The PLANETARY REPORT

Volume XIX Number 6 November/December 1999

Destination Mars

On the Cover:

The spring equinox for Mars' southern hemisphere arrived August 2, 1999, bringing in the warm seasons of the year. The frosts of the southern polar cap began to retreat. As summer approached, so did the *Mars Polar Lander* (*MPL*), scheduled to touch down near the edge of the frost cap on December 3. What will *MPL* find? We don't know yet, but the lander may encounter dust storms, which frequently blow in this region. In this image, taken in late July, we see grayish-orange dust clouds just above the frost cap at the lower left.

Image: Malin Space Science Systems/NASA

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From The Editor

It's hard to explore planets, really hard. Those of us of a certain age remember John F. Kennedy, explaining that we chose to go to the Moon precisely because it was hard to do. That made the accomplishment all the more remarkable and satisfying.

Looking back at the triumph of the Moon missions and other missions that took us far beyond our little planet, we often forget the failures that became stepping stones to other worlds. Lost spacecraft, named *Ranger, Mariner, Venera, Mars,* and *Phobos,* litter the solar system—robots that have crashed, missed their targets, or simply vanished. But space explorers have persevered.

As I write this, scientists and engineers who work on the *Mars Polar Lander*—including some Planetary Society staffers—are scrambling to rebound from the loss of the *Mars Climate Orbiter* and its communications link. Mission sequences must be reexamined, reevaluated, and rewritten. But the mission will go on, valuable data will be returned to Earth, and we will live through another hair-raising approach, entry, landing, and deployment.

At Planetfest '99, we will celebrate *Mars Polar Lander*, *Galileo,* and the new millennium. We will hear sounds collected by our own Mars Microphone. We will exult in our accomplishment. I hope you will join us, either in Pasadena or on the Internet (**planetary.org**), and we will exult in doing what is hard.

—Charlene M. Anderson

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Members' **Dialogue**

Watching the Clock

I enjoyed Owen Gingerich's article in the July/August 1999 issue of *The Planetary Report*. It was fascinating to learn how our calendar was established.

Regarding the millennium issue, I agree that formally the start of the next millennium is January 1, 2001. However, I think it would be utterly stupid to insist on celebrating on this date (especially since, as Gingerich reminds us, we're celebrating the 2000th anniversary of a nonevent!) and would ask those who advocate this the following question: when did you celebrate the beginning of the '90s—January 1, 1991? Do you think that 1980 was the last year of the '70s or the first year of the '80s?

—ANDREAS EKHOLM,
Tucson, Arizona

Owen Gingerich's opinion piece "Why Is the Day 24 Hours . . ." is no doubt well researched. Yet I was disappointed that he made no reference to timekeeping by ancient Chinese people—which took place before the mechanical clock was introduced by western missionaries during the Ming dynasty (1368 to 1644 AD).

From very early on in Chinese history, the scholars had marked the lunar year into 24 agricultural seasonal milestones. Farmers would follow their pattern to sow, replant, and harvest. These milestones also corresponded to different lengths of daylight available. The day, in turn, was divided into 12 segments, each equal in length to 2 hours by our reckoning. In this system, the first day-segment begins at our 7 pm, the third (important to thieves) is astride our midnight, while the ninth segment covers high noon—an auspicious time for major government activities, which might involve the emperor.

Being the "Son of the Heavens," the emperor had at his command astronomers and clock makers. These early versions of "clocks" were not of the conventional modern type. They were called *clepsydra* (water clock) and were usually made of bronze. (There is still one such *clepsydra* on display in the Imperial Palace in Beijing.)

Humble village dwellers, though, had to rely on their own diurnal instincts. Small towns and cities had timekeepers who traversed the roadways on foot to announce the change of day-segment with the help of small drums.

But, as with the ancient Egyptians, interest in these long-obsolete modes of Chinese timekeeping now only resides in the realm of historians.

—MICHAEL CHUI,
Etobicoke, Ontario, Canada

In "Why Is the Day 24 Hours, and When Will the Millennium Begin?" Owen Gingerich states, "On December 31, an extra second will be added before midnight, so don't celebrate early!"

I asked Raymond Pelletier of the National Research Council of Canada's Institute for National Measurement Standards about this because he set up and administers our millennium countdown clocks. He referred me to the website **http://hpiers.obspm.fr/iers/bul/bulc/bulletinc.dat**, where the International Earth Rotation Service (IERS) says, "No positive leap second will be introduced at the end of December 1999."

Ray also informs me that "they can only predict an impending leap second six months ahead. At this time no one knows if there will be a leap second at the end of December 2000." So, don't delay; celebrate on time!

—GREG KRESKO,
Ottawa, Ontario, Canada

Greg Kresko is right in pointing out that there won't be a leap second at the end of 1999. While, on average, one extra second is needed each year, the slowing is sufficiently irregular that sometimes a couple of years pass with no additional second, and, very occasionally, there are two extra seconds in a year, one at the end of June and the other at the end of December. During the 1990s the average has been closer to one second added every 18 months, and none at all will have been added in 1999.
—Owen Gingerich

Praise for Planetfest

I was a volunteer at Planetfests '97 and '89. Looking back, I thought it would be hard to top *Voyager 2*'s spectacular 1989 encounter with Neptune—liquid nitrogen geysers on Triton, the fastest winds in the solar system, *and* Chuck Berry at the wrap party on the Jet Propulsion Lab Mall! Meeting Charley Kohlhase and Ed Stone was terrific.

But, with *Mars Pathfinder*, I was seeing the beginnings of our grasp catching up with our reach. Watching the robot *Sojourner* trundling around the Martian surface at our command took us to a whole new level of knowing the place, and each time we go back, we get to know it a little better.

This December, we will see Mars' south pole. How will it be like Earth's Antarctic region? How will it be different? Questions such as these keep me coming back.

I was recently at a friend's house and saw a panoramic photo poster of the *Pathfinder* landing site. At the bottom was the Planetary Society's logo and the words "We Make It Happen." It brought back good memories. I'm proud to be a member! See you there in '99!

—CRAIG FLEMING,
Concord, California

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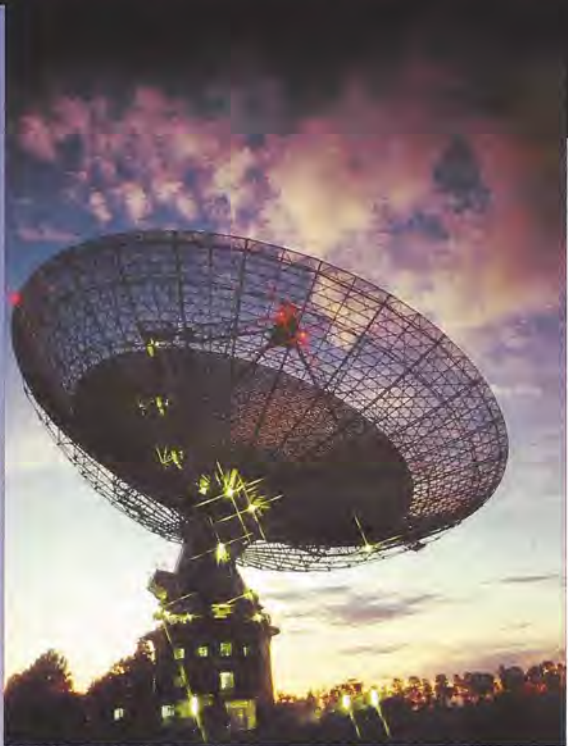
An Interview With Tim Ferris



The Parkes radio telescope in Australia is one of the dishes searching for signals that might be beamed in our direction by an extraterrestrial civilization. *Photo: Seth Shostak/SETI Institute*

Tim Ferris is one of the leading science writers working today. Well known for books such as *Coming of Age in the Milky Way* and *The Whole Shebang: A State-of-the-Universe(s) Report*, Tim has broadened his audience as a presenter of PBS television specials, beginning with *The Creation of the Universe* (1985). He returns to PBS November 10 with a two-hour special, *Life Beyond Earth*, which he dedicated to The Planetary Society's first president, Carl Sagan.

Tim worked closely with Carl in the creation of the *Voyager* record, a gold-plated artifact containing the sights and sounds of our planet and a message from the people of Earth to whatever civilization might someday find the *Voyager* spacecraft drifting among the stars.

On August 3, 1999, I spoke briefly with Tim about "Is Anybody Listening?" the segment of *Life Beyond Earth* concerned with the Search for Extraterrestrial Intelligence (SETI), a major focus of Planetary Society programs. Here is that interview.

—*Charlene M. Anderson, Associate Director*

What attracted you to the subject of extraterrestrial life?

It's just a natural, isn't it? But one of the things that troubles me about this subject is that the human species has only begun to learn how to think about it. I'm most often asked if I believe there is life out there, and that's the wrong question. Questions of belief have their place in life, but they are wholly irrelevant to questions of what might be out there. I've always couched the question in empirical terms.

For scientific and philosophical reasons, we won't understand ourselves until we know about extraterrestrial life. Socrates posed the question: why should I be concerned about the stars before I understand myself? That is best answered by looking outward.

Why are governments leery of sponsoring SETI?

It's fear of ridicule. It turned out to be an easy program to make fun of, and SETI has divided scientific support, with not all of the community supporting it. Searching for extraterrestrial life is literally groping in the unknown. On the other hand, the NASA Origins program does have an imperative about investigating life elsewhere in the solar system, so there's some government support.

There's a divide between points of view that encourage or discourage learning. If we act on the assumption that there is a possibility of life beyond Earth, we will continue to search. Of course, we tried not searching for 10,000 years and it didn't work. I would prefer as a scientific strategy that we search.

Why have we yet to transcend the "giggle factor"?

Alfred North Whitehead, the American philosopher, said it takes about 1,000 years for a genuinely new idea to enter into the fabric of a culture, and that's true of science. Science hasn't fully entered our culture yet. People haven't begun to cope with the findings of science yet, let alone with its method. If you begin to think in a scientific way, you can cope with the idea of a universe about which you know nothing. But that ability is known to only a tiny portion of the population so far, none of which are in Congress.

It's often said that discovering a signal would change the course of history or humanity forever or some other hyperbole. Are such claims overstated?

I think they're overstated. I've had a long-running quarrel with some of my friends in the SETI community about their predictions of what would happen if we received an extraterrestrial signal. Some of the claims are shameless: we'd learn to cure cancer, to create world peace. It's in the nature of people to try to predict, but it's almost an impossible exercise. We simply don't know.

There would be two phases of reaction. The simple fact that we're not the only intelligent creatures would be a long-overdue bit of information for us. And there's the content of the message we'd receive. To predict the reaction would be as if a pre-Columbian civilization were speculating about the nature of the lakes in the future state of Minnesota.

Is there a time window within which, if a signal is not found, interest will be lost?

I would encourage the SETI folks to adopt the model of the great explorers who persevered through great difficulties, including the sheer boredom of not finding what you're looking for. It's like the Fountain of Youth: you may or may not find it, but it's interesting looking along the way.

I suspect that interest will not die out completely. It's possible that if nothing is found in 15 to 20 years, funding will lag. But in that time, people may eventually be able to roll out [some sort of radio-receiving] carpet in their backyard and look with that. That's what I like about humans—they keep doing things that don't fit into anyone else's plan.

Why did you dedicate the show to Carl?

In addition to having been a friend of mine, I think he was-the foremost planetary astronomer of his time, and he was also a champion of the search for life beyond Earth, which is a very stimulating way of conducting astronomy. If you look at a satellite as not just a cold ball in space but as a possible abode for life, it's a much more exciting way to look at the science. ■

Over One Million Served: SETI@home Passes the Million Mark

by Charlene M. Anderson

One million people around the globe are now joined in one of the greatest and most ambitious experiments ever undertaken: the search for extraterrestrial intelligence (SETI). The vehicle for their efforts is SETI @home, the ingenious software program that allows individuals—at home or at work—to process radio-telescope data that might contain a signal from another civilization.

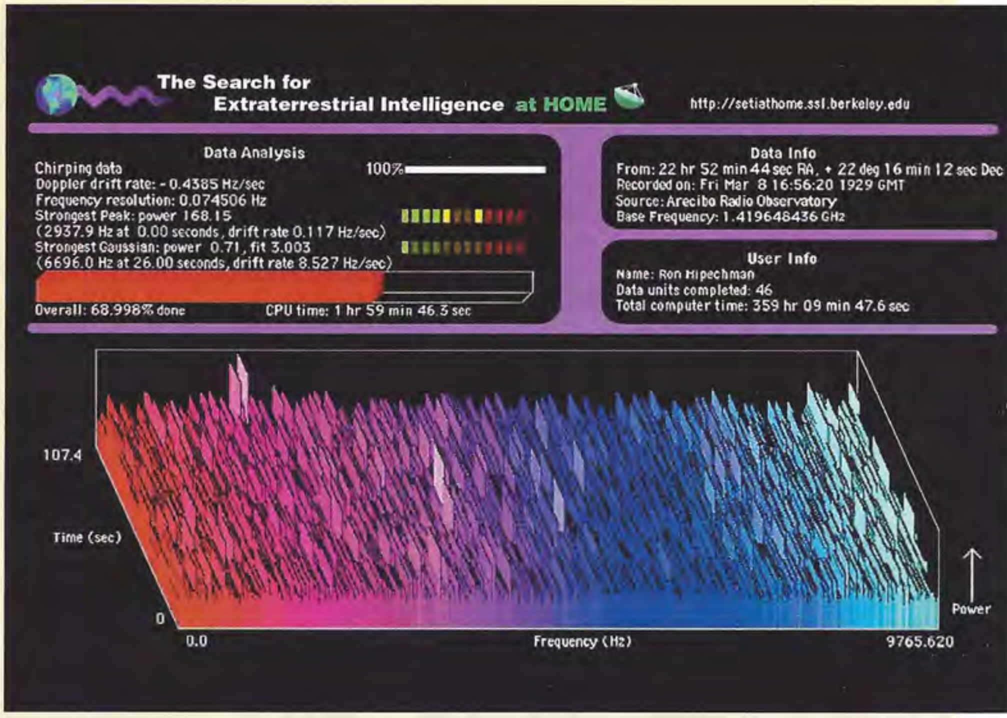
We've reached this milestone in less than a year. It was only in October 1998 that The Planetary Society, with help from Paramount Pictures, home of the Star Trek television series and films, agreed to provide the seed money to get the project under way. Project Director David Anderson and Project Scientist Dan Werthimer had been trying for nearly two years to find funding for their software idea, and when they came to the Society, we were able to help them out.

And now, SETI@home has the largest distribution of any computing experiment running, and its popularity has overwhelmed its creators. Dave and Dan had planned the experiment for about 200,000 to 300,000 participants. That many and more had signed up before the first version of the software was even released. On the day it was released, Dan reported that "our servers are on their knees."

It has been overwhelming, but gratifying, for the project's founders. Dave admitted that he had been silently hoping to reach the million mark. And people continue to sign up.

To help deal with the multitudes, The Planetary Society recently committed another grant to SETI@home. The funds will be used primarily to support customer service. Dan and Dave are volunteer leaders, helped by a few part-time students, and requests for information or help installing and running the program have been enough to swamp them.

The Society's monies have been matched by the University of California Digital Media Innovation Program. SETI@home has also received support from Sun Microsystems; Fujifilm; Informix; the Santa Cruz Operation; Quantum Corporation; space.com; the Engineering Design Team; Crystal Group, Inc.; and the SETI Institute.



This is how the SETI@home screensaver appears on computers while processing data collected by Project SERENDIP. *Image: University of California, Berkeley*

Join a SETI@home Group

One unexpected development of the SETI@home experiment is the spontaneous generation of groups competing to process the most data. From primary schools to major universities, from small mom-and-pop companies to giant corporations, from clubs to government agencies, people have organized themselves into online communities working together to find that possible signal from another world.

If you've already signed up for SETI@home and would like to join The Planetary Society's group, go to **setiathome.ssl.berkeley.edu/stats/team/team_707.html**.

To sign up for SETI@home, go to the Society's website, **planetary.org**, or to **setiathome.ssl.berkeley.edu** and follow the links. It's a grand adventure. And who knows, we may just change the course of galactic history.

Charlene M. Anderson is Associate Director of The Planetary Society.

Assessing the HAZARD: The Development of the

by Richard P. Binzel

Sometimes, all you need are a few words of encouragement and a bit of persistence . . . In late 1994, at a Planetary Society event in Boston, I was sitting at a large dinner table between Carl Sagan and Lou Friedman. The table's company had broken into several small conversations, and I was explaining to Carl an idea I was developing to help the public comprehend relative threats from asteroid and comet impacts. Carl reacted immediately, interrupting everyone at the table by exclaiming, "Lou, did you just hear what Rick said? We should follow up on this immediately!" My idea of a numerical rating for the dangers of impacts also intrigued Lou: with a bit of arm twisting, he persuaded me to write up some preliminary ideas for *The Planetary Report* (March/April 1995).

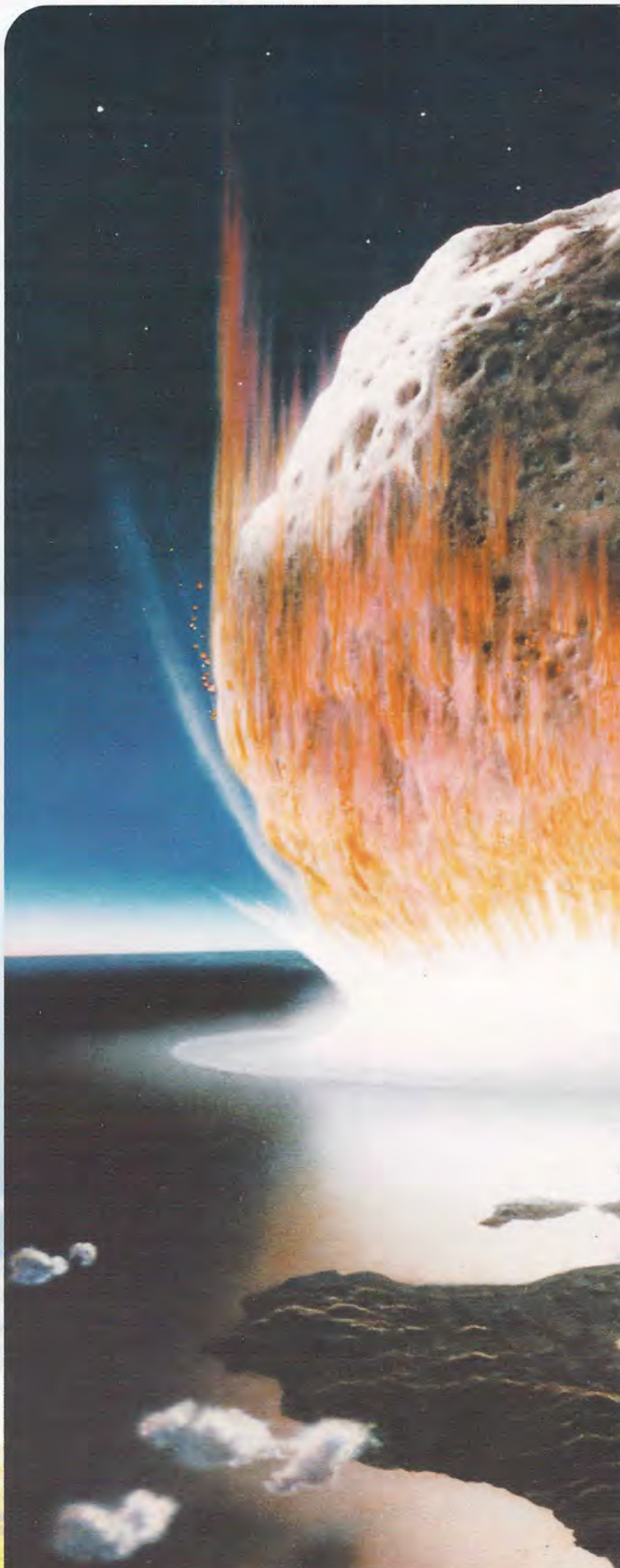
At the same time, I prepared a formal presentation of my ideas to a United Nations Conference on Near-Earth Objects (NEOs), cosponsored by The Planetary Society. While these preliminary ideas did not take root in 1995, I continued to ponder and discuss the problem with colleagues and members of the science media. This past summer, a reformulation of my idea finally took hold and was endorsed at another Planetary Society-cosponsored event: an international workshop on impact hazards held in Torino, Italy.

Now known as the Torino Scale, this public communication system runs from 0 (no danger) to 10 (certain global catastrophe). The purpose of the Torino Scale is to allow scientists to convey concisely how much real danger (if any) Earth's inhabitants face from newly discovered asteroids and comets, most especially those that can be predicted to make very close passes by our planet in the 21st century.

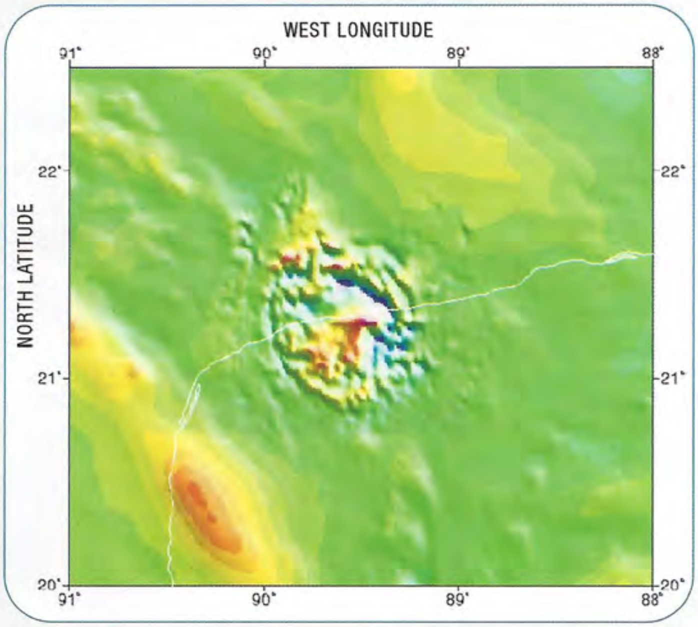
Recognizing the Hazard

We inhabitants of planet Earth have been slow to recognize that we live in a cosmic shooting gallery, and throughout the year we face some small, but not insignificant, risk of seeing life on Earth irreparably altered. We received our first clue nearly 400 years ago, when Galileo turned his telescope to the Moon and observed its cratered face. In the following centuries, scientists could not agree on what had so scarred Earth's near companion, and they divided into camps, one favoring volcanic eruptions as the crater-makers, the other postulating impacts from small objects from space. In the 1960s, robotic and human explorers finally reached the Moon and collected evidence to settle the debate. Those holes in the lunar surface were blasted out by explosive impacts of asteroids and comets.

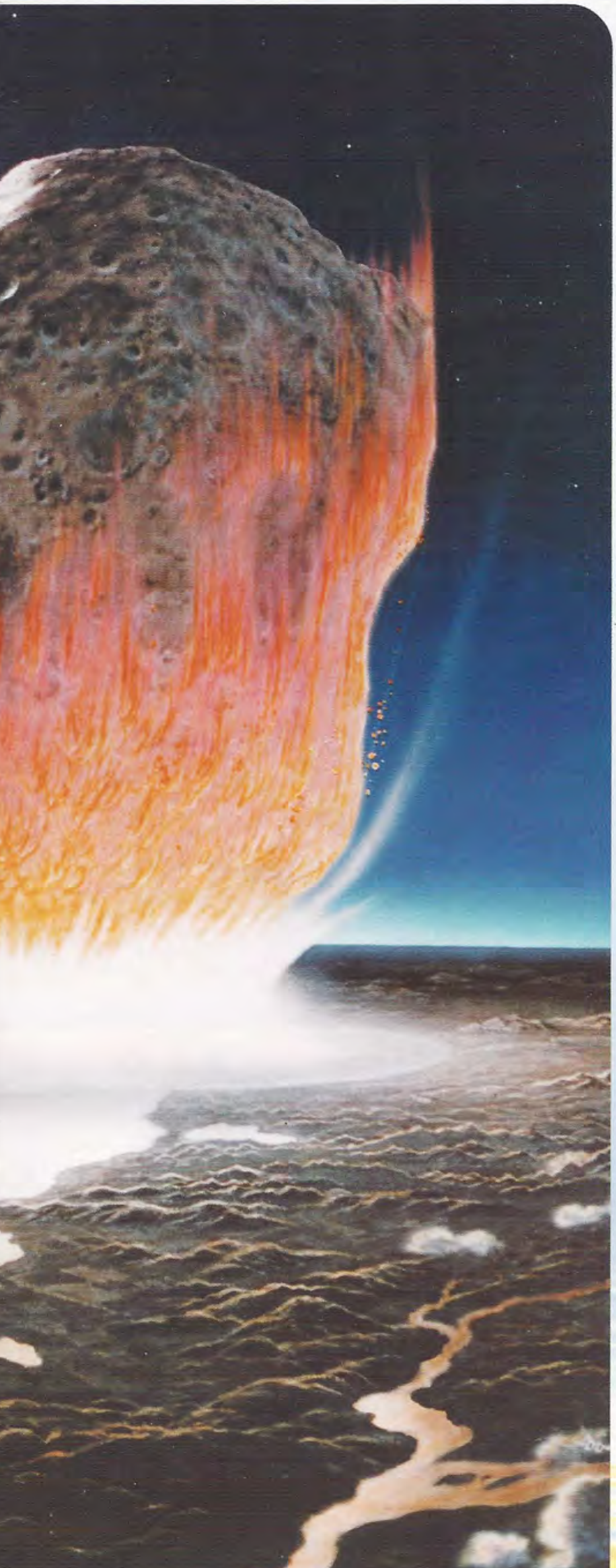
At the same time, geologist Eugene Shoemaker conclusively showed that impact craters exist on Earth as well, with what is now known as Meteor Crater in Arizona being the premier



TORINO SCALE



***Above:** Although the crater formed by the Cretaceous-Tertiary impact is buried under layers of sediment near the Mexican town of Chicxulub, we can still discern its presence in the rocks below. Magnetic anomalies show that something drastic happened here. The anomalies were probably caused by rocks melted by the impact and basement rocks uplifted from below. The white outline traces the present Yucatan coast.* Image: Natural Resources Canada



***Left:** Caught at just the moment of impact, the instant the old world changes irrevocably to the new, an asteroid strikes Earth and ravages the immediate landscape. But landforms and life-forms thousands of kilometers away will not escape its effects. Tidal waves will reshape coastlines, dust clouds will blanket the land, and darkness will cover the Earth. Such were the effects of the asteroid that struck our planet 65 million years ago, when the dinosaurs went extinct.*
Painting: Don Davis for NASA

example. Still more sobering evidence followed in the 1980s. A team led by Luis and Walter Alvarez realized that 65 million years ago something big smacked into Earth and killed off the dinosaurs. Creatures that had dominated life on this planet for 140 million years were gone within an instant of geologic time. If even the mighty dinosaurs could be eliminated by asteroid impact, what about the danger to puny life-forms such as humans?

Then, in 1994, we saw that even giant planets can be greatly affected by incoming cosmic debris. Comet Shoemaker-Levy 9 had been captured into orbit about Jupiter and ripped into kilometer-sized bits by the planet's gravity. One by one, these relatively small impactors slammed into the giant world as we watched, and the resulting explosions were the most powerful witnessed in our solar system in modern times. Those of us in the field of near-Earth object studies now reached a point where we no longer had to prove that killer rocks did indeed come from outer space. The new problem was how to responsibly convey that fact to the public and to the media that inform their concept of Earth's precarious place in the solar system.

Responsible Communication

As the threat of asteroid and comet impacts became generally accepted, the NEO community faced a new problem: sensationalism in the press. And it wasn't just the tabloids that used the menace from outer space to sell copies: both *Time* and *Newsweek* ran doomsday cover stories after some unguarded

An impact crater formed about 20,000 years ago is well preserved and accessible to the curious public. Barringer Crater, often called Meteor Crater, lies not far from Flagstaff in northern Arizona. At this site, a fragment of an iron asteroid some 50 meters across blew out a crater 1 kilometer wide (about 0.6 miles).

Photo: Glen P. Gordon

scientific speculation about the impact probability of comet Swift-Tuttle. Hollywood studios recognized the marketing potential of the end-of-life-as-we-know-it stories and last year released two blockbuster films with celestial villains: *Deep Impact* and *Armageddon*.

We were caught in a dilemma. On one hand, we wanted the public to recognize that there is a real threat from asteroids and comets. We need much more research to find and characterize near-Earth objects so that we can more deeply understand them and the dangers they pose. To support that research, we need funding from governments and other organizations that respond to the concerns of the public. So responsible publicity is good. But when responsible scientists are not extraordinarily careful in their public statements and the press and the public overreact to a NEO threat, the whole endeavor can lose credibility. As with the little boy who cried "Wolf," if people are warned repeatedly of a threat that never materializes, when a real one comes they will dismiss it.

What's more, our science can be diminished by the "giggle factor." If one scientist announces an object is coming with even a remote probability of impact, and another scientist immediately disproves the claim, there is a danger that the press and public will not see this as the normal process of science, but rather as the squabbling of a group that can't get its story straight.

Last year the NEO community lived through what some

The explosion over Tunguska in Siberia in 1908 was relatively small as asteroid impacts go. But it was the biggest event of the 20th century. Working from eyewitness accounts and recent research, planetary scientist and artist Bill Hartmann has recreated how the event might have appeared before and after the explosion. Two seconds before the event, a person in Kirensk (a town about 400 kilometers, or 250 miles, southeast of ground zero) watches as a brilliant fireball flares in the morning sky. At right we see the resulting devastation from a distance of 6 kilometers (about 4 miles). *Paintings: William K. Hartmann*

call the XF11 affair. Some probability calculations indicated that asteroid 1997 XF11 had a small chance of colliding with Earth in 2028, with additional potential for hitting Earth at subsequent passes by our planet. Although an independent evaluation of the same data immediately showed there was "zero" chance of a collision in 2028, Pandora's box had been opened. The press jumped on the initial 2028 prediction, and nightly news broadcasts trumpeted the coming of a possibly real Armageddon, while newspapers ran headlines like "Kiss Your Asteroid Goodbye." Within a day, the correct news finally emerged. Further calculations (partly based on Planetary Society-sponsored research by Eleanor Helin) solidly verified that there was no real hazard from XF11 in 2028 and throughout the entire 21st century.

I was incredibly frustrated by these events. If we had had an accepted hazard index in place, the brouhaha might never have happened. On the scale I wanted to develop, even the first announcement of a possible 2028 collision would have rated only a mere 1 or 2 out of 10. The subsequent calculations would have placed the risk at the even more comforting level 0.

The Time Was Right

With the NEO community still smarting from the XF11 affair, the time seemed right to propose my hazard scale idea once again. Opportunity was at hand in June 1999, with the community gathering in Torino, Italy under the auspices of the International Astronomical Union (IAU). If I could develop an improved version of my scale, there was a chance it would be accepted. At last we would have a useful tool to help us communicate with the press and the public!

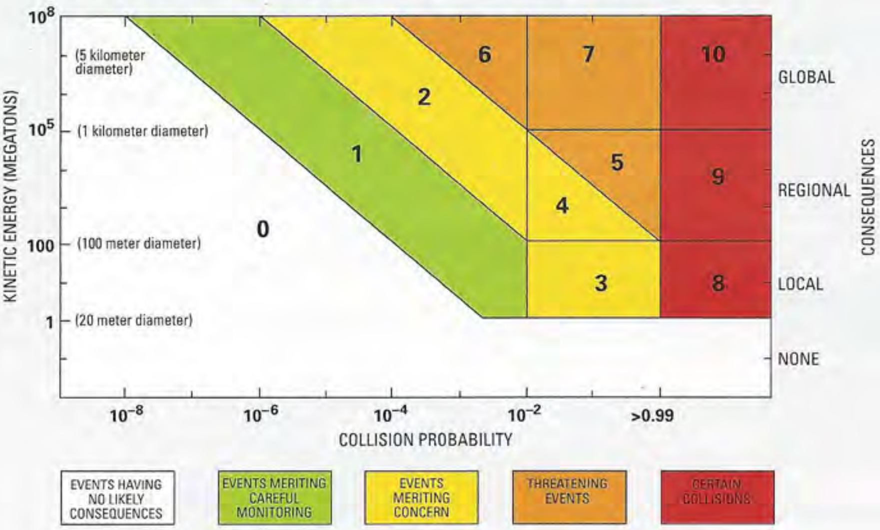
The key to success, I came to believe, was to utilize a 0 to 10 scale that somehow simultaneously conveys information about an object's collisional probability and potential consequences. (My previous version ranged from 0 to 5, with these numbers accounting for probability only.) Alas, there is no "best" way to compress the multiple dimensions of the problem into a 0 to 10 scale, but through the use of color it is possible to achieve a reasonable and easily understandable solution. You see the results in figure 1 [page 10], where I have carved and color-coded the graphical space to depict the consequences of an impact (in terms of the kinetic energy that would be released) along with the collision probability. The graph is anchored by category 1, which traces out the chance, over the next 30 years or so, that some as yet undiscovered object might strike the Earth. The sideways slope of the region indicates our understanding that large collisions are less likely than smaller ones.

I presented my impact scale at the Torino conference, and it was received quite favorably. But, as at any gathering of scientists, there were many differing opinions and suggestions on how to assign numbers, especially since there is no unique solution that is clearly best. Michael A'Hearn, of the University of Maryland and a high-ranking IAU official, chaired the session at which I presented the scale and moved to accept it, pending my consideration of the fine points raised in drafting a final version. While making these revisions, incorporated in figure 1, I sought additional scientific and public communication advice from experienced colleagues and familiar science journalists. I am most grateful to Clark Chapman, asteroid researcher (and columnist for *The Planetary Report*); Kelly Beatty, senior editor of *Sky & Telescope*; and David Chandler, science writer for the *Boston Globe*, for their involvement in developing the final version, which was approved for public release on July 22, 1999.

Using the Torino Scale

When a new asteroid or comet is discovered, only a short piece of its full orbital track is known, leading to substantial uncertainties as to exactly where that object will be months, years, and decades into the future. Sometimes the region of uncertainty for the object includes the Earth, whose position is precisely known, and thus there is some calculable collision probability. From this collision probability and the velocity of the object (plus estimates for its size and mass to calculate its kinetic energy), the close encounter can be plotted as a specific point within figure 1. This point's location within

Figure 1
Graphical Representation of the Torino Scale



An object receives a Torino Scale value based on where it falls within this diagram, depending on its impact probability and estimated kinetic energy.

Figure 2
Descriptions of Each Torino Scale Category

ASSESSING ASTEROID AND COMET IMPACT HAZARD PREDICTIONS IN THE 21ST CENTURY

Events Having No Likely Consequences	0	The likelihood of a collision is zero, or well below the chance that a random object of the same size will strike the Earth within the next few decades. This designation also applies to any small object to reach the Earth's surface intact.
Events Meriting Careful Monitoring	1	The chance of collision is extremely unlikely, about the same as a random object of the same size striking the earth within the next few decades.
Events Meriting Concern	2	A somewhat close, but not unusual, encounter. Collision is very unlikely.
	3	A close encounter, with 1% or greater chance of a collision capable of causing localized destruction.
	4	A close encounter, with 1% or greater chance of a collision capable of causing regional destruction.
Threatening Events	5	A close encounter, with a significant threat of a collision capable of causing regional devastation.
	6	A close encounter, with a significant threat of a collision capable of causing global catastrophe.
	7	A close encounter, with an extremely significant threat of a collision capable of causing global catastrophe.
Certain Collisions	8	A collision capable of causing localized destruction. Such events occur somewhere on Earth between once per 50 years and once per 1000 years.
	9	A collision capable of causing regional devastation. Such events occur between once per 1000 years and once per 100,000 years.
	10	A collision capable of causing a global climatic catastrophe. Such events occur once per 100,000 years or less often.

Color categories indicate the increasing seriousness of predicted close encounters with the Earth, with the red zone (8, 9, 10) denoting "Certain Collisions" capable of local, regional, or global damage.

Graphics: provided by the author

figure 1 determines the 0 to 10 Torino Scale value. If an object has an orbit that will lead to multiple close passes by the Earth, each close encounter will have a separate Torino Scale value.

For all events, the value is intended to be quoted as an integer. It is possible that an event that plots near a boundary might be cited as, for example, "a 1 or 2." As longer portions of the orbital track are measured, it is natural for the object's position uncertainties to shrink. In most cases, the chance of collision will ultimately shrink to 0, meaning that a Torino Scale value is likely to change—for example, from 1 to 0—through the ordinary scientific process and not because of any initial mistake. A recently discovered object, 1999 AN10, is precisely such a case. This object would have rated a 1 when first seen, but subsequently uncovered observations allowed researchers to determine the orbit with greater accuracy and consequently eliminate the chance of a threat.

The combination of colors and numbers is designed to make the Torino Scale understandable at many levels. The most widely published form of the Torino Scale is shown in figure 2, a chart that concisely interprets the meaning of each value. Colors ranging from white to green to yellow to orange to red are intended to communicate the level of public concern that is merited. The numbers increase within each color zone as one increases in either collision probability or kinetic energy. Transition into the red zone occurs if an object's collision probability becomes "certain"; categories 8, 9, and 10 denote impacts that are capable of causing local, regional, or global damage.

At the time of this writing, we know of no objects that threaten Earth, meaning every known object falls within category 0. Nevertheless, the Earth has experienced events that would earn numbers at the upper end of the scale. The asteroid that blasted out kilometer-sized Meteor Crater in Arizona would have rated an 8. The object that exploded in 1908 over Tunguska in Siberia and flattened 2,000 square kilometers of forest would have also received an 8. And whatever struck Earth 65 million years ago and eliminated the dinosaurs would have earned an unenviable 10.

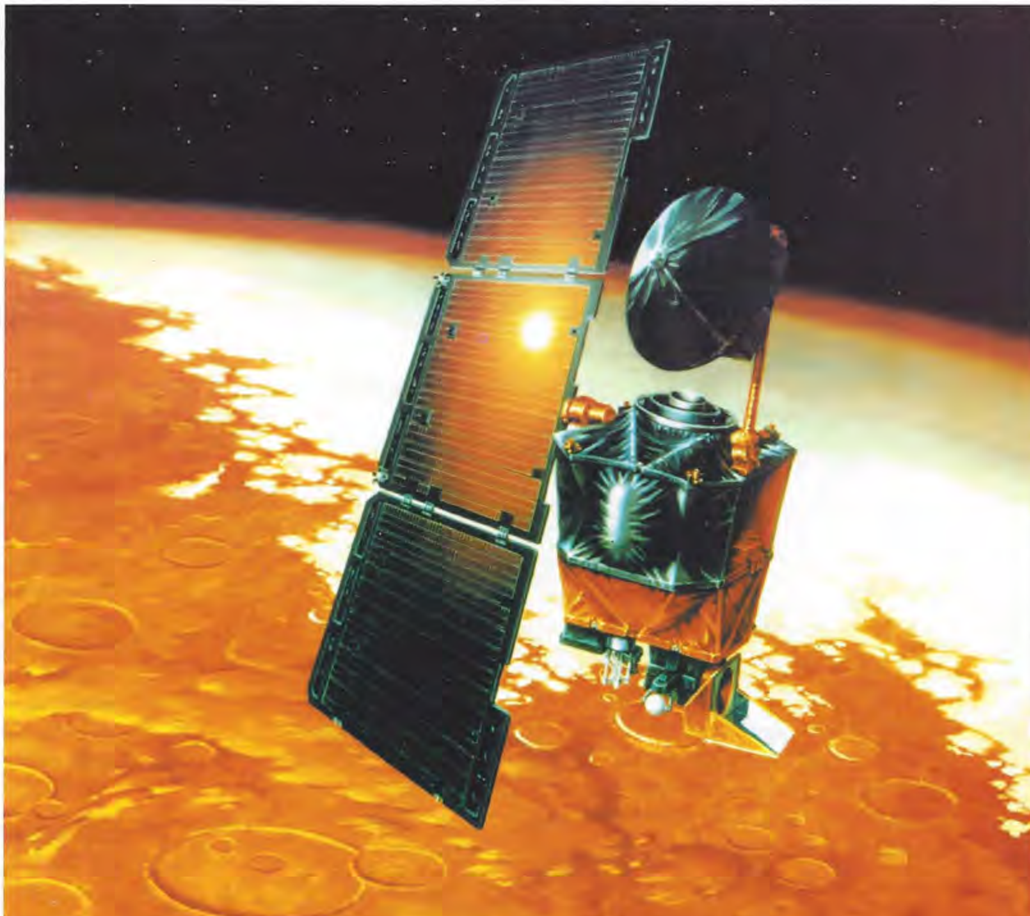
My overriding hope for the Torino Scale is that it will help people put into perspective the hazard posed by any comet or asteroid entering Earth's neighborhood. There is a low probability that any of us alive today is threatened by an impact. But if one were to occur, the consequences could be exceedingly, perhaps unimaginably, great. Given human nature, it is difficult to figure out what level of anxiety we should assign to an approaching NEO. The Torino Scale is one attempt to solve that problem.

Richard P. Binzel is a professor of planetary science at the Massachusetts Institute of Technology, where his research activities include characterizing the compositional properties of near-Earth asteroids.

World Watch

by Louis D. Friedman

Mars—The road to Mars is full of bumps and potholes. The list of failures is about as long as the list of successes. In this decade alone there have been three failures (*Mars Observer*, *Mars '96*, and now *Mars Climate Orbiter*). There have been two successes (*Mars Global Surveyor*, working now in Mars orbit, and *Mars Pathfinder*). Two missions are on their way to Mars—*Mars Polar Lander* and Japan's *Nozomi* (whose arrival will be delayed three years due to an anomalous entry onto its interplanetary trajectory). Flying a remote-control robot to another planet is very hard to do—and we expect failures and setbacks.



Artist's rendering of Mars Climate Orbiter *above the Red Planet.* *Illustration: JPL/NASA*

But the failure of *Mars Climate Orbiter* (*MCO*) is a stunning surprise. To hit a planet by accident is something that has never happened in 37 years of interplanetary flight. The precision of interplanetary navigation has been amazing, and we have taken for granted the ability of engineers to aim spacecraft precisely at and around planets. Indeed, we are taking it for granted about once a month as the *Galileo* spacecraft zips around in Jovian orbit among the Galilean satellites.

MCO was being aimed at a point 150 kilometers (about 90 miles) above the Martian surface—where rockets were supposed to fire to slow the spacecraft into orbit around Mars. Big propulsion maneuvers like that are dramatic events—*Mars Observer, Mars '96,* and *Nozomi* all encountered problems during rocket firings. But it appears that the rockets on *MCO* fired perfectly. Unfortunately, the spacecraft was not 150 kilometers above the planet as planned but only 60 kilometers (about 40 miles). At that altitude the Martian atmosphere is just thick enough to generate the aerodynamic forces and heat that destroyed the spacecraft.

Navigation is statistical. We never know anything perfectly in navigation, though at most times the instantaneous error in measuring spacecraft position and velocity is about one part in 10 billion. Rocket firings introduce errors in magnitude and direction, and these errors lead to errors in the prediction of future positions (typically by tens of kilometers). After midcourse maneuvers, it may take days or even weeks to refine our knowledge of a spacecraft's trajectory.

When we predict the position of a spacecraft, we always assign some estimated error and probability of error. In the case of *MCO*, the position at 150 kilometers altitude was said to be accurate to about 20 kilometers (12 miles) with a 99 percent certainty (sometimes called the three-sigma error of statistics). Being off by 90 kilometers would be nearer a ten-sigma error—an improbability of about one part in a billion.

As we go to press, the source of the

(continued on page 19)

Mars Polar Lander—Countdown to Touch

We are almost there! For nearly 11 months, *Mars Polar Lander* has been sailing through space, headed toward its new home—near the south p There it will begin a 90-day mission to study the Martian soil and search for water ice beneath the planet's surface. But before that mission ev *Mars Polar Lander* must brave the most dangerous part of its voyage—the entry, descent, and landing.

Here we have outlined events leading up to *Mars Polar Lander*'s arrival on the Martian surface. The landing is scheduled to take place on Decembe around 12:00 noon Pacific Standard Time (PST). Our countdown below starts at roughly 10:00 p.m. PST on December 2.

14 hours before entry into the Martian atmosphere
The final, 4-hour tracking session of the cruise begins. Ground controllers have their final opportunity to gather navigation data before entry.

12 hours before entry
Ground controllers will disable the software that puts the spacecraft in safe mode (in reaction to unexpected events during cruise) for the remainder of the spacecraft's flight and descent to the surface.

7 hours and 25 minutes before entry
A 30-minute tracking session will begin. This is the last chance to make a trajectory correction to fine-tune the spacecraft's flight path.

5 hours before entry
A 1-hour tracking session will begin. Controllers will use this session to monitor spacecraft health and status and to perform tracking after the final thruster firing.

4 hours and 40 minutes before entry
A series of valves will open to vent the descent engines. Ten minutes later, a pyro valve will fire to pressurize the descent engines.

25 minutes before entry
The spacecraft team has its final 15 minutes of contact with the spacecraft and will receive information on the status of the propulsion system.

20 minutes before entry
Heaters on the lander's thrusters will be turned on.

15 minutes before entry
Software controlling the Mars Descent Imager (MARDI) will be initialized.

10 minutes before entry
Controllers will command the spacecraft to switch to inertial navigation, which computes *Mars Polar Lander*'s position, course, and speed from gyroscopes and accelerometers.

6 minutes before entry
The spacecraft will fire its thrusters for 80 seconds to attain entry orientation.

5 minutes before entry
The cruise stage will separate from the aeroshell-encased lander. Cut off from the cruise stage's solar panels, the lander will rely on its internal battery until it can unfold its own solar panels on the planet's surface. The *Deep Space 2* microprobes, piggybacking on the lander's cruise stage, will be separated about 18 seconds after cruise-stage separation. The lander will then be commanded to assume the correct orientation for atmospheric entry.

Entry
Traveling at about 6.8 kilometers per second (15,200 miles per hour), the spacecraft will enter the upper fringe of Mars' atmosphere. Onboard accelerometers, sensitive enough to detect *g*-forces as small as 3/100ths of Earth's gravity, will sense when friction from the atmosphere causes the lander to slow slightly. At this point, the lander will begin using its thrusters to keep the entry capsule aligned with its direction of travel.

Descent
The spacecraft's descent—from the time it hits the upper atmosphere until it lands—takes no more than 4 minutes and 33 seconds. As it descends, the spacecraft will experience *g*-forces up to 12 times Earth's gravity, while the temperature of its heat shield rises to 1,650 degrees Celsius (3,000 degrees Fahrenheit).

2 minutes before landing
The lander's parachute will be fired from a mortar (small cannon) when the spacecraft is moving at about 493 meters per second (1,100 miles per hour) some 7.3 kilometers (4.5 miles) above the Martian surface. Ten seconds after the parachute opens, the MARDI will be powered on, and the spacecraft's heat shield will be jettisoned. The first descent image will be taken 0.3 seconds before the MARDI heat-shield separation. The MARDI will take about 10 pictures during the spacecraft's descent to the surface.

About 70 to 100 seconds before landing
The lander legs will deploy, and the landing radar will activate. The radar will be able to gauge the spacecraft's altitude about 44 seconds after it is turned on, at an altitude of about 2.5 kilometers (1.5 miles) above the surface.

When the spacecraft is traveling at about 80 meters per second (180 miles per hour) some 1.4 kilometers (4,600 feet) above the surface, the thrusters that the spacecraft has used for maneuvers during its cruise will turn off, and the backshell will separate from the lander. The descent engines will turn on one-half second later, turning the

Celebrate This Millennium's Last Mission to Mars

You can follow *Mars Polar Lander*'s daring descent to the Red Planet step by step at Planetfest '99. We'll be linked directly to the Jet Propulsion Laboratory, so you'll see the first images and hear the first sounds as they come in.

We know that not everyone will be able to join us in Pasadena, so we have found a way to bring Planetfest '99 to you through Planetfest Online at our **planetary.org** website. We'll have live webcasts from the convention center, featuring interviews with mission scientists and engineers as well as many of our other illustrious guests. We will also post all the images, sounds, and latest information from Mars. Check the website often for more detailed information and webcast schedules.

Whether in person or in cyberspace, we hope you will be celebrating with us December 3 to 5. See you at Planetfest '99!

down

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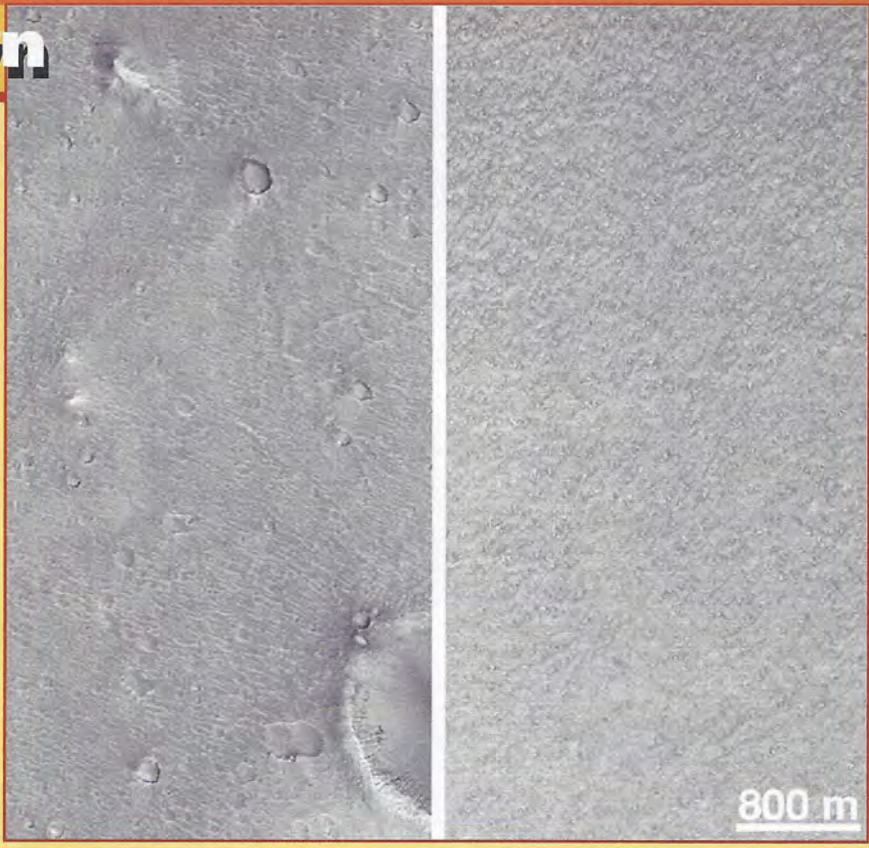


Here the Mars Pathfinder *landing site (left) and* Mars Polar Lander *landing site appear side by side. Familiar landmarks at the* Mars Pathfinder *site include the Twin Peaks (center left), North Peak (top), and Big Crater (lower right). The wavy texture at the* Pathfinder *site is the result of the movement of sediment by a flood that swept through billions of years ago.*

In comparison, the south polar layered deposits (right image) are generally devoid of large craters and hills. The Mars Polar Lander *site shows a random arrangement of low ridges and grooves that suggest the surface has been exposed to ice erosion. When this picture was taken, the surface was still mostly covered by wintertime carbon dioxide frost. The dark spots that are barely visible in this image will become more noticeable in Martian spring and summer as the carbon dioxide frost sublimes (goes directly from solid to vapor).*

Images:MSSS/NASA

lander so its flight path gradually becomes vertical. These pulse-modulated engines will maintain the spacecraft's orientation as it descends. The radar will turn off at an altitude of about 40 meters (130 feet) above the surface, and the spacecraft will rely on its gyros and accelerometers for guidance as it lands.

● Landing

Once the spacecraft reaches either an altitude of 12 meters (40 feet) or a velocity of 2.4 meters per second (5.4 miles per hour), the lander will drop straight down at a constant speed. The descent engines will turn off when sensors in the footpads detect touchdown.

Mars Polar Lander will set down near the northern edge of the layered terrain surrounding the south pole, at 76 degrees South latitude and 195 degrees West longitude.

● 30 minutes after landing

First direct-to-Earth contact will last 20 minutes. The next period of contact will occur 8 hours after landing.

● 1 hour after landing

First image expected to be transmitted back to Earth.

● 5 hours after landing

The Mars Microphone will record the sounds of the Surface Stereo Imager as it is deployed.

Of course, this schedule is based on everything going perfectly. The abrupt loss of *Mars Climate Orbiter* just as it reached its destination is a reminder that nothing is guaranteed in the real world of space exploration. Even small mishaps can cause big changes in mission plans. Two recent, and very successful, missions to Mars—*Mars Pathfinder* and *Mars Global Surveyor*—both had unforeseen problems (one of *Pathfinder*'s ramps didn't deploy, and a broken damper arm threatened a solar panel on *Mars Global Surveyor*). Both missions overcame these malfunctions and delivered a wealth of data, dramatically reshaping our understanding of Mars.

Mars Polar Lander still has a lot of work to do just getting down to the surface, but, along the way, we on Earth will be cheering it on, anticipating the sights and sounds to come. —*Jennifer Vaughn, Assistant Editor*

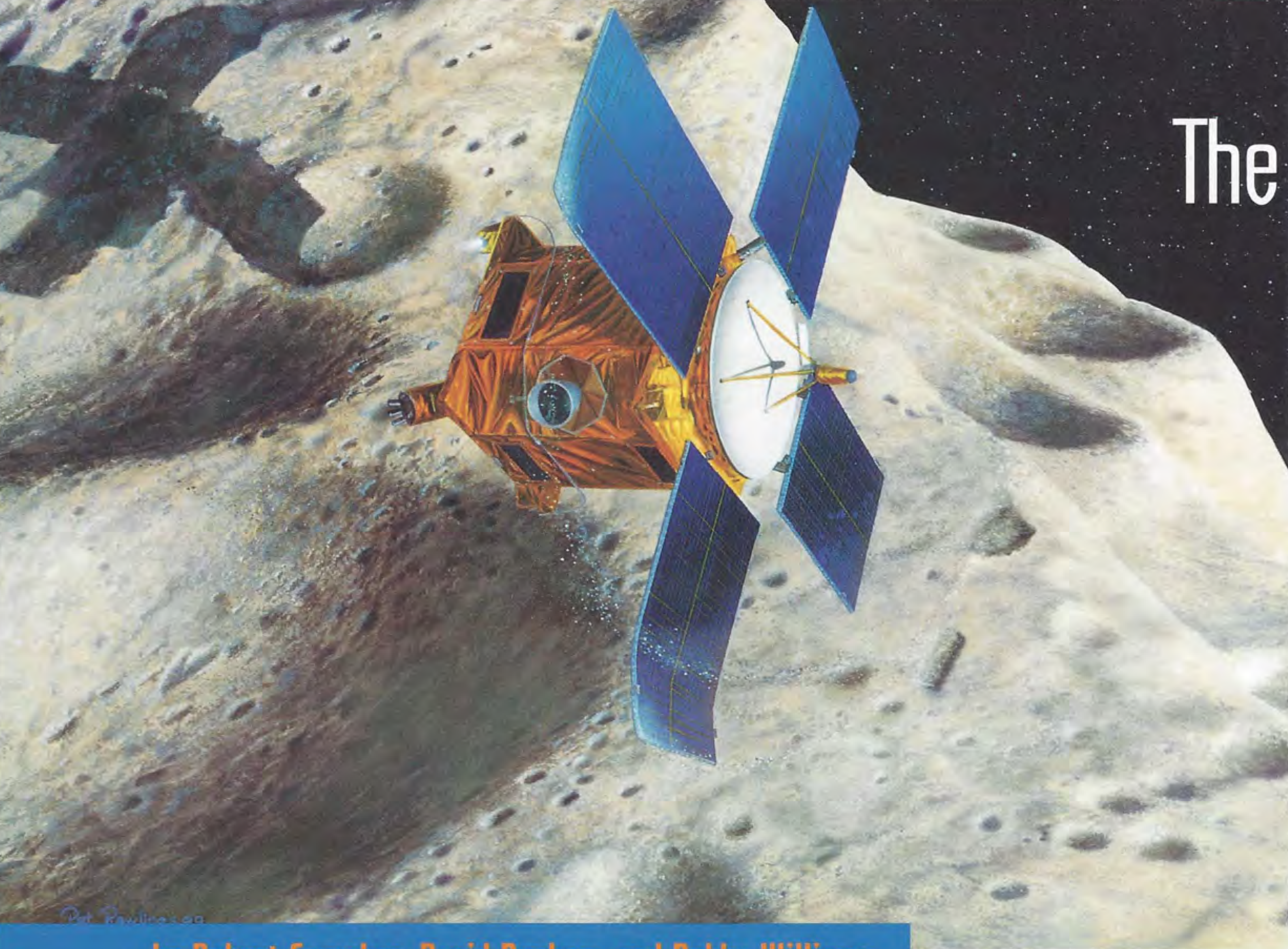
Delving Into Mars: The New Millennium Microprobe Mission

Minutes before the capsule containing *Mars Polar Lander* passes through the Martian atmosphere, two basketball-sized aeroshells will crash onto the Martian surface at about 200 meters per second. Shattering on impact, each aeroshell will release a miniature, two-piece science probe that will punch into the soil as deep as 2 meters.

The goal of the Mars Microprobe mission, also known as *Deep Space 2*, is to determine if water ice is present in the Martian subsurface—an important clue in the puzzle of whether life exists, or ever existed, on Mars. Designed to land some 200 kilometers (about 125 miles) from the *Mars Polar Lander*, the probes will penetrate the layers of dust and ice near Mars' southern polar ice cap.

Operating for only about 50 hours, the microprobes will act as tiny science stations, searching for water, measuring soil temperature, and monitoring local weather.

For more information on the *Deep Space 2* microprobes, please visit the *Deep Space 2* Microprobe website at **http://nmp.jpl.nasa.gov/ds2/**.



The

by Robert Farquhar, David Dunham, and Bobby Williams

In early December 1998, the mood in the NEAR project office was one of quiet confidence and anticipation of the spacecraft's orbit insertion at 433 Eros. So far, everything had gone according to plan. NEAR had already accomplished a number of notable successes, such as:

- establishing a new distance record for a spacecraft using solar cells to power onboard systems (2.19 astronomical units from the Sun),
- conducting the first reconnaissance of a C-class asteroid (253 Mathilde), and
- obtaining spectacular images of Antarctica during its January 1998 flyby of the Earth.

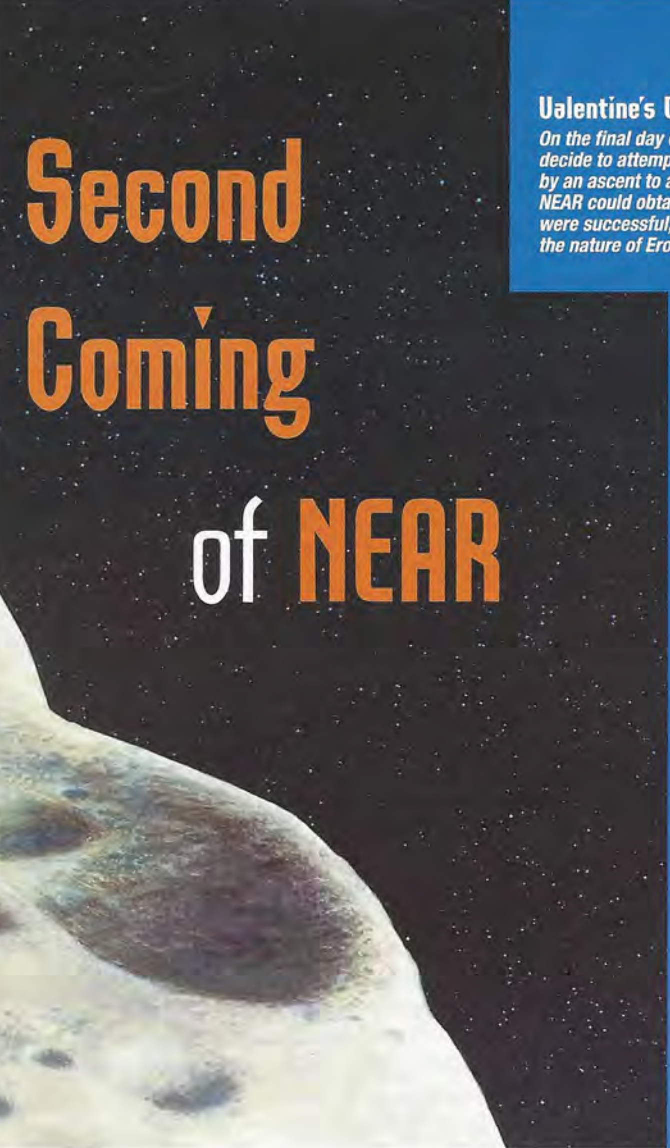
To carry out the rendezvous with Eros, a conservative plan calling for five propulsive maneuvers over a three-week period was to begin on December 20, 1998. The first propulsive maneuver required a 15-minute firing of NEAR's large bipropellant rocket engine. This engine had already performed a critical 7-minute maneuver on July 3, 1997 that successfully targeted NEAR for its Earth gravity-assist on January 23, 1998. Although the December 20 burn was to be about twice as long, there was every reason to expect that this burn would go as smoothly as the one before.

The fifth propulsive maneuver, a small orbit-insertion firing, would complete the Eros rendezvous operation on January 10, 1999. It must be acknowledged that this date was not chosen for purely technical reasons. It was determined by romantic considerations as well as celestial mechanics. Because January 10 would be the fifth anniversary of the marriage of NEAR's Mission Director to his wife Irina, and because Eros is named for the Greek god of love, this date seemed appropriate for NEAR's arrival. (To forever commemorate the dual event, Gene and Carolyn Shoemaker had arranged the renaming of asteroid 1988 JN to 5957 Irina.) A party celebrating the wedding anniversary and the asteroid encounter was scheduled for the afternoon of January 10, 1999. The party took place as planned. However, the reason for celebrating NEAR's status had changed considerably. Instead of toasting a successful orbit insertion, NEAR team members were just thankful for the spacecraft's survival.

Black Sunday, December 20, 1998

NEAR's first rendezvous maneuver began on schedule at 5:00 p.m. EST (Eastern Standard Time) on December 20. Doppler signals confirming the start of the "settling burn"

Second Coming of NEAR



Valentine's Day, 2001

On the final day of NEAR's scheduled mission, NASA may decide to attempt a brief touchdown on Eros' surface, followed by an ascent to an altitude of a few hundred meters, where NEAR could obtain images of its "footprint." If this experiment were successful, it would reveal important information about the nature of Eros' surface. Painting: Pat Rawlings/SAIC

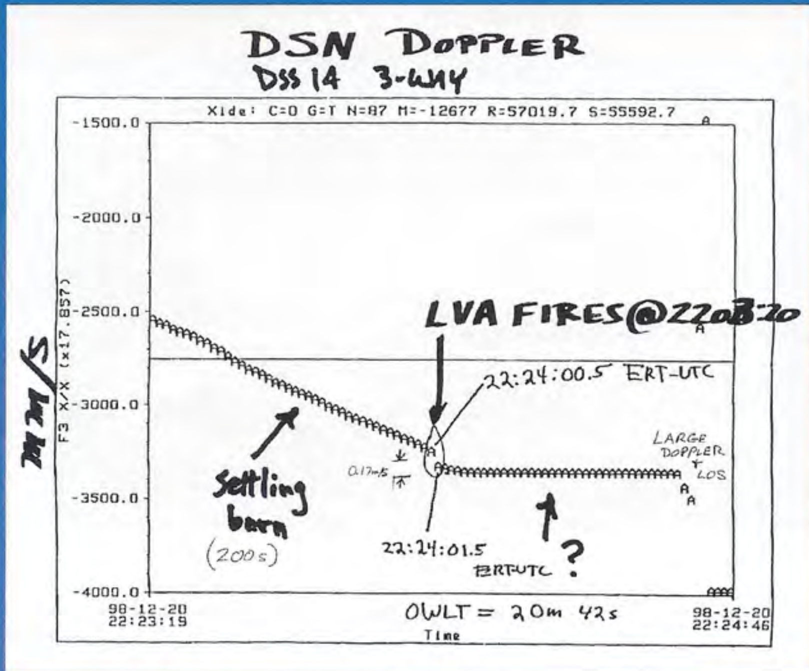


Figure 1: Fax From JPL Navigation Team Showing NEAR's Doppler Signature (December 20, 1998)

This fax, with annotations by various NEAR team members at JPL, is a remnant from the scramble to find out what happened to the spacecraft on its approach to Eros. From left to right, the stream of A's represents Doppler tracking data received at the Deep Space Network's 70-meter Goldstone antenna (DSS 14) in California. The data-points slope smoothly through the 200 seconds of the "settling burn," reflecting a gradual velocity change.

At 22:24:00.5 Earth Receive Time/Coordinated Universal Time, the bipropellant (LVA) engine fires and the velocity jumps, but only by 0.17 meters per second—much less than planned. The line of data stays flat, indicating constant velocity, for about 37 seconds. Then (at the right-hand edge of the graph), there is a wild scatter of data-points, followed by loss of signal (LOS).

After 27 hours of silence, the spacecraft resumed radio transmissions.

by the small thrusters began to arrive at the Jet Propulsion Laboratory (JPL) navigation center at about 5:21 p.m. (one-way light time between NEAR and Earth was 20.7 minutes). The settling burn proceeded as expected, and it appeared that the next step, firing the bipropellant engine, had begun on time. At this point, the operation started to unravel rather quickly.

Although sparse and inconclusive, the initial Doppler measurements indicated that the bipropellant burn was not normal. Worse yet, we lost all contact with the spacecraft 37 seconds after ignition of the bipropellant engine. Another two hours went by before the navigation team was able to obtain a complete set of Doppler data, which was crucial to determining just what had gone wrong. These measurements showed that the bipropellant engine had shut down after less than one second. More ominously, large Doppler excursions had occurred just before NEAR's loss of signal (see figure 1).

A spacecraft emergency was declared, and the NEAR team worked throughout the night trying to restore communications. By the following morning, with NEAR still silent, the outlook was grim. The chief hope was that the transmitter had turned off autonomously due to a power shortage on the spacecraft. If this had happened, the transmitter would come back on-line automatically in 24 hours. Of course, this was only one of several theories under investigation. By Monday afternoon (December 21), many people feared that NEAR was gone forever.

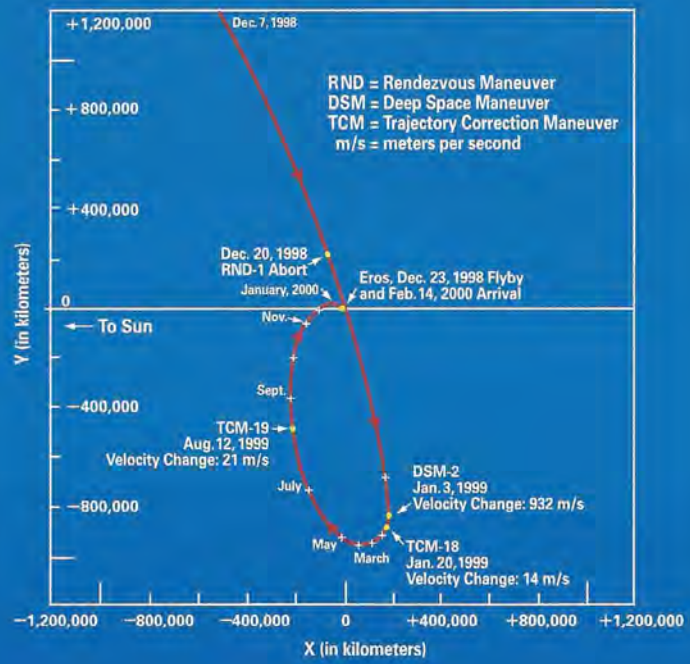
Then suddenly at 8:01 p.m. on December 21, a miracle . . . transmissions from NEAR were received at the Canberra station of the Deep Space Network. The spacecraft was still alive! After 27 hours of gloom and doom, joy had returned to the NEAR control center.

Good News and Bad News

By early morning on December 22, enough engineering data had been downloaded from NEAR to permit an assessment of the spacecraft's status. There was good news.

- There was no damage to the spacecraft or the propulsion system.
- The fault-protection software had identified the problem and placed NEAR into a safe mode. The spacecraft's

Figure 2: NEAR's Motion Relative to a Fixed Sun-Eros Line (Dec. 1998 to Feb. 2000)



transmitter had turned off to save power and switched back on 24 hours later.

- The cause of the engine abort was identified as a spike in lateral acceleration that exceeded limits set in the onboard software. It would be relatively easy to modify the software to eliminate this problem for future maneuvers.

And there was bad news.

- The recovery was seriously deficient. Following the engine shut-down, the spacecraft experienced anomalous attitude fluctuations, and the battery discharged to dangerously low levels.

- The spacecraft expended roughly 30 kilograms (66 pounds) of hydrazine fuel while stabilizing its attitude.

- There was some contamination on the camera optics from the hydrazine fuel. However, we don't expect this to be a major problem in obtaining quality images at Eros.

Naturally, the flawed recovery was a major concern. Another misfortune of this magnitude would effectively end the NEAR mission. Therefore, the project instituted a number of new operational and contingency testing procedures that should prevent a recurrence of this problem.

The loss of so much hydrazine was totally unexpected. Although a rendezvous with Eros was still achievable, the depletion of fuel precluded any possibility for a quick return. Had another 15 kilograms (33 pounds) been squandered, NEAR would have lost all hope of ever attaining a rendezvous with Eros.

Fortunately, NEAR had a forgiving mission design that had planned for adversity. The design included generous fuel margins and a variety of contingency options. More than any other factor, the resilient mission design was responsible for giving NEAR a second chance. However, at the moment we had no time for worrying about which contingency option we would use. We had to prepare for a flyby of Eros that would take place on December 23.

Flyby of Eros

With less than 24 hours to get ready for the Eros flyby, engineers and scientists worked throughout the night to update NEAR's observing sequence. Due to uncertainties in the asteroid's position relative to the spacecraft, we would have to image a significant area of the sky to be sure of getting pictures of Eros near closest approach. Unfortunately, the aborted rendezvous burn and ensuing attitude maneuvers had pushed the spacecraft far off its intended course. Instead of the originally planned 1,000-kilometer (600-mile) miss distance, NEAR's closest approach to Eros was 3,827 kilometers (2,378 miles). This meant that the smallest detail resolved by NEAR's camera was about 400 meters across. Nevertheless, humankind's first close-up encounter with a near-Earth asteroid yielded 222 images of Eros as well as supporting spectral observations. From these we gained new and useful information about Eros.

- The elongated, cratered body has a ridge-like linear feature that extends at least 20 kilometers (12 miles).

- The asteroid's shape is irregular but can be geometrically approximated as a triaxial ellipsoid with diameters of 33 x 13 x 13 kilometers (20 x 8 x 8 miles).

- Its bulk density is 2.5 ± 0.8 grams per cubic centimeter (for comparison, the density of water is 1.0 grams per cubic centimeter), as calculated from the asteroid's mass (determined through spacecraft tracking data) and estimated volume.

- We found no satellites, down to a detection size limit of 50 meters.

- We obtained a more accurate position for Eros' rotation pole.

The flyby images of Eros provided a tantalizing preview of the imaging program that NEAR will carry out on its return to Eros. From orbit, NEAR's camera will image the surface at a resolution of about 5 meters (80 times better than the best flyby image). We plan to use occasional low-altitude passes to view interesting features at even better resolution.

NEAR Makes a U-Turn

While scientists were savoring the pictures of Eros, other members of the NEAR team (especially mission design, navigation, and operations personnel) were focused on formulating a plan to get NEAR back on track for a rendezvous with Eros. Existing contingency plans included options for a second attempt later in January 1999, in July 1999, or sometime between February and May 2000. Because of NEAR's unscheduled fuel dump, the January 1999 option was no longer possible, and the July 1999 option was marginal. Therefore, NEAR's mission planners quickly

These are the 17 best views of Eros, as seen by NEAR when it flew by the asteroid on December 23, 1998. As this sequence was taken, NEAR closed from 11,100 kilometers (6,900 miles) to 3,830 kilometers (2,380 miles). The sunlit portion of the asteroid appeared to shrink as the spacecraft moved from the day- to the night-side. Images: APL/NEAR Project

settled on a strategy that would achieve a rendezvous in mid-February 2000. The new target date was February 14, 2000, Valentine's Day.

Figure 2 [page 16] illustrates NEAR's current trajectory profile. As shown, we reversed the spacecraft's movement away from Eros with a large propulsive maneuver on January 3, 1999. The maneuver was accomplished with the bipropellant engine, which this time performed flawlessly. There was a collective sigh of relief after this maneuver because all future propulsive maneuvers were to be significantly smaller (with a net velocity change of less than 21 meters per second, compared to 932 meters per second for the January 3 maneuver). Furthermore, it would not be necessary to use the bipropellant engine to carry out these smaller maneuvers.

A clean-up maneuver on January 20 and a midcourse correction on August 12 targeted NEAR to the vicinity of Eros. Notice in the figure that NEAR remains relatively close to Eros throughout 1999 (less than 1 million kilometers away, or about 600,000 miles). Finally, a rendezvous maneuver on February 2, 2000 and an orbit-insertion maneuver on February 14 will place NEAR into a 330 x 500-kilometer (about 200 x 310-mile) elliptical orbit around Eros.

Orbital Operations at Eros

Shortly before its orbit-insertion maneuver, NEAR will fly by Eros on the sunward side at a distance of 200 kilometers (about 125 miles). The initial close pass will give us the more precise information we need about Eros for close-in navigation. Measurement goals for the first pass include a mass determination to better than 1 percent accuracy, identification of several hundred surface landmarks, and a refined estimate of Eros' spin orientation. As the spacecraft maneuvers closer to Eros, we will obtain ever more precise estimates of the asteroid's mass, moments of inertia, gravity harmonics, spin state, landmark locations, and so on.

We will use the early high-altitude orbits to obtain global images of Eros, resolving features as small as 20 meters. Later, when NEAR reaches its mission orbit of 50 x 50 kilometers (31 x 31 miles), NEAR's camera will map the surface at scales of 5 to 10 meters. At the end of the mission in 2001, NEAR will close in to image selected features at distances of only 500 meters, where we can detect objects as small as 10 centimeters (about 4 inches)!

Of course, NEAR's science objectives at Eros are not limited to collecting a stack of pretty pictures. In addition to its multispectral imager, NEAR's science payload includes a near-infrared spectrometer, a gamma-ray/X-ray spectrometer, a magnetometer, a laser altimeter, and a radio-science package. The near-infrared spectrometer will map the mineral makeup of the surface. With these mapping data, we can relate variations in minerals to surface features and clarify the connection between geological and geochemical processes. The gamma-ray/X-ray spectrometer will measure the abundance of several dozen key elements, making it possible to relate the asteroid's composition to the compositions of meteorites. Data from the laser altimeter will be used to determine the shape and topography of Eros' surface. Finally, the magnetometer and radio-science measurements will unveil the internal state of Eros.

In figure 3 [page 18], we show NEAR's primary orbit around Eros, as viewed by an observer on the Sun. The orbit and Eros are drawn to scale, but obviously the spacecraft is

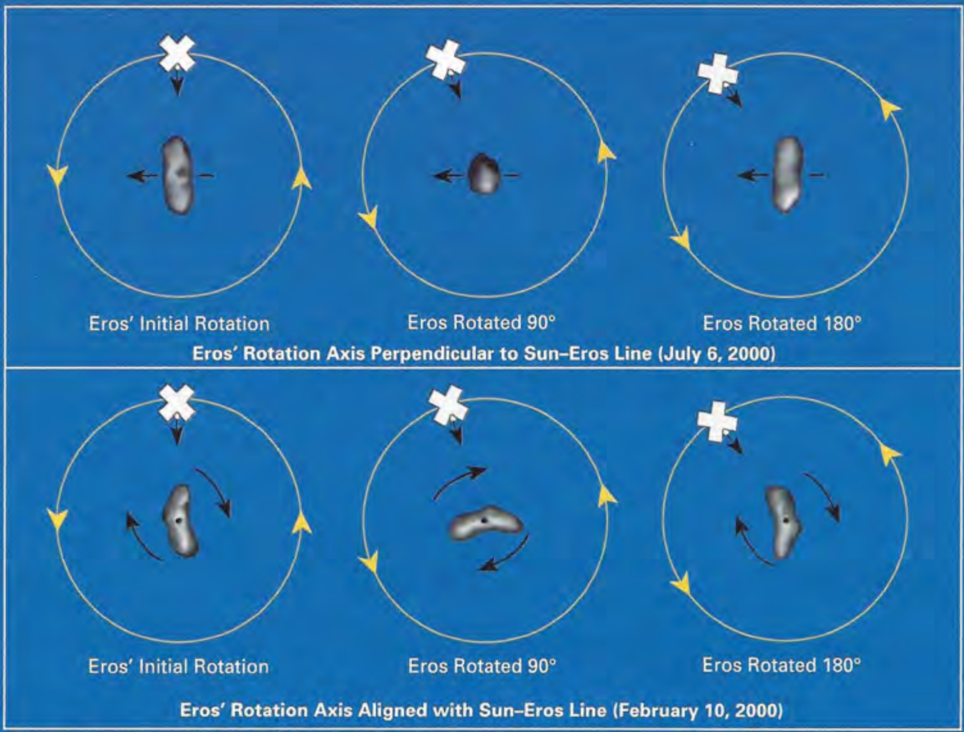


Figure 3: NEAR's Primary Mission Orbit Around Eros as Viewed From the Sun (Orbital Period: 1.2 days)

not. This viewpoint is convenient for showing NEAR's orbit because the orbit will be controlled so that it is always within 30 degrees of a plane perpendicular to the Sun-Eros line. In this orientation, NEAR's fixed solar panels will be aimed toward the Sun. The science instruments will view Eros as the spacecraft slowly rolls in its orbit.

In the top frame of figure 3, notice that Eros' rotation axis is perpendicular to the Sun-Eros line. Approximately seven months later, as Eros proceeds in its orbit around the Sun, the asteroid's rotation axis will align with the Sun-Eros line. The south pole of Eros will point toward the Sun, which means that Eros' northern hemisphere will be dark. In February 2000, when NEAR first arrives at Eros, the north pole will be oriented fairly close to the sunward direction.

Bouncing Off an Asteroid

NEAR's orbital operations at Eros will follow a well defined timetable throughout the year 2000. But then in 2001, during the final five weeks of the mission, the flight plan is more flexible and adventurous. NEAR's scientists have a strong desire to investigate areas of Eros at a much closer range. NEAR will make several close passes at altitudes between 2 to 5 kilometers (roughly, 1 to 3 miles). On the final day of the mission, February 14, 2001, NEAR will slowly descend to an altitude of about 1 kilometer (0.6 miles) over the south pole. During its descent, the spacecraft will keep its high-gain antenna pointed at the Earth to transmit images and other science data as quickly as possible.

As a final experiment, NEAR may attempt a brief touchdown on Eros' surface, followed by an ascent to about 500 meters. There the spacecraft would obtain images of its "footprint" and transmit them back to Earth. If this test can be carried out, it will reveal important and unique information about the nature of Eros' surface. It would also provide invaluable engineering experience concerning landing operations on small bodies, which could aid a number of future missions. Japan's *MUSES C* mission is planning to land on asteroid 1989 ML in 2003.

On December 20, 1998, NEAR experienced a near-fatal reversal of fortune. However, largely because of robust mission design, NEAR overcame the adversity and will have an opportunity to snatch victory from the jaws of defeat. If all goes well, this will be the first time in spaceflight history that a spacecraft has recovered from an aborted orbit-insertion maneuver and then returned to the targeted body to complete all of the objectives of the original mission.

Robert Farquhar is the NEAR Mission Director, and David Dunham is the Head of the Mission Design Team. Both are affiliated with the Johns Hopkins University Applied Physics Laboratory. Bobby Williams of the Jet Propulsion Laboratory is Head of the Navigation Team.

Operations Timeline at Eros

February 14, 2000	Eros Orbit Insertion
February 14 to April 30	High-Orbit Phase [Orbit radius: 50 to 500 kilometers]
May 1 to August 27	Low-Orbit Phase [50 x 50 kilometer orbit]
August 28 to December 13	High-Orbit Phase [Orbit radius: 50 to 500 kilometers]
December 14 to January 10	Low-Orbit Phase [Orbit radius: 35 to 50 kilometers]
January 10 to February 14	Low-Altitude Operations [Mimimum altitude: 2 to 5 kilometers]
February 14, 2001	End of Mission

(continued from page 11)
error has been traced to a mix-up of English and metric units. That is, the amount of thrust generated by the attitude-control system was given in pounds of force instead of newtons. This discrepancy skewed calculations by computer models and led to the buildup of errors. Some of these errors may actually have been noticed on the way to Mars but were not recognized as system errors (as opposed to expected position errors) and were thought to have been compensated for when *MCO* initiated the fatal trajectory-correction maneuver. The profound question is not about the mix-up in units but why such a mix-up went undetected. Somehow the system broke down. That is what engineers at the Jet Propulsion Laboratory are trying now to understand.

The loss of *MCO* is a setback. One instrument (the Pressure Modulated Infrared Radiometer) was on its second ride to Mars—it had been on board *Mars Observer*. Because of this second loss, for many years more we will lack data on Mars' atmosphere, water content, and climate. Moreover, *MCO* was to have been the prime relay for data from the *Mars Polar Lander* (*MPL*), scheduled to land on December 3, 1999. *MPL* will have to make more use of its slower, direct-to-Earth communications link to send observations, including the sounds from The Planetary Society's Mars Microphone.

Fortunately, with great credit to NASA Administrator Dan Goldin, the US has a continuing Mars program, of which *MCO* was only one mission. With missions scheduled to launch every two years, that program is robust and has the resilience to give us an additional way to receive communications from *MPL*—through the *Mars Global Surveyor* (*MGS*). Current plans call for *MPL* to start with the direct-to-Earth mode and gradually introduce the higher-capacity *MGS* communications. *MGS* will be used immediately to relay data from the two *Deep Space 2* microprobes carried by *MPL*. Expectations are still very high for *Mars Polar Lander*, and it appears there will be no science lost on that mission as a result of *MCO*.

Scientists and mission planners are also examining the effects of *MCO*'s loss on future Mars missions. The *Mars Surveyor 2001* mission plan was to use *MCO* as a communications backup. Now that backup is not available. Some changes will be made to the *2001* mission (and there may be modifications of later mission plans as well) to recover the atmospheric and climatological data that *MCO* was to return.

We hardly need reminders that space exploration is difficult. This is true with robotic missions—which involve only lost money and shattered dreams—and it is true of human missions, in which the stakes are much higher. But the value and the joy we find in exploration are due in part to its adventure and to the great effort it requires. We look forward to realizing the rewards of that effort with the December 3 landing of *Mars Polar Lander* and with missions to come in the 21st century.

> It will take some time to find and evaluate the deeper causes of the mistake in use of metric and so-called English* measurement units that caused the loss of the *Mars Climate Orbiter*. Undoubtedly human errors will be found. Meanwhile, the technical nature and the in-flight consequences of those errors are now known. In navigating the spacecraft, it was necessary to account for the small impulses (force multiplied by time) of its attitude control thrusters. One such accounting used newton-seconds (metric) and another used pounds force-seconds (English). The spacecraft was performing perfectly but its actual trajectory was erroneous and, due in part to the mix-up in units, the tiny error (about 80 kilometers at a distance of 200 million kilometers) was not corrected.
> *—James D. Burke*
>
> *Great Britian is now a metric country, along with every other nation in the world except Liberia, Myanmar, and the United States.

Washington, DC—Like the road to Mars, the road to a budget for a space agency (or any government agency) is full of bumps and potholes. Fiscal year 2000 has been especially bumpy. As you have undoubtably heard from us, repeatedly, the US Congress was threatening draconian cuts to NASA—cuts that would have canceled many space-science missions, including exploration missions to other worlds. When the smoke cleared, there were cuts: *Champollion*, a comet lander, was canceled. But the worst was averted—the final budget contained even a bit more than the total funds requested for NASA and most of the funds requested for space science. Check our website for the latest information on the effect of these cuts.

The Planetary Society was extraordinarily active in the legislative consideration of the budget. With our members' support—your individual support—we bombarded Congress with letters and arguments in favor of planetary exploration. We opposed the big reductions being planned for NASA as a whole, and we loudly proclaimed our support for space science. For the third year in a row, I have had members of Congress and their staff tell us that we were effective and influential. It may be too bad that the system demands yelling (and campaigns of letter writing and the like), but it does. The Society must be the voice for deep-space exploration.

We used the World Wide Web extensively in this effort. We used our website to post the latest information, we e-mailed our members (those who have joined our e-mail list), and we linked to congressional information pages to help members get their voices heard. The Society is a leader among nonprofit groups in use of the World Wide Web, and we hope to develop our use of the Web further—making it even more world wide and world deep—to help us in our mission of inspiring the peoples of Earth to explore other worlds and seek other life.

Thanks to everyone who helped in influencing government to support planetary exploration. You made a difference.

Washington, DC—The launch of the first crew to the International Space Station has been postponed until probably February or March 2000. In a reversal of roles, the United States told Russia that the US would not be able to meet the schedule set for crew launch and asked Russia to delay the launch of the service module, planned for mid-November 1999. That launch will probably be no earlier than January 2000.

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

Questions and Answers

Extrasolar planetologists seem puzzled by the notion of a "gas giant" orbiting closely to its parent star and have sought to explain detections of such planets by modifying theories about solar system formation.

Isn't it possible that these very large planets are simply terrestrial-style bodies with a mass greater than Jupiter? Why must they be gas giants?

—Del Stone Jr.,
Fort Walton Beach, Florida

Many extrasolar planets have a mass that is a significant fraction (up to 0.5 percent) of the mass of their host stars. The spectra of these host stars indicate that the fraction of their mass which is contained in heavy elements (other than hydrogen and helium gas) is about 2 percent. If these planets were made primarily of heavy elements, like terrestrial planets, they would need to be much more efficient in accreting those heavy elements than their host stars. By "more efficient" I mean that the planets would need to pick up more total mass of heavy elements (rather than a higher percentage) than their star. Thus, more efficient planets are inconsistent with current theory on solar system formation—even more inconsistent than the hypothesis that these planets are solar in composition (gas giants like Jupiter and Saturn).

Planets rich in heavy elements are likely to resemble terrestrial planets because this material has a lower condensation temperature and is likely to be a solid form.
—DOUG LIN,
University of California, Santa Cruz

Earth's magnetic field maintains the Van Allen belt and shields our biosphere from toxic solar radiation. Periodic shifts (reversals and variations in intensity) have been known to occur in the magnetic field. Do these shifts impact the biosphere?

—Bob Barauskas,
Philadelphia, Pennsylvania

Factinos

A lot of Sun-like stars in our galaxy have close-orbiting gas giant planets, comparable to Jupiter, or stillborn stars called brown dwarfs—offspring that will eventually be gobbled up by their parent stars. Mario Livio and Lionel Siess of the Space Telescope Science Institute have found significant evidence that certain giant stars once had large planets that the stars have since swallowed up. As a result of this planetary ingestion, the devouring stars release excessive amounts of infrared light, spin rapidly, and are polluted with the element lithium.

About 4 to 8 percent of the stars in the Milky Way show these characteristics, according to Livio and Siess. This is consistent with estimates of the number of close-orbiting giant planets, based on discoveries of extrasolar planets through precision Doppler spectroscopy, or observations of wobble in stars caused by the tug of unseen companions. (See "First Reconnaissance" by Paul Butler in the July/August 1997 *Planetary Report*.)

An aging Sun-like star will expand into a red giant eventually and take in any bodies in low orbits. If the companions have a mass like Jupiter's (or more), they will have a major effect on the red giant's evolution. First, according to Livio, the parent stars absorb gravitational energy from their companions. This heats the stars so that they puff off expanding shells of dust that radiate huge amounts of infrared light, making them appear bigger and brighter. Then the orbiting companion transfers angular momentum to the star, causing it to "spin up" to a much faster rate than normal. Finally, the newly consumed planet delivers a fresh supply of lithium—an element that is normally destroyed inside stars—resulting in an unusual excess in the star's spectrum.

—from the Space Telescope Science Institute

Detections of extrasolar planets tell us that Jupiter-size bodies can orbit unexpectedly close to their parent stars—even closer, sometimes, than Earth is to the Sun. Eventually, these doomed worlds will be consumed and incinerated by their parent stars. This won't happen to Jupiter when our own Sun expands to a red giant (in about 5 billion years) because Jupiter's orbit is too far out. Illustration: Space Telescope Science Institute

The short answer is that Earth's atmosphere is far more important than its magnetic field in shielding the biosphere from potentially significant radiations from the Sun and other extraterrestrial sources. In other words, the radiation exposure of Earth's surface would be changed only slightly if our magnetic field ceased to exist.

The most important part of a fuller answer is that most of the Sun's radiations—gamma rays, X-rays, ultraviolet and visible light, infrared, and radio emissions—are electromagnetic waves and are not affected by Earth's magnetic field. Of these, gamma rays, X-rays, and much of the ultraviolet spectrum are absorbed in the upper atmosphere. The Sun also emits a flow of low-energy ionized gas—the solar wind—and sporadic bursts of high-energy particles. The solar wind is one of the principal sources of the particles in the radiation belts and is the cause of the polar aurorae. But in the absence of Earth's magnetic field, the solar wind would simply be absorbed into the upper atmosphere. Energetic particles from occasional solar flares are affected by the magnetic field, have free access to the polar caps, and are sometimes detected by sensitive ground-based instruments, though again these particles are mostly absorbed by the upper atmosphere.

The very energetic (billions of electron volts) particles in galactic cosmic rays are affected by Earth's magnetic field, have free access to the polar caps, and have lesser access to lower latitudes. But, after passage through the upper atmosphere, only their secondary radiation reaches the surface of Earth, and this exposure has not been shown to have biological significance, either with or without the presence of Earth's magnetic field.

Let me add that all of the above is in response to your specific question. The radiation situation above Earth's atmosphere is quite a different matter.
—JAMES A. VAN ALLEN,
University of Iowa

I am reading a book in which two people are standing on the Moon. When they look in the direction of the Sun and Earth, they see very bright light (Sun) and icy blue (Earth) colors. However, when they look away from the light into space, they see nothing. It is totally black. Why don't they see stars as we do on Earth?
—Michelle Bomba,
Middleburg, Florida

In a word: contrast. Because the rest of the stars are so much farther away than the one we orbit (the Sun), they appear much fainter to the eye—by a factor of 10,000,000,000 or more. Even the brightly illuminated lunar landscape outshines the stars by a dazzling amount. The contrast is especially strong on the Moon because there's no atmosphere to scatter light the way it is scattered in the blue skies of Earth. Our eyes are good with contrast but not *that* good. An astronaut on the Moon would have to get into the shade and block out reflected light from the landscape to see the stars well.
—KEVIN POLK,
Science and Technology Coordinator for The Planetary Society

Frozen sulfuric acid shows up in this* Galileo *image of Europa. The brightest yellow at upper left (Europa's trailing hemisphere) depicts the areas with highest concentrations of this caustic material.

Image: JPL/NASA

Sulfuric acid—the noxious substance in automotive batteries—has been detected on the surface of Jupiter's moon Europa. "This demonstrates, once again, that Europa is a really bizarre place," said Robert Carlson of the Jet Propulsion Laboratory (JPL). "You're not likely to find sulfuric acid on Earth's beaches, but on Europa it covers large portions of the surface." Carlson is the principal investigator for the near-infrared mapping spectrometer (NIMS) on board *Galileo*.

At first Carlson thought the new findings would quash any talk that life might exist on Europa. But Kenneth Nealson, head of JPL's astrobiology unit, was excited by the discovery. "Although sulfur may seem like a harsh chemical, its presence on Europa doesn't rule out any possibility of life," he declared. "In fact, to make energy, which is essential to life, you need fuel and something with which to burn it. Sulfur and sulfuric acid are known oxidants, or energy sources, for living things on Earth. These new findings encourage us to hunt for any possible links between the sulfur oxidants on Europa's surface and natural fuels produced from Europa's hot interior."
—from NASA Headquarters

Luann Becker of the University of Hawaii and her colleagues from NASA's Space Science Division have confirmed that a form of carbon previously thought to exist only in the laboratory also exists in nature. Their discovery indicates that the pure carbon molecules known as fullerenes could have been a factor in the early history of Earth and might have played a role in the origin of life.

Becker and NASA colleagues Theodore E. Bunch and Louis J. Allamandola discovered the fullerenes in the Allende meteorite that fell in Mexico 30 years ago. The researchers published their report in the July 15, 1999 issue of *Nature*. This is the first discovery of higher fullerenes in a natural sample.

"It's not every day that you discover a new carbon molecule in nature; that's what makes this interesting," said Becker. "If it played a role in how Earth evolved, that would be important."
—from the University of Hawaii

Society News

New Members-Only Website Opens

You asked, and we finally did it: a website just for Planetary Society members. From our main page, go to the Members' Galaxy (**members.planetary.org**). Here you can save time and money, for yourself as well as the Society, by renewing your membership, reporting a change of address, or giving a gift membership.

Want to meet new friends? Now you can get that dialogue going with fellow members on one of the discussion boards. And you'll also be able to access *The Planetary Report* online using Adobe Acrobat™ Reader.

We have big plans for the Members' Galaxy, so stay tuned.

—Cynthia Kumagawa,
Manager of Electronic Publications

Your Help Needed in Mars Mission Contest

The worldwide essay contest to select the Red Rover Goes to Mars student scientists who will serve on NASA's *Mars Surveyor 2001* mission is now under way. Our members can make the difference when it comes to reaching the greatest possible number of children throughout the world with this Society program to educate, inform, and offer actual participation in a planetary exploration mission. We need regional centers (which are easily formed) throughout the United States, and around the world, to judge student entries.

By supplying students and institutions with entry forms and background materials, you can help us give thousands more young people a chance to participate in this groundbreaking project.

Please contact us for a Red Rover Goes to Mars Action Pack, which contains all the materials you'll need to help make sure this unprecedented opportunity reaches students everywhere.

—Linda Hyder,
Manager of Program Development

More News

Planetfest '99 is almost here! Attend online through *Planetcast*, the live webcast of Planetfest '99! Watch our home page for details: **planetary.org**

Mars Underground News:
Read updates on *Mars Polar Lander* and The Planetary Society's Mars Microphone.

Bioastronomy News:
Reports from the Sixth International Conference on Bioastronomy and more news about SETI@home.

For more information on the Society's special-interest newsletters, phone (626) 793-5100.

MECA Team Testing NanoExperiments

Prototypes of student NanoExperiments are being integrated with the MECA experiment (Mars Environmental Compatibility Assessment) aboard the *Mars Surveyor 2001* lander. If qualification tests in early 2001 go well, one or more student experiments will be on their way to Mars in April 2001!

Journals and prototypes from the 10 finalists in the Student NanoExperiment Challenge will be on display at Planetfest '99, opening December 3 at the Pasadena Convention Center in Pasadena, California. To read more about this exciting contest, visit the Society Projects section of our website (**planetary.org**).

—Kevin Polk,
Science and Technology Coordinator

Design a Livable Mars Station for Year 2030

On August 26, 1999, US Secretary of Education Richard Riley officially unveiled the Mars Millennium Project (MMP) website. As a national arts, sciences, technology, and education initiative, MMP has been sponsored by the Department of Education, NASA, the National Endowment for the Arts, the Getty Trust, and the White House Millennium Council. The goal of MMP is to excite and engage students from kindergarten through high school in forming small teams to design a Mars community to be inhabited by 100 humans in the year 2030.

The student teams will be led by teachers or professionals acting as mentors from each school's local area, and the challenge will be to utilize the best elements of human culture to design a new community on the Red Planet. No longer will a mere collection of drab engineering "habs" for basic survival suffice, but rather, student designs for a Martian village must incorporate the arts and other humanistic qualities to enhance overall livability for the community. Issues addressed by MMP will cross diverse areas of human life, and the students' ideas may even promote improvement of communities on Earth.

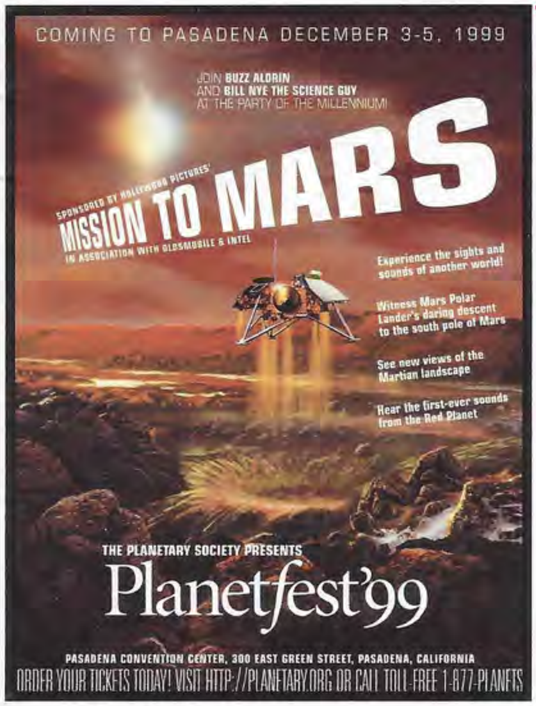
The Planetary Society has played a major role in making the MMP a success. Advisory Council member Charles Kohlhase designed and hosted the Artists, Scientists, and Astronauts (AS&A) portion of MMP. Visit **mmp.planetary.org** on the World Wide Web and read what AS&A contributors have to say about how they were originally motivated to choose their professions, how they carry out their creative processes, and what ideas they would suggest for the future community on Mars.

To date, more than 50,000 US schools and other youth organizations have signed up. Ireland has joined, and France and Japan are expected soon.

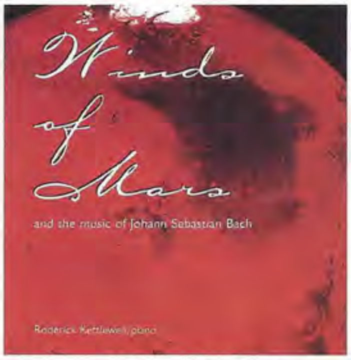
To participate, or just brush up on your knowledge of Mars, go to MMP's main site: **mars2030.net**.

—Donna Stevens,
Associate Editor

Celebrating Our Return to the Red Planet!

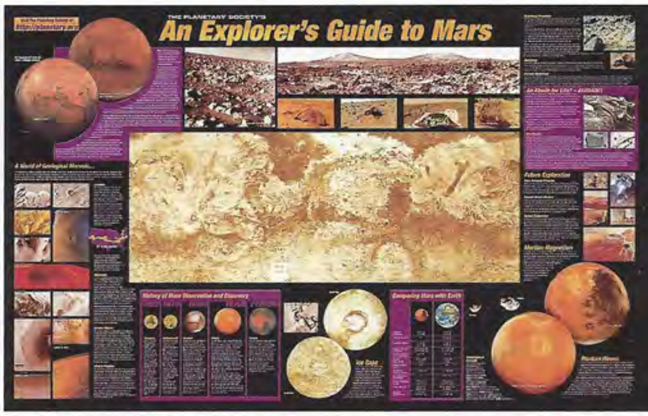


Planetfest '99 Poster
Introducing the official Planetfest '99 poster—Mission to Mars. The image is space artist Don Dixon's vision of the final seconds of *Mars Polar Lander*'s descent to the Martian surface. Created to announce the final Planetfest of the millennium, this poster will be available for a limited time only.
24" x 18" 1 lb. **#810 $10.00**



***Winds of Mars* and the Music of Johann Sebastian Bach**
This audio CD features digitally simulated sounds of the winds of Mars between 17 of Bach's finest compositions, played on piano. The wind data were collected by an instrument on the *Mars Pathfinder* lander and were translated into wind sounds through a Musical Instrument Digital Interface (MIDI). CD includes extensive liner notes explaining the production of the Martian sounds and giving a general history of Mars exploration.

Mars Polar Lander is carrying The Planetary Society's Mars Microphone to record the first actual sounds from the Martian surface. It will be interesting to compare this simulation recording to the real thing.
1 lb. **#785 $14.99**



An Explorer's Guide to Mars
New images from *Mars Global Surveyor*, speculative paintings of the Red Planet's past and future, informative captions and charts, and images of Mars' surface from the *Pathfinder* and *Viking* spacecraft enhance a detailed US Geological Survey map. 24" x 37" 1 lb. **#505 $10.00**

Mars Microphone T-Shirt
The Planetary Society's Mars Microphone hitched a ride on the *Mars Polar Lander*. This T-shirt features the official Mars Microphone logo, depicting the lander, the microphone, and The Planetary Society Penguin.
Adult sizes: M, L, XL, XXL 1 lb. **#770 $15.00**
Child sizes: S, M, L 1 lb. **#771 $12.00**

Mars Microphone Lapel Pin
Share the excitement of the Society's Mars Microphone project with this stunning pin.
1 lb. **#775 $3.00**

Panoramic View of Mars Poster
10" x 36" 1 lb. **#328 $5.00**

Carl Sagan Memorial Station T-Shirt
Adult sizes: M, L, XL, XXL
1 lb. **#581 $15.00**

Future Martian T-Shirt
Child sizes: S, M, L
1 lb. **#565 $12.00**

Search, Discover, Explore T-Shirt
Adult sizes: M, L, XL, XXL
1 lb. **#582 $15.00**

Dive Europa T-Shirt
Adult sizes: M, L, XL, XXL
1 lb. **#557 $15.00**

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34" x 22" 1 lb. **#310 $10.00**

Earth and Its Moon Poster
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Except for the blue skies, Chesley Bonestell's *Exploration of Mars*, first published in 1956, depicts a landscape very close to the real Mars we know today. Arizona-like buttes, dry valleys, and wind-eroded rocks surround these explorers of the 21st century. This visionary panorama hangs in the National Air and Space Museum in Washington, DC.

Chesley Bonestell (1888–1986) spent his long career "designing the future." From his early architectural work on the Golden Gate Bridge and the Chrysler Building to his backgrounds for famous films such as *War of the Worlds* and *Conquest of Space* and his artistic contributions to a young space program in the United States, Bonestell showed us how tomorrow would look.

Many of the space scientists, artists, and science-fiction writers working today were inspired as children in the 1940s and 1950s by Bonestell's paintings of the space age in publications like *The World We Live In*, *Collier's*, and *Life*.

Thanks, Chesley, for sowing the seeds of today's "conquest of space."

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