust is strewn all around a comet's orbit. When the Earth intersects this stream of cometary debris, a meteor shower (or storm) results. Almost every well-observed meteor shower is associated with a known comet.

Whipple's was a neat, easily understood picture of the cometary aging process. Yet Whipple himself pointed out in 1983 that the orbit of the Geminid meteor stream closely resembles that of an asteroid (3200 Phaethon). Asteroid 3200 Phaethon follows a rather eccentric, cometlike orbit. In fact this asteroid and a handful of others with associated meteor streams are probably defunct comets that have lost the ability to emit gas and dust.

A few years earlier, in 1977, C. T. Kowal discovered the asteroid Chiron in an orbit taking it from just inside the orbit of Saturn to just inside the orbit of Uranus. We now know several dozen of these so-called Centaurs, asteroids whose orbits lie in the outer planetary system.

Although initially labeled an asteroid, by early 1988 when approaching its minimum distance from the Sun (its perihelion), Chiron began to act in a decidedly nonasteroidal and more cometlike manner. First it became abnormally bright. Then in 1989 it developed a dust atmosphere and, by January 1990, cyanogen gas emission was detected spectroscopically.

Comets: *The* Distinction Blurs



***Above:** Fragments flew when at least 21 pieces of an object designated as comet Shoemaker-Levy 9 (named after discoverers Eugene and Carolyn Shoemaker and David Levy) collided with Jupiter from July 16 through July 22, 1994. Hubble captured this image in January 1994—just months before the fragments plunged into the gas giant. Twenty nuclei are visible in the image, with one just slightly outside the field of view (right). Each nucleus has its own coma and tail. The fourth nucleus from the left (the first bright one) appears to be separating into at least two pieces. The width of the image covers approximately 605,000 kilometers (376,000 miles).*

Image: Harold Weaver and T. Ed Smith (STScI)/NASA

***Right:** The fiery fragments shown in close-up (lower right) are key to understanding what happened to comet LINEAR's nucleus after the body broke apart on its closest approach to the Sun in July 2000. Hubble's Wide Field Planetary Camera 2 captured this image showing LINEAR's nucleus wasn't actually "missing" but was instead reduced to a shower of "mini-comets" resembling exploding aerial fireworks. This image offers astronomers their first view of the smallest building blocks of cometary nuclei, called* cometesimals. *The fragment farthest to the left, now very faint, may be the remains of the parent nucleus that shattered into the cluster of smaller fragments to the right.*

Image: NASA, Harold Weaver (Johns Hopkins University), and the HST Comet LINEAR Investigation Team

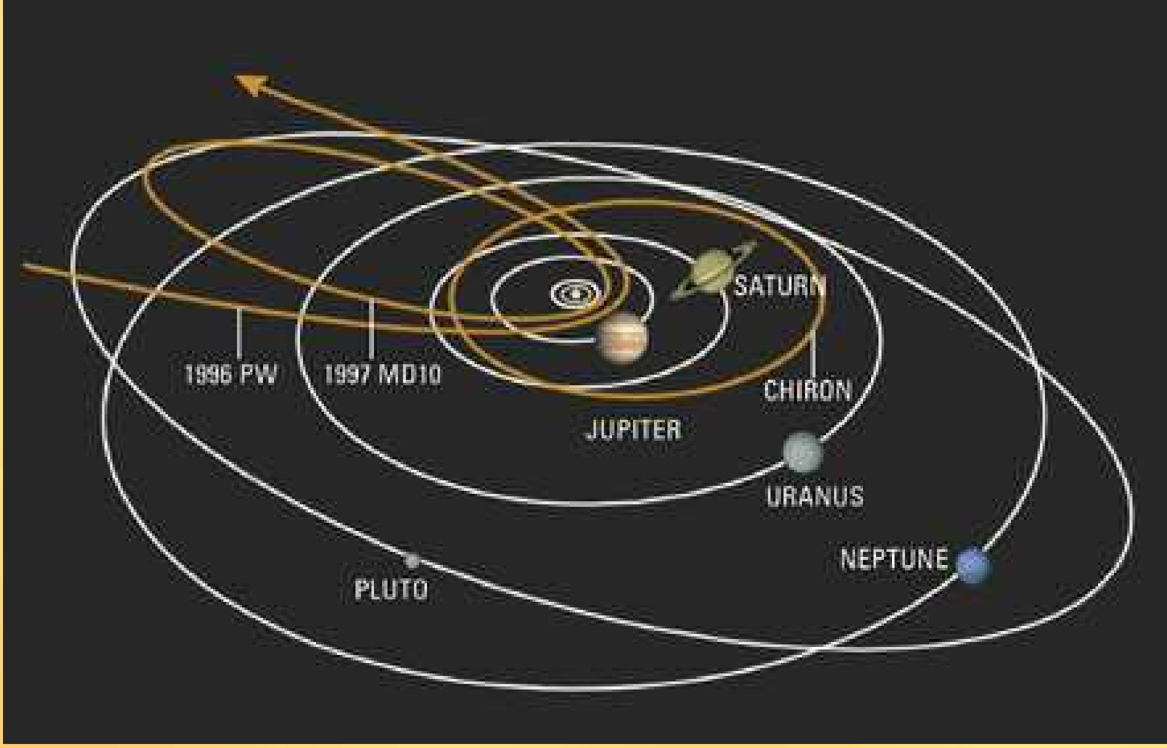
Chiron was the first object to receive a double designation as both an asteroid and a comet. It is now known as the 95th periodic comet (95P) and the 2,060th numbered asteroid (2060). So we have 95P/Chiron = (2060) Chiron.

To date, three objects have officially received dual designation. The second, asteroid 1979 VA, was discovered in 1979 in an eccentric, cometlike orbit. Indeed, a look back through old Palomar Sky Survey plates showed that the orbit predicted for this asteroid was identical to that of a comet discovered by Albert Wilson and Robert Harrington in 1949. Because asteroid 1979 VA had evidently been a comet 30 years earlier, it has become known as 107P/Wilson-Harrington = (4015) Wilson-Harrington.

The third object given a dual designation is 133P/Elst-Pizarro = (7968) Elst-Pizarro. Although its orbit resembles that of a main-belt asteroid circling the Sun between the

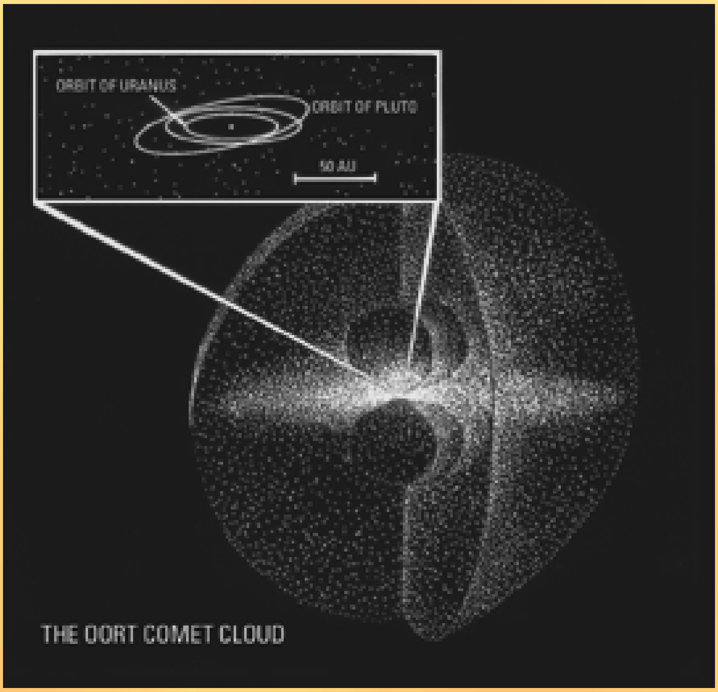
Right: Sometimes asteroids behave more as comets. The orbits of some of these bodies take them outside the main asteroid belt and into the outer solar system. Like a comet, Chiron—which runs its course in 50 years—has been observed emitting gas and dust. Other asteroids, such as 1997 MD10 (with a 140-year orbital period) and 1996 PW (with a 5,900-year orbital period), display eccentric, cometlike orbits.

Illustration: Reprinted by permission from Nature *(404:829–832), © 2000 Macmillan Magazines Ltd.*



Below: In 1950, Jan Oort published a paper deducing that a vast sphere of comets—stretching over one thousand times as far as the distance from the Sun to Pluto—encompasses our solar system. The Oort cloud, as it's now known, likely contains more than a trillion icy comets, and perhaps a small percentage of asteroids, ejected as the giant planets formed 4.6 billion years ago.

Illustration: Courtesy of Donald K. Yeomans



orbits of Mars and Jupiter, it temporarily displayed a cometlike dust tail in 1996.

Crossed Paths

In the 1950s Jan Oort argued that comets with long orbital periods (millions of years) spend most of their time in a vast spherical cloud surrounding the planetary system. While there is no direct observational evidence for this so-called Oort cloud, it is thought to extend out to about 100,000 times the Earth's distance from the Sun, or 100,000 astronomical units.

Later work by Gerard Kuiper and others on the origin of long-period comets established that they formed in the outer planetary region from bits and pieces remaining from the emergence of the outer solar system. Once formed, many of these comets suffered close gravitational encounters with the major planets and have been propelled either out of the solar system entirely or into the distant Oort cloud.

On reaching the Oort cloud, some bodies are thrown back into the planetary system by the gravitational perturbations of individual passing stars, the galactic disk of stars, or giant molecular clouds of gas and dust. Emerging from the roughly spherical Oort cloud, these long-period comets enter the inner solar system with orbits either random prograde (same direction as the planets) or retrograde (opposite direction to planets).

By contrast, short-period comets (periods less than 200 years) have come under the gravitational influence of Jupiter, and they usually orbit closer to the main plane of the solar system in a prograde direction.

Granted, most of the objects in the Oort cloud are probably comets that formed in the outer solar system. However, up to 3 percent of the current population could be asteroids that formed just inside Jupiter's orbit and were then pushed out, by way of gravitational interactions with Jupiter, to the solar system's very edge.

The peculiar asteroid 1996 PW could be one of these objects. It shows no cometlike activity and yet has a very eccentric orbit plus an orbital period of about 5,900 years. This indicates it evolved back into the inner solar system from the Oort cloud.

Several other asteroidal objects travel highly eccentric orbits—once considered the hallmark of comets. These include 3200 Phaethon with an orbital period of 1.4 years, 1997 MD10 with an orbital period of 140 years, and 1999 LE31 and 1999 LD31 with orbital periods of 23 and 120 years respectively. The latter two objects are the first in the solar system designated as asteroids with retrograde orbits.

As mentioned earlier, object Elst-Pizarro has been given a dual comet and asteroid designation because it has shown cometary activity despite its nearly circular orbit—similar to the orbits of asteroids in the main belt between Mars and Jupiter.

So we now have comets in asteroidlike orbits and asteroids in cometlike orbits. Because both comets and asteroids can evolve from the Oort cloud into highly inclined, even retrograde, orbits about the Sun, orbital behavior is not necessarily a better criterion than physical behavior for telling them apart. Efforts to sort comets and asteroids into separate boxes have clearly failed, and astronomers should now consider these objects as members of a highly diverse family: the small bodies of the solar system.

Comets in Transition

The blurring of the boundary between comets and asteroids forces us to reassess our knowledge of their nature and origin. For example, if all comets were solid, dirty balls of water ice, their bulk densities would average 1 gram per cubic centimeter—that is, the standard measure for the density of water. But it seems some comets have rather crumbly, low-density structures composed of several bits held together by little more than their own self-gravity.

This conclusion follows from our observation of comets breaking up because of either the Sun's or Jupiter's tidal forces. Most dramatic was the disintegration of comet Shoemaker-Levy 9 into nearly two dozen fragments when it passed close to Jupiter in July 1992. This occurred before the comet crashed into the surface of the giant planet two years later.

Some contemporary press accounts reported that "the mighty tidal forces of Jupiter tore the comet to pieces," but the reality was less impressive. The tidal acceleration on the comet was no more than a wimpy 3 millimeters (0.12 inch) per second, squared. In fact, a piece of comet Shoemaker-Levy 9 held in your hand would have easily broken apart with only modest pressure.

A comet made up of discrete chunks and held together by little more than self-gravity is best described by the "rubble pile" model. A rubble pile has almost no internal strength, very high porosity, and correspondingly low bulk density. This model could explain how a comet like Shoemaker-Levy 9 shatters under very modest external forces. It could also explain why some comets, such as the recent LINEAR (1999 S4), can break apart before disintegrating completely into a stream of meteoric particles with no remaining nucleus.

Possibly the most fragile comets are created by millions of years of mutual collisions in the outer planetary system. The nuclei are first broken apart and subsequently re-accrete as loosely bound rubble piles. Or, near the end of their active lifetimes, comets may lose the ices that bind together their separate pieces.

Existing comets that have already gone from active to quiescent (for example, Wilson-Harrington) offer evidence that some comets do in fact become defunct and join the ranks of the asteroids. Comet Encke, with its stable orbit within the orbit of Jupiter, is generally considered an active comet in transition to an asteroidal object. Low-density extinct comets probably make up a significant fraction of the near-Earth asteroid population. We therefore cannot assume all objects that threaten Earth will have the same composition or structure.

Down to Earth

Astronomers have classified asteroids according to the light reflected from their surfaces—their optical spectra. Although no two spectra are exactly alike, most asteroids fall into one of two groups, the C-type or the S-type.

The darker C-type asteroids have low reflectance (albedo) and may contain mixtures of hydrated silicates, carbon, and organic compounds. S-type asteroids have higher albedos and can contain pyroxene (silicates containing magnesium, iron, and calcium), olivine (magnesium and iron silicates), and nickel-iron metal. The less common M-type asteroids contain mixtures of nickel-iron metal and magnesium or iron silicates.

C-type asteroids are most common in the outer part of the main asteroid belt between the orbits of Mars and Jupiter. S-type asteroids, however, are mostly found in the inner asteroid belt.

C-type asteroids are apparently the most primitive type because they fail to show chemical differentiation. Contrastingly, some S-type asteroids show evidence of the heating that separated them into different layers of material (similar to the Earth's separation into a core, mantle, and crust). The metals found in a number of S- and M-type asteroids can be explained by melting processes similar to those observed in volcanic rocks on Earth.

Asteroid collision fragments that have fallen to Earth are known as meteorites. By definition, then, meteorites may hold clues regarding the early history of asteroids. Because most asteroid fragments are rocky, they can survive the passage through Earth's atmosphere. By contrast, debris from comet streams nearly always burns up in the atmosphere, sometimes

Determining Bulk Density

Short of landing on an asteroid and drilling down below the surface, it's very difficult to probe its interior structure. However, we can determine the asteroid's bulk density by dividing its mass by its volume. We get the mass by observing the asteroid's gravitational perturbation on a neighboring spacecraft and, using images of the asteroid, we can develop a shape model and hence estimate its volume. For example, by monitoring the slight tug on the *NEAR Shoemaker* spacecraft as it flew past asteroid Mathilde in June 1997, we determined the asteroid's mass and volume and then derived its bulk density as 1.3 grams per cubic centimeter.

Compare this with the bulk densities of solid chunks of carbonaceous chrondrite meteorites, which average 2.8 grams per cubic centimeter. (Observations of Mathilde suggest it is made up of much the same materials as such meteorites.) So if Mathilde's density is less than half this amount, more than half of Mathilde's interior structure probably consists of empty space. An object with more than 50 percent empty space is evidently a loose collection of individual fragments. Thus, although *NEAR Shoemaker* never got closer than 1,212 kilometers (753 miles) to the surface of Mathilde, we were able to discern that Mathilde's interior was not solid rock but rather a rubble pile of material. —*DKY* producing spectacular meteor showers in the sky but leaving little evidence on the surface of the Earth.

The most common meteorite is the ordinary chondrite. Composed mostly of rocky silicates, chondrites do not evidence the chemical differentiation associated with melting. Possibly some of the most primitive rocks in the solar system, they are likely collision fragments from metal-poor S-type asteroids.

On March 22, 1998, seven boys in Monahans, Texas saw a chondrite fall to Earth. Within 48 hours, researchers were examining this meteorite at the Johnson Space Center in Houston.

Laboratory analysis of the Monahans meteorite detected salt crystals embedded with water in the form of brine. These crystals were dated to the very beginning of the solar system some 4.6 billion years ago.

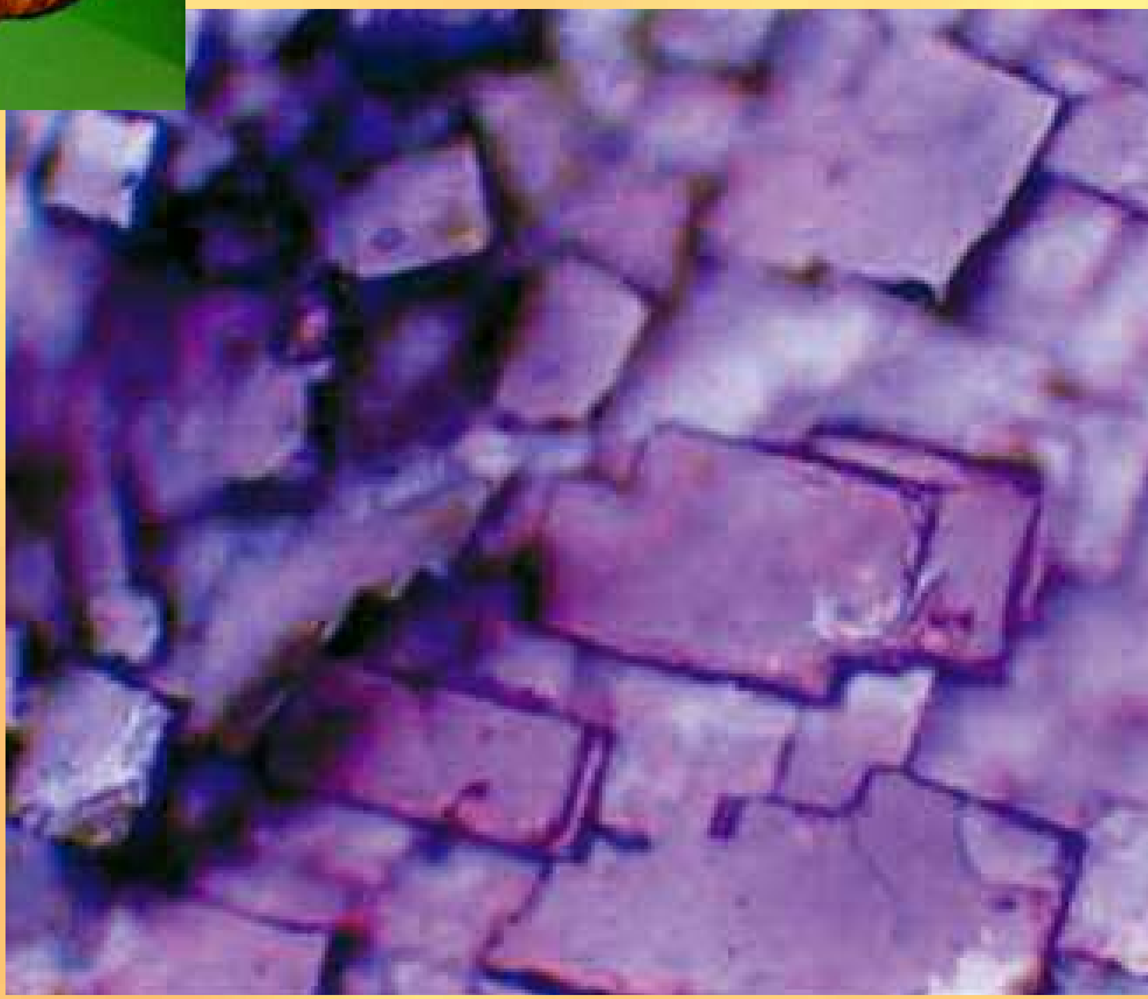
Early in the meteorite's lifetime, then, its parent asteroid contained liquid water. Unless this water came from an early collision with a salt-bearing icy comet, the parent asteroid must have harbored water within its own interior structure. Thus, far from being the dry, rocky bodies we once thought they were, some asteroids might in fact, along with comets, be significant sources of water.

Asteroids in Space/Space in Asteroids

Two C-type asteroids for which we have reliable density information—253 Mathilde and 45 Eugenia—both have bulk densities (about 1.3 grams per cubic centimeter) just higher than that of water. If these objects were a bit less dense, they would float.

Close-up images of Mathilde taken by the *NEAR Shoemaker* spacecraft in 1997 suggest that the five unusually large impact craters on its surface may have been created by compression during a collision rather than by excavation of material. In fact, Mathilde may have merged with some of the objects that hit it—increasing rather than reducing its mass. This means its bulk density could once have been even less than it is now.

Mathilde and Eugenia must have very porous structures (greater than 50 percent) to resemble, compositionally, the meteorites found on Earth. The bulk densities of meteorites thought to be collision fragments from C-type asteroids are about twice those of their parent asteroids. Growing evidence



Above: A 2-pound, 11-ounce meteorite fell out of the sky in March 1998, startling a group of boys in West Texas. The meteorite, named Monahans after the city where it landed, was claimed as property of the city but later returned to the boys who found it. The meteorite was eventually auctioned off for $23,000.

Photo: Mark Sterkel

Right: Purple areas up to 3 millimeters (0.12 inch) across were observed by scientists cracking open a sample of the Monahans meteorite at a Johnson Space Center lab. Closer inspection revealed the purple mineral to be sodium chloride (NaCl), a.k.a. table salt. The decorative color (sometimes blue rather than purple) is attributed to exposure to cosmic rays and perhaps solar radiation when the meteorite was in space. The image measures 1 millimeter (0.04 inch) across.

Image: Michael Zolensky/NASA

indicates the interior structures of at least some asteroids closely resemble rubble piles.

NEAR Shoemaker is now orbiting an S-type asteroid (433 Eros) whose bulk density was found to be 2.7 grams per cubic centimeter. In 1993 the *Galileo* spacecraft imaged the S-type asteroid 243 Ida and its moon. The bulk densities calculated for both S-type asteroids—Eros and Ida—are about twice those of the C-type asteroids Mathilde and Eugenia. Consequently S-type asteroids may be more solid than their C-type cousins.

Radar observations of the M-type asteroid 16 Psyche indicate it is likely metallic. Moreover the abundance of solid iron-nickel meteorites found on Earth suggests there must be several solid metallic asteroids in near-Earth space to supply these bits of iron. Other asteroids are spinning at such a rate that they must be solid rock. For example, the 30-meter-diameter asteroid 1998 KY26 evidently has considerable internal strength because it rotates in only 10.7 minutes, which is more than fast enough to break up a rubble pile. From physical evidence alone, then, it appears the structures of asteroids run from fluff-ball former comets to rubble piles, solid rocks, and slabs of solid iron.

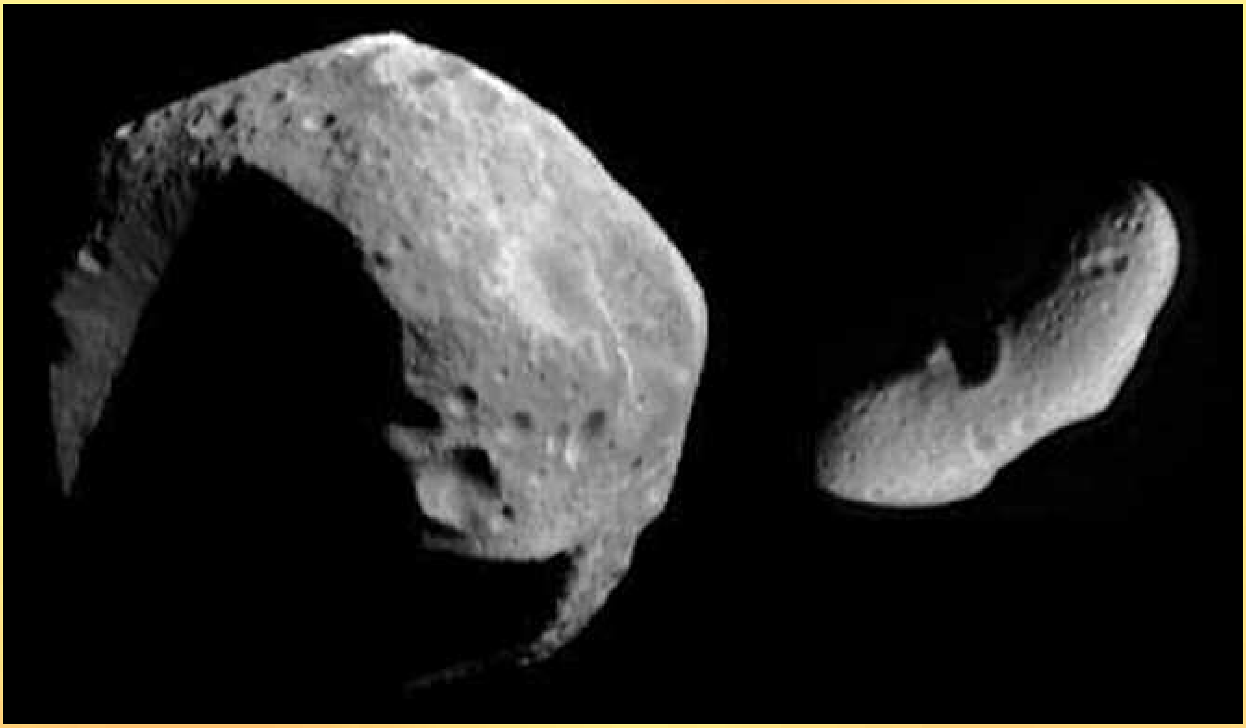
Friend or Foe?

Comets and asteroids are the relatively unchanged bits and pieces left over from the formation of the solar system. Studying their structure and composition therefore provides clues to the preplanetary accretion disk the planetary bodies agglomerated from some 4.6 billion years ago.

It's also important that we know the structure and composition of these bodies in the unlikely event that one is found on an Earth-threatening trajectory. That's because the technology we'd use to deflect an object out of harm's way would depend on the nature of that object. More than one deflection strategy is needed to deal with objects ranging from fluff-ball ex-comets to solid iron slabs.

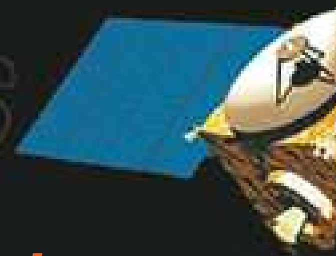
The close approach of these small bodies to Earth also means they're accessible for mining sometime in the future. The great expense of launching materials into Earth's orbit and beyond makes it far more cost-effective to build interplanetary structures such as habitats from natural resources found nearby in space. If the inner solar system is to be colonized within the coming years, the materials for these structures are likely to come from the wealth of minerals and metals provided by asteroids. Meanwhile the water supplies necessary for sustaining life and for providing the hydrogen and oxygen to produce rocket fuels are likely to come from comets. Asteroids and comets may therefore one day provide the habitats, fueling stations, and watering holes for future planetary exploration.

Donald K. Yeomans is Manager of NASA's Near-Earth Object Program Office at the Jet Propulsion Laboratory.



The* NEAR Shoemaker *spacecraft encountered the C-type asteroid Mathilde in June 1997 and the S-type asteroid Eros in February 2000. S-types, whose colors are consistent with "stony" or rocky compositions, prevail among asteroids that orbit closer to the Sun. C-types have a dark gray color consistent with a "carbonaceous" composition, rich in carbon compounds and other dark materials. They prevail in the outer part of the asteroid belt. In this montage, Mathilde (at left) and Eros (at right) are shown at the same scale, as imaged by* NEAR Shoemaker *from about 1,800 kilometers (1,116 miles). However, Mathilde's brightness is greatly exaggerated—it's actually six times darker than Eros, with about the same reflectivity as soot. *Image: Johns Hopkins University Applied Physics Laboratory/NASA*

THE EXPRESS TO MARS



by Robert Burnham

Spacecraft from several nations, including the United States, are due to arrive at Mars in 2003 and 2004. But only one of them is searching for life: the European Space Agency's Mars Express mission.

At times it seems as if the United States owns Mars. It doesn't, of course, even if whole stretches of the US Southwest do resemble the Red Planet. But the fact remains that our idea of what Mars looks like has been shaped by data and images from US missions.

That's about to change. In June 2003, the European Space Agency (ESA) will launch an ambitious, two-part spacecraft called *Mars Express*. Its goal is to image the entire planet in more detail than any previous mission. Plus it carries a lander named *Beagle 2*, designed to search for signs of life existing either now or formerly.

Europe Goes to Mars

If all goes according to plan, on June 1, 2003, a Russian Soyuz/Fregat rocket will blast off from Tyuratam, Kazakhstan, carrying the *Mars Express* and *Beagle 2* spacecraft. (If that booster is not ready, ESA's fallback plans call for a US Delta II or a European Ariane 4 booster.) Arrival at Mars is scheduled for December 26, 2003. On arrival, the orbiter will fire its main engine and go into an elliptical first orbit of 250 by 150,000 kilometers (155 by 93,000 miles). Successive firings will move *Mars Express* into its initial operating orbit—measuring 250 by 11,583 kilometers (155 by 7,198 miles), with a nearly polar orientation (87 degrees inclination) and a period of 6.7 hours. Later on, the high point of the orbit will reduce to 10,243 kilometers (6,365 miles). The orbiter's prime mission is scheduled to last one Mars year, or 687 Earth days.

Five days before the *Mars Express* spacecraft will enter Martian orbit, a spring mechanism will shove the *Beagle 2* lander away from the orbiter and set it spinning for stability. The probe, protected by a heat shield, will enter the Martian atmosphere at over 35,000 kilometers (20,000 miles) per hour. When the velocity slows to about 1,600 kilometers (1,000 miles) per hour, a parachute will open to brake the descent. At an altitude of about a kilometer (half a mile), airbags will inflate to cocoon the lander. At touchdown, the parachute will be cut loose and the airbags deflate.

The lander, which is built like a clamshell, opens correctly however it sets down. Opening the top unfolds four solar panels, deploys an antenna, and releases the lander's arm. *Beagle 2*'s nominal mission lasts 180 Martian days, or sols. An extended

Background: ESA's Mars Express *at Mars*
Image: European Space Agency

mission would continue to a full Mars year, 669 sols, after landing.

Mars Through Euro-Glasses

Beagle 2's search for life may draw considerable attention, but the orbiter is a lot more than just a delivery truck. Once it takes up its science mission, seven experiments swing into play.

The High-Resolution Spectroscopic Camera (HRSC) operates primarily during the midmorning or midafternoon, when shadows are neither too long nor too short. Its goal is to provide stereoscopic imaging, in full color, at 10 to 30 meters' resolution for all of Mars. At best resolution, the camera can detect features as small as 2 meters across—sharp enough to spot the *Beagle 2* lander on the ground.

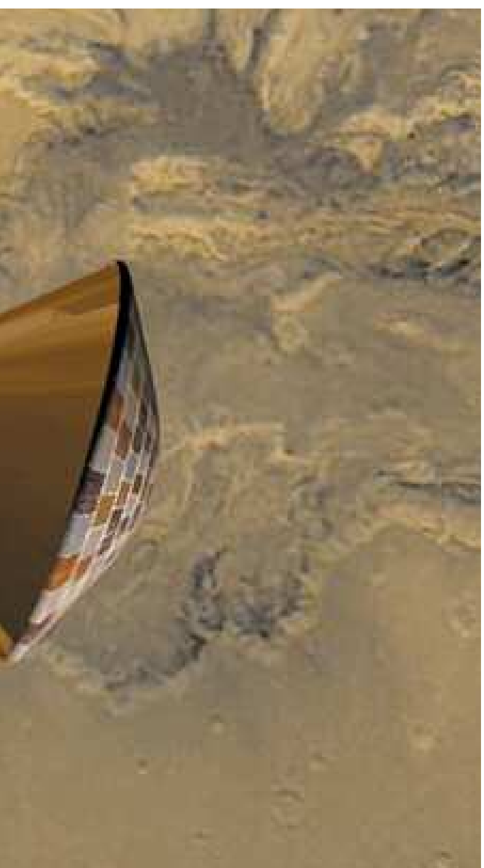
During the mission, the camera will also examine clouds, fog, dust devils, and the edges of the ice caps. It will let scientists find beach coastlines (if they exist) from the hypothesized northern ocean, and it will probe what happened to the water that carved such canyon systems as Kasei Vallis. Not surprisingly, HRSC "owns" the largest share of data returned to Earth, about 40 percent. (*Beagle 2*, by comparison, gets just 2 percent of the data stream. It stores the data for relay up to the orbiter, once each orbital pass, for transmission to Earth.)

The OMEGA infrared mapping spectrometer, meanwhile, will map the surface composition of Mars. While previous missions have sketched the outlines, OMEGA can create a map with a global resolution of 1 to 4 kilometers (0.6 mile to 2.5 miles), and selected areas can be scanned at 300 meters' resolution. Scientists are especially interested in deposits of carbonate rocks, which form when carbon dioxide dissolved in water reacts with substances such as calcium, magnesium, or iron. Surveying carbonate deposits and other sedimentary rocks will help scientists map Mars' ancient climate and perhaps point toward areas where water may have ponded long enough for life to start.

Out of Thin Air

The role of the PFS, or Fourier spectrometer, is to study the Martian atmosphere. Scientists know the atmosphere is more than 95 percent CO_2, but they still understand little of its structure, winds, and changes throughout the Martian year.

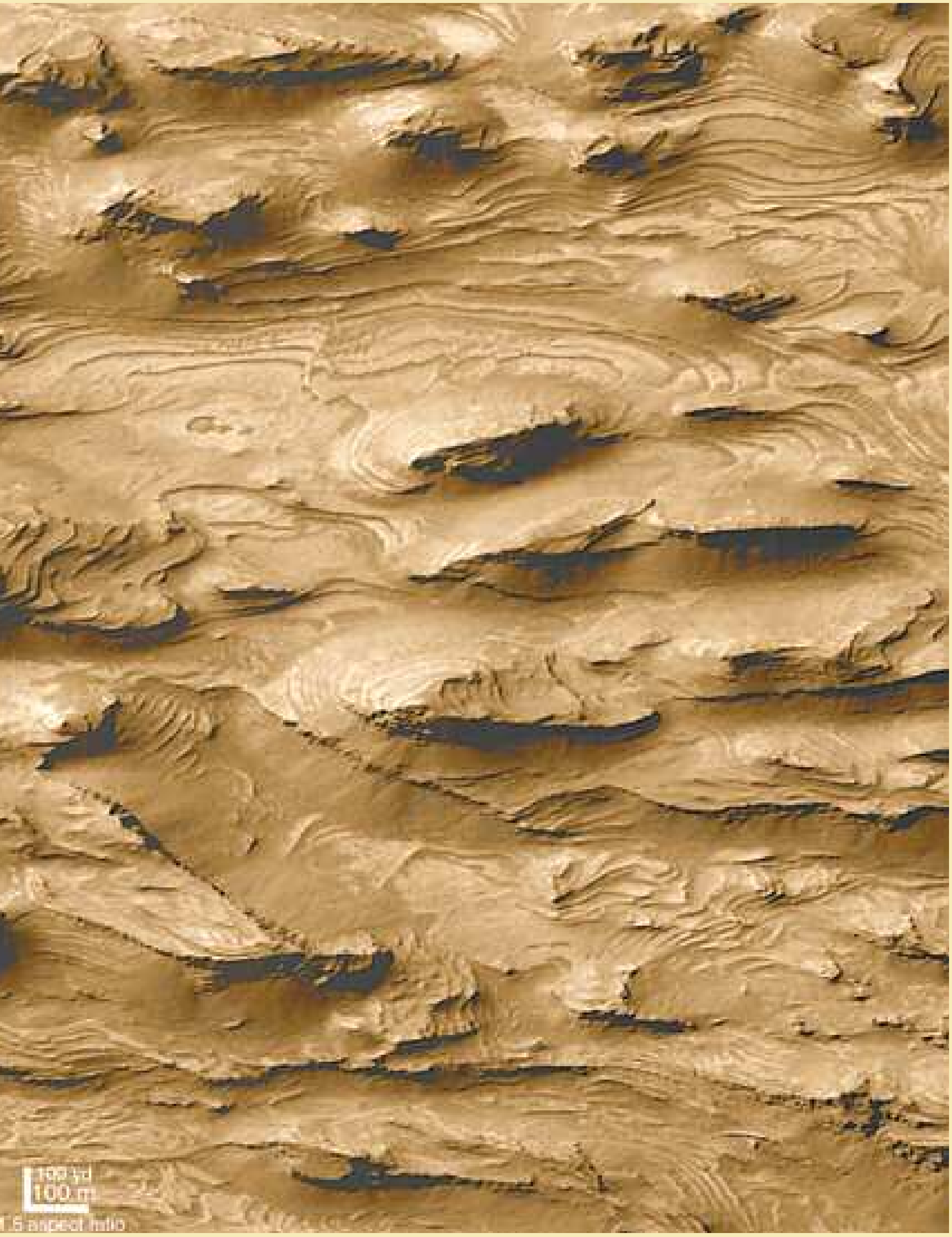
The planet's atmosphere is indeed tenuous—at its surface the pressure equals that of Earth's atmosphere 40 kilometers (25 miles) up. In addition, the pressure varies during the year as CO_2



With the aid of its robotic arm, Beagle 2 *will be able to study and obtain samples of nearby rocks and soil. The concentration of instruments at the end of* Beagle 2*'s robotic arm has been dubbed, fittingly, the "paw." The arm can also deploy a crawling mole, called PLUTO, to gather subsurface soil samples and return them to the onboard analytical laboratory.*

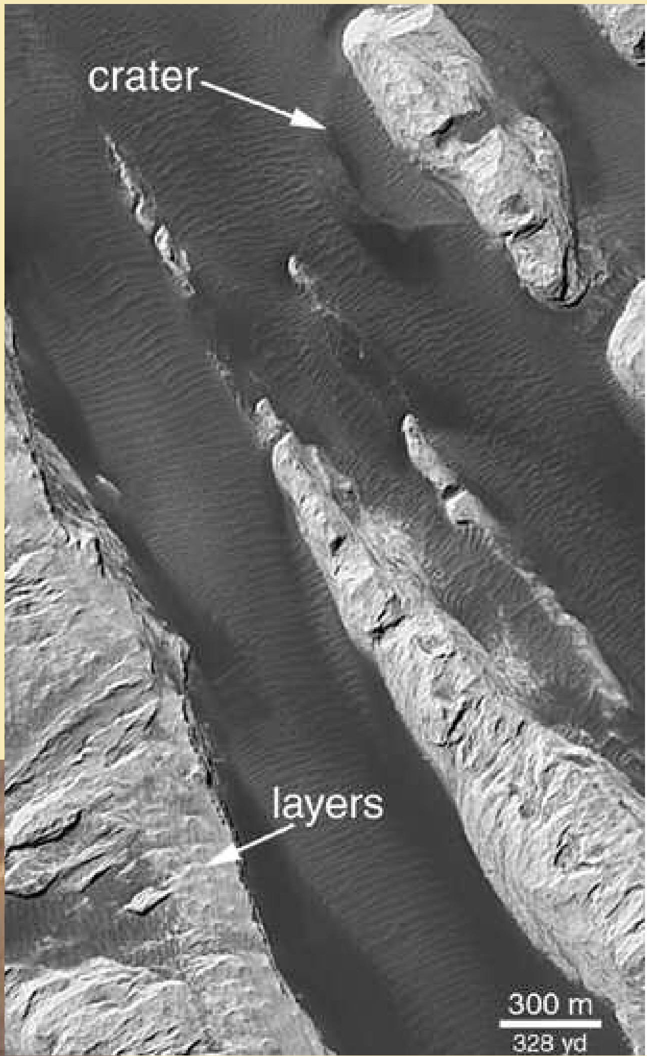
Images: © Beagle 2

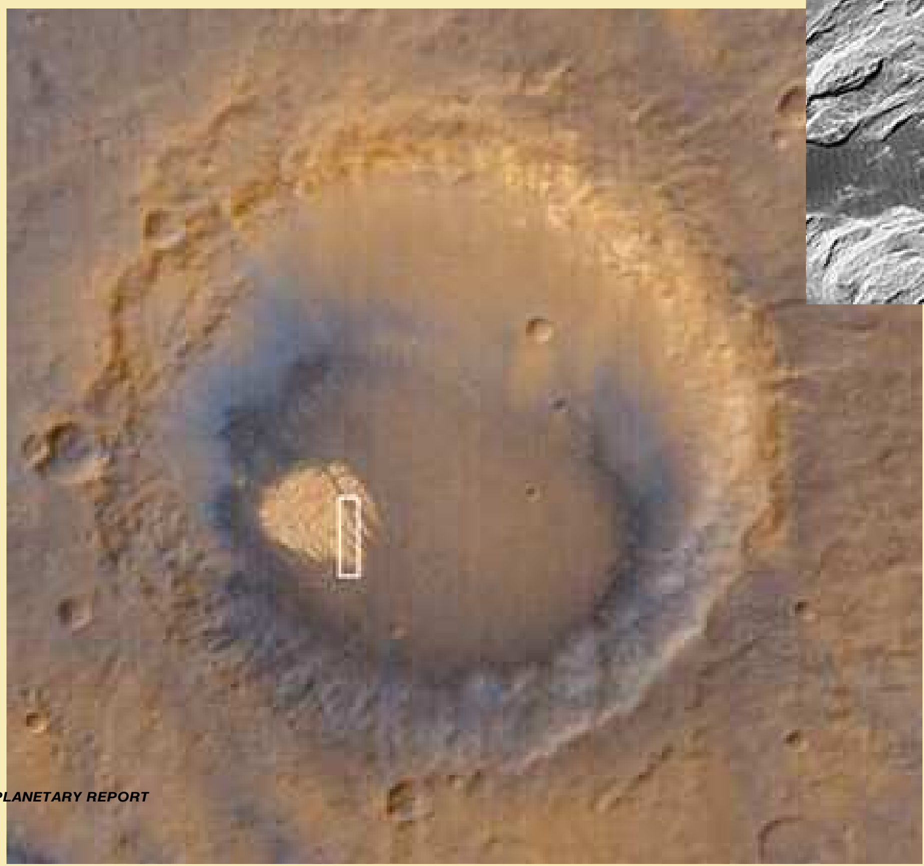
Left: After six months of traveling together, and just five days before Mars Express *enters Martian orbit, the* Beagle 2 *lander will separate from the orbiter to begin a journey of its own.*



Left: In its aim to search for signs of life, past or present, the Beagle 2 *will target areas showing evidence of ancient water flows. Martian landforms displaying layered sediments—like those imaged by* Mars Global Surveyor's *Mars Orbiter Camera (MOC)—may supply just that evidence. This groundbreaking image shows a 1.5-by-2.9-kilometer (0.9-by-1.8-mile) area of the floor of western Candor Chasma, an unexpected location to find layers. What is striking is not only the presence of layers (or beds) at this location but also their large number and uniformity. In fact the beds in this area number over 100, and each measures about the same thickness, about 10 meters. In addition, each layer has a relatively smooth upper surface and enough solidity to form steep cliffs at its margins.*

Layers indicate change. The uniform pattern seen here suggests the deposition of materials was interrupted at regular or at least episodic intervals. Patterns like this, when found on Earth, usually indicate the presence of sediment deposited in dynamic underwater environments. On Mars these same patterns could very well indicate deposition in a lake or shallow sea. However, it is not known for certain such materials formed underwater; the possibility remains that uniquely Martian processes occurring in the distant past mimic the pattern of sedimentation in water. *Image: NASA/JPL/MSSS*





Located in Pollack Crater, an impact basin 95 kilometers (59 miles) wide, White Rock appears as the lighter circular feature with the rectangular white box drawn over it in the context view (left). The white box indicates the location of a subframe of an MOC image acquired in September 2000, shown above. The light-toned material that gives White Rock its name forms steep cliffs with valleys covered by dark, windblown, rippled sand. Arrows point out layers in the bright material and call attention to the old impact crater partly uncovered beneath the White Rock material.

The layering in White Rock suggests sediment deposited sometime in the distant past within Pollack Crater. The fact that the material erodes to form steep cliffs suggests it is hard as rock. Thus, White Rock is interpreted to be an outcrop of sedimentary rock and could in fact be a remnant of a larger body of rock that may have once covered the entire floor of Pollack Crater.
Image: NASA/JPL/MSSS

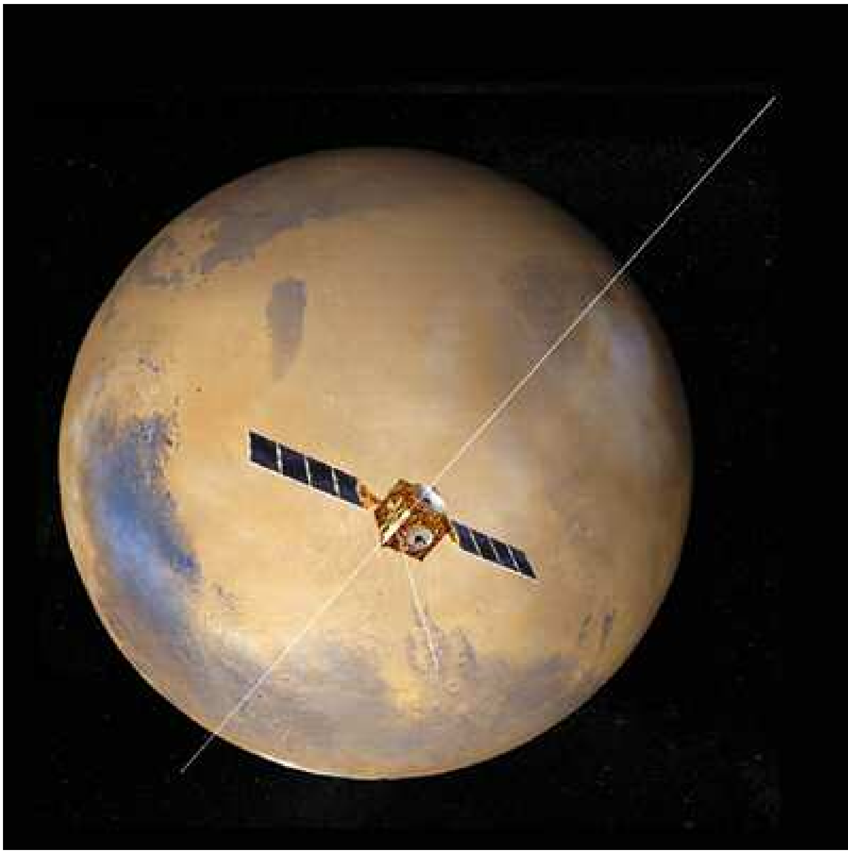
evaporates or condenses in the polar regions. Temperatures on Mars vary enormously, from terrestrial room temperature at the equator in summer to – 130 degrees Celsius (– 200 degrees Fahrenheit) over the poles in winter. The atmosphere also carries a lot of dust, which interacts in a poorly understood way with clouds and temperature changes.

Working with PFS is SPICAM, an ultraviolet and infrared spectrometer designed to study other aspects of the Martian atmosphere. One goal is to determine why the atmosphere is so strongly oxidizing that it destroys any organic molecule it touches, a question with major biological import. SPICAM can also profile atmospheric ozone, water vapor, aerosols, cloud structures, and temperatures by observing how a star's light changes as it traverses the atmosphere.

What lies underground is the target for MARSIS, a sounding radar. After *Mars Express* reaches orbit, it will unfurl two 20-meter antennas. These will beam low-frequency radio waves at Mars. Most waves will reflect from the surface, but some will penetrate a few kilometers into the planet. The instrument should reveal the general structure of the uppermost Martian crust. If any water or brine is present, liquid or frozen, it should produce a strong reflection. But the sounder can also map the thickness of sand in dunes, for example, or probe layers in the ice caps to reveal a history of the Martian climate.

The two remaining orbiter experiments focus (1) on probing the electromagnetic properties of the surface and the planet's gravity field (MaRS) and (2) examining the interaction of the solar wind with the Martian atmosphere (ASPERA).

The orbiter's work will be augmented by the arrival of a Japanese mission named *Nozomi* ("Hope"), also in December 2003. *Nozomi*'s focus dovetails neatly with the *Mars Express* orbiter's, since its goal is to study the dynamics of the Martian ionosphere, looking at its composition, structure, and changes (see the November/December 1998 issue of *The Planetary Report*).



Is there water on Mars today? Many scientists believe so—whether frozen or trapped in liquid reservoirs underground—and recent* Mars Global Surveyor *findings support this possibility. MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding), one of the instruments on board* Mars Express, *will set out to map underground water and ice in the upper portions of the Martian crust.

Specifically, MARSIS will send low-frequency (1.3–5.5 megahertz) radio waves toward the planet from a 40-meter-long antenna to be unfurled after* Mars Express *goes into orbit. Using techniques similar to oil prospecting on Earth, the instrument will analyze reflections of radio waves in the upper 2 to 3 kilometers (1.2 to 1.9 miles) of Martian crust to reveal dry, frozen, and wet soil.

Image: European Space Agency

Ground Truth

The *Beagle 2* lander will set down at a site that shows evidence of ancient water flows. Two candidate locations are in Maja Vallis and Tritonis Lacus. Both lie at low elevations and not far north of the Martian equator, so sunlight is plentiful. (*Beagle 2* requires solar power.) The site must be scientifically interesting and technically feasible, which means that boulder-strewn regions are taboo. And the site has to be picked carefully, since *Beagle 2* cannot simply stroll over to a different one.

Still, *Beagle 2* is not without mobility. It has both a moveable arm with instruments on the end, dubbed the "paw," and a small device called PLUTO (Planetary Undersurface Tool). PLUTO is a mechanical mole that can crawl up to 5 meters from the lander and burrow into the soil. This is important because the Sun's damaging ultraviolet light hits the Martian surface essentially unabated. Scientists theorize that UV light has turned the Martian surface so oxidizing that it will destroy any organism unable to find shelter in the soil or inside rocks.

On landing, *Beagle 2*'s first job is to take a 360-degree panorama and begin recording weather observations (wind speed, temperature, pressure, and so on). The lander carries four cameras: a stereo pair, a wide-angle viewer, and a microscopic imager mounted on the robotic arm. After analyzing the panoramic image, scientists will direct the robotic arm toward a likely-looking rock. A Mössbauer spectrometer on the arm can determine the type of rock, and an X-ray spectrometer will reveal its elemental composition.

The surface of every Mars rock has been chemically altered by the atmosphere; to get a fresh exposure, the arm carries a grinder to remove the rock's weathered rind. It then uses the microscope like a geologist's hand lens to examine the small-scale structure of the rock. This may (or may not) reveal signs of life. The grinder can also drill into the rock and extract a core sample 1 centimeter (0.4 inch) long and 2 millimeters (0.08 inch) in diameter.

From Under a Rock

When scientists want to collect a subsurface soil sample or take one from beneath a rock, they will use the PLUTO mole. It can crawl forward at a rate of 10 centimeters (4 inches) a minute. Tethered by its power cord, the mole has jaws that can open to snatch a sample of dirt or a small pebble. The lander retrieves PLUTO by reeling in its cord.

Samples brought back by the arm or the mole end up in the GAP (Gas Analysis Package). This instrument heats the samples to calibrated temperatures to cook off any carbon-containing substances. A mass spectrometer examines the vapor to detect signs of carbon, determining if it is organic or nonorganic in nature by identifying its isotopic composi-

Just Your Basic Spacecraft

Mars Express and *Beagle 2* were built by Astrium, a company formed by a merger of aerospace firms based in France, Germany, and England. The budget for the orbiter is 60 million Euros (a little over $50 million), a very low price achieved in part by sharing hardware with ESA's upcoming *Rosetta* mission to comet Wirtanen. The *Beagle 2* lander, for its part, cost £29 million ($46 million). The *Mars Express* project's total budget is 150 million Euros ($125 million).

The orbiter, which weighs a little over 1 metric ton, is a near-cube about 1.5 meters on a side. Its solar panels unfold to spread 12 meters, and it carries a nonsteerable, high-gain antenna 1.8 meters across. The orbiter is stabilized in three axes, using thrusters and reaction wheels to steady its aim.

The *Beagle 2* lander measures about 60 centimeters (2 feet) in diameter. By itself, it has a mass of 30 kilograms (66 pounds); with the heat shield and parachute (jettisoned at landing), the total mass is 60 kilograms (133 pounds).

Beagle 2's name was chosen to honor the small exploring ship that, from 1831 to 1836, carried naturalist Charles Darwin on his epoch-making voyage around the world. *—RB*

tion. The GAP can also measure other gases, including methane, often a thumbprint of life. Scientists hope the GAP will pin down whether or not samples contain biological remnants. If the GAP does find remains, the chemical analysis may also tell what biological process—for example, photosynthesis—the life-form used for metabolism.

To buttress the bio-investigations, *Beagle 2* will take measurements of the atmosphere's composition and the character of rock samples picked up by the arm or mole.

One big worry with all lander spacecraft, especially those searching for life, is contamination of Mars by terrestrial organisms. (Conceivably, this could foul up the whole planet, not to mention the experiment!) *Beagle 2* will thus be sterilized to the extent it has at most 300 spores per square meter and a total bio-load of no more than 300,000 spores. This meets international agreements for planetary quarantine (see the July/August 1994 issue of *The Planetary Report*). The biology experiments, however, will be sterilized and cleaned to much higher standards because any carbon-containing residue would skew the findings, preventing clear-cut results.

Next Steps

Beagle 2 won't have the Martian surface to itself for very long. NASA is planning to land two Mars Exploration Rovers in January 2004. Each a modified version of the *Athena* rover planned for the canceled 2001 lander mission, these are like big cousins of the *Sojourner* rover from the 1997 Mars *Pathfinder* mission. But where *Sojourner* crept a total distance of about 100 meters during the entire mission, both Mars Exploration Rovers will travel 100 meters every sol and should remain active for at least 90 sols.

Each Mars Exploration Rover carries five experiments, plus a rock abrasion tool (RAT). The instruments on board include a high-resolution panoramic camera, spectrometers for mineral analysis and mapping of chemical elements in rocks, and a microscopic imager. Coupled with the RAT, the imager (like *Beagle 2*'s) will function as a hand lens, giving extreme close-up views of rocks. The two rovers, while identical, will go to different sites, chosen from *Mars Global Surveyor* images and other data.

Looking further ahead, in 2005, NASA will send the *Mars Reconnaissance Orbiter* to recover the science lost when the *Mars Climate Orbiter* failed. It will image thousands of Martian landscapes at a resolution high enough to spot rocks the size of beach balls.

In 2007, the French space agency (CNES) is planning a remote-sensing orbiter plus four Netlanders. (These are small spacecraft that function as weather and seismic stations on the planet's surface.) The same year, the Italian space agency (ASI) aims to send a powerful orbiter to provide a high rate of data transmission from Mars to Earth for the Netlanders and future spacecraft. (The growing volume of data from Mars missions makes some sort of relay system essential.)

In 2007, NASA plans to place a long-range, long-duration mobile science laboratory on the surface. It will hunt out sites for a future sample return mission. In this same launch opportunity, "scout" missions are planned. These may include small landers, Mars balloons (a technology pioneered by The Planetary Society; see the January/February 1991 issue of *The Planetary Report*), and perhaps even remotely piloted aircraft. In the decade to follow, NASA looks to more science orbiters, rovers, and landers, plus the first sample return mission. Current plans call for a sample return mission to be launched in 2014 and a second in 2016, though a first return in 2011 is a possibility.

Overall, NASA remains the executive producer for most acts in The Great Mars Show. But as Europe's *Mars Express* mission promises to demonstrate, increasing participation by other countries helps spread out the costs while broadening science perspectives. It has taken a lot of years, but the exploration of the Red Planet is finally coming around to what many science fiction writers always thought it should be—an international enterprise.

Robert Burnham is the author or editor of several recent books on astronomy and Earth science. His latest book is Great Comets, *published in 2000 by Cambridge University Press.*

To stay current on developments regarding *Mars Express*, the *Beagle 2* lander, and other Mars missions, check these websites regularly. (For brevity, "http://" has been omitted.)

Mars Express
sci.esa.int/marsexpress

Beagle 2
www.beagle2.com

National Space Science Data Center
nssdc.gsfc.nasa.gov/planetary/planets/marspage.html

Mars Exploration at JPL
mars.jpl.nasa.gov

The Planetary Society
planetary.org

The Mars Society
www.marssociety.org

World Watch

by Louis D. Friedman

Washington DC—Although distant and small, Pluto currently occupies most of our political effort and attention. The Planetary Society's campaign to restore a Pluto exploration mission to NASA's schedule has struck a loud chord with the media and the public. But not yet with NASA.

NASA maintains it simply does not have the budget to handle cost increases in planetary missions and must therefore cancel some missions to preserve others. The Pluto mission is not the only to fall: the Jet Propulsion Laboratory (JPL) was ordered to stop development of a nanorover for the Japanese *Muses-C* asteroid sample return mission. (For more information see "The World" in the next column.)

Evidently the past optimism of the "faster, better, cheaper" philosophy has been replaced by a paradigm requiring extraordinary risk mitigation to ensure success. Some would say this conservatism is driving up cost estimates. Regardless, NASA, along with the political decision makers who determine its budget, is faced with a critical choice: will we return to the one-big-mission-per-decade strategy of the past, or will we continue a vital series of smaller missions exploring an array of solar system targets to achieve year-by-year advances?

The cost increase affecting the Pluto project, while large for planetary missions, could easily be accommodated by a 2 percent increase in NASA's budget. After eight straight years of budget decline, and with the peak of space station funding now supposedly behind us, The Planetary Society has no trouble arguing for this kind of increase to the planetary mission budget.

Join us in this political action by visiting our website, **planetary.org**, and voicing your opinion to the policy makers in Washington, DC. Or you can join us in person in Washington on February 1 when we hold a conference promoting the reinstatement of a Pluto mission for launch in 2004.

Pasadena CA—NASA supports a huge structure of advisory committees and subcommittees—each with a barely pronounceable acronym. There is, for example, a Space Science Advisory Committee (SSAC) with a Solar System Exploration Subcommittee (SSES). These advise NASA officials about scientific priorities and the conduct of missions. (So does the National Research Council, an independent arm of the US government, set up as part of the National Academies of Science and Engineering.)

Recently, the SSES met in Pasadena to review the NASA planetary program and comment on the new plans for Mars exploration, the Pluto mission cancellation, and implications for a Europa orbiter mission to the outer planets, among other issues. Despite NASA's cancellation of the *Pluto Express* project, the committee gave strong support to a Pluto mission. (The full text of its counsel to NASA can be found at **planetary.org**.)

This statement of support was significant because some in government dismiss the importance of exploring Pluto given doubts about discovering life there. But the search for extraterrestrial life is not just about finding it on some distant world—that is indeed a long shot. Rather, we aim to conduct a range of exploratory missions to piece together the puzzle of the origins of life. Some of the puzzle pieces will come from distant Pluto. We applaud the SSES advisory committee's support for this crucial mission.

The World—International cooperation in planetary exploration seems to be getting tougher. The NASA/European Space Agency (ESA) interface suffered a blow when a design flaw, jeopardizing communications with its parent NASA *Cassini* spacecraft, was discovered in the ESA *Huygens* probe destined for Saturn's moon Titan. Mission engineers are redesigning the mission to cope with this problem, but the missions of both the *Cassini* and *Huygens* will be affected.

In another arena, political and industrial pressure in the US continues to make it difficult, and occasionally impossible, to use foreign launch vehicles, even in clear cases of scientific and economic benefit. Most egregious (in my opinion) is NASA's failure to consider using the Russian Proton to launch a Pluto mission.

With a Proton launch, NASA could speed up the mission and launch more payload while saving tens of millions to perhaps more than a hundred million dollars. But fear of congressional and aerospace industry objections paralyzes the agency and probably will prevent a Pluto mission from flying in this decade.

On another front, the cancellation of the tiny 1.5-kilogram (3.3-pound) nanorover for the Japanese *Muses-C* mission is another blow to international cooperation. The *Muses-C* mission is an audacious one: a robotic sample return from an asteroid by a country still seeking its first planetary encounter. The nanorover would have provided a valuable intermediate goal on that ultimate mission, as well as a vital new technology for planetary exploration. But JPL found the cost of development much larger than anticipated, and NASA was unwilling to absorb that cost.

Meanwhile, despite the stationing of resident astronauts on board the International Space Station, this cooperative endeavor is seen in some political circles as a failure. I don't understand this assessment—without international participation, there would have been no space station, or the US would have had to develop and launch many extra vehicles to carry it out. Certainly the inclusion of Russia at just the time that country underwent huge economic and political dislocations was upsetting and caused delays. But I'm mystified that the cooperative way the project was achieved—unimaginable in the Apollo or shuttle eras—is not viewed as a great success. International cooperation is difficult, but so is space exploration—and great enterprises require great solutions.

Louis D. Friedman is Executive Director of The Planetary Society.

Hunting the Elusive "Wow"

On August 15, 1977, a Columbus, Ohio man analyzing data from the Big Ear's recording device saw a signal so strong that he excitedly scribbled "Wow!" right onto the printout—and the name stuck. For the next month, and periodically since, the massive scope scanned that same part of the sky. Nevertheless the signal hasn't been recorded again. For more information on the "Wow" signal and what each letter and number represents in the 6EQUJ5 code, go to http://www.bigear.org/6equj5.htm.

Photo: Big Ear Radio Observatory

by Robert H. Gray

One of the most intriguing events in the short history of searching for ET with radio telescopes is the Wow signal, detected at the Ohio State University Radio Observatory in 1977. It looked a lot like a radio signal from the stars—relatively narrowband (less than 10 kilohertz), frequency near the hydrogen line, and with the characteristic signature of the telescope's antenna sweeping across a celestial object. But Ohio State could not detect the signal again despite many attempts, and no other observatory followed up—partly because few details were published and partly because it's easy to dismiss such events as local interference, which radio astronomers see all the time.

For more than 20 years the Wow has remained a loose end in SETI—a tug on the cosmic fishing line—maybe interference, maybe something exciting. With partial support from The Planetary Society (thanks, everyone!), I've tried to settle the matter, hunting the elusive Wow with the Very Large Array (VLA) near Socorro, New Mexico—one of the world's most powerful radio telescopes.

Assisted by Kevin Marvel, I searched the area of sky where the signal was reported. One possibility we investigated was that the Wow might be a weak source that brightened briefly due to interstellar scintillation, much like the twinkling of a star. With 27 antennas, each 25 meters in diameter, the VLA was sensitive enough to detect a weak underlying source.

We "discovered" a few dozen weak radio sources—but natural ones, the kind scattered across the sky by the millions—typically distant galaxies with energetic cores, some perhaps black holes. We are sure they are natural because they radiate across the frequency spectrum; artificial radio signals usually do not. The sources are also hundreds of times weaker than the Wow, far too weak for scintillation to have made them brighten enough to produce the Ohio State signal.

Our null finding means the Wow was probably neither a transmitter nor a natural source shining constantly that happened to twinkle brighter during Ohio State's observation.

Our search covered other scenarios as well. One is that the Wow might have been a strong but brief signal designed to attract attention to a weaker but continuous broadcast. That's a thrifty broadcast strategy—keeping the volume low most of the time—but we found no obvious signals even 1,000 times weaker than the Wow. In yet another scenario, the signal might drift in frequency; we covered a wider frequency band than Ohio State but still failed to find the elusive signal.

Our search, while sensitive, did not last very long—less than an hour at any position. The possibility remains that the Wow may be entirely absent most of the time, so brief searches have little chance of catching it. That could happen, for example, if a fixed antenna on a rotating planet swept its beam across us once each "day," illuminating us like a lighthouse. I am currently investigating this kind of scenario with Simon Ellingsen by tracking the Wow locale for 14-hour periods using the University of Tasmania's 26-meter radio telescope—observing from the Southern Hemisphere because, for telescopes in the North, the position is below the horizon most of the day.

The VLA search, meanwhile, scored several "firsts." For one thing, it was the first time a major observatory was used to attempt confirmation of the Ohio State signal—it might have been just sitting there with a Cheshire grin, waiting to be discovered by a closer look. Second, it was the first time an imaging interferometer was used for an area search in SETI—a big advantage because you can see if the position of a radio source falls on a star; few stars shine at radio frequencies. Finally, it was the first time the full VLA was used for SETI—contrary to popular belief since the movie *Contact*, the prestigious $80 million telescope hardly ever listens for broadcasts from the stars.

The Very Large Array (VLA), made famous in the movie **Contact**, *consists of 27 antennas, each measuring 25 meters in diameter and, electronically combined, equaling the sensitivity of a dish 130 meters in diameter. Located just west of Socorro, New Mexico, the antennas are arranged in a huge Y pattern measuring up to 36 kilometers (22 miles) across—roughly one and a half times the size of Washington, DC.*

Photo at left: Brian Parker/Tom Stack & Associates
Photo below: Dave Finley, courtesy National Radio Astronomy Observatory and Associated Universities, Inc.

I happened to be at the VLA shortly after a visit by filmmakers planning the movie, and I got a few curious looks from staffers wondering if my business there were fact or fiction. Like SETI in general, the business is gathering facts—usually that there's no signal at some frequency, place, or time—and in the case of the elusive Wow, the facts begin to weigh toward its having been interference. The only way to find out for sure is by looking, and our looks still amount to less than a day of observations.

The fact that searching for signals from other worlds has yet to be successful should not discourage us, because the bulk of the cosmic haystack still awaits sifting. Most searches examine only a sliver of the electromagnetic spectrum, viewing only a small spot of sky at any moment. The sky could be dotted with bright, steady beacons whose frequency we've not yet tuned, be blinking with distant lighthouses we've still not looked at long enough to glimpse. Advanced searches mounted by The Planetary Society and the SETI Institute will soon cover more of the spectrum and more of the sky and perhaps result in more tugs on our cosmic fishing lines.

Robert H. Gray is a data analyst and the owner of Gray Data Consulting in Chicago. Currently he is writing a book on SETI. His research was supported in part by the SETI Institute and The Planetary Society.

For more information on this search, see the January 10, 2001 issue of *Astrophysical Journal*. Learn more about the VLA at **www.nrao.edu** and about the Ohio State Observatory and Wow signal at **www.bigear.org**.

Questions and Answers

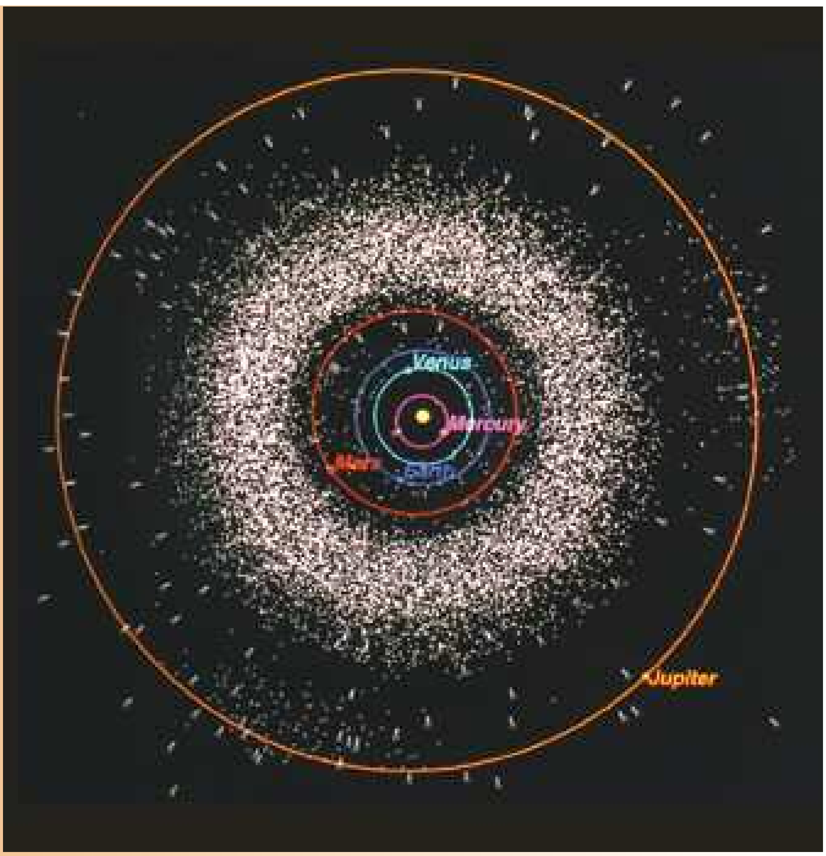
What can that asteroid belt between Mars and Jupiter be? A destroyed planet?
—George I. Epsimos,
Kos Island Resort, Greece

When Giuseppe Piazzi discovered the first asteroid, Ceres, in 1801 (we can now celebrate the bicentennial of asteroids) there was great joy in finding what many had considered a "missing planet" between Mars and Jupiter. Dismay followed when Heinrich Olbers found a second asteroid (Pallas) in 1802. Olbers reasoned that the missing planet must actually be in pieces, an idea apparently confirmed when Karl Harding found Juno in 1804 and Olbers himself found Vesta in 1807. However, our increasing knowledge of the physical nature of the asteroid belt (more than 15,000 asteroids are now cataloged) leads us to a different conclusion. These asteroids are the remnants of a planet that failed to form.

We now understand that Jupiter's dominating gravity prevented the formation of a planet between it and Mars. In order for planetesimals to succeed in joining together to form a single large planet, they must be on nearly circular orbits. When two planetesimals on adjacent circular orbits bump into each other, their relative speeds are slow enough that they fuse together and grow larger.

Jupiter's gravity, however, was strong enough to perturb the orbits of planetessimals in the asteroid zone, resulting in orbits that were no longer circular. Planetesimals on these elongated, or eccentric, orbits began to bump into each other at speeds that were too high to allow them to fuse. The growth of a sizable planet was therefore halted. Only a few large "protoplanets" like Ceres and Vesta formed, and many, many planetesimals remained. This means asteroids are leftover building blocks from the beginning of our solar system.

The compositions of asteroids, which we infer from their spectral colors, lead us to the same conclusion. Asteroids in the inner regions of the belt appear to have surfaces containing minerals similar to those commonly found on the inner terrestrial planets. In the outer regions, the surface compositions appear more carbon-rich and perhaps water-rich, just as we see among planets and satellites in the outer solar system. This variation—which shows the effect of decreasing temperature with increasing distance from the Sun—is just what we would expect to see within a zone of material marking the transition between the terrestrial planets and the gas giants.
—RICHARD P. BINZEL,
Massachusetts Institute of Technology



Scientists have cataloged more than 15,000 asteroids—most all of which crowd the space between Mars and Jupiter to comprise the main belt. These rocky leftovers from the birth of our solar system are now thought to be the vestiges of a planet that failed to grow. Here positions for the planets Mercury through Jupiter, as well as for many asteroids and periodic comets (symbolized by sunward-pointing wedges), are shown as they appeared on the ecliptic plane on June 1, 1997. Only asteroids and comets in the Jet Propulsion Laboratory's DASTCOM database were used.

Illustration: Jeff Bytof and Alan Chamberlin, JPL/NASA

I have often wondered why the Moon appears gray in close-up images taken by the* Apollo *astronauts but looks yellow to the naked eye and through a telescope on Earth. Is this due to the photographic film used by the astronauts, or did they indeed have the same visual impression?
—Philipp R. Heck,
Zurich, Switzerland

The Moon looks gray to either an eye or a camera beyond Earth's atmosphere, and lunar samples look generally gray or whitish in the laboratory. If the Moon appears yellow or even reddish from Earth, that is a result of atmospheric absorption.
—JAMES D. BURKE,
Technical Editor

What are the chances of an extrasolar gas giant having a satellite? How about a life-sustaining, Earthlike satellite?
—Andrew Christopher Meszaros, San Dimas, California

Can extrasolar gas giants have satellites? Almost certainly. When a giant planet forms, it captures material from its parent star's protoplanetary nebula to form a disk around itself. Solid material in this disk then accretes to form satellites. This happened to all four giant planets in our solar system, and it would probably happen to extrasolar giants, too.

A giant planet has a region around it where satellites can move on stable orbits. This region becomes smaller if a giant lies close to its star, but a giant lying at 1 astronomical unit (AU) can still have stable satellites. (An astronomical unit is equal to 150 million kilometers, or 93 million miles, the distance between the Sun and Earth.) However, these satellites may not survive if the star forms multiple giants. If the planets grow large enough, they can develop unstable orbits that bring them close to one another. A close encounter between two giants would gravitationally fling any satellites away from their respective planet.

If such satellites exist, could they support life? Possibly. Small satellites like Europa and Titan may be able to sustain life, but to be Earthlike, a satellite needs to be large. A large satellite can have a thick enough atmosphere to shield its surface from the lethal radiation produced by giant planets. It can also have plate tectonics, which would keep the climate at liquid-water temperatures.

To be life sustaining, a satellite additionally needs water and other volatile materials to create organics. A giant planet that formed 1 AU from a Sunlike star would capture only dry, volatile-poor solids from the star's nebula. This giant would have satellites similar to the Moon or Mercury. Earthlike satellites could form if this planet migrated inward from about 3 AU, where the nebula would contain some solid water and volatiles. Alternatively, a satellite could obtain these materials by accreting asteroids and comets that formed in the outer parts of the nebula.

There is one other problem, however: giant planets are very effective at attracting flying debris, as comet Shoemaker-Levy 9 demonstrated. The satellites of these planets are likely to suffer a substantial and sustained bombardment, which may make them inhospitable places.

Can we discover these satellites? Yes. Extrasolar planets can be detected when they pass in front of their parent star, causing the star to dim. Satellites can be found the same way. Because the dimming effect is small, a space-based telescope is needed to see it. However, if such satellites exist, NASA's proposed Kepler mission should find some of them.
—JOHN E. CHAMBERS,
NASA Ames Research Center

To read more about the assortment of international missions being planned to search for Earthlike worlds around other stars, visit **http://ast.star.rl.ac.uk/darwin/searches.html**.

Send Us Your Questions

We enjoy finding answers to your queries, so please keep asking! But remember, we must restrict our attention to those topics that fall under the purview of The Planetary Society: planetary exploration and the search for extraterrestrial life—in our own solar system and beyond.

This means we cannot answer questions on astronomy and cosmology—dealing with, for example, such things as supernovas, gamma rays, quasars, pulsars, black holes, the big bang, dark matter, and the expansion of the universe. We also do not cover human space travel to other star systems, faster-than-light travel, UFOs, or the aerospace industry.

Send your questions about the science and exploration of planets (and other solar system bodies such as comets and asteroids) and the search for extraterrestrial life, including the many facets of SETI, to "Questions and Answers," c/o The Planetary Society, 65 N. Catalina Avenue, Pasadena, California 91106-2301. You may also e-mail them to **tps.des@planetary.org**.

Factinos

A new solar system body, roughly one-quarter to one-half the size of Pluto, has recently been discovered in the boondocks of our solar system. The new object is about 530 to 1,207 kilometers (330 to 750 miles) in diameter. Robert McMillan of the University of Arizona's Lunar and Planetary Laboratory first spotted the space rock November 28, 2000 with a 1-meter telescope on Kitt Peak.

Named 2000 WR106, the body has been classified as a Trans-Neptunian Object, or TNO—a class of icy rock that orbits the Sun out beyond Neptune's orbit. The newly found TNO has an apparent magnitude of 20, making it the brightest "minor planet" found to date. On this magnitude scale, larger positive numbers represent fainter objects—the faintest body visible with the naked eye has an apparent magnitude of about 6. On the other hand, bright Venus shines at – 4 on this scale.

Scientists estimate there to be at least 70,000 TNOs with diameters larger than 100 kilometers (60 miles) in orbit between 30 to 50 astronomical units from the Sun.
—from SPACE.com

It seems that life on land appeared at a much earlier stage in Earth's history than most scientists believed, according to researchers at NASA's Astrobiology Institute. The team has discovered fossilized remnants of microbial mats that formed between 2.6 and 2.7 billion years ago in the Eastern Transvaal district of South Africa.

The mats are composed primarily of cyanobacteria (blue-green algae), organisms that play a major role in generating oxygen from water and atmospheric carbon dioxide using sunlight. These findings suggest that an ozone shield and an oxygen-rich atmosphere existed on Earth at the time—both necessary conditions for the development of life on land.

"The suggestion that an ozone shield existed as early as 2.6 billion years ago boosts our chances in the search for life on planets orbiting other stars," said Michael Meyer, astrobiology scientist at NASA Headquarters. "Ozone would be easily detectable by the Terrestrial Planet Finder, a planned interferometer mission in NASA's 'Origins' program."
—from NASA Ames Research Center

Society News

Red Rover Goes to LEGOLAND

The week of February 11 to 16, the Red Rover Goes to Mars international student scientist team will gather in Carlsbad, California. When they program the camera on the *Mars Global Surveyor* to image the planet's surface, these nine students will be the first members of the public to operate a scientific instrument on a NASA planetary exploration mission. On February 13, visitors to LEGOLAND will not only witness the students working on their data but will also discuss the project's objectives with them. In addition, Bill Nye the Science Guy will be on hand to deliver a lecture. Throughout the week, LEGOLAND will feature special Mars exhibits. For more information, visit the Red Rover Goes to Mars page at **planetary.org**.

—Susan Lendroth, Manager of Events and Communication

Shoemaker NEO Grant Winners Announced

In an effort to advance the study of Near Earth Objects (NEOs), the Planetary Society created the Shoemaker NEO Grant program in 1997. Named after planetary geologist Eugene Shoemaker, who dedicated much of his life to NEO research, the grant program aims to increase the rate of discovery and follow-up studies of asteroids and comets in Earth's vicinity.

The deadline for the latest batch of proposals was September 2000. The Planetary Society received 22 proposals from 13 countries: Australia, Brazil, Canada, the Czech Republic, Italy, New Zealand, Poland, Romania, Slovenia, Sweden, the United Kingdom, the United States, and Uruguay.

An international advisory group of noted NEO scientists—led by Dan Durda, an asteroid researcher at Southwest Research Institute in Boulder, Colorado—studied the proposals over the course of three months. A list of winners and a summary of their proposals can be found within the NEO section at **planetary.org**.

—Melanie Melton, Web Editor

Jungle Diaries at planetary.org

Visit our website to travel with our expedition members as they trek through Belize and Mexico, looking for clues to the mysteries of the Chicxulub impact. The journey begins January 16, 2001.

Annual Audit Completed

The firm of Hensiek & Caron has completed its yearly audit of The Planetary Society. The firm determined that the Society's 2000 financial statement was in conformity with generally accepted accounting principles. Copies of the financial statement are available upon request.

—Lu Coffing, Financial Manager

Attention, Artists: International Space Art Contest

The Planetary Society needs your artistic talents and imagination! Draw, paint, or otherwise artistically depict what you think the surface of Mars will look like near the site of a future robotic exploration mission—and what that same site might look like 100 years from now. (You may include a spacecraft in the picture, but it is not required.) Also, write a brief description of why you think there would be differences between the 2001 image and the 2101 image. Be creative!

The contest is open to people of all ages and from all countries and will be judged in three age categories: 10 and under, 11 to 18, and over 18 years of age. On the back of each picture and on your written description, print your full name, age, mailing address including country, telephone number, e-mail address, language preference, and other contact information. The two pictures may be judged individually or as a pair, at the judges' discretion.

Entries must be two-dimensional images (not sculptures), with maximum dimensions of 28 by 43 centimeters (11 by 17 inches) per picture, in any nonelectronic artistic medium. Computer-generated artwork is prohibited. Only one entry (the two drawings and descriptive paragraph) per person is permitted. Art will be judged by Planetary Society staff and members of the International Association of Astronomical Artists. Judging criteria include creativity, knowledge of Mars, and artistic merit. Winning entries will be acknowledged in *The Planetary Report* and on The Planetary Society's website. All entries become the property of The Planetary Society and cannot be returned.

Submissions will be accepted at Red Rover Goes to Mars Regional Centers from January 2 to April 2, 2001. Winners from each participating country will be selected, and winning art will be included on a CD-ROM to be distributed to planetariums, science museums, and art galleries around the world.

Prizes for first-, second-, and third-place winners include gift certificates at The Planetary Store. Special merit honorable mention designees and "Best of Nation" winners will receive a Planetary Society lapel pin and a Mars panoramic poster. All winners and national finalists will be signed up for a year of free membership in The Planetary Society.

A Grand Prize winner will be selected from among the three international first-prize winners in August 2001, based on "viewer's choice" online voting. (Be sure to visit **planetary.org** to vote in August 2001!) The Grand Prize winner's art will be featured on the cover of the finalists' CD-ROM. The Grand Prize winner will also receive an autographed print by a professional space artist.

We hope you will join us in this opportunity to explore your imagination and to expand your knowledge of Mars. For more information about the contest, visit The Planetary Society's website or contact Rachel at (626) 793-5100 or **rachel.zimmerman@planetary.org**.

—Rachel Zimmerman, Education Projects Coordinator

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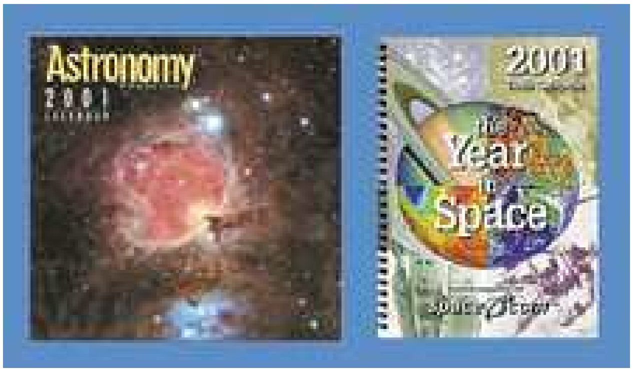

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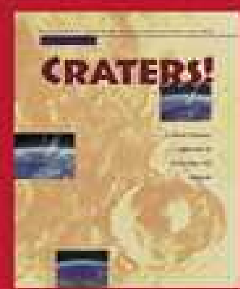

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