The PLANETARY REPORT

Volume XXI Number 5 September/October 2001

. . . this distant image of our tiny world.
To me, it underscores our responsibility
to deal more kindly with one another, and
to preserve and cherish the pale blue dot,
the only home we've ever known.

—*Carl Sagan,* Pale Blue Dot

Look again at that dot. That's here. That's home. That's us. On it everyone yo
er heard of, every human being who ever was, lived out their lives. The aggregate
religions, ideologies, and economic doctrines, every hunter and forager, every l
civilization, every king and peasant, every young couple in love, every mother
every teacher of morals, every corrupt politician, every "superstar," every "s
of our species lived there—on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. Think of th
perors so that, in glory and triumph, they could become the momen
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frequent their misunderstandings, how eager they are to kill one

Our posturings, our imagined self-importance, the delu
challenged by this point of pale light. Our planet is a lonel
this vastness, there is no hint that help will come from el

The Earth is the only world known so far to har
species could migrate. Visit, yes. Settle, not yet. Lil

It has been said that astronomy is a humb
stration of the folly of human conceits than t
to deal more kindly with one another, and

—*Carl Sagan,* Pale Blue Dot, *1994*

In the anguish following September 1
to build a hopeful future for our tiny
Now, more than ever.

—The Officers and The Board of Di

ou love, everyone you know, everyone you ev-
e of our joy and suffering, thousands of confident
hero and coward, every creator and destroyer of
r and father, hopeful child, inventor and explorer,
supreme leader," every saint and sinner in the history

he rivers of blood spilled by all those generals and em-
tary masters of a fraction of a dot. Think of the endless cruel-
rcely distinguishable inhabitants of some other corner, how
another, how fervent their hatreds.

sion that we have some privileged position in the Universe, are
y speck in the great enveloping cosmic dark. In our obscurity, in all
sewhere to save us from ourselves.

bor life. There is nowhere else, at least in the near future, to which our
ke it or not, for the moment the Earth is where we make our stand.

bling and character-building experience. There is perhaps no better demon-
his distant image of our tiny world. To me, it underscores our responsibility
to preserve and cherish the pale blue dot, the only home we've ever known.

1, we at The Planetary Society renew our commitment to our founding vision—
planet through the peaceful exploration of the cosmos.

rectors of The Planetary Society

A PUBLICATION OF THE PLANETARY SOCIETY

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Space exploration and the science that drives it have the potential to inspire all humankind. Future generations of explorers will come from all continents, even those that today do not support a major spacefaring nation. With this in mind, The Planetary Society helped sponsor "Under African Skies," as you'll read here.

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From The Editor

This is not a special issue of *The Planetary Report*; our cover does not signal content directly addressing the events of September 11, 2001. But both the Board of Directors and the staff of The Planetary Society agreed we could not publish the next issue without some reaction to the terrorist attack on the United States.

Our response was to return to our roots, to look for inspiration in the words of our cofounder Carl Sagan. We found the words in the essay "You Are Here" in the book *Pale Blue Dot*, published in 1994. There, Carl ruminated on the lessons we could draw from seeing our tiny planet, Earth, from the perspective of a spacecraft hurtling toward the edge of the solar system.

The spacecraft was *Voyager 1*, which, after finishing its duty as a planetary explorer, looked back one last time at the world from which it came. The viewpoint it gave humankind of our home world is possible only from such an exploratory ship. The perspective gained—of ourselves as well as of our planet—is achievable only by a spacefaring species. That is why we continue to explore. That is why The Planetary Society will go on and why, we hope, even now, you will continue with us on the journey.

—Charlene M. Anderson

On the Cover:

Voyager 1 turned its camera back on its home planet for the last time on February 14, 1990. For the first time, humankind could see itself in perspective from the edge of our solar system—something possible only through our efforts to explore other worlds. This evocative representation of Earth appeared in the book *Pale Blue Dot* by Carl Sagan. To see the image of Earth taken by *Voyager 1*, go to *http://planetary.org/html/society/advisors/sagandot.html*.

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Calibrating Success in Science: How Failure Fits In

by Glenn E. Cunningham

The civilian exploration of space is a high-visibility endeavor. It utilizes large amounts of taxpayers' money. It significantly impacts segments of the economy. It pushes new frontiers of science, technology, and learning. Yet when it works well, it garners little press—maybe some corner of an inside page of *USA Today*. It's when it fails that it makes big headlines.

What gets obscured is the fact that each mission is an experiment furthering scientific progress. And experience tells us that science progresses with a few steps forward and many steps backward. This is the essence of the scientific method: propose a hypothesis; design an experiment to test the hypothesis; if the experiment yields the desired result, then declare success and move forward to another hypothesis; but if it fails, change the hypothesis or the experiment and try again. Failure is expected. It is key to the scientific process.

In the laboratory, no one sees the little failures. In space, everyone sees the big failures.

Greater Complexity, Greater Risk

In the laboratory, the experiments are small and focused. In space, they become large and complex. Why? First, because experimenters are forced to pack as much of a payload as possible to make a launch cost-effective. Second, it takes a lot of overhead to support an experiment in space—power generation, computational control, complex articulations, information management, thermal control, communications, and propulsion—so space systems become highly complex. Many are one-time-use systems and therefore without a time frame to work out the bugs. Others are forced, for one reason or another, to use new and sometimes less-mature technologies.

Complexity breeds error—in judgment, in design or implementation, in human communication. Modern management systems are supposed to eliminate or contain the possibility of error leading to failure. For the most part, they do, but sometimes because of cost containment or schedule acceleration, they don't.

Management says they expect setbacks. Certainly not every experimental hypothesis proposed will be proved, and the experimenter always anticipates failure. Clearly, management systems will not eliminate all human error. But still, management and taxpayers are loath to accept failure when it occurs. Even worse is the emotional letdown for the team of experimenters, who strive diligently for success.

We see many small failures in every space mission. We go to great lengths to prepare ourselves with procedures and processes to deal with them when they occur. Typically, such events never make the news. Very few people except insiders know about them, and they usually prove to be learning experiences for the spacecraft designers and mission operators. But if one of these events, however small, cripples or terminates a mission, it gets big-time attention because the consequences are big time—thousands or millions of taxpayers' dollars are lost, and scientific progress is stymied.

High Expectations

I landed on the management team of one such mission—*Mars Observer*. It had its share of small failures during development and the early portion of its flight mission, but these were all mitigated in due time. Expectations were high for the first US Mars mission in nearly two decades as the spacecraft was just three days away from its encounter with the Red Planet. And then, after the supposedly simple event of pressurizing the propulsion system, we never heard from *Mars Observer* again.

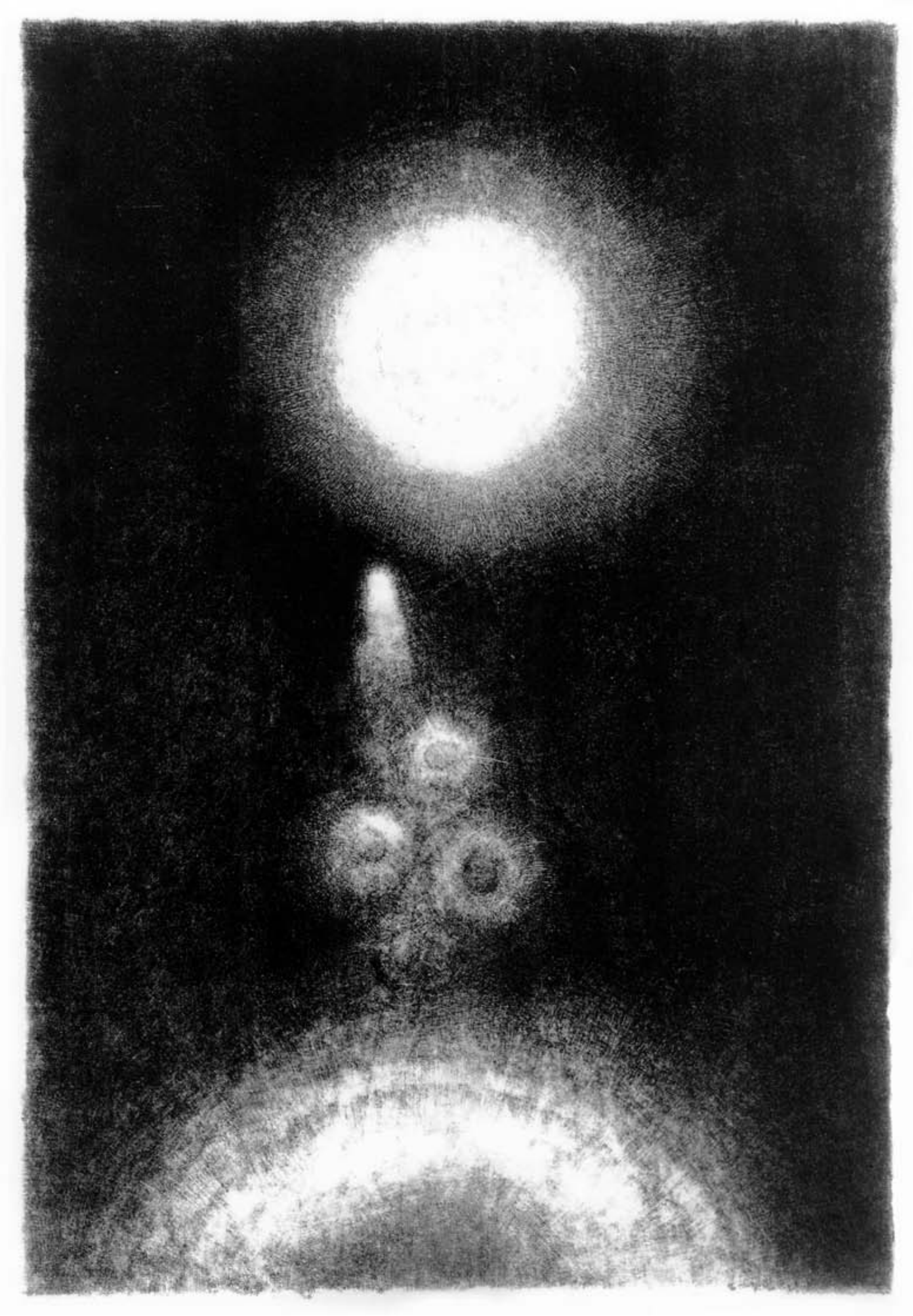
The speculation was that some valves leaked propellant vapor, the propellant lines were cold, the vapor condensed the fuel and oxidizer mixed in the propellant lines, and the spacecraft exploded. We'll never really know, but it looked as if several small failures combined for a devastating consequence.

In the wake of headlines blazing forth the failure, an enlightened NASA management recognized the value of continuing to explore Mars. Plans were made to send most of the same science instruments back to the Red Planet. These were to travel on a smaller spacecraft, with less reliance on propulsion. Reliance shifted to the mission's management and technical teams, to correct for the failures of *Mars Observer*. The result was *Mars Global Surveyor*, launched just three years following the loss of *Mars Observer*. *Mars Global Surveyor* remains an unqualified success.

Reality Check

This experience shows that management must have realistic expectations. Failures will occur. For progress and eventual mission success, we need to correct the small failures and ensure that there will be more steps forward than the inevitable steps backward.

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



Rodolfo Abularach,* Ascension, *1966.
Lithograph, edition of 20. Norton Simon Museum, Pasadena, California, Anonymous Gift, 1969.

Every aerospace manager at every opportunity preaches mission success. Every aerospace organization lists success as its first priority. Every organization chart now includes a mission success manager.

Can we manage mission success? Probably not. But we must set the stage to minimize the consequences of the inevitable failures and to make each failure a learning experience. We all—experimenters and managers as well as taxpayers—need to learn to tolerate failure in the pursuit of progress.

The Planetary Society has recently experienced a failure on its *Cosmos I* mission. The design decision to not separate the payload if the launcher's attitude destabilized led to failure to demonstrate the solar sail apparatus. This was a small failure with a big consequence. But, as with *Mars Observer*, the proper response is to assess the problem, mitigate it for future flights, and move ahead to ultimate success.

Glenn E. Cunningham retired from NASA in June 1999, after 33 years working on planetary spacecraft design and flight operation. While at NASA, he served as project manager for Mars Surveyor Operations, Mars Global Surveyor*, and* Mars Observer*, and was deputy director of the Mars Exploration Directorate. Since "retirement," Cunningham has served as a consultant for a number of commercial and government clients. In addition, he volunteers at The Planetary Society, where he is project manager of the Red Rover Goes to Mars project.*

TOUCHDOWN!

NEAR's Historic Landing

The NEAR Shoemaker *spacecraft, its jets still firing, kicks up dust seconds before landing on the surface of asteroid 433 Eros.* *Illustration: Don Davis*

by Robert Farquhar, Joseph Veverka, and Bobby Williams

At 3:02 p.m. EST on February 12, 2001, *Near Earth Asteroid Rendezvous* (*NEAR*) *Shoemaker* became the first spacecraft ever to touch down on an asteroid. This achievement is all the more remarkable because the *NEAR* spacecraft was designed to simply orbit its target, Eros.

NEAR Shoemaker had been intensively studying Eros for a year, having arrived on Valentine's Day, February 14, 2000. The mission was scheduled to end one year to the day later, after which the spacecraft would be abandoned in orbit around the asteroid. But there was an alternative well worth considering: if the spacecraft were going to "die" anyway, why not try to land it on Eros? As it descended toward the surface, it could take highly detailed images of the asteroid and provide us with better data than we could ever collect from orbit.

And it did just that. Our story concerns what *NEAR*'s unprecedented images revealed, as well as how the spacecraft made its remarkable journey from its home on Earth to its ultimate resting place on the floor of a football-field-size crater on Eros.

NEAR Is Launched

Asteroids and comets that closely approach Earth's orbit in their journeys around the Sun are collectively called near-Earth objects, or NEOs. Asteroid 433 Eros (numbered by the order of discovery) is an irregularly shaped body about 33 by 13 by 13 kilometers (20.5 by 8.1 by 8.1 miles) that spins once every 5.2 hours. It is also one of the largest NEOs.

Asteroids and comets are generally understood to be debris left over from the formation of our solar system. As such, they carry clues to how our solar system evolved to its present state. But that's not all. They also are the parent bodies of the meteorites that fall to Earth. One of their number wiped out the dinosaurs 65 million years ago. It therefore benefits us to know more about the ones that pass close to Earth.

With this in mind, the *Near Earth Asteroid Rendezvous* spacecraft was launched on February 17, 1996 (Figure 1, below). Rather than travel straight to Eros, it looped around the Sun, positioning itself to rendezvous with the asteroid. On February 18, 1997, *NEAR* reached its most distant point from the Sun at 2.18 astronomical units (one AU is the mean distance from Earth to the Sun, about 150 million kilometers, or 93.2 million miles), setting a new distance record for a spacecraft powered by solar cells.

About four months later, on June 27, 1997, *NEAR* carried out the first reconnaissance of a C-class asteroid when it flew by 253 Mathilde, a denizen of the main asteroid belt between Mars and Jupiter. Asteroids are divided into types by the spectra of the light they reflect. The most common are the dark C-types, apparently rich in carbon compounds. Eros itself is an S-type asteroid, which is brighter and more reddish than the C-type.

NEAR took 534 images of dark Mathilde. These determined that the asteroid's density is so low, its interior must be full of holes. Mathilde thus seems to be some sort of orbiting rubble pile, perhaps repeatedly blasted to bits by impacts over the eons, only to re-

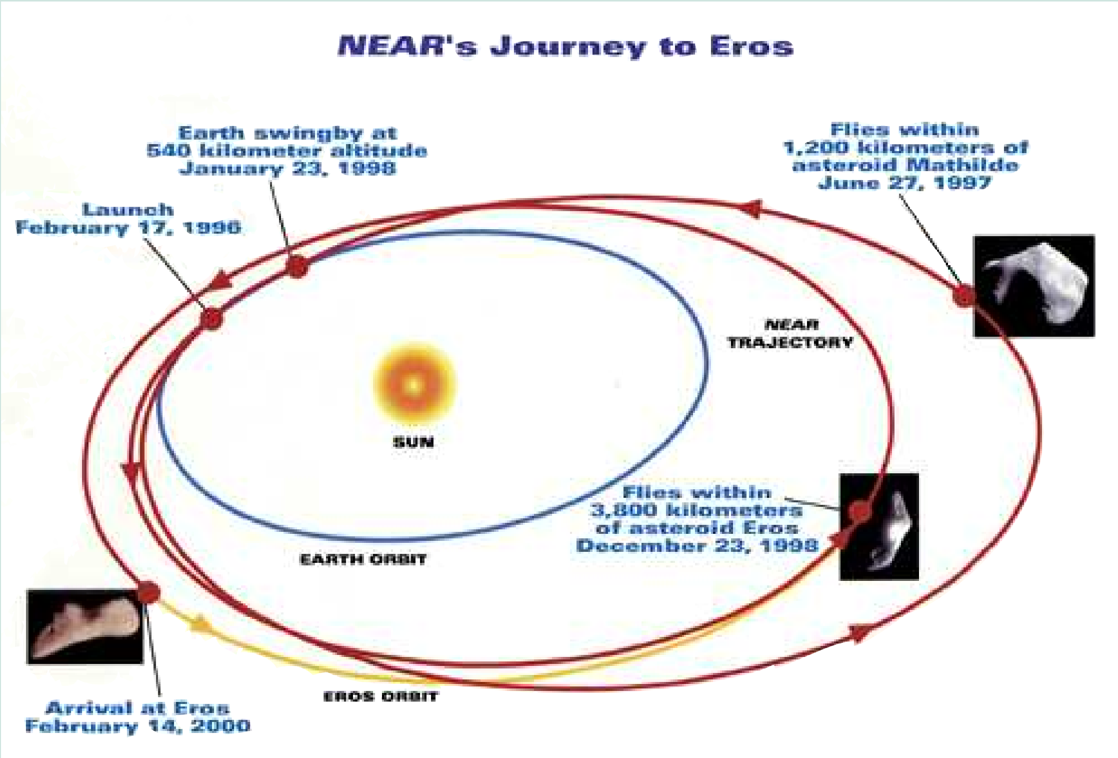


Figure 1: Four years after launch, NEAR Shoemaker *became the first spacecraft to orbit an asteroid. One year later, the spacecraft would make history again by landing on its target, asteroid 433 Eros.* *Illustration: APL/NASA*

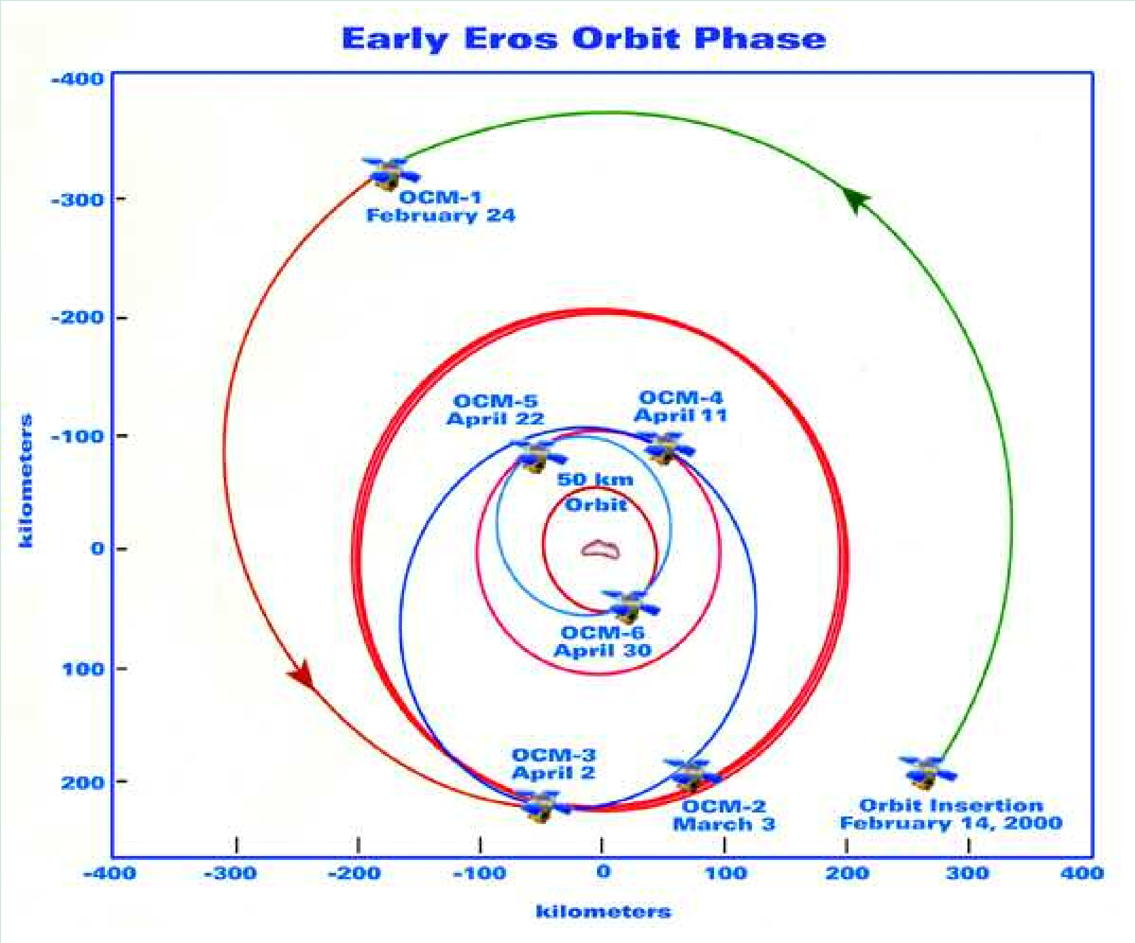


Figure 2: When NEAR Shoemaker *finally arrived at Eros, mission controllers gradually narrowed the spacecraft's orbit of the asteroid down to 50 by 50 kilometers (31 by 31 miles). This view, from the direction of the Sun, traces* NEAR Shoemaker*'s path during its first weeks at Eros. The abbreviation* OCM *stands for "orbit correction maneuver."* *Illustration: APL/NASA*

form again and again as the bits' gravity pulls them back together.

Then, on December 20, 1998, almost three years after launch, *NEAR* began a sequence of propulsive maneuvers planned to culminate in orbit insertion at Eros on January 10, 1999. But mission controllers aborted the December 20 engine burn after it fired for less than a second. Instead of heading toward a rendezvous, on December 23, *NEAR* flew by Eros. (For details, see the November/December 1999 issue of *The Planetary Report*.)

Unfortunately, in its recovery from the botched rendezvous maneuver, the spacecraft used up almost 30 kilograms (66 pounds) of its precious hydrazine fuel. Fortunately, though, *NEAR*'s mission design could cope with this setback. On January 3, 1999, the spacecraft again fired its thrusters, and then reversed its movement away from Eros. This critical event was followed on January 20 by a cleanup maneuver; a midcourse correction on August 12 retargeted *NEAR* toward Eros.

As the spacecraft got closer and closer to Eros, *NEAR*'s camera captured better and better views of the asteroid. The camera searched particularly for any moons orbiting Eros. In 1993, as it traveled to Jupiter, the *Galileo* spacecraft had discovered a small moon, Dactyl, orbiting the asteroid Ida. But although *NEAR* thoroughly searched the sky around Eros, it found no moons. If any do exist, they must be tiny indeed, less than 20 meters across.

In Orbit

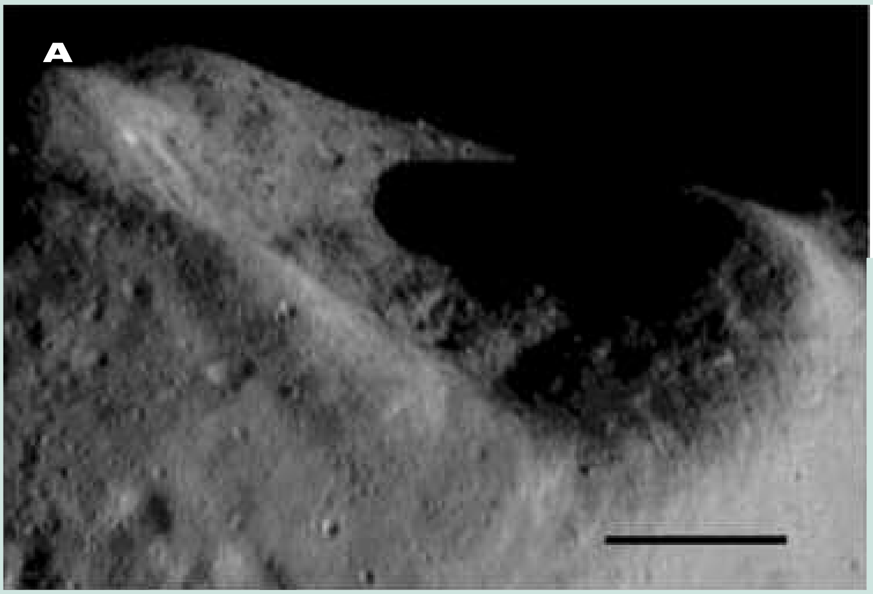
On its final approach to Eros, on February 13–14, 2000, *NEAR* traveled between the Sun and the asteroid at a distance of about 200 kilometers (125 miles). The relative velocity between the spacecraft and the asteroid was only 10 meters per second, and the slowly changing angle of view from the spacecraft, with sunlight behind it, provided especially good conditions for the infrared (IR) spectrometer to do its work. The IR spectrometer measures how sunlight is reflected off the asteroid's surface, and by noticing subtle variations in the wavelengths of that light, the spectrometer can tell us what types of rock cover Eros. The data collected confirmed that, by and large, Eros is blanketed with one type of rock, probably similar to the rock forming the ordinary chondrite meteorites that have fallen to Earth.

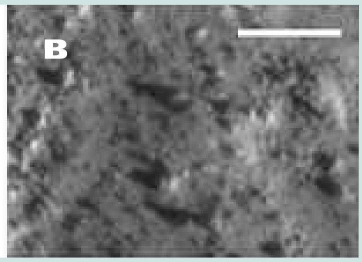
Shortly after that flyby, at 10:47 a.m. EST on February 14, 2000, *NEAR* entered a 321-by-366-kilometer (199.5-by-227.4-mile) orbit around Eros. By so doing, it became the first spacecraft ever to orbit a small body. One month later, on March 14, NASA added *Shoemaker* to *NEAR*'s name, honoring Gene Shoemaker, the distinguished planetary scientist who had done so much to advance humankind's understanding of the smaller members of our solar system.

You can trace *NEAR Shoemaker*'s orbital history for its first two months at Eros in Figure 2 on page 8. Gradually, mission controllers brought the spacecraft closer to the asteroid. On April 30, it reached its planned orbit of 50 by 50 kilometers (31 by 31 miles). As the spacecraft descended through these early orbits, scientists determined with increasing precision such physical parameters as Eros' mass, gravity harmonics, and rotational pole position.

Confidence gained during *NEAR*'s first four months in orbit encouraged mission managers to attempt lower orbits. This allowed the x-ray/gamma-ray spectrometer (XGRS) to operate for about two months in an orbit that regularly reached altitudes under 20 kilometers (12 miles). The XGRS requires long periods at low altitudes to detect signals from the key elements (silicon, magnesium, aluminum, and iron) it uses to map surface composition.

But low-altitude orbits around a potato-shaped body such as Eros are strongly influenced by that body's irregular gravity field. To operate a spacecraft safely at low altitudes requires vigilance and close coordination among the science, mission design, navigation, and mission operations teams.





Figures 3A and 3B: Eros' surface is scattered liberally with blocks (boulders) ejected from various impacts in its past. The vast majority of these blocks were kicked up by the impact that formed Eros' youngest large crater, Shoemaker. This image mosaic depicts Shoemaker Crater as viewed from the south. The black scale bar in 3A represents 2 kilometers (1.2 miles).

Image 3B is a close-up of the inside of Shoemaker Crater, showing the high density of ejected blocks there. The white scale bar is 200 meters long.

Images: APL/NASA

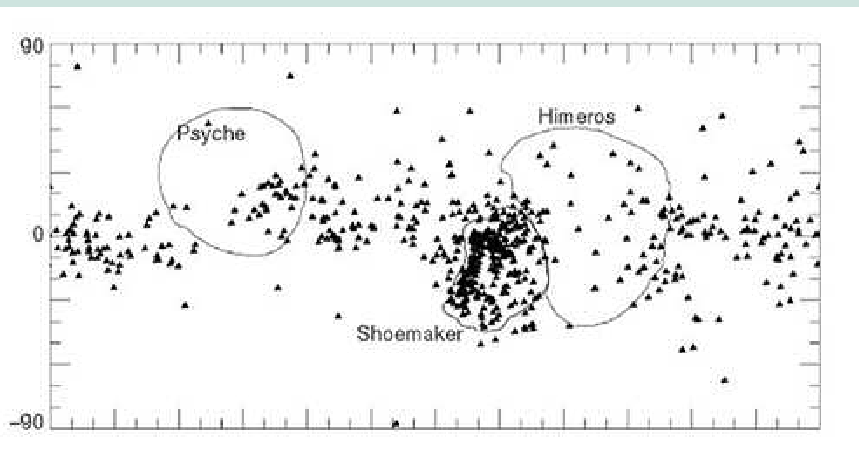
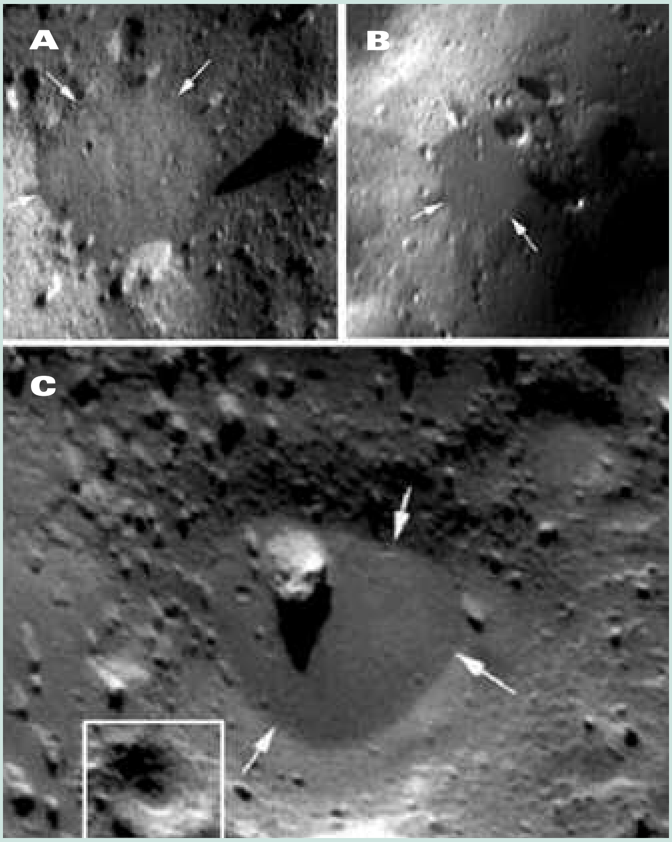


Figure 4: The* NEAR Shoemaker *team created this simple cylindrical projection map of Eros to mark the distribution of all ejected blocks larger than 30 meters. The asteroid's three largest craters are outlined. ***Illustration: APL/NASA***



Figures 5A, B and C: These three images show the "ponding" of debris in the bottoms of craters on Eros. The fine material that forms these ponded deposits sharply embays the preexisting topography (arrows). The crater in image 5A is 76 meters in diameter; the one in B is 210 meters across. In image C, the crater is 90 meters in diameter. The white box highlights a topographically isolated crater with a small interior pond, indicating the ponded material did not flow in from the surrounding terrain.
Images: APL/NASA

NEAR was able to confirm that Eros is an undifferentiated asteroid with a homogeneous structure. Larger bodies, such as Earth, are so large that their own gravity generates internal pressures that melt the rocks composing them. The melted rocks settle out differently—or differentiate—causing layers within these rocky bodies. Evidently, Eros is not a fragment of a larger, differentiated body blasted apart in early solar system history. Neither is it a mass of fragments from multiple impacts bound together by gravity, as is Mathilde, for example. Eros is just one big rock.

But impacts have shaped that rock. Covering it are craters large and small, and it shows a curious saddle-shaped depression that may be impact generated. These impacts have completely covered Eros' surface with debris, ranging in size from dust grains to giant boulders many meters wide.

At 33 kilometers (20 miles) long, Eros is the second-largest near-Earth asteroid, but it's still small compared with some of the main-belt bodies, such as Ceres, which is 457 kilometers (284 miles) in radius. Its small size gives Eros only weak gravity, about one thousand times less than Earth's. So, fast-moving bits of debris kicked up by impacts could easily escape to space. Scientists have suspected that asteroids as small as Eros can hang on to impact debris, but some on the *NEAR* project were surprised by the abundance and ubiquity of the debris on Eros.

Everywhere, we find ejected blocks tens of meters across (Figure 3, page 9). Most of the craters are partially filled in by finer debris. One important task was to make a global map of all blocks bigger than 30 meters (Figure 4, page 9). This effort produced clear evidence that most of the conspicuous blocks were produced by the impact that formed the youngest large crater on Eros: Shoemaker Crater, a scar some 7 kilometers (4 miles) wide. However, the complexity of the ground-up debris and the way it coats the surface raised many questions that we could answer only by getting a closer look.

Dropping Down for a Closer Look

Our first opportunity for really close images came on October 25, when *NEAR* swept down to 6.4 kilometers (3.9 miles) over one end of Eros. The camera registered details as small as 1 meter. On October 26, the spacecraft flew over at an altitude of 5.5 kilometers (3.4 miles). Emboldened by this success, we started a second series of low-altitude passes in January 2001, ending with a run of 2.74 kilometers (1.7 miles) on January 28. The images taken that day showed details under 0.5 meter across.

NEAR's low-altitude images revealed a subdued, gently undulating surface marked by abundant blocks and conspicuously degraded craters. Many craters showed evidence of infilling by fine debris. We were surprised to find smooth, flat areas, which we called "ponds," inside certain craters (Figure 5, this page). The ponds' smoothness indicates that some efficient process sorts out the finest grains of the impact debris from the coarser, more blocky portions and concentrates the fine material into low-lying areas such as crater bottoms.

This process remains a big puzzle. Eros has no atmosphere; hence no winds can sort the fine from the coarse materials. Nor is there water to carry and distribute the grains, as rivers do on Earth. What could be going on? Do impacts shake the asteroid enough to sift some of the debris and send the fine stuff downhill? Or are the fine grains charged by solar radiation, causing them to repel one another and move downhill under the influence of the asteroid's weak gravity?

We are still working to answer these questions.

The End Is *NEAR*

One question asked even before the launch of *NEAR* was what to do with the spacecraft once it completed its primary mission. Should we abandon it in orbit, or should we find something scientifically valuable to do with it?

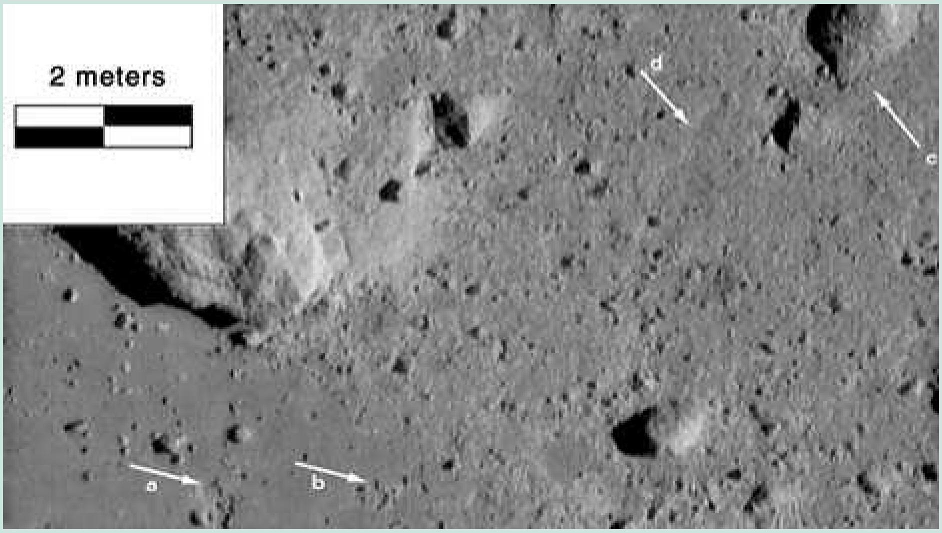


Figure 6: The last two images that NEAR Shoemaker *captured before landing are combined in this frame. Taken only 125 meters above Eros' surface, with an average resolution of 1.4 centimeters (0.5 inch), this is the best view of a pond with collapse features. Two enclosed pitlike depressions are indicated by arrows a and b in the smooth pond deposit at lower left. A moatlike depression surrounds a meter-size boulder indicated by arrow c. Arrow d points to a somewhat sinuous, channel-like depression.* *Image: APL/NASA*

One adventurous proposal was to attempt a landing on Eros. In this scenario, as it descended, the spacecraft would keep its antenna pointed at Earth, transmitting images and other science data as quickly as possible. Although a landing would definitely attract media attention, several key members of the *NEAR* team worried that failure would tarnish the mission's earlier successes.

After weighing the arguments, NASA managers decided on a controlled descent to the surface. The primary goal would be a series of high-resolution images; a secondary goal, a soft landing on the asteroid. We harbored hope that the spacecraft would survive to transmit from the surface.

The controlled descent was scheduled for February 12, just two days before the formal end of the mission—that is, the funding cutoff for mission operations. The plan would allow a couple of days to contact the spacecraft after it had set down on Eros.

To prepare for the landing, on January 28, *NEAR* moved back into a 35-by-35-kilometer (22-by-22-mile) orbit. On February 12, a de-orbit maneuver at about 10:30 a.m. EST began the descent. After four braking maneuvers, *NEAR Shoemaker* touched down on Eros at 3:02 p.m. EST with an impact velocity of only 1.7 meters per second. That's less than the 2.4-meter-per-second landing velocity of *Viking 1* on Mars. *NEAR*'s touchdown was far from the controlled crash some had predicted.

NEAR's camera performed beautifully during the descent, returning 69 crisp images. The best was taken from only 125 meters above the floor of a 50-meter crater (Figure 6, this page). The final image shows detail on the scale of inches and provides a close-up of one of the enigmatic ponds we'd seen during the low-altitude flybys in January.

In these images, we again see evidence of fine material being moved efficiently into low-lying areas, but now we can observe channel-like depressions apparently associated with that movement. Unexpectedly, we also see evidence of an erosion process leading to the formation of elongated, pitlike depressions.

Amazingly, *NEAR* settled so softly on the surface that it could continue to operate and send signals back to Earth. When we determined that the gamma-ray spectrometer was still working and could collect valuable data from a mere 10 centimeters (4 inches) from the surface, NASA granted *NEAR* a 14-day mission extension. These gamma-ray data are an extremely valuable bonus to mission science, and their analysis is telling us much about Eros' composition.

Finally, on February 28, mission controllers ordered *NEAR* to enter a deep sleep. Still, the spacecraft might be heard from again. In November 2002, *NEAR* will be back in sunlight, its solar cells could charge again, and it will be only 0.77 AU from Earth—so, we may try to contact the spacecraft one more time.

The spectacular success of the *NEAR Shoemaker* mission was the product of many individual and collective contributions. Its highly motivated team succeeded in spite of considerable adversity. That team was willing to accept risks to achieve a prominent place in the history of space exploration.

Yet, the complexity of the surface features discovered by *NEAR* tells us we need to visit other asteroids before we can truly understand the processes that shape these bodies. We need to build on *NEAR*'s success and, with landers and sample-return missions, continue to explore the small objects that share the solar system with us.

Robert Farquhar, affiliated with Johns Hopkins University Applied Physics Laboratory, is NEAR*'s mission director. Joseph Veverka, from Cornell University, leads the* NEAR *Imaging Team. Bobby Williams, from the Jet Propulsion Laboratory, is* NEAR*'s navigation team leader.*

Looking Back, Moving Forward:
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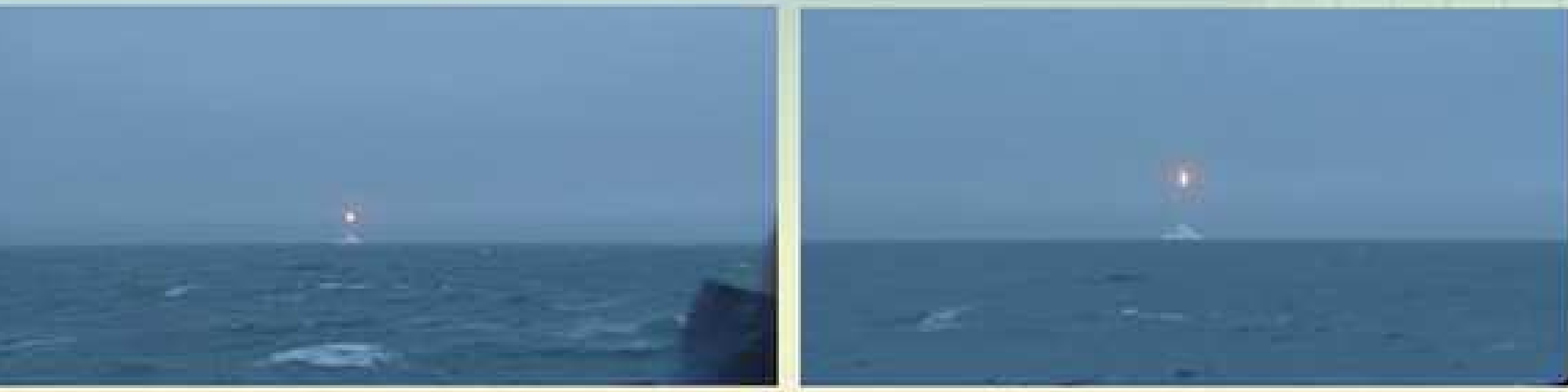


These frames (captured from videotape) show the launch from the Barents Sea as it looked from the deck of the observation v

by Louis D. Friedman

Shortly before the launch of the Cosmos 1 *test flight, Louis Friedman makes contact with a room full of anxious staffers, media, and guests at Society headquarters in Pasadena, California.*

Photo: Dave Banks, courtesy of Cosmos Studios/MPH Entertainment

Viewed from the rolling deck of the ship out in the Barents Sea, the *Cosmos 1* test launch looked perfect—and not just for the three seconds we could see the rocket shoot out from the ocean and into the low clouds on the horizon, but also for the following hour as we listened to reports based on tracking data. These data indicated the rocket was on course to its designated landing site on Russia's Kamchatka peninsula.

I was on a satellite telephone reporting live to our Project Operations–Pasadena (POP) room at Planetary Society headquarters. The group at POP, headed by our data systems manager, John Garvey, was keeping informed on the progress of the flight both through me and through Mission Operations–Moscow (MOM) at the Babakin Center, our principal contractor for the spacecraft.

I had prepared an attention-getting opening for my eyewitness report. I had wanted to say:

The sun was shining on the sea,
Shining with all his might; . . .
And this was odd, because it was
The middle of the night.
—*Lewis Carroll, "The Walrus and the Carpenter"*

We were above the Arctic Circle; it was mid-July; the Sun was supposed to be shining all night. But it was cloudy and, for a while, almost dark—although it brightened a bit by the 4:40 a.m. launch time. So, I had to forget about reciting Carroll's lines. Still, I could convey the excitement felt that morning.

Harder to convey was the poignancy of being on a Russian Navy ship to witness a submarine launch of an intercontinental ballistic missile (ICBM) rocket off the northern coast of Russia. The ICBM is at the heart of international debate concerning nuclear missile defense, strategic arms treaties, and national weapons policies.

Breaking Precedents

It had taken us about four hours to get from Murmansk harbor to the launch area in the Barents Sea. The submarine and a second observation boat carrying the navigation and communications team supporting the launch were only a couple of hours ahead of us getting into position. We were to launch the flight test of solar sail technology by deploying two blades of an eight-bladed sail design. The test would mark the culmination of months of work toward what we hope will be the first orbital flight of a true solar sail.

We were breaking precedents everywhere. Every aspect of our trip to the launch area was subject to last-minute reviews by operatives of a secretive, classified system developed during the Cold War. But, once aboard the Navy vessel, we were treated warmly by the crew and had the run of the ship's common areas. I was

sing Our Solar Sail Test Flight

essel. (That's the cuff of Louis Friedman's sleeve in the first frame.) Images: Courtesy of Cosmos Studios/MPH Entertainment

even permitted to use the satellite phone and the Global Positioning System (GPS), despite warnings this might not be allowed.

Working as part of an international team is an added benefit (a "spin-off," if you like) of space exploration. Efforts to probe the universe have the power to bring people together in every bit as challenging—but so much more productive—a way as war. The captain of the ship, in honor of our mission, presented The Planetary Society with a Russian Navy flag. And the Russian Navy fleet now has an operational missile support ship with *Cosmos 1* stickers pasted on it.

A Tense Wait

Despite the goodwill all around, the wait was tense. The first indication of something wrong came from a satellite phone call. *Cosmos 1*'s mission and payload manager Viacheslav (Slava) Linkin received word from the recovery team in Kamchatka that they'd picked up no signal from the reentry capsule at all. With three different locating sources onboard, including our own GPS navigator, no signal at all meant either (1) the spacecraft hadn't landed at the targeted area or (2) it had never turned itself on. And we knew from the tracking data that it had come down on the peninsula.

The next hour was a nail-biter. We were hearing nothing from our spacecraft, which should have begun signaling us over 30 minutes before. We flailed about trying to get information, calling the recovery team in Kamchatka, calling POP to find out if they'd heard anything, calling MOM for any news they'd received about the flight. At first, the Navy and the Makeev Rocket Design Bureau personnel had been smiling and jovial; it appeared the flight was a success.

Then, about an hour later, the Makeev representative told us that telemetry data from the rocket indicated it had failed to separate from the spacecraft. Safety systems inside a rocket associated with a submarine launch prevent the spacecraft from turning on until free of the rocket. So, our spacecraft was never turned on. The sail deployment test and the reentry and recovery sequence were never initiated. The spacecraft and rocket flew together to crash in some unknown spot in Kamchatka.

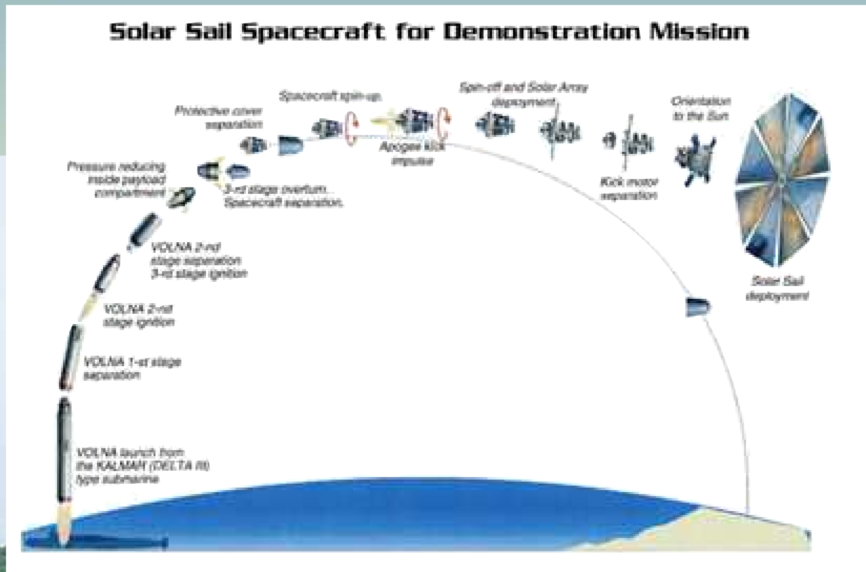
Name That Spacecraft

Our project is *Cosmos 1*; our goal, to accomplish the first solar sail flight. The spacecraft carrying out this project should be named, but, following tradition, only if and when successfully launched and operating in space. The suborbital spacecraft got to space but never operated there—hence, no name. We are now planning two spacecraft: one for an orbital test, the other as a backup to complete the mission.

We would like to involve our members in naming the craft. So, we invite you to visit our website and submit a name in the form provided in the Solar Sail section of the site.

A team from The Planetary Society, along with Cosmos Studios and those working on the mission in both Russia and the United States, will make a final selection. The winning selection will be announced during the Arts &Entertainment (A&E) Network documentary to be produced about the *Cosmos 1* project.

We await your ideas at *planetary.org*. *—LDF*



Here is the sequence of stages **Cosmos 1** *will follow from launch until its insertion into Earth orbit.*

Illustration: Babakin Space Center

The **Volna** *rocket bearing the* **Cosmos 1** *test capsule as it was lowered into the* **Borisoglebsk**, *the submarine that carried it to the Barents Sea.*

Photo: Makeev Rocket Design Bureau

Cosmos Studios is producing a documentary of the **Cosmos 1** *project for the Arts & Entertainment Network. The video camera is trained on Slava Linkin,* **Cosmos 1**'*s mission and payload manager.*

Photo: Louis Friedman

Taking Stock

The landing site in Kamchatka is densely wooded and covered with rivers and lakes, and it's doubtful the spacecraft will ever be found. Not that it matters much; there's no technical reason to recover it. I would, however, have liked a souvenir from The Planetary Society's first flight to space. (It would have been like collecting Babe Ruth's first foul ball hit into the stands.)

Let us remember that we did make it to space, to our intended 400-kilometer (about 250-mile) altitude. We flew even higher than the shuttle. Although we failed to perform our mission, we did successfully develop, integrate, and check out a test spacecraft and conduct a launch. I consider that an achievement for a space interest group and for our sponsor, Cosmos Studios. Yet, it is a bittersweet achievement at best. Still, the lessons learned will serve us well in future planning. The launch failure means we must rethink that planning both for prudent preparation and for schedule goals.

The project's technical team, the relevant Russian space organizations, The Planetary Society, and Cosmos Studios are all proud of what we achieved, disappointed at what we did not, and determined to move forward to the first solar sail flight.

Our New Plan

We have decided not to retry the suborbital test flight. In truth, we had to make compromises to perform the test. We had to integrate with an experimental reentry capsule unconnected to solar sailing, to fly without telemetry, and to build a spacecraft designed differently than our orbital craft. Rather than retrace these steps—which are diversionary to our orbital development—we will next conduct a test deploying the sail blades in orbit, where they really should be tested.

We will also test sail control and dynamics, both critical components of solar sail technology. We can test these with the telemetry and sensors we lacked in the suborbital test. The test mission will be conducted this winter with the orbital spacecraft currently in development.

Because we insured the suborbital mission, we can proceed within the cost and schedule constraints of our project. In addition to testing in orbit this winter, we will build a backup orbiter spacecraft, which can be used for a second orbiter mission. If all goes smoothly, the orbital test flight may be expanded to allow us to reach our goal of the first controlled solar sail flight, gradually increasing the orbital energy of the craft and then slowly moving it away from Earth. Otherwise, we

So, What Happened? by Jim Cantrell

In the early morning of July 20 (Moscow time), the Russian *Delta III* submarine *Borisoglebsk* issued a launch command to our converted *Volna* intercontinental ballistic missile (ICBM) tucked away in its launch tube. The launch vehicle was ejected and ignited and then safely cleared the submarine and, finally, the ocean surface. Its roar was stupendous as it rapidly ascended through the clouds and toward the cosmos. On board, it carried the suborbital spacecraft designed to deploy the solar sail blades of *Cosmos I*.

All systems appeared to be go as the fuel and oxidizer inside the first stage were expended and the first stage separated from the vehicle, then dropped and tumbled slowly away from the remaining stages and spacecraft. In turn, the second stage burned its mixture of hydrazine (a fuel that smells like rotten fish) and nitrogen tetroxide and performed flawlessly throughout its segment of the flight.

During this flight, the converted *Volna* ICBM transmitted data to ground stations signaling that, so far, all was well with the launch. Word of the successful first- and second-stage firings and separations made its way to the vessels bearing our crew out on the Barents Sea and also to our project operations center in Pasadena. We all rejoiced as we imagined that one of the riskiest parts of the mission had passed without incident.

The *Volna*'s third stage was originally designed to position, target, and dispense nuclear warheads and thus possessed some very precise navigation and maneuvering capabilities. With our suborbital spacecraft mounted as payload in place of these warheads, the third stage had only to reorient and separate the spacecraft from the rocket.

The payload is attached to the third stage by 12 bolts, which are released by very small explosive devices. Six bolts were released at the start of the separation, but, for reasons not understood, the third stage experienced low thrust for part of its reorientation operation. The software routine sensed the smaller-than-programmed velocity change and locked out the remainder of the separation procedure. The second set of six bolts therefore did not release, and the spacecraft remained attached to the third stage.

As long as the spacecraft does not separate, its systems cannot be turned on. It's understandable why the *Volna*'s designers included this feature—to be sure a payload wouldn't veer off course. Our design would not allow the spacecraft to be switched on until separation. That way, it wouldn't accidentally become operable while still attached to the rocket nestled inside the submarine.

If the spacecraft were permitted to separate, we could have flown our mission satisfactorily, even with the lower velocity. That's because the velocity difference was minuscule for our purposes. (Navigating a solar sail test craft is a much less precise job than targeting an ICBM.)

The spacecraft was scheduled to land in Kamchatka, where a ground crew had been well placed to retrieve it. The crew did spot an incoming object. However, its reentry point ended up outside the intended target area. Because the third stage failed to separate, the object on reentry differed in its aerodynamic drag from that of the inflatable reentry shield we were expecting. This difference was enough to send our return payload on a different trajectory.

A subsequent helicopter search failed to find the spacecraft. Since the spacecraft was operationally on "off," none of our three navigation systems or beacons could track it. Plus, the landing region was full of trees, lakes, hills, and thick growth. We assume the payload made a good-size hole in the soil. If only we could locate that hole—covered though it is by the dense terrain of Kamchatka.

Jim Cantrell is the contract manager for Cosmos 1 *and a longtime friend of The Planetary Society.*

will have the backup spacecraft to try again. The decision about use of the backup spacecraft will be made after the orbital test flight.

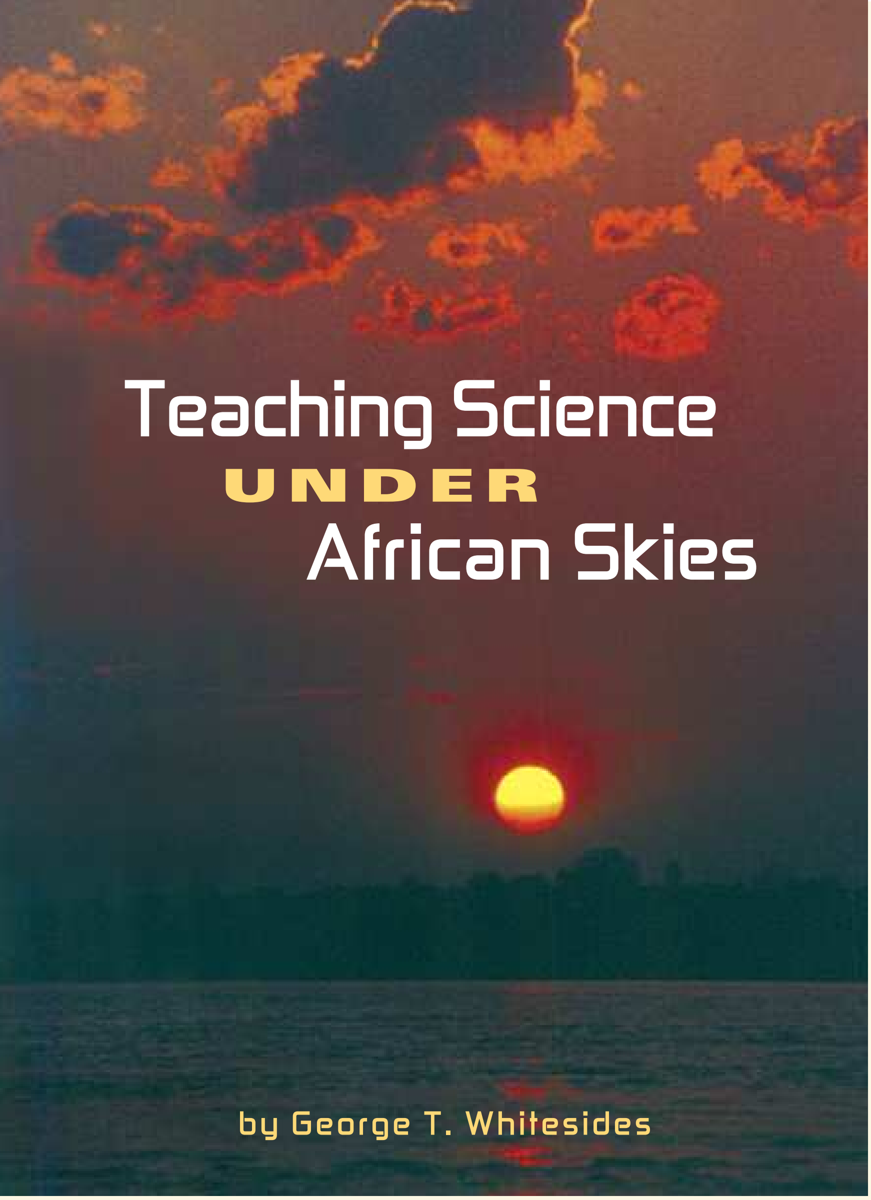
Even with the launch failure, The Planetary Society has accomplished something no other space interest organization has ever accomplished, and our partner, Cosmos Studios, has done something no other media organization has ever done. We went to space. And we will do so again.

A Personal Note

We successfully integrated our spacecraft with a converted submarine-launched ballistic missile. We successfully coordinated Russian space agencies and the Russian Navy to carry out an unprecedented flight. We checked out a flight-ready sail deployment system and got it launched.

Nevertheless, we failed to complete the last step of the swords-to-plowshares conversion. I thought about this while sailing back into Murmansk harbor on the Russian Navy ship we'd boarded to witness the launch. The conversion of a rocket designed to carry a nuclear warhead to one adapted to conduct our little spacecraft on a pathway to the stars may not have been complete. But it is happening, and we're making it happen.

Louis D. Friedman is executive director of The Planetary Society.



Teaching Science UNDER African Skies

by George T. Whitesides

Sunset over the Zambezi River.

"I want you to imagine that our Sun is the size of this orange!"

Kevin Hand, the 26-year-old president of Cosmos Education and its 2001 Under African Skies project, raises a ripe orange high above his head. Gazing at him, 73 students ages 6 through 14 from the Nkhwazi Primary School of Lusaka, Zambia lean in, captivated.

"If this were the size of the Sun, how big would the Earth be?"

The students thrust their hands in the air and begin crying out answers. "Bigger!" "Smaller?" "Smaller!"

"Good," says Hand, sweeping his eyes across the students. "Smaller. But how much smaller?" Hand looks around, reaches down, and picks up a speck of rock, barely visible to the eye.

"If our Sun were the size of this orange, our Earth would be the size of this tiny pebble."

Gasps erupt from the kids. For the first time in many of their lives, they really comprehend how big the Sun is. And how small their own planet.

For more information about Cosmos Education, please visit *www.cosmoseducation.org*.

This summer, a group of teachers, graduate students, and young professionals traveled from South Africa to Kenya, visiting primary and secondary schools throughout the journey and teaching kids about science, technology, and space. All had signed up for Cosmos Education's Under African Skies project. Cosmos Education, a nonprofit educational organization, is partially funded by The Planetary Society.

Members of the group represented a total of 11 nations. During their 40-day journey, they covered more than 6,000 kilometers (3,700 miles), visited over 27 schools and museums, and, most important, talked with more than 4,000 students.

As part of the expedition, Cosmos Education also organized a three-day conference at the University of Zambia to coincide with the total solar eclipse on June 21. The conference, which drew more than 500 students, teachers, and citizens, provided an occasion for sharing knowledge on both scientific and cultural levels.

The Expedition

Many of the schools visited by Cosmos Education had no idea what to expect when the team took the stage, the floor, or—as was often the case—the ground. While most schools were contacted in advance, the team would frequently drop in on classrooms along the road. The team's mix of races, nations, and languages was always a great source of excitement for the students.

"At the core, Cosmos Education is all about getting kids excited about learning," explains Kevin Hand. "We use the topics of space and astronomy to tap into the imagination, and then we bring the presentation back down to Earth by discussing the ways in which science and technology—in particular space science and technology—are helping to create a healthier planet.

"Beyond that, I think our greatest impact is showing these students how well we work together and cooperate. I doubt that any of these students had ever seen a Ugandan meteorologist laughing with a Croatian astrophysicist while an American engineer juggles oranges. Cooperation is critical for the future of sustainable development and healthy globalization. We hope the students saw us working together and keep that in mind as they grow and become the scientists, artists, and leaders of their nations."

The team's varied presentations covered such topics as how to gauge the scale of the solar system, how satellites can help life on Earth, how pollution happens and why it's bad, and even whether there is life on other planets. To close their program, the team presented each school with educational materials, books, posters, copies of past issues of *The Planetary Report*, and a complimentary Planetary Society membership.

How It Got Started

In the winter of 2000, Hand made roughly the same expedition—visiting schools from South Africa to Kenya—all by himself. Growing up, the Stanford graduate student earned extra money as a magician, so he was able to capture the attention of the students quickly with tricks and sleight-of-hand skills like juggling. When he completed his trip, Hand resolved to return the following year, but this time with colleagues from the space community.

Thanks to a series of conferences organized by the United Nations Office of Outer Space Affairs, Hand was able to tap into a global network of young space professionals and students—people like Katiellou Lawan, a remote-sensing specialist from the Niger Republic; Nicholas Ochanda, a professor of geography at the University of Nairobi; and Bojan Pecnik, an astrophysics graduate student from Croatia.

"This has been a real eye-opener," says Pecnik. "As a scientist, it's easy to become wrapped up in your work and forget about the world around you. This project has helped open my eyes to the planet and see how I can make a difference in the lives of all these students."

Top: A Zambian woman watches the eclipse using homemade eclipse glasses. Thousands of Zambians converged on the campus of the University of Zambia to view the eclipse, and many of them brought homemade viewing instruments. The Cosmos Education team saw a lot of Mylar taped to cardboard (not recommended), and one person even wore a welding helmet!

Top right: The total eclipse of the Sun. The elliptical shape of the image is an artifact of the camera.

Center right: Cosmos Education team member Will Marshall helps students from the University of Zambia watch the eclipse. The Meade telescope (donated by Telescope House of London) was equipped with a solar filter that enabled the students to see sunspots on the Sun's surface.

Bottom right: Students from a Lusaka primary school at the University of Zambia eclipse festival. People from all walks of life came to view the eclipse —from these kids to world-famous astronomers, from manual laborers to the highest officials of Zambia's government.

Photos: George T. Whitesides

The Eclipse Conference

The conference and eclipse were focal points of the five-week expedition. Members of the Cosmos Education team presented on such diverse topics as remote sensing, alternative energy, life in the universe, and space exploration, while the students and professors from the University of Zambia gave talks on everything from religion and history to geophysics and computer science. The keynote speakers, Mazlan Othman, director of the United Nations Office of Outer Space Affairs (OOSA), and the Honorable Valentine Kayope, Zambian Minister of Science and Technology, set the conference on an inspirational trajectory by stressing the importance of the peaceful uses of outer space, the role of space technology in sustainable development, and the continued importance of international cooperation.

A highlight of the event was a talk by Dr. M. Mtonga, a humanities professor at the University of Zambia and self-proclaimed social activist dedicated to connecting the youth of Africa with centuries of indigenous knowledge. "For me, the opportunity to work with young students while at the same time learn about my heritage from people like Professor Mtonga has been incredible," said Fezile Vuthela, a Cosmos team member and research student at the South African Astronomical Observatory.

Following Dr. Mtonga's talk, just a few hours before the eclipse, the university theater group and the Lusaka Players reenacted the events surrounding the total solar eclipse of 1835, during which the Ngoni tribe crossed the Zambezi River and began migrating into Zambia.

The conference culminated with a fantastic display of the beauty of space, the first total solar eclipse of the millennium.

Planetary Society Support

"The Planetary Society is proud to support Cosmos Education," says Rachel Zimmerman, Planetary Society Volunteer Coordinator. "This is a fine example of the type of grassroots outreach project that makes space accessible to everyone. Perhaps one day, African astronauts will look back at the Earth and remember their introduction to space via the Under African Skies program."

By all measurements, this expedition, funded in part by Planetary Society members, was a resounding success. And it's just the beginning: plans for Under African Skies 2002 are already in the works.

George T. Whitesides is a graduate student at the Southern California Institute of Architecture, where he studies space structures. Whitesides is project director of Permission to Dream, a space education project focused on astronomy.

World Watch

by Louis D. Friedman

For more than 20 years I have been writing this column in *The Planetary Report*—first under the name Washington Watch, and then, as the Society developed internationally, as World Watch. I usually devote the column to space program policy, very often commenting on the state of program budgets or unraveling the politics of funding missions to space.

But as I write this in late September, all such considerations are dwarfed by the horrific terrorist attack on the United States and the resulting loss of life. The global impact is certain to be profound.

While not a space exploration issue, the September 11 attack touches on everything The Planetary Society seeks to promote through the world's space programs. I have overcome my first reaction; that is, to wonder if space were relevant considering the much bigger global implications of the attack or the much deeper personal implications for so many lives.

But then I remembered why we support space exploration at all when so many Earthly problems clamor for our attention, such as famine, disease, social injustice, environmental degradation, and so on. It's not that space is preeminently important; it clearly ranks lower on the priority scale than the basics of life and liberty. Still, the exploration of space seeks more than to solve immediate problems, pressing as they may be. It endeavors to create a limitless and hopeful future for the betterment of humankind. Our investing in space is like a family investing in the education of its young, even when its budget is strained. Ultimately, if space were relevant before September 11, 2001, then it remains just as relevant afterward.

The Society's directors and staff were deeply moved by the very kind thoughts expressed to us by members and friends living around the world. Many came from Russia, where we have close relationships resulting from our cooperative space projects, including our current *Cosmos 1* solar sail mission. But many came, too, from non-spacefaring countries. A number of people consider The Planetary Society their special link to America, and they wanted us to know they were standing with us at this terrible time. We deeply appreciate the sentiment.

Such widespread support confirmed for me that, although the attack was directed against the United States, it constituted an attack on freedom- and peace-loving peoples of the whole Earth. Many Americans lost their lives that day, but so did many others, representing a variety of nationalities, races, and religions. This was a terrorist strike against Russia, Japan, Germany, France, England, the countries of the Middle East and the Balkans that have seen so much war, and all civilized nations.

Herein lies my hope that something good will come from all this. We now have a greater realization that peoples all over the planet share the same aspirations for a positive future. We may, I hope, be brought together to fight terrorism and hate, as we may also join together to fight disease, famine, and the destruction of the environment. And, then, with that discretionary part of ourselves that looks to build a better future even while combating present danger, we can band together to seek new knowledge and explore new worlds. The Planetary Society will continue to work toward that hopeful future. In this way, our organization continues to be relevant, even in the wake of this atrocity, at the close of 2001.

Louis D. Friedman is executive director of The Planetary Society.

Society Expands Its Leadership

After serving five years as Planetary Society president, Bruce Murray is stepping up to chair our Board of Directors. Although Bruce will maintain his active role within the Society, two new officers will helm the organization in the coming years: Wesley T. Huntress Jr. as president and Neil de Grasse Tyson as vice president.

Huntress and Tyson are both outstanding leaders of space science. In addition, both are professionally identified with the popularization of space exploration and are committed to the goals of The Planetary Society.

Wes Huntress, who has served as vice president of the Society since 2000, is elected to a five-year term as president of the Board. Huntress is the director of the Geophysical Laboratory of the Carnegie Institute of Washington, D.C. As associate administrator for Space Science at NASA until 1998, he was a key architect of the revitalization of the planetary exploration program.

Neil Tyson, a member of the Board of Directors since 1997, is elected for a three-year term as vice president. Tyson is the first occupant of the Frederick P. Rose Directorship of the Hayden Planetarium in New York. He is a visiting research scientist in astrophysics at Princeton University, where he also teaches. —*LDF*

Society News

Introducing Our New Logo

Here it is: our new logo! It took a while, but we think you'll agree it was worth the wait.

Nearly two years ago, we asked you, our members, to give us your ideas for a new logo. After a tough process reviewing more than 200 outstanding entries, we announced that member Jim Cubberly of Villa Park, Illinois had come up with the winning design: a simple line drawing of a sailing ship swooping around a planet.

Our original logo, designed more than 20 years ago by renowned space artist Jon Lomberg, also featured a sailing ship. That ship was a Dutch caravel, a vessel that once peacefully explored parts of our own planet. Keeping this element in our new logo seemed a perfect fit.

THE PLANETARY SOCIETY

After the rigorous process of choosing a design, we went though an equally painstaking process of rendering the design into a multi-use logo.

Now that we have it, we want to show it off. We're featuring it on some new Society products, including a bold new mug and a brass key chain. Plus, a new T-shirt is in the works.

We extend our sincerest appreciation to Jim Cubberly and to everyone who participated in the contest.

—Jennifer Vaughn, Managing Editor

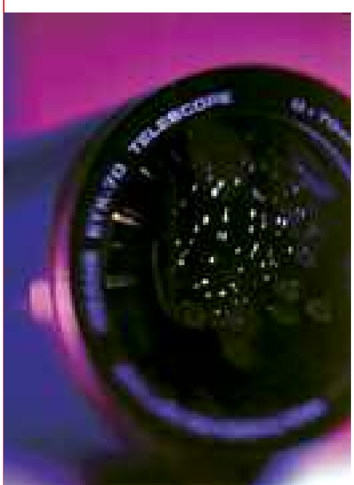
Erratum

There was a conversion error on page 21 of the July/August 2001 issue of *The Planetary Report*. The sentence should have read: "As the dust storm has expanded, Mars' atmosphere has increased by more than 20 degrees Celsius (36 degrees Fahrenheit) over prestorm levels." We apologize for the error.

New Planetary Society Member Benefits

We're hunting down ways to give our members more. So, we're connecting with planetariums in the US, Canada, and abroad. Already, nearly two dozen US planetariums will offer Planetary Society member discounts ranging from 15 percent to as much as 100 percent off! So far, our list includes the Ohio Center of Science and Industry (COSI), Boston's Charles Hayden Planetarium, the Miami Space Transit Planetarium, the Adler Planetarium and Astronomy Museum in Chicago, and the Morrison Planetarium at The California Academy of Sciences in San Francisco, just to name a few. And more planetariums are being added all the time! For a full, up-to-date list, check our website at *planetary.org*, or call Linda Wong at (626) 793-5100.

Special Limited-Time Offer on Telescopes!



Just in time for the holidays—the Discovery Channel Store is partnering with The Planetary Society to offer our members a 10 percent discount on Meade telescopes and telescope accessories. This offer is valid only through December 31, 2001, and applies to Discovery Channel Stores and *discoverystore.com*. Members must present a current Planetary Society membership card at the time of purchase to qualify for the discount. Those choosing to buy online, just use the coupon code "PLANET" when finalizing your purchase at *discoverystore.com*.

Whether you're looking for an inexpensive starter telescope for a budding young astronomer or you've been waiting for the right time to spring for Meade's top-of-the-line LX 200 12-inch Schmidt-Cassegrain (a discount of more than $400), the 10 percent discount amounts to big savings. We did a little searching on the Internet and found our Planetary Society member prices through the Discovery Channel Store were the lowest available! So don't miss this special opportunity—remember, it's good only through December 31!

—Charles Nobles, Chief Operating Officer

Questions and Answers

What's to prevent a meteorite or a piece of space junk from hitting and damaging the solar sail?
—Thad Coffing, Redlands, California

Not much. There is a real, though minimal, possibility that such an object will hit the sail. However, this danger is common to all space missions. Early space pioneers, like solar sail project team member Bud Schurmeier, were asked a comparable question when they developed the first satellites over four decades ago. And just as those pioneers did then, the solar sail team acknowledges the risk and deems it small enough not to be a showstopper.

The level of uncertainty in a number of important mission parameters—such as *Cosmos 1*'s initial orbit (still being refined by Russia's Babakin Space Center and Space Research Institute) and anticipated orbital changes—make it nearly impossible to come up with a credible numerical estimate for the probability of an impact. However, there are several factors we hope will reduce the threat compared with more typical low-Earth orbit missions.

First, we expect *Cosmos 1*'s mission to last only a few months. This is significant because the probability of an impact is directly related to the sail's duration of exposure. In comparison, the International Space Station, which has a planned lifetime of at least 15 years, does incorporate extensive bombardment shielding because the probability of impact is far greater and the potential loss much more significant.

Second, the planned orbital regime for the *Cosmos 1* demonstration flight is not one routinely used for other missions. Consequently, the amount of human-derived space junk in its path will be reduced. This factor is even more relevant for deep-space solar sail missions. The threat from natural objects remains a concern, but this is true of all interplanetary missions.

For the operational solar sails that we hope will follow *Cosmos 1*, we have chosen design features that can reduce damage should an impact occur. In particular, as with marine sailboats, the sail sheet may incorporate "ripstops." These reinforcing strips limit the propagation of tears caused by a particle passing through the sheet. Obviously, such a technique would not help should a large enough object hit a key subsystem on the spacecraft bus.

Overall, many other issues rank higher on the solar sail program's risk list. Getting to the phase in the mission where space debris becomes an issue will first require successes in launch, spacecraft power-up, sail deployment, and vehicle control. Once those challenges have been met, I wouldn't be surprised if the *Cosmos 1* team draws on such age-old techniques as prayer and good luck rituals to improve our chances for completing the mission.

—JOHN M. GARVEY,
Garvey Spacecraft Corporation

How many celestial objects in our solar system have been cataloged as of January 1, 2001?
—Michel Renaud, Charlesbourge, Quebec, Canada

The number of "cataloged" celestial objects in the solar system depends on how well one considers them to be cataloged. The very best cataloging effort would be dominated by the 19,910 objects in the "asteroid system," at least 94 percent of which populate the main asteroid belt. Yet, the total number of named bodies—which includes the major planets, 68 satellites, Ceres and other asteroids, as well as perhaps 140 comets that seem to return regularly at intervals of up to a century and a half—would still be under 8,200. However, one could also include more than 40,000 other main-belt asteroids that have been observed on dates more than a year apart and that have orbits determined well enough to allow the asteroids to be found in the future with minimal effort.

If we add in further near-Earth asteroids, Trojans, centaurs, transneptunian objects, another couple dozen satellites, and a few hundred comets that, though now too far away to see, have had their orbits determined fairly accurately, the 19,910 objects originally mentioned would increase to more than 65,000. Now, if we were performing this count in September 2001, the number would already have swelled by more than 20,000. And that omits the 45,000 or so orbit computations done for objects observed over only a few days to several months—complicating matters further as at least some unsuspected duplications no doubt have crept onto the list.

But there is still more to the story. Perhaps 80,000 (increasing by tens of thousands per year) "mere identification codes" have been given to asteroids observed on only one or two nights. Clearly, there must be lots of duplications among these objects, but the task of determining definite asteroid linkages is almost intractable—until those objects return and are well enough observed that linkages become obvious.

The cataloging of solar system objects is a continuing project of the International Astronomical Union's

Minor Planet Center and its collaborators. This process is amply fueled by some dozens of active observing programs around the world. Any objects observed beyond Earth's atmosphere (including some of the comets recorded imperfectly in the ancient Chinese dynastic records) are tallied. So are objects that have been seen to dissolve near the Sun or crash into Jupiter. The Tunguska object and terrestrial meteorites are not included, however. That is because the cataloging has been done on the basis of observations of objects out in space. So far, we have not observed a natural object in space that we have subsequently known to enter Earth's atmosphere.

—BRIAN G. MARSDEN,
Minor Planet Center, Smithsonian Astrophysical Observatory

Factinos

The aging star CW Leonis (IRC+10216) has reached the peak of both its radius and its luminosity. This process could be responsible for a cloud of water vapor recently discovered around the star. The heating of a previously undisturbed collection of comets in orbit around CW Leonis could trigger the outward-moving wave of evaporation depicted here.
Illustration: The Smithsonian Astrophysical Observatory

A dying giant star known as CW Leonis, or IRC+10216, is vaporizing a swarm of comets that surround it (see illustration above), resulting in a huge cloud of water vapor. This discovery is the result of observations from the Submillimeter Wave Astronomy Satellite (SWAS), a small radio observatory launched by NASA in 1998.

"Over the past two years, SWAS has detected water vapor from a wide variety of astronomical sources," said Gary Melnick of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. "What makes the results so unusual is that we have found a cloud of water vapor around a star where we would not ordinarily have expected to find water." Melnick and his team reported their findings in the July 12, 2001 issue of *Nature*.

To explain the water vapor concentration that SWAS has detected at CW Leonis, several hundred billion comets would be needed at distances from the star between 75 and 300 times the distance of Earth from the Sun. Saavik Ford, a graduate student at Johns Hopkins University in Baltimore and a coauthor of the *Nature* article, explained, "The total mass required of this swarm of orbiting comets is similar to the original mass of the Kuiper Belt [a collection of comets that orbits our Sun beyond the orbit of Neptune]. But IRC+10216 is so much more luminous than the Sun that comets start to vaporize even at the distance of the Kuiper Belt. So one has several hundred billion comets all vaporizing at once."

CW Leonis is located 500 light-years from Earth in the direction of the constellation Leo.
—from NASA Headquarters

Until recently, scientists assumed that Venus' retrograde rotation was due to a massive impact early in its history. But now, Alexandre C. M. Correia and Jacques Laskar of France's National Center for Scientific Research have new models that explain the planet's backward spin. Over time, tides raised by the Sun in Venus' thick atmosphere, and friction between the atmosphere and the planet itself, gradually slowed the planet's rotation to the point that it stopped and reversed. Somewhat as the Moon's tug on our oceans produces tides whose friction is slowing Earth's rotation, the Sun's pull on Venus' atmosphere slowed that planet's spin.

In the new models, retrograde rotation occurred regardless of the rotation with which the planet began. "Most initial conditions will drive the planet toward the configuration at present seen at Venus," the scientists say; this effect "is a very general feature of the rotational evolution of a [terrestrial] planet with a dense atmosphere." Correia and Laskar reported their findings in the June 14, 2001 issue of *Nature*.
—from *Sky & Telescope*

There may be an asteroid belt around a nearby star, say scientists from the University of California, Los Angeles. Their findings suggest that planets are forming there or may have already formed. At the June 2001 meeting of the American Astronomical Union, Christine Chen and Michael Jura reported their observations that zeta Leporis (HR 1998) is enveloped by swirling dust in quantities and temperatures that indicate the presence of a massive asteroid belt around the star. Chen and Jura used the infrared camera on the 10-meter telescope at the Keck Observatory on Mauna Kea, Hawaii to make their observations.

"Because of the conditions we identified near zeta Leporis, we believe the dust around this star may contain asteroids that appear to be colliding violently with one another," said Jura. "Zeta Leporis is a relatively young star—approximately the age of our Sun when the Earth was forming. The system we observe around zeta Leporis is similar to what we think occurred in the early years of our own solar system when planets and asteroids were created."

"We want to know if the asteroids around this star are similar in composition to objects in our solar system," said Chen. "We want to learn if the processes we see unfolding on zeta Leporis can help us understand how the planets in our own solar system formed."
—from the University of California, Los Angeles

The Planetary Society 2002 Catalog

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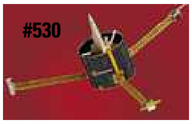

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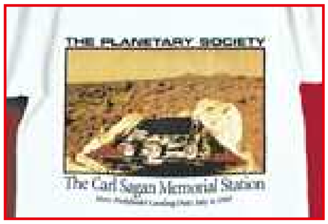

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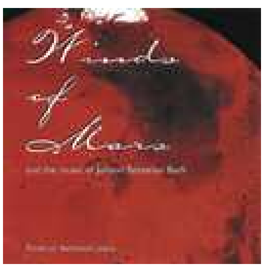

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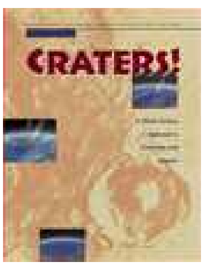

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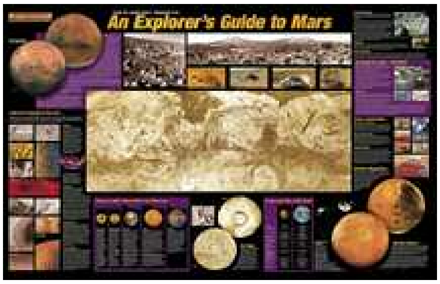

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It may look like our own Grand Canyon, but Daniel D. Durda was inspired to paint *Cosmic Chasm* by the possibility of moons orbiting Jovian planets around nearby Sun-like stars. Space scientists are working to find out if any of the many recently discovered extrasolar planets exist in the "habitable zone," that band of space surrounding a star where life is most likely to crop up.

Durda is a planetary scientist at the Southwest Research Institute in Boulder, Colorado. His professional interests include the evolution of asteroids and the effect of their impacts on Earth, as well as airborne astronomical observations from high-performance jet aircraft. He also serves as the coordinator of The Planetary Society's Shoemaker NEO Grant Program.

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