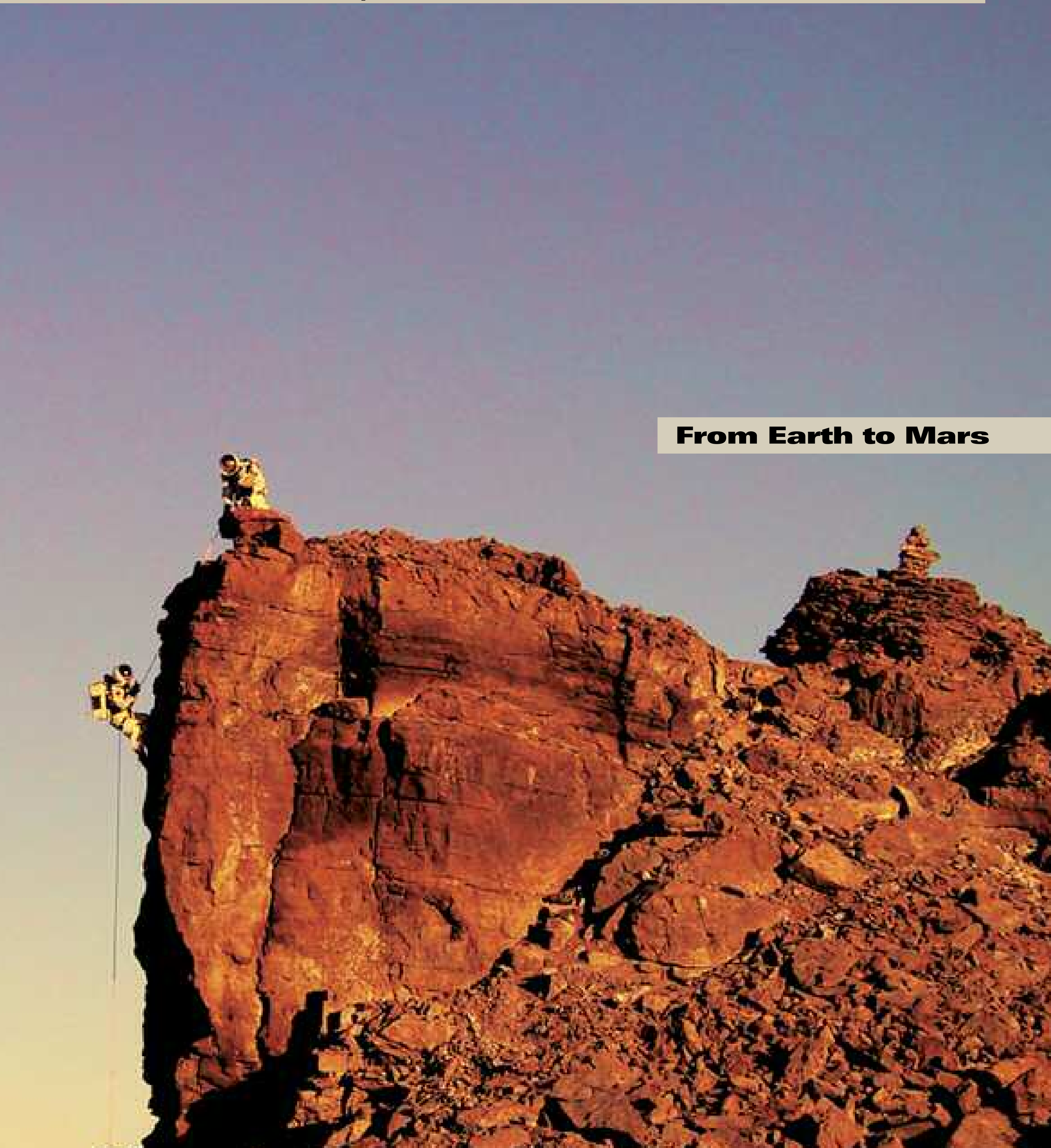
The PLANETARY REPORT

Volume XXII Number 3 May/June 2002



From Earth to Mars

A PUBLICATION OF THE PLANETARY SOCIETY

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Remember the Mars Microphone? Our first experiment designed to listen for sounds on Mars crashed with the *Mars Polar Lander* in 1999. But a great idea will endure beyond such setbacks, and ours does live on. Our microphone team was contacted by scientists working on the *NetLander* mission, led by France's Centre National d'Etudes Spatiales, who asked us to join their mission to Mars. We didn't hesitate to say yes. Greg Delory, a scientist at the University of California at Berkeley, built our first Mars Microphone and is leading the development of the eight microphones that will reach Mars in 2007. Here, he brings Planetary Society members up-to-date on our pioneering project.

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Part Two: Robots and Humans Working Together**
In our January/February issue, Pascal Lee, leader of the Haughton-Mars Project in the Canadian High Arctic, recounted some of the intriguing scientific work he and his team have undertaken on Devon Island. He's back to report on the team's efforts to understand what it will take for humans to explore Mars.

18 Student Navigators Train with the Best
We've just completed the second leg of our continuing Red Rover Goes to Mars project, which is giving students around the world opportunities to learn what real Mars exploration is like. This time, our contest-winning Student Navigators traveled to the Jet Propulsion Laboratory, where they operated a test rover being used by Mars scientists to practice for the upcoming *Mars Exploration Rover* mission. Stay tuned: we're working on new contests and activities, which we'll announce in the coming months.

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From The Editor

We didn't set out to make this a mostly Mars issue. But among the world's planetary programs today, missions to Mars are grabbing a lot of attention. Even here at The Planetary Society, Mars exploration is a major theme. The Red Planet is the only place we know besides Earth that might someday support human habitation. As long as humans still dream of flying to other worlds, Mars will demand our attention.

But this is The Planetary Society, and we work to ensure that no one forgets there are nine planets in our solar system, not to mention countless other orbiting objects. We've fought long and hard to save the NASA mission to Pluto and the Kuiper belt. With much help, last year we succeeded in keeping the mission alive one more year.

But this year, the Bush administration has again canceled the mission. The planned Europa orbiter mission is also gone. You can read Lou Friedman's report on the situation in this issue's World Watch.

We have a lot of work ahead of us. We need each member's support as we fight to keep the planetary program broad and vibrant. So, while in this issue, you may read "Mars, Mars, Mars," remember that The Planetary Society is about so much more.

—Charlene M. Anderson

On the Cover:

Pascal Lee, project lead and principal investigator of the NASA Haughton-Mars Project (HMP), and his brother, camp doctor Marco Lee (left), donned mock spacesuits, made by Mars Society volunteers, to rappel down a cliff face on Canada's Devon Island. They examined stratified rock formations and collected samples along the way. The exercise, part of the HMP's education and public outreach program, was aimed at sharing the vision—and the promise—of human exploration of Mars.

Although hard to see, the rope used by the intrepid explorers actually extends down to the base of the cliff. Pascal warns, "Don't try this at home!"

Photo: NASA Haughton-Mars Project / K. Snook

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The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, 626-793-5100. It is available to members of The Planetary Society. Annual dues in the US are $30 (US dollars); in Canada, $40 (Canadian dollars). Dues in other countries are $45 (US dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

Members' **Dialogue**

Let's Go to Europa

While I agree that the development of nuclear propulsion is a good idea and long overdue, I cannot overemphasize its importance in the exploration of Europa. Indeed, isn't one of the driving forces in space exploration to find life elsewhere in the universe? And isn't Europa the most likely place right now to find it? I cannot understand how anyone in the scientific community wouldn't literally jump for joy at the news that NASA was committing itself to a Europa orbiter quickly followed by a mission to explore the great Europan ocean—should the orbital mission find evidence of one.

Outside of a manned mission to Mars, the exploration of Europa would be the most exciting and rewarding effort in space exploration for years to come. Let's go!
—RANDY WEBER,
Carmel, California

Looking Beyond

January/February 2002 brought another outstanding issue of *The Planetary Report*, in part because it looked beyond the planets into deep space—where our ultimate concerns lie.

The treatise by James D. Burke and John Young ("Whither, O Splendid Ship?") was elegant and inspiring in its simplicity. I would say it meets all the tests of great writing: simple, lucid, and profound. This one's a keeper.
—GARY TURNER,
Munich, Germany

On "Sounding Off"

It was disappointing to me and, I am sure, to most of your Canadian readers to see that you chose to print the letter from Robert Gardias. Dropping one's membership because of a disagreement over the "Society's focus" seems petty indeed, and you would have difficulty finding others who would even consider such an action.

I disagree with the SETI project, but I wouldn't for a minute consider dropping my membership over it. Nor will I drop my membership because I feel you embarrassed me and the majority of your Canadian readers by printing Mr. Gardias' letter.
—WARREN WRIGHT,
Napanee, Ontario, Canada

As you can tell from every survey you have sent and I have returned, I agree wholeheartedly with Robert Gardias that Mars exploration should be a priority, but not for humans! There is plenty of time for human exploration of Mars—when it becomes cost-effective and our many problems here on Earth have been solved.
—EUGENE KOSSO,
Gualala, California

Lunar Outposts

I recently received a Society mailing announcing a new program called the Mars Outpost Campaign. Establishing robotic base camps to create infrastructure for future manned missions and to provide telerobotic operations is very exciting but, I believe, a little too far-sighted right now.

The biggest problem our space program has is sustaining public and congressional interest. Mars is too far away to keep the general public excited for long. For a short time after launch, the whole world is buzzing about a mission, then, over the next 18 months, forgets about it. Meanwhile, Congress is slashing budgets because it sees no profit in venturing to Mars.

Now, change "Mars Outpost" to "Lunar Outpost." A three-day trip would maintain interest through the launch, voyage, and landing. Adding web cameras would allow people around the world to watch the base being built. A program like Red Rover Goes to Mars would be fantastic on the Moon—the short signal delay would allow for true real-time telepresence. And, with a web cam permanently aimed at Earth, people would be able to see our home as only the *Apollo* astronauts have.

A lunar base would provide a springboard for all future planetary missions. It should be "easy" to plan sample-return missions from the Moon, and the International Space Station could be used as a go-between. Isn't that what the station is best used for, besides low-gravity experiments?

Even though Society members would love to see a manned mission to Mars in our lifetimes, it would be more practical to go to the Moon first. We can initiate a Mars base program once a successful lunar base has been established.
—DOUGLAS E. APPELT,
Lisle, Illinois

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MARS MICROPHONE FLIES AGAIN

Thanks to NetLander*, we have another four chances to listen in on the sounds of Mars.* NetLander *will carry the Mars Microphone to the Red Planet on each of four identical landers. France's Centre National d'Etudes Spatiales (CNES) leads the international consortium planning the mission.* NetLander *is the first planetary mission to focus on the interior of Mars and the large-scale circulation of its atmosphere.* *Image: CNES*

by Greg Delory

It was December 3, 1999, and scientists, engineers, students, and reporters were gathered around a multitude of monitors and displays awaiting the first transmission from NASA's *Mars Polar Lander* (*MPL*). The gathering at the University of California, Los Angeles Science Operations Center—organized by *MPL* science Principal Investigator David Paige—was buzzing with anticipation for the imminent landing of *MPL* in the high southern latitudes of Mars.

The *MPL* mission was particularly thrilling for Planetary Society members, whose support had helped the Society, along with the University of California, Berkeley Space Sciences Laboratory, develop a microphone on the lander to record sound on the Mars surface for the first time.

The Mars Microphone had captured the world's attention, and the microphone team (Greg Delory, Janet Luhmann, Dave Curtis, Forrest Mozer, Henry Primbsch, and The Planetary Society's Louis Friedman) was caught up in the excitement. We waited for the first radio transmissions from *MPL* with greater anticipation than many of us had experienced on other space missions.

We were in for a long wait. After the craft fired its descent motors and began its landing sequence to the Red Planet, all contact with *MPL* ceased. Investigations into the *MPL* program revealed a number of possible causes of the failure. Most were spelled out in the Thomas Young report, which documented problems with the landing system in particular. Ultimately, we must acknowledge that space exploration is a risky business.

A Second Chance (Times 4)

Our first chance to listen to sounds from another world had apparently come and gone. However, within a month after *MPL* was officially declared a loss, we on the Mars Microphone team were contacted by scientists involved in *NetLander*, an ambitious European mission designed to send four identical landers to the Martian surface in 2007. The Centre National d'Etudes Spatiales (CNES), the French space agency leading the mission, was overseeing the selection of instruments for the landers. The scientists who contacted us were convinced that if we submitted a proposal for a microphone system, it had a good chance of being accepted by CNES. Indeed, with the support of several *NetLander* scientists, in January of 2000, our team became part of the *NetLander* mission. The Mars Microphone will fly again.

NetLander is an exciting mission, and each of the four landers is teeming with a variety of instruments. The first three landers will disperse over distances of 100 kilometers (roughly 60 miles), while the fourth will land somewhere in the opposite hemisphere. This will allow the seismometer experiment to "image" the internal structure of the planet, possibly down to the core. A complete weather station package on each lander will form a global network to study Martian winds and temperatures, and ground-penetrating radar will search for water beneath the surface.

These investigations are even more impressive considering they are being shoehorned into a remarkably small lander less than a meter across and about one-third of a meter high, plus they will have an operational lifetime in excess of one Earth year. These requirements translate into even tougher engineering challenges than we faced for the *MPL* mission—tempering our excitement at this new opportunity with a sense that we should be careful what we wish for.

While commodities like instrument mass had previously been measured in sizable fractions of kilograms, the mass margins on *NetLander* are forcing us to count every gram. The Mars Microphone on *MPL* was already an engineering marvel, containing a microphone, onboard sound processor, and rugged memory chips, all in a package about 1 centimeter (a little less than half an inch) thick, 5 centimeters (2 inches) on each side, and less than 50 grams (2 ounces) in mass. On *NetLander*, our microphone instrument must now occupy about 75 percent of that same volume and weigh a mere 30 grams (1 ounce).

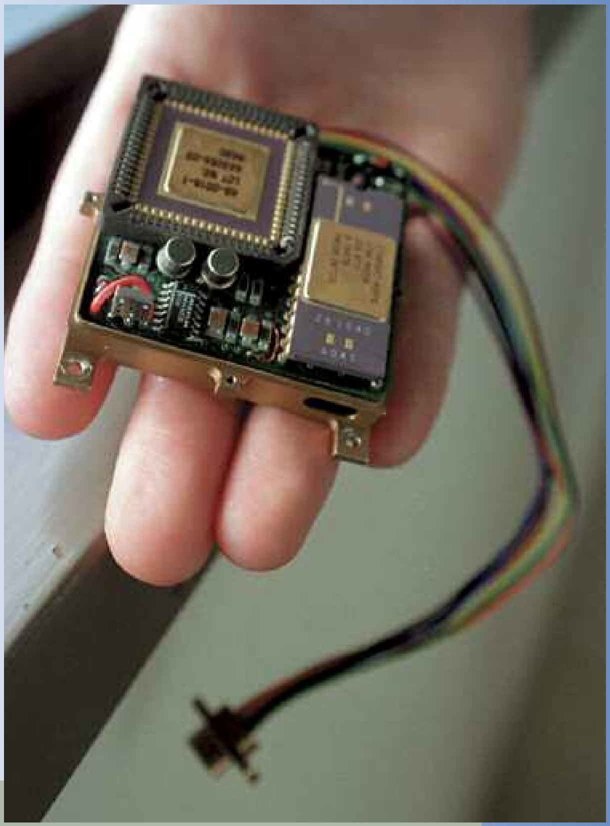
With new challenges come new opportunities. CNES officials and our European colleagues have welcomed our participation in almost every facet of the design and implementation of the *NetLander* mission, thus allowing us to optimally accommodate the microphone instruments on nearly every level. This is in stark contrast to our experience on *MPL*. At that time, we were fortunate to hitch a ride at the last minute thanks to the generosity of our Russian colleagues who constructed the Light Detection and Ranging (LIDAR) experiment. Literally bolted on the side of the LIDAR, the original Mars Microphone had to "fool" the *MPL* flight computer into thinking that it was producing LIDAR data for the data to be accepted and transmitted to Earth. Also, the microphone's position on the main lander platform was partly obscured behind a solar panel.

The Mars Microphone will be integrated into the *NetLander* science package in a much more advantageous manner—each lander will have not one but two microphones mounted on the vehicle's panoramic camera, or "PanCam," built by the German Space Agency (DLR). These will be raised along with the PanCam about 0.5 meter above the main lander deck and so record sounds in different directions as the camera head scans the horizon. Our ability to operate the microphone instrument during the mission will also be greatly enhanced, as we will have a dedicated interface to the *NetLander*'s main flight computer, which is being designed with our data and control requirements in mind.

3-D Sound

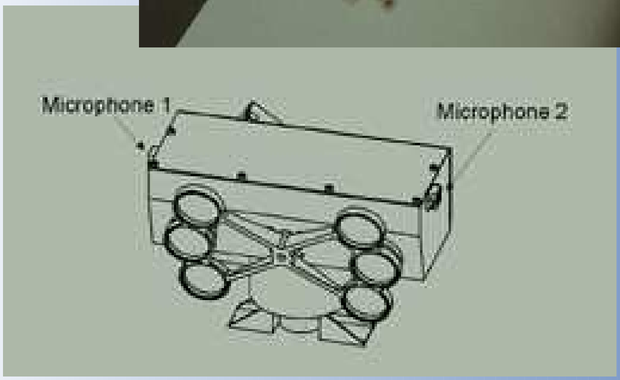
Including two microphones on each *NetLander* more than simply doubles the amount of data that will be returned from the experiment. In the same way that stereo cameras can produce three-dimensional (3-D) images using binocular vision, stereo microphones will add a depth to sound sources that simulates real-life conditions—thanks to recent advances in the study of how humans perceive and process sound signals received by the ears (see sidebar, page 7).

The ability of humans to localize a sound source is



The Mars Microphone is built mostly from off-the-shelf parts, including a microphone similar to those used in hearing aids and a microprocessor chip used in speech recognition devices. This engineering marvel descends from a long line of robust miniaturized devices, several of which were used for astronaut communications during the* Apollo *Moon landings.

Photo: Robin Weiner of the Associated Press



In 1999, only one Mars Microphone was allowed to hitch a last-minute ride on the ill-fated* Mars Polar Lander. *But* NetLander *will carry a total of eight microphones to Mars—two on each lander—in 2007. The microphones will be mounted on either side of the spacecraft's panoramic camera, or PanCam, built by the German Space Agency (DLR). The placement of the microphones will enable them to capture, in stereo, sounds coming from different directions on Mars. *Illustration: DLR*

After touchdown, the PanCam will rise up about 0.5 meter from the main lander deck and, like a little robotic head, will scan the horizon, taking in the sights and sounds of Mars. *Illustration: CNES*

Lightning cracks as a ferocious dust storm gathers force on this less-than-idyllic Martian day. We have seen other worlds and even had contact with them via robotic sensors, but the Mars Microphone will offer humanity the first opportunity to hear noise on the surface of another world.

Painting: Chris Butler

remarkable; in many circumstances, most of us, when we concentrate, can point in the direction of arriving sound waves to within a few degrees or so in azimuth (stand and turn around the room once, and you've gone 360 degrees). The brain uses up to three separate audio cues to make this determination, combining differences in sound arrival time, intensity, and frequency, which all vary between the ears.

Microphones called *binaural mics* are specialized to mimic how the ears respond to sounds in our environment. University- and NASA-funded research has generated detailed mathematical models that describe the amplitude and timing of sound waves detected by the eardrums, as well as the effect the shape of the head and ears has on these waves.

Such models can digitally reprocess almost any recording so it sounds as if it were arriving from a multitude of directions when played back over standard stereo headphones. Sound reproduction of this type is far more advanced than the stereo systems with which most of us are familiar. The possibilities for application to the microphone instrument on *NetLander* are compelling. A model could be developed for the microphone-camera combination based on the human head-ear structure, allowing us to understand how amplitude, phase, and, in some cases, frequency are altered with the direction of incoming sound waves.

Based on this information, the sound data acquired by the microphone experiment could be reprocessed and played back over stereo headphones to provide a complete, three-dimensional auditory experience—enhanced from our previous mono recordings in the same way that donning a pair of 3-D glasses provides depth to the stereo camera images obtained on the 1997 *Mars Pathfinder* mission. The three-dimensional capabilities of both the PanCam and the microphones

will extend our virtual presence on the Red Planet that much further.

Extraterrestrial Acoustics

As our approach to recording sounds on Mars has advanced with *NetLander*, so has our understanding of the theoretical properties of these sounds. The presence of the original Mars Microphone on the *MPL* mission may have encouraged the development of a new field: extraterrestrial acoustics. Students and researchers from several universities have begun a detailed investigation into the nature of sound propagation in the cold, rarefied atmosphere of Mars.

The field of extraterrestrial acoustics has received attention from one of the largest professional sound research organizations in the world. In June 2000, the Acoustical Society of America

HOW HUMANS LOCALIZE SOUND

Research into human hearing—sometimes called psychoacoustics—began more than 120 years ago when British physicist Lord Rayleigh (John William Strutt) surmised that different intensities of the same sound reaching the two ears might cue the brain to a sound's direction. Thus, a sound from the left of a listener would impact the left ear directly, while the right ear would be shadowed from the sound by the listener's head; this difference in intensity would serve as an auditory cue helping the hearer perceive the direction of the sound.

This effect is now known as the Interaural Level Difference (ILD). However, ILD alone is insufficient to determine direction to the accuracy demonstrated by most people. For example, for low-frequency sounds—say, below 500 hertz—the wavelengths are much larger than the head itself, so sound waves at these frequencies are unaffected by the head's presence. The sound level therefore seems the same at each ear regardless of the sound's direction.

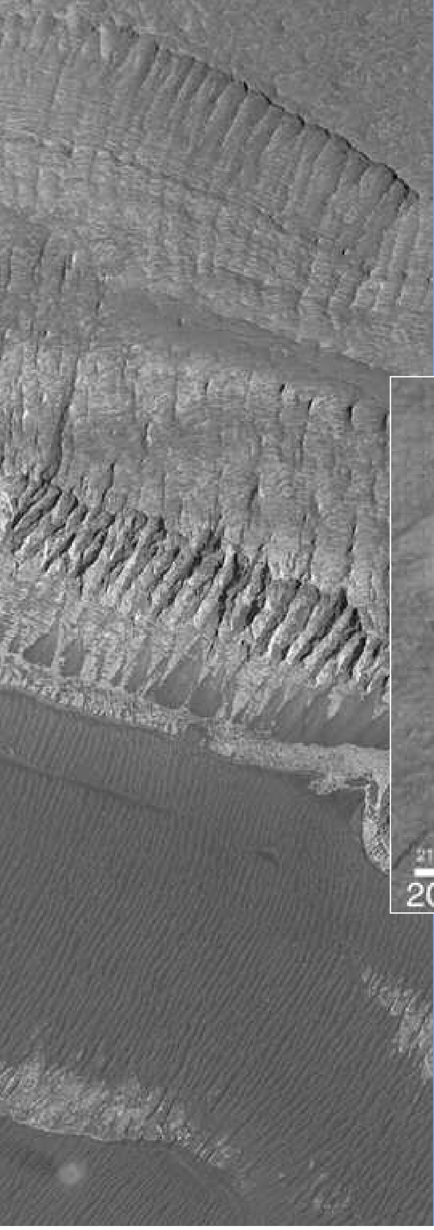
For these low frequencies, another mechanism is necessary. In fact, researchers have determined that the brain uses a time delay between sounds received by each ear as an indicator. Because sound waves travel at definite speeds, there is a small time delay as sounds arrive at one ear and then the other. This auditory cue, called the Interaural Time Difference (ITD), is very effectively used by the brain to isolate the sources of low-frequency sounds (less than 500 hertz).

The use of ILDs and ITDs doesn't tell the whole story, though. Even with these two cues combined, ambiguities in determining direction remain—the most notable being the infamous front-back ambiguity, whereby people find it difficult to determine whether a sound source is directly in front of or behind them.

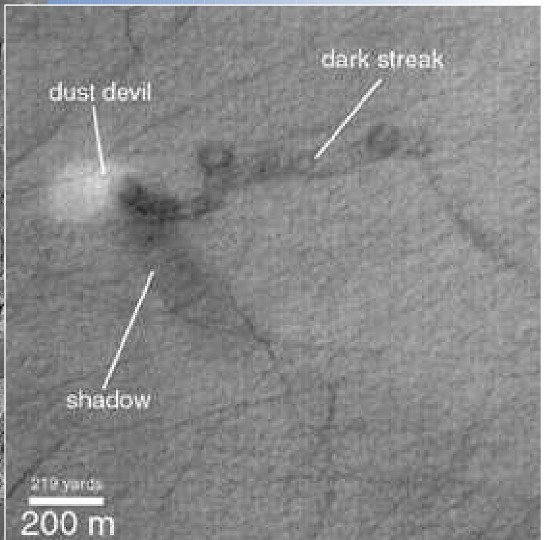
Enter the Anatomical Transfer Function (ATF), a fancy mathematical term for the effect of the ears, head, and shoulders on incoming sounds, particularly for higher frequencies. It turns out that the anatomical structure of these features in humans modifies incoming sound waves depending on the direction of their arrival, thus altering their frequencies slightly. Sounds coming from the rear are enhanced in the 1,000 hertz area, while sounds coming from the front are boosted in the 3,000 hertz region. These subtle yet consistent modifications to incoming sound frequencies are picked up by the brain and aid in determining direction.

Even with a combination of ILDs, ITDs, and ATFs, the complete mechanism for how humans are able to "image" external sounds so well is still a subject of research. Visual cues and the ability to turn the head while listening to a sound also appear to help resolve directional ambiguities. In any case, the advantage of having two listening sensors—in the case of humans, ears, and in the case of *NetLander*, microphones—becomes clear. With the capability of dual, or binaural, microphones, *NetLander* will explore the acoustic environment of Mars in a manner much closer to the human experience. —*GD*

[Adapted from W. M. Hartmann, "How We Localize Sound," *Physics Today* (November 1999).]



Left: If a wind vortex passes over a dusty surface, it will pick up the dust and become a visible feature, also known as a dust devil. *In the lower left corner of this frame, a bright circular dust devil casts a columnar shadow as it skims across the floor of Melas Chasma in Mars' Valles Marineris. This image covers an area 3 kilometers (2 miles) wide and 8 kilometers (5 miles) long.* Mars Global Surveyor*'s Mars Orbiter Camera (MOC) took the picture on July 11, 1999.*



Above: Would hearing an approaching dust devil warn future explorers to move out of its disruptive path? Researchers and students from a new field of study called extraterrestrial acoustics are investigating the way sound moves through Mars' cold, rarefied atmosphere. Mars Global Surveyor *caught this dust devil in the act of sandblasting a trail through the soil of Promethei Terra on December 11, 1999.*

Images: JPL/NASA/MSSS

offered a special session in extraterrestrial acoustics at its 141st meeting, where several papers addressed sound on Mars. One consistent theoretical result so far concerns the damping of sounds at different frequencies. On Earth, sounds lose energy proportional to their frequency, so higher-frequency sounds do not travel as far as lower-frequency sounds. A familiar example of this phenomenon is lightning: near to the source, it sounds like a sharp "clap" that at great distance becomes a lower-frequency, dull "boom."

It turns out that on Mars, higher-frequency sounds will likely be damped even more heavily, so most distant sources will sound lower in frequency than on Earth. For very low frequency sounds—near one cycle each second (1 hertz)—the damping rates for sounds on Earth and Mars are the same, a surprising result. Although these frequencies are below the range of human hearing, in a regime called *infrasound*, future instruments sent to Mars may be able to take advantage of this finding and detect very distant sound sources in the infrasonic range.

In the acoustic frequency range (20–20,000 hertz) detected by the *MPL* and *NetLander* microphones, the sounds we expect to hear on Mars will be generated from a combination of natural and artificial sources. Natural sources would include wind, dust, or sand and perhaps dust devils or storms. *NetLander*, like most other Mars exploration craft, has a multitude of instrument deployments and motors that emit artificial sounds. Perhaps the most-exciting

Hellas, June 10 | **Hellas, July 31** | **Hellas, September 24**

Although dust storms happen all year long on Mars, they occur more often in certain seasons. The largest global dust events kick up during Mars' southern spring and summer. Throughout the month of June 2001, scientists paid particular attention to the planet's local and regional dust storms in anticipation of capturing—for the first time—high spatial and time-resolution observations of the beginning of a

On August 29, 2000, Mars Global Surveyor *observed this dust storm near Mars' north pole. The image is part of MOC's daily global map—a low-resolution, two-color view of Mars acquired from pole to pole during every orbit. In this image, the storm is moving as a front, outward from a central jet, about 900 kilometers (560 miles) from the north pole's seasonal frost cap, visible at right.* *Image: JPL/NASA/MSSS*

sounds heard from *NetLander* will be obtained during the entry, descent, and landing phases of the mission, when the microphones will record the entry of the probes into the atmosphere and the subsequent bounces of the lander as airbags cushion its touchdown.

An Ear to the Future

Despite the first Mars Microphone's meeting its demise on *MPL*, this novel, exciting technology lives on and will again fly to Mars. *NetLander* is one confirmed opportunity, and others may exist with the upcoming Mars *Scout* program as well as additional future missions to the Red Planet.

If successful on *NetLander*, the microphone concept could be expanded on future missions. Infrasound measurements could detect weather fronts, distant dust storms, and even the motion of the atmospheric boundary layer, adding to our knowledge of the Martian climate and atmosphere. For manned exploration, we can imagine helmets equipped with dual microphones, providing explorers of the Martian surface an enhanced auditory sense of the external environment. Auditory feedback from activities like hammering, digging, and repairing equipment could someday prove crucial to the safety of crews working on Mars.

For now, we'll have to content ourselves with the binaural sensors on each *NetLander* package, which will allow the general public as well as scientists to experience for the first time the acoustic environment of Mars.

Greg Delory is a research scientist at the University of California Space Sciences Laboratory in Berkeley. His current research topics include understanding the nature of Martian dust, and he is developing novel electromagnetic sensors to detect subsurface water for future Mars or other planetary missions.

planetwide storm. Their observations revealed that last year's global dust storm was actually a set of smaller dust events that occurred simultaneously. These images of Mars' Hellas and Tharsis regions show the evolution of the stratospheric veil of dust that rose up from the individual storms.
Image: JPL/NASA/MSSS

FROM THE EARTH TO MARS Part Two:

Left: Last summer, Jaret Matthews of Purdue University (far right) led an investigation that compared field exploration using a single two-person rover (foreground) with two one-person all-terrain vehicles (background). Meanwhile, Kelly Snook of NASA's Ames Research Center (riding shotgun with Jaret) conducted studies of EVA (extravehicular activity) procedures defined in collaboration with the Exploration Office at NASA's Johnson Space Center.

Right: The interior of "St. John's," the HMP's mess tent. Over the years, as the project's field infrastructure has steadily been built up, the comfort level at the HMP base camp has increased. As its infrastructure and safety systems are developed over time, a future Mars base might experience a similar improvement in comfort.

Photos: NASA Haughton-Mars Project/P. Lee

IN PART 1 OF "FROM THE EARTH TO MARS," THE TEAM'S PRINCIPAL INVESTIGATOR, PASCAL LEE, DESCRIBED THE WORK OF SCIENTISTS AT THE NASA HAUGHTON-MARS PROJECT ON DEVON ISLAND. HERE, LEE REPORTS ON HOW THE REMOTE AND HOSTILE ENVIRONMENT OF THE CANADIAN HIGH ARCTIC OFFERS EXCITING OPPORTUNITIES TO LEARN ABOUT MARS EXPLORATION.

In August 1997, during our first season of Mars analog fieldwork on the Arctic's Devon Island, it became clear that the Haughton Crater site offered a unique opportunity to learn not only about the Red Planet but also about how to explore it and other planets. At Haughton, we could test out new robotic systems, learn valuable lessons about how humans will one day explore Mars, and eventually train the astronauts who will make the journey.

In addition to being set in a polar desert, Devon Island is rugged, vast (the size of West Virginia, or 20 times the area of the Antarctic Dry Valleys), diverse in terrain types, radio-quiet, tree- and power line–free (important for aircraft operations), remote, isolated, unpopulated, and still poorly mapped.

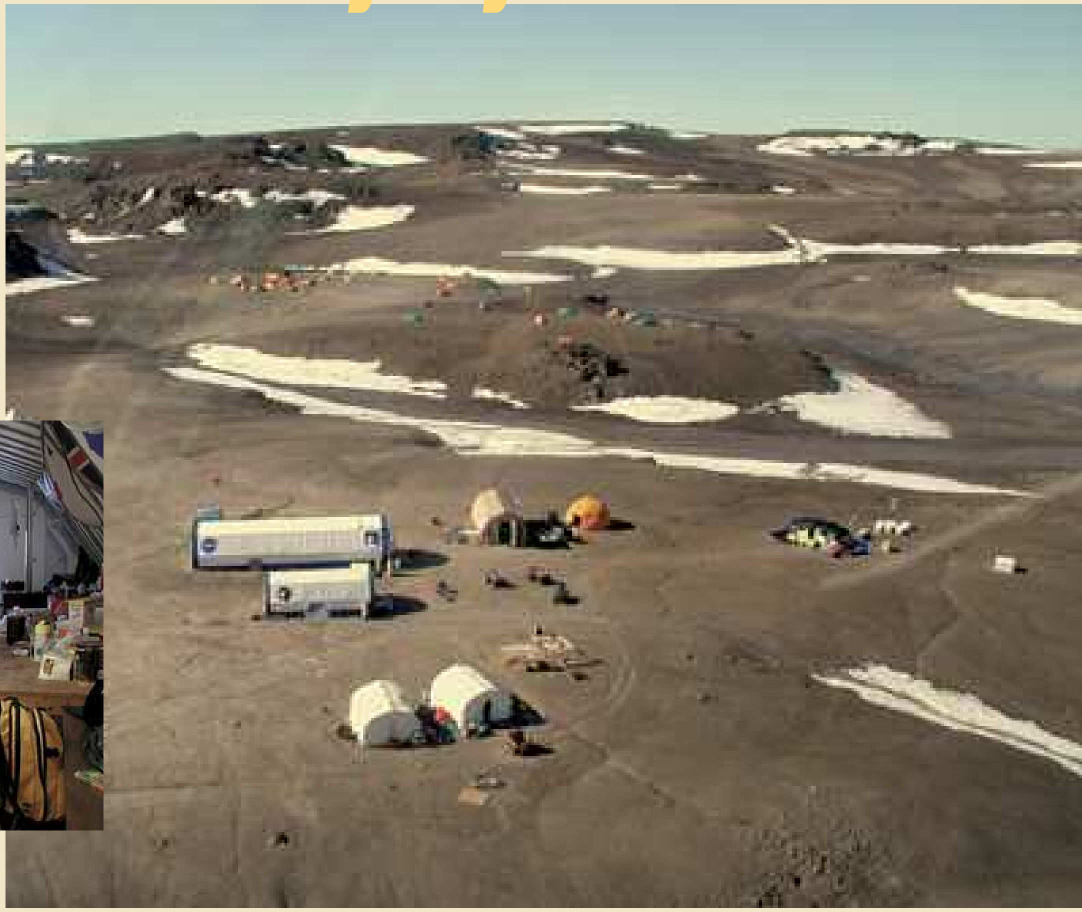
Day after day in this relatively challenging environment, scientists on our field team explore their surroundings while paying constant attention to safety. They then have to share their findings with others remotely. Beyond the task of surviving the Arctic, our activities are driven by a bona fide quest for knowledge and the need to stay in touch with home—as will be the activities of early explorers on Mars.

On Devon, it must be emphasized, we are engaged in actual fieldwork, not mere simulations. We are carrying out our activities in a setting that is relevant to Mars, but, importantly, we are driven by a genuine need to understand the place. The operational lessons we learn are thus more likely to represent the true requirements of field exploration.

While much research has been directed to solving the problem of getting humans to Mars and back (that is, the rocketry aspect of a Mars mission), comparatively little attention and almost no dedicated field studies have addressed what humans will do once they reach the Red Planet. How will human explorers live and work on Mars during sojourns that could last weeks to months or more? What tools, instruments, lab equipment, and robotic devices should they have on hand? How often will EVAs (extravehicular activities) be performed and how far will they extend? What vehicles should be available for them? How should long-distance traverses be planned? How much time should be spent collecting data and how much time spent analyzing these data? How will Mars explor-

Robots and Humans Working Together

by Pascal Lee



***Right:** This is the base camp for the NASA Haughton-Mars Project (HMP). "Downtown" sits in the foreground, and "Tent City" is off in the distance. Life never stops downtown, where generators run round the clock and a wireless local area network provides continuous access to the Internet. Some users are subjected to a built-in Mars time delay. The camp's mess hall is inside "St. John's," the largest tent. Other downtown tents function as computer labs and workshops.*

Tent City, with its tens of individual tents, is a quiet zone. There we sleep at "night," under the midnight summer Sun. Photo: NASA Haughton-Mars Project/P. Lee

ers communicate with one another and with Earth? What information should they have available to them during EVAs? These are but a few questions that might seem straightforward but actually are difficult to answer, given the large number of conceivable mission scenarios and the fast pace of progress in technology.

We can draw lessons from the *Apollo* missions, but only in a limited way. Humans on the Moon had very little total surface time. EVAs were few and scripted in detail. Also, located only 1.5 light-seconds away, Mission Control was able to track and support the astronauts essentially "live." On Mars, the scenario will be significantly different. Extended sojourns are expected, while the time delay resulting from the greater distance from Earth (4 to 20 light-minutes each way) will preclude any truly live interaction. Mars explorers will in many ways be on their own. While Mission Control—or, perhaps more appropriately, "Mission Support"—and the crew on Mars will experience delayed situational awareness, data streaming in both directions should still produce a relatively complete picture of events taking place at both ends. A new, more complex interaction between astronauts and the Earth is anticipated, the understanding of which will be key to planning a successful mission to Mars.

At Haughton and other Mars analog sites on Earth, we have the opportunity to investigate how field exploration can be accomplished, how it can be optimized for field safety and science yield, how new technologies can help enhance exploration, and what specific constraints associated with Mars exploration must be faced.

THE NASA HAUGHTON-MARS PROJECT

In 1998, for our second field season, we began an exploration program that would build on and complement the initial science program. The exploration program offered a chance to bring aboard existing research efforts at NASA and elsewhere; these would help enhance our science investigations, benefit from the logistical infrastructure in place to access a planetary analog site, and, at the same time, allow valuable lessons to be learned at minimum overhead cost. So began the NASA Haughton-Mars Project (HMP).

That summer, in addition to studying the natural wonders of Devon Island, we conducted field tests of a helicopter capable of autonomous flight. The aircraft, developed by Omead Amidi's team at the Robotics Institute of Carnegie Mellon University, provided laser altimetry directly applicable to our studies of valleys and gullies.

We retrieved core samples 3 inches (7.6 centimeters) in diameter of Miocene lake beds from Haughton Crater (down to depths of 25 feet, or 7.6 meters) employing drilling technology consistent with what would be required on Mars. No liquid water could be used as a coolant because the drilling auger would freeze in Martian permafrost at – 70 degrees Celsius (– 94 degrees Fahrenheit). We also conducted ground-penetrating radar surveys using a rover-deployed system to gauge the distribution of ground-ice in various terrains at the crater. In all these experiments, we investigated how similar technologies might be employed on Mars robotic and human missions.

That same summer, Steve Hoffman of the Exploration Office at NASA Johnson Space Center (JSC) joined our field team to initiate studies of Mars human expedition logistics and EVA metrics. In order to build a database to help design surface exploration missions by humans, Steve monitored a variety of our field activities, including the purpose of EVAs, time required to prepare for traverses, distance traversed and time spent on excursions, mobility systems and other tools used, frequency of stops, and number of samples collected.

In parallel, Bill Clancey of NASA's Ames Research Center (ARC), who directs the Human-Centered Computing research group there, undertook studies of the ethnography of exploration. As a participant-observer in the full range of field science activities on HMP, Bill studies all aspects of interactions between humans engaged in exploration (in the field, at base, and at Mission Control), their tools (computers, robotic assistants, rovers, rock hammers), and their living space (habitats, tents, furniture). With these data, his team creates computer models that will eventually help design and optimize future human missions of exploration.

By 1999, we began contributing to NASA's ongoing studies of the requirements for a robotic roving assistant to accompany field explorers on Mars (or the Moon). Graduate students Nicolas Vandapel and Kimberly Schillcutt of Carnegie Mellon University's Robotics Institute spent part of the summer following field scientists on all-day excursions. At times, they served as passive observers, documenting every task performed. At other times, they acted as mobile robotic assistants themselves, helping field scientists reduce burdens and enhance safety. This was a start-from-basics approach whereby the field needs of human explorers engaged in science activities were first identified and analyzed, then addressed by recommended robotic technologies.

Also by 1999, through a communications network set up by Rick Alena and Brian Glass of NASA ARC and Stephen Braham of Simon Fraser University (SFU), we had established links with the Exploration Planning and Operations Center (ExPOC) at NASA JSC in Houston—a newly created mission control facility designed as a testbed for supporting studies of future human exploration

Encased within the upper torso of the Hamilton-Sundstrand concept spacesuit, Stephen Braham of Simon Fraser University tests out a Xybernaut wearable computer to help develop new information technologies for exploration. Here, he's looking at an eyepiece-mounted computer display while controlling the cursor with a chest-mounted mousepad.

To avoid the risk of fire, no electrical systems involving substantial voltage are ever used in the pure oxygen environment of an actual spacesuit. However, on this occasion, the research is focused less on hardware specifics than on the content of the data to be exchanged and the communications infrastructure required to support that exchange.

The team has extracted a frozen core sample of ancient (23-million-year-old) lake bed sediments from the permafrost at Haughton Crater. The sample contains a well-preserved paleoenvironmental record of what the Arctic was like during Earth's Miocene period. Invaluable clues to Mars' past could be locked inside similar core samples to be gathered one day from the surface of the Red Planet.

Photos: NASA Haughton-Mars Project/P. Lee

missions. In an experiment led by Steve Hoffman on Devon and Tony Griffith and his ExPOC team at JSC, two-way wireless audio, video, and data exchanges were conducted over a period of two weeks between "Mars" (Devon) and "Earth" (ExPOC). Field activities and science findings were downlinked daily, while future EVA and science plans, weather forecasts, and news bulletins were uplinked. One-way time delays of up to 20 minutes were introduced to simulate the time barrier.

The experiment was a success, leading to a higher-fidelity simulation in the summer of 2000 during which Tony Griffith led operations from Devon. The experiments confirmed that ensuring Mission Support's situational awareness will excessively burden a crew on Mars unless extensive automated procedures are in place. The streaming exchange of data and messages between base or EVA parties and Earth, whether audio, video, or telemetry, proved effective in spite of the time delay. Audio and home-style video also proved useful for relaying daily summary reports.

A far-reaching finding from our field experience on Devon to date is that individual surface mobility systems such as ATVs (all-terrain vehicles, or "quads") will likely play a key role in the human exploration of Mars. While not a new concept (personal motorcycles were designed and tested during the *Apollo* program but never made it to the Moon), the possibility of explorers driving their own ATVs on Mars had never proceeded much past the idea stage.

Our use of ATVs on the HMP (sponsored by Kawasaki Motors USA), combined with prior experience with snowmobiles in the Arctic and Antarctica, has demonstrated the benefits of such a mobility system in the context of field exploration. ATVs offer a high degree of flexibility, reliability, redundancy, and, ultimately, safety. However, they are adequate only for medium-range exploration; that is, within a few miles from a local base (a pressurized habitat or rover). Beyond that distance, exploration is more effectively and safely done by pressurized rover, with ATVs available in tow for local excursions.

The most complex piece of hardware to be developed for the human exploration of Mars may be the spacesuit itself. Working on it now, even at a moderate pace, will pay off further down the line. A spacesuit should be viewed not only as a garment but also as a wearable spacecraft—one that must prove reliable in the lethal environment of Mars and also be as reusable and as lightweight and comfortable as possible. Current estimates of the felt weight on Mars of such a suit are roughly 50 to 70 pounds, or 20 to 30 kilograms (the spacesuit's actual mass might be anywhere from 130 to 185 pounds, or about 60 to 85 kilograms).

Above: Louis Friedman, executive director of The Planetary Society (at right), and Rainer Effenhauser, M.D., cram into a Twin Otter packed with cargo bound for Devon Island. Rainer, the chief flight surgeon of the space shuttle program at NASA's Johnson Space Center, is a member of a broader team of flight surgeons who have participated over the years as researchers on the HMP. On this trip, he conducted experiments in telemedicine and expeditionary medicine for advanced planetary exploration while serving, on a samaritan basis, as the base camp's medical officer. Lou was visiting the Haughton Crater site to plan future joint Mars Outpost activities with the Haughton-Mars Project.

Left: Viewed through a window on the Mars Society's Flashline Mars Arctic Research Station (FMARS), a small robotic rover has been dispatched on a reconnaissance mission in preparation for EVA. Such teleoperation is done without a time delay, as both rover and humans are assumed to be on Mars. In the future, Mars exploration will best be done through a synergistic partnership between robots and astronauts on the planet.

Photos: NASA Haughton-Mars Project/P. Lee

While these numbers may seem high, compare them with the mass of the current Space Shuttle/International Space Station EMU (EVA Mobility Unit) spacesuit system: in excess of 300 pounds (about 135 kilograms). Because of their use in zero gravity, the suits worn by shuttle and space station astronauts remain relatively comfortable. However, such suits would be inadequate on Mars. The felt weight of each would be 115 pounds (about 50 kilograms), an impractical load to bear—not to mention the fact that the EMU lacks joints to allow walking.

Joe Kosmo's group at NASA JSC is leading an effort to develop a spacesuit that will help pave the way toward an operational Mars EVA system. Recognizing the long lead time needed for the development of a viable mobile life support system for future space exploration, the aerospace company Hamilton-Sundstrand (HS) has joined the effort and begun investing resources to create a concept suit system for advanced planetary missions. With Ed Hodgson's team at HS and Steve Braham's group at SFU, and in coordination with ongoing efforts led by NASA JSC, we have conducted a series of field tests at Haughton of various components of the 65-pound (roughly 30-kilogram) HS concept suit—with a specific focus on developing the information systems needed to support scientific fieldwork.

Steve Braham, HMP chief field engineer, leads our efforts to develop communication and computing technologies for Mars exploration, in particular the testing of wearable computers (donated by Xybernaut) in support of field geology on simulated EVAs. Last summer, we successfully established multiple-relayed broadband wireless radio links and remote control of wearable computers over distances in excess of 2 kilometers (1.2 miles) on simulated EVAs. Information systems such as the ones being developed at Haughton will help ensure the safety and productivity of future human exploration activities on Mars and, indeed, elsewhere in space.

The HMP is now in its sixth year, with five consecutive field seasons in the Arctic. The project draws its core funding from NASA but is a collaborative government-private venture with substantial support (almost half) contributed from non-NASA sources. The SETI Institute manages the project. Coinvestigators and other participants from a wide variety of government agencies in the US, Canada, and other countries; universities and research institutions; private industrial partners; corporations; and space interest groups (including The Planetary Society) contribute to the project's field activities.

Each summer, researchers, students, support staff, and visiting media join in on field activities. At any given time, only 30 people or so are admitted at the field site in order to keep it protected. A core team of 10 individuals spends the entire summer on Devon, while coinvestigators and visitors rotate in and out for shorter stays. Louis Friedman, executive director of The Planetary Society, visited Devon Island last summer to explore the possibility of conducting research with the HMP for the Mars Outpost concept.

Since 1999, US Marine Corps C-130 crews have supported the NASA HMP with the transportation and delivery of tons of mission-critical cargo, including expeditionary gear, research equipment, exploration vehicles, and field supplies. The "paradrops" on Devon, which are among the highest-latitude drops ever performed by the Marines, are often done under extreme

Right: Rock hammer in hand, Pascal Lee goes about geological fieldwork while helping test new EVA information systems on the Hamilton-Sundstrand (HS) concept spacesuit. As the needs of geological exploration are diverse, other field scientists are invited to participate in this effort to develop EVA systems.

Far right: An aerial view of FMARS, which joined the Haughton-Mars Project in July 2000. Intended as a prototype of the central element in various NASA "humans to Mars" mission scenarios, the habitat was conceived by Pascal Lee in 1998. Later that year, the Mars Society approved the FMARS as its first project.

Private funds raised in large part by Mars Society President Robert Zubrin financed the FMARS. Architect Kurt Micheels designed the station, and Infracomp and Mesa Fiberglass in Denver, Colorado manufactured it. Delivery to Devon Island was made possible thanks to the United States Marine Corps. Eventually, the FMARS was assembled and outfitted at the Haughton Crater site by architect and musician Frank Schubert and his team, which included many Mars Society volunteers and HMP team members, local Inuit hires, and even visiting media. ***Photos: NASA Haughton-Mars Project/P. Lee***

conditions. Twin Otter airplanes chartered from local flight operators are also used to fly cargo and personnel from the hamlet of Resolute Bay (on Cornwallis Island) to the field site and back.

A recently added element to our activities at Haughton is the Flashline Mars Arctic Research Station (FMARS). In 1998, I suggested to Robert Zubrin, then about to form the Mars Society, that the organization should contribute a simulated Mars habitat to our ongoing exploration work on Devon. The FMARS was established at Haughton Crater in July 2000. Last summer, a rotation of six crews, each comprising between five and seven people, lived and worked out of the "Hab" for five to ten days at a time, allowing a first wave of operational experiences to be logged. With key lessons learned for the design and operation of future-generation, higher-tech Mars simulator habitats, the NASA HMP will continue to focus on research at the field site, with the FMARS remaining an important tool for Hab occupation experience and public outreach.

During some Hab shifts last summer, we experimented with specific operational constraints and EVA procedures defined in consultation with flight surgeons and the Exploration Office at NASA JSC. For instance, our assumptions on Hab cabin pressure (8.3 pounds per square inch) and air composition (70 percent nitrogen and 30 percent oxygen) would require 30 minutes of (simulated) pure oxygen prebreathing time before exiting the Hab. We found this constraint easily acceptable in the conduct of normal field outing activities. We also limited our EVA time to durations allowed by plausible life support systems (two to three hours on a backpack and two to three additional hours on ATVs, including a 30-minute "don't use it" margin on each). We also simulated the use of pre-positioned caches of supplies (with auxiliary oxygen) on extended traverses. Field traverse planning, science implementation, and in-Hab data analyses (using a petrographic and epifluorescence microscope system donated by Olympus) were carried out for a week in consultation with a Science Operations Center established at NASA ARC by Michael Sims, Kelly Snook, and Carol Stoker. Jeffrey Moersch of the University of Tennessee, Melissa Lane of the University of Arizona, and James W. Rice of Arizona State University provided support as the Earth-based science team.

We learned quantitatively that medium- to long-range EVAs on Mars (on ATVs directly out of the base site to locations a few kilometers away) will require substantial allocations of time to both the crew and Mission Support for advance robotic reconnaissance data collection and analysis, traverse planning, cache emplacements, EVA execution, post-EVA debrief and data analysis, and interactions with Earth. While crew and ground personnel training, optimized robotic support, and the development of effective EVA planning tools will help streamline such excursions, extended traverses on Mars will remain expeditions within a larger expedition, with deadly consequences if not planned and implemented with extreme care.

HUMANS TO MARS

I strongly support the human exploration of Mars. There are many reasons why humans should go to Mars, many of them unrelated to science. But there is no question in my mind that humans on Mars will be good for science. Not only will Mars science be advanced, but so will our

Still encased in the HS concept suit's upper torso, the author takes a break. He's been participating in helmet-on sessions aimed at training voice recognition software to pick out and transcribe field notes made on future simulated EVAs.
Photo: NASA Haughton-Mars Project/S. Murray

understanding of Earth, other planets, and the possibility of life elsewhere in the universe. Human exploration of Mars is, in my view, preferable to a robots-only approach. I also believe that humans should not go to Mars *in place* of robots but assisted by a mix of precursor and accompanying robotic systems.

What would convince a nation to send humans to Mars? NASA does not have a mandate to do so. Indeed, NASA-funded research on the HMP is not specific to preparing a human mission to Mars but, instead, is generic in its scientific and technological applicability to advancing planetary and space exploration.

Although advancing science should be enough of a reason to fund a human mission to Mars, it is unrealistic to expect a nation to set policy and dedicate substantial resources based on the interests of science alone. A look at history shows it is ultimately the issue of national interest that proves to be the deciding factor. Nations have never committed large amounts of resources for the primary purpose of satisfying scientific curiosity. Rather, the desire to ensure national preeminence, prestige, security, economic growth, and commercial competitiveness has driven national policy. Thomas Jefferson may have been a scientifically curious individual, but that wasn't why, as president, he dispatched Meriwether Lewis and William Clark out west. Although it produced reports of scientific value, their mission was primarily one of strategic reconnaissance. Similarly, wonderful lunar science was done through the *Apollo* program, but Presidents John F. Kennedy and Lyndon B. Johnson sent Americans to the Moon not because the nation was eager to understand the origin of the Earth-Moon system but because of the Cold War.

This then begs the question: how might a human mission to Mars serve our national interest? The answer, I believe, lies in realizing that preparing for such a mission now would be the best possible strategic investment in our future. We would be going to Mars not only for what might await us there but also for the journey itself: for what it would take to get humans there, for what we would create and learn to achieve that goal.

Yes, going to Mars will certainly require substantial resources—possibly the equivalent of a few years of the Department of Defense's annual budget (which I am not suggesting we should reduce) spread over a decade or so. But the money would not be "wasted in space." The money would be invested here at home. Investments in almost all sectors of industry, science, and public outreach would create high-tech jobs and products, stimulate research and education, and foster new knowledge and economic growth.

But why Mars? Why not the Moon, asteroids, or Pluto? Here's where the scientific potential, as well as the undeniable public appeal of Mars, kicks in: (1) Mars might have once harbored life and might still; it is a world with the potential to spark revolutions in the life sciences and other scientific and applied disciplines; (2) Mars bears clear similarities to Planet Earth and so is directly able to help us understand and manage our own environment; (3) Mars is accessible to human exploration, and, in fact, its exploration would be most effectively accomplished by humans on-site; (4) Mars represents a goal that would give the nation's space program a well-defined focus—a program that needs to be sustained as a matter of national interest in its own right.

If our micro-scale experience on the NASA HMP analog project has been any indication, a mission to Mars initiated by the government will likely draw significant support from the private sector, students of all ages, and the public at large if its benefits, which are often indirect, are explained. Going to Mars also might provide an opportunity for international collaboration, binding allied nations in a positive, forward-looking enterprise that would help promote world peace and a more secure global future.

Last but not least, going to Mars will be exciting.

Pascal Lee, a planetary scientist at the SETI Institute, is based at NASA Ames Research Center in Moffett Field, California. He is the project lead and principal investigator for the NASA Haughton-Mars Project on Devon Island, Nunavut, Canadian High Arctic.

For more information on the NASA HMP, visit *www.marsonearth.org.*

The "Hyperion" Sun-synchronous robotic rover underwent successful field trials on Devon Island in July 2001, under the leadership of David Wettergreen and Red Whittaker of Carnegie Mellon University's Robotics Institute. Navigating through rock fields and avoiding obstacles autonomously, the rover also managed its power on its own by tracking the never-setting Sun. Hyperion went on circuitous tours several kilometers in diameter and roved 24 hours a day without human intervention.

The technologies developed here are helping pave the way for future exploration of extreme (often polar) environments on the Moon, Mercury, and Mars. *Photo: NASA Haughton-Mars Project/P. Lee*

World Watch

by Louis D. Friedman

Washington, DC—The Planetary Society continues to campaign to save US missions to Pluto and Europa. In April, we submitted statements to both the House and Senate Appropriations Subcommittees overseeing the NASA budget and urged Congress to overturn the agency's proposed cancellation of these outer planets missions. (Check our website, *planetary.org*, for updates on our progress.)

Also in April, *Aviation Week and Space Technology* awarded its "laurels" to The Planetary Society for our leadership in last year's grassroots campaign on behalf of the Pluto mission. We've resumed that leadership and added to the campaign the Europa orbiter, which the Office of Management and Budget (OMB) also targeted for cancellation. Congress is now considering the fiscal year 2003 federal budget proposed by the Bush administration—if the missions are to be saved, Congress must act.

One important political factor is the opinion of the science community. Of course, the science community is not monolithic; different special interests have different priorities. Still, the National Research Council (NRC) of the National Academy of Sciences has been given the responsibility of sifting through these different priorities and producing recommendations. The NRC is conducting a "decadal survey" to prioritize planetary missions in the next decade. The results of this study, which should be available in early July, not only will influence mission plans for Pluto and Europa but also could determine all mission proposals for the next 10 years.

Although science reviews can reach opposite conclusions, another advisory panel to NASA, the Solar System Exploration Subcommittee, offered a possible preview of the NRC's conclusions. The subcommittee endorsed the *New Horizons* Pluto mission, selected last year but placed in next year's budget, and reiterated the high priority of the Europa orbiter.

The subcommittee also reviewed NASA's plans for Mars and expressed concern over the "viability of a vital Mars program after 2009." Faced with increasing fiscal conservatism after the loss of the *Mars Climate Orbiter* and *Mars Polar Lander* in 1999, NASA has drastically altered direction over the last three years. Sample return, widely considered the next major goal of Mars exploration, has been dropped. Yet, only a few years ago, a series of missions to Mars leading to sample return and human flight was enthusiastically discussed at NASA.

Sample return also had been the focus of Mars planning among international space agencies, with plans for French and Italian orbiters and other types of participation from Europe, Canada, and Russia. Now, the goal of sample return has been abandoned, and nations are developing independent mission plans. In early June, the International Mars Exploration Working Group will meet and, I hope, consider cooperative efforts to explore Mars.

Beijing, China—In March, China took another step closer to becoming the third nation to launch humans into space when it carried out a successful orbital and reentry flight test of its *Shenzhou* spacecraft. The reentry vehicle successfully landed and was recovered at the designated landing area in central Mongolia. It was China's third successful flight test since 1999.

The second flight in the Chinese program included small animals; this flight carried "dummy" astronauts equipped with biological instruments and experiments. Although China has kept its intentions about human spaceflight secret, the development of *Shenzhou* is widely seen as preparation for sending humans to space.

Laurel, MD—The *MESSENGER* mission to orbit Mercury passed its critical design review and is now on track for a spring 2004 launch. The spacecraft will fly past Venus twice, receiving gravity assists to shape its trajectory toward Mercury. It will then fly past Mercury twice before entering orbit in 2009. *MESSENGER* is one of the competitively selected missions in NASA's Discovery program.

During the critical design review, NASA management and outside experts evaluated the *MESSENGER*'s development and mission plan before giving final approval to build the flight spacecraft. Key technical questions addressed the spacecraft's ability to cope with extreme heat when passing over the hot side of Mercury.

The spacecraft will carry cameras; gamma ray, neutron, and additional spectrometers for measuring the composition of Mercury's surface; a laser altimeter; and a magnetometer. The principal scientist is Sean Solomon of the Carnegie Institution in Washington, DC.

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

Student Navigators Train with the Best

by Emily Stewart Lakdawalla

The Student Navigators meet the Field Integrated Design and Operations (FIDO) rover for the first time. From the left: Shaleen Harlalka, Bhushan Mahadik, Avinash Chandrashekar, Kimberly DeRose, Kevin Hou, Jacqueline Hayes, Paul Bonato, and Daniel Hermanowicz. Photo: Emily Stewart Lakdawalla

On February 12, a team of eight bright minds assembled in a laboratory at the Jet Propulsion Laboratory (JPL) for a challenging task. Their mission: to simulate two days of exploring Mars with an advanced prototype robotic exploration vehicle.

These weren't just any rover engineers—they were the Red Rover Goes to Mars Student Navigators, kids age 11 to 17 selected from thousands of applicants by The Planetary Society last March. The Navigators had devoted all of the previous year training and studying for this exciting opportunity.

The Planetary Society, with funding from the LEGO Company, conducted an international competition to select the student team. Applicants submitted journals describing how they would use a *Sojourner*-type rover to explore a hypothetical site on Mars. Thousands of students from more than 40 counties participated.

The winning Student Navigators were Avinash Chandrashekar, 12, of India; Bhushan Mahadik, 15, of India; Daniel Hermanowicz, 11, of Poland; Jacqueline Hayes, 17, of Australia; Kevin Hou, 13, of the United States; Kimberly DeRose, 15, of the United States; Paul Bonato, 17, of Australia; and Shaleen Harlalka, 17, of India.

Working with JPL Engineers and Scientists

The Navigators were part of a core operations team that also included engineers in the JPL Robotics Lab and several Planetary Society staff. The team, led by JPL's Robert Anderson, a scientist for the *Mars Exploration Rover* (*MER*) mission, operated the Field Integrated Design and Operations (FIDO) rover.

The exercise was very similar to the training that actual mission scientists have undergone in preparation for the *MER* mission. Upon their arrival at the lab, the Navigators examined image data already taken by FIDO on its first simulated sol, or Martian day, of operation. They could not see FIDO, located several hundred yards away in JPL's outdoor Mars Yard, nor would they until the end of the day's activities; their only information came from the rover's instruments.

The Navigators split into two teams to study the images and pick targets for a trenching operation. In trenching, the rover is used as a digging tool: it locks five of its six wheels and slowly rotates the sixth backward so that it scoops dirt into a pile in front of the wheel. When the rover backs up, it exposes subsurface soil in the resulting hole.

After each team picked its favorite trenching site, a hot debate between the two teams ensued about the scientific merits and safety of traversing to each location—with FIDO team members Edward Tunstel and Ashitey Trebi-Ollenu interjecting cautions about the safety and feasibility of the Navigators' proposals.

Finally, the Navigators reached consensus on which site to explore. They then developed a sequence, or list of instructions, to send to the rover, with help from Rover operations engineer Mark Powell. The sequence took advantage of several "targets of opportunity" near the rover. The Navigators proposed having FIDO's cameras, spectrometer, and microscopic imager take images and measurements of nearby rocks before the rover moved to the trenching site. This is good practice, because if there is a mechanical failure as the rover moves or if the rover's onboard computers detect a hazard, it will still gather some data from that sol of activity.

As often happens with remote rover operations, the science activities had mixed success: FIDO took many images and spectra, successfully traveled to the trenching site, and dug a hole, but the microscopic imager captured an unfocused image of its intended target. Still, the JPL staff were very impressed with the Navigators: "They did as well as, if not better than, the real scientists," Anderson remarked. "It's very difficult, because you have to bring together what the science team wants with what the engineering constraints are."

An Empowering Opportunity

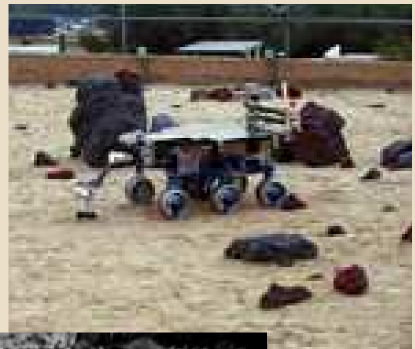
The event was a rewarding opportunity for all involved. For lead FIDO systems engineer Edward Tunstel, "the enthusiasm of the Student Navigators was instant validation that what the FIDO team does is 'cool'!" For the Navigators, their radiant expressions showed how excited they were about the opportunity.

The day after the FIDO activity, the Navigators responded to questions from more than 100 Los Angeles-area students who turned out at a student press conference

Student Navigators Paul and Shaleen discuss what they learned from the FIDO activity with mission manager Robert Anderson as FIDO engineers Ashitey Trebi-Ollenu and Edward Tunstel look on. According to Anderson, working with the students was not much different from working with professional scientists, except that the students tended to be more ambitious and willing to take risks with the rover. It was Trebi-Ollenu and Tunstel who helped the students avoid such risks. The JPL participants were impressed with the Student Navigators' knowledge and enthusiasm as well as the amazing speed at which they took to using FIDO's mission operations software. Photo: ESL

The Student Navigators explore the Mars Yard at the Jet Propulsion Laboratory (JPL) with the help of FIDO's five pairs of cameras from JPL's Planetary Robotics Laboratory. Images taken by the paired cameras can be displayed as 3-D anaglyphs, so scientists can use red-blue glasses to view FIDO's world in three dimensions.

Just as with a real Mars mission, the Student Navigators had to glean what information they could from the rover's instruments, pick targets for further scientific investigation, and develop a command sequence to instruct FIDO through one full sol, or Martian day, of activity—all without actually seeing the rover, located in JPL's Mars Yard. The FIDO engineers then sent the command sequence to the rover, and the students had to wait, without watching the rover, to see if the sequence worked as they had planned. To determine whether or not they'd been successful, the students examined the data FIDO returned after executing the entire command sequence. Photo: ESL



FIDO's instrument arm is deployed to examine the small rock in front of it in JPL's Mars Yard. This rock appeared much larger to the Student Navigators, who saw it through the paired hazard cameras visible at the front of the rover. Photo: ESL

held at the California Science Center. The conference panel consisted of the Student Navigators, Edward Tunstel, and Bill Nye. Nye also delivered a rousing speech to the gathered students about why exploring Mars is "cool": the first Mars astronauts will likely come from the ranks of today's children, and "the discoveries that you make may change human history."

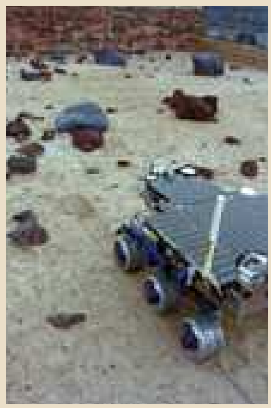
The conference showed that the effects of the Student Navigator Event will be long lasting. One local student asked the Navigators what they thought they had contributed to science by participating in the activity. Bhushan and Shaleen both expressed their intentions to become space scientists or engineers. Jacqui said that the opportunity gave her a vision of her future as a scientist, which she had not before imagined for herself. Kim expressed hope that international collaboration on space exploration projects—simulated or real—were "bigger than war" and, as such, could be a vehicle for international peace.

Emily Stewart Lakdawalla is The Planetary Society's science and technology coordinator.

Stay tuned to our website, *planetary.org*, for information about the next Red Rover Goes to Mars opportunity.

Thanks to the LEGO Company, the Red Rover Goes to Mars National Centers, the JPL Mars Program, the entire FIDO team, the California Science Center, Witold and Carlonina Sokolowski, and Charles Lindgren for making the Student Navigator event such a success!

Above: The Mars Yard, through FIDO's "eyes." Image: JPL/NASA



FIDO backs away from the trench it dug with its left front wheel in the soft sand of the Mars Yard. Photo: ESL

FIDO's view of the trench. Image: JPL/NASA

The day would not have been complete without a "test" of FIDO's hazard avoidance cameras. Image: JPL/NASA

Questions and Answers

At what speed does Earth rotate? How fast does it move through space in its orbit around the Sun?
—Luiz Araujo dos Santos, Aracaju, Brazil

Some basic calculations will answer your questions. Earth rotates, of course, at a speed of roughly once every 24 hours. If you're standing on Earth's equator, you'll travel the planet's entire circumference in that time. For thousands of years, humans have been refining the relationship between a circle's diameter and its circumference. This relationship, or ratio, is known as pi. For the value of pi, let's use 3.14159—it's close enough. Using a calculator, multiply 12,756 (Earth's equatorial diameter in kilometers) X pi. The answer is 40,074. That's how many kilometers you'll travel in 24 hours. If you'd rather know the value in kilometers per hour, just divide your answer by 24. (To convert kilometers to miles per hour, multiply by 0.62.) That's how fast you'd have to run west to stop the Sun from setting in front of you!

But suppose you're standing 1 kilometer (0.6 mile) from the north (or south) pole. You'll make a much smaller circle in 24 hours. Here, your circle's diameter would be 2 kilometers (1.25 miles). So, 2 kilometers X 3.14159 = 6.28318 kilometers (about 4 miles), which is the circumference that you would travel in 24 hours. If you divide 6.28318 kilometers by 24, you'll get 0.261799 kilometer (0.16 mile) per hour.

Our planet moves in an ellipse, not a perfect circle, around the Sun. But to get an approximation of Earth's speed around the Sun, let's assume it's a circle. The distance from Earth to the Sun at the center of the circle is 149,597,870 kilometers (about 93 million miles). Multiply that by 2 to get the diameter of the circle; then multiply the diameter by pi, and you'll travel about 940 million kilometers (584 million miles) in one year, along the circumference of the Earth's orbit around the sun.

If you want to express that figure in kilometers per hour, simply divide by 8,760—the number of hours in a year.
—DAVID F. DOODY,
Jet Propulsion Laboratory

I know an important factor in radio astronomy is how far apart the receivers are in the baseline array. Has anyone considered placing radio telescopes at the Lagrangian points leading and following our planet in its orbit? It's a much larger array than anything we have on Earth.

What would such an array's resolution be, and could it contribute significantly to the search for extrasolar planets?
—Adam Staley, Cincinnati, Ohio

The resolution of an interferometer does increase with increasing baseline length, but there is a fundamental limit beyond which higher resolution is not useful. This limit is imposed by the angular size of the object being observed. If the resolution of an interferometer is much higher than the size of the object, there will be very many positive and negative fringes (regions where wave fronts from a point source add up or cancel each other out) across the object, and the measured fringe (brightness) will be nearly zero.

For example, the angular diameter of a star similar to our Sun located 30 light-years away would be about 1 milli-arcsecond. That's small, but the angular resolution of an interferometer using telescopes at the Earth-leading and Earth-following Lagrange points would be far smaller, even at radio wavelengths.

The fringe spacing (angular resolution) of a simple two-telescope interferometer, in radians (1 radian equals 57.3 degrees), is approximately the observing wavelength divided by the baseline length. The distance between the Earth-leading and Earth-following Lagrange points is about 260 million kilometers (about 161 million miles), so for a typical radio wavelength of 10 centimeters, we get an angular resolution of 0.4 pico-radian (which is equal to 8×10^{-8} arcseconds or 2×10^{-11} degrees).

This is more than 10,000 times smaller than the diameter of the star. It is even smaller than the angular size of Earth at a distance of 30 light-years. This is a case of having too much of a good thing (angular resolution). Therefore, it is unlikely we would observe any detectable fringe from a star or a planet with such a long interferometer baseline.
—DAYTON JONES,
Jet Propulsion Laboratory

The Factinos section of your January/February 2002 issue mentioned an article in* Nature *regarding a community of archaebacteria that obtain energy by reacting hydrogen with carbon dioxide to produce methane.

Are the bacteria using actual free elemental hydrogen gas, or are they breaking down water, as in photosynthesis? If the latter, what is the source of energy for the decomposition? And what is the other product of the reaction—oxygen gas or water?
—Allen McDonald, Toronto, Ontario, Canada

The microorganisms are using free elemental hydrogen gas (H_2) in their metabolism, not hydrogen from water as in photosynthesis. The hydrogen appears to come from the reaction of hydrothermal waters with the volcanic rocks.

Portions of the DNA sequence of the microorganisms predominating in the subsurface at the Idaho site indicate that those subsurface microorganisms are closely related to methane-producing microorganisms isolated from other environments and studied intensively in pure culture in the laboratory.

These well-studied microorganisms gain energy from coupling the oxidation of hydrogen gas to the reduction of carbon dioxide. This reaction yields methane gas and water. The availability of hydrogen at the Idaho site and the accumulation of methane in the groundwater suggest that the microorganisms living at depth gain their energy for growth from the same methane-producing reaction as do the microorganisms previously studied in laboratory cultures.

—FRANCIS H. CHAPELLE,
United States Geological Survey
—DEREK LOVLEY,
University of Massachusetts

Factinos

For the first time, astronomers have discovered a bunch of new extrasolar planets—and perhaps other small dark objects as well—by detecting the slight dimming they cause when passing across the face of a star.

For 32 nights in June and July 2001, from the Las Campanas Observatory in Chile, the OGLE-III experiment monitored 5 million Milky Way stars toward the galaxy's center. Andrzej Udalski of the Warsaw University Observatory reports that out of this vast sample, 52,000 main-sequence stars roughly similar to the Sun met the study's key criterion: their brightnesses were measured many times with high (1.5 percent) precision. Of these stars, 46 clearly showed signs of smaller objects passing across their faces. And 42 of them displayed more than one transit event, thereby revealing the companion object's orbital period—generally one to six days.

The dark, transiting silhouettes range in size from about one to four times the diameter of Jupiter, as indicated by the stars' loss of light. The larger ones must be dim red-dwarf stars, judging by their size. But the smaller ones could be either very small red dwarfs, lower-mass brown dwarfs, or true giant planets. All these types of objects have about the same physical size (one to two Jupiter diameters) despite their wide range of masses (from roughly one to more than 100 Jupiters). Follow-up spectroscopic observations of the OGLE-III candidates will provide the final classification.

—from *Sky and Telescope*

Asteroids in our solar system may be more numerous than we once thought, according to the European Space Agency's Infrared Space Observatory (ISO), which performed the first systematic infrared search for these objects. The ISO's Deep Asteroid Search indicates that there are between 1.1 and 1.9 million space rocks larger than 1 kilometer (0.6 mile) in diameter in the main asteroid belt—about twice as many as previously believed. However, scientists think it is premature to revise current assessments of Earth's risk of being hit by an asteroid.

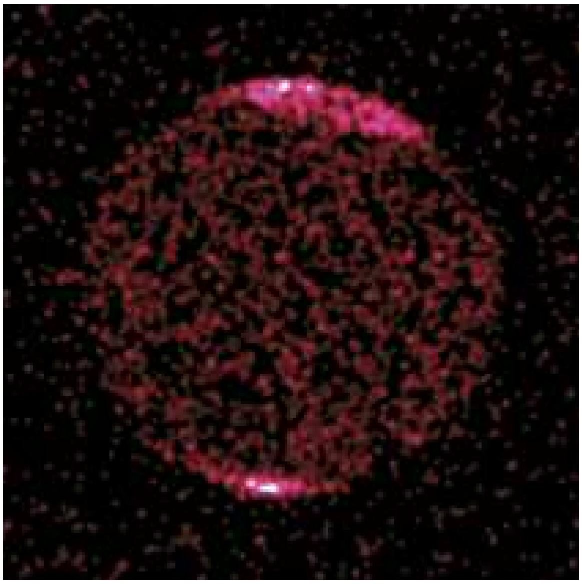
—from the European Space Agency

NASA's Chandra X-ray Observatory has discovered a pulsating hot spot of X-rays in the polar regions of Jupiter's upper atmosphere. Previous theories cannot explain either the pulsations or the location of either hot spot, causing scientists to search for a new explanation for Jupiter's X-rays.

"The location of the X-ray hot spot effectively retires the existing explanation for Jupiter's X-ray emission, leaving us unsure of its origin," said Randy Gladstone of the Southwest Research Institute in San Antonio, Texas. Gladstone and his colleagues reported their findings in the February 28, 2002 issue of *Nature*. "The source of ions that produce the X-rays must be a lot farther away from Jupiter than previously believed," he added.

Chandra observed Jupiter for 10 hours on December 18, 2000, as *Cassini* was flying by Jupiter on its way to Saturn. Chandra's observations revealed that most of Jupiter's auroral X-rays come from the pulsating area at a fixed location near the planet's north pole.

—from NASA Headquarters



The glowing areas in this Chandra X-ray image of Jupiter are concentrations of auroral X-rays near the planet's north and south poles. Although other telescopes have detected X-rays at Jupiter, no one expected the sources of these emissions to be so near the poles.

Image: Randy Gladstone, SWRI, and NASA

Society News

Take a Tour of the Universe in 10 Minutes!

The Planetary Society is pleased to announce our sponsorship of Space Wander.com. This website's exciting virtual space tour takes visitors on a voyage that leaves Earth, lands on Mars, flies by Jupiter, then travels outside our solar system to other destinations in the universe. The tour is available in English (with measurements in both the imperial and metric systems), French, and Spanish. An Italian version is coming soon. The goal of Space Wander.com is to inspire and educate the general public about space. One way this goal is achieved is through SpaceWander.com's targeting of teachers and students via online tools and resources. To learn more, log on to *www.spacewander.com*.
—Darrin Dennis, Web Marketing Coordinator

Planetary Society Volunteers Active in Great Britain

The Planetary Society's British Volunteer Team, which has been in operation in Great Britain for more than 10 years, continues to present popular and exciting live events, exhibitions, lectures, and leading-edge activities such as Red Rover, Red Rover to an enthusiastic and appreciative British public.

The British Volunteers' core activity is a long-running series of free public lectures in Birmingham, Britain's second city. In 2002, the Volunteers began their second year of these monthly events at their latest venue: Soho House Museum in Handsworth, Birmingham. The theme of the new lecture season is "The Cosmic Ocean."

Now, the Internet has become the medium by which the "Brit Squad" extends the mission of The Planetary Society. With an acclaimed website at *www.planetary.org.uk* and a newly launched British Members Forum in the form of an interactive e-group and mailing list at *groups.yahoo.com/group/tps_britain/*, the time has come for British members to link up in cyberspace and take part in the wider world of Planetary Society activities. The invitation is out—so, come on board!

For more information, contact Andy Lound at *hn81@dial.pipex.com* or Stuart Williams at *tps.sw@v21.co.uk*.
—Andy Lound, Regional Coordinator, Great Britain

The Spirit of Exploration in South America

Sergio Stinco, Volunteer Regional Coordinator of Argentina, is disseminating news about The Planetary Society to a large audience in South America. His daily radio and Internet programs reach approximately 500,000 people in Argentina and Chile. Check out Stinco's website (in Spanish) at *www.geocities.com/sergiostinco*.
—Susan Lendroth, Manager of Events and Communications

Planetary Society at NSTA

The Planetary Society spread the word about its projects to science teachers from all over the US at the annual National Science Teachers Association (NSTA) convention, held in San Diego, California, from March 27 to 30.

More than 13,000 teachers attended the convention. The headliner for the full day of Planetary Society–sponsored presentations on March 28 was Society Board member Bill Nye, who spoke to a rapt crowd of about 1,000. Other presenters included Alan Harris, of the Jet Propulsion Laboratory, on the risks of asteroid and comet impacts; Dan Werthimer, of the University of California, Berkeley, on the successes of SETI@home; Greg Delory, also of UC Berkeley, on the Mars Microphone project; Louis Friedman, of The Planetary Society, on the *Cosmos 1* solar sail project; and Emily Stewart Lakdawalla, also of The Planetary Society, on the Society's educational outreach projects, such as Red Rover Goes to Mars and Red Rover, Red Rover. The Planetary Society has brought its message—of space exploration for everybody—to teachers at NSTA meetings for 12 years.
—Emily Stewart Lakdawalla, Science and Technology Coordinator

Shoemaker Grant Winners to Be Announced This July

March 31, 2002 marked the deadline for accepting proposals for the 2002 Shoemaker NEO Grants. The Planetary Society received 37 proposals from 14 countries, including Australia, Belgium, Bulgaria, Luxembourg, Uruguay, Spain, and the United States. An international team of scientists is now reviewing the entries.

Winners will be announced on our website, *planetary.org*, in July 2002.
—Melanie Melton, Web Editor

Expedition to Argentina

Interested in accompanying us on our next expedition? We are considering traveling to Argentina in January–February 2003 to study some intriguing outcrops in Patagonia. The expedition is still in the initial planning stages, so details are not yet available. If you're curious and want to be added to a list for updates, call Lu at (626) 793-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.
—Lu Coffing, Financial Manager

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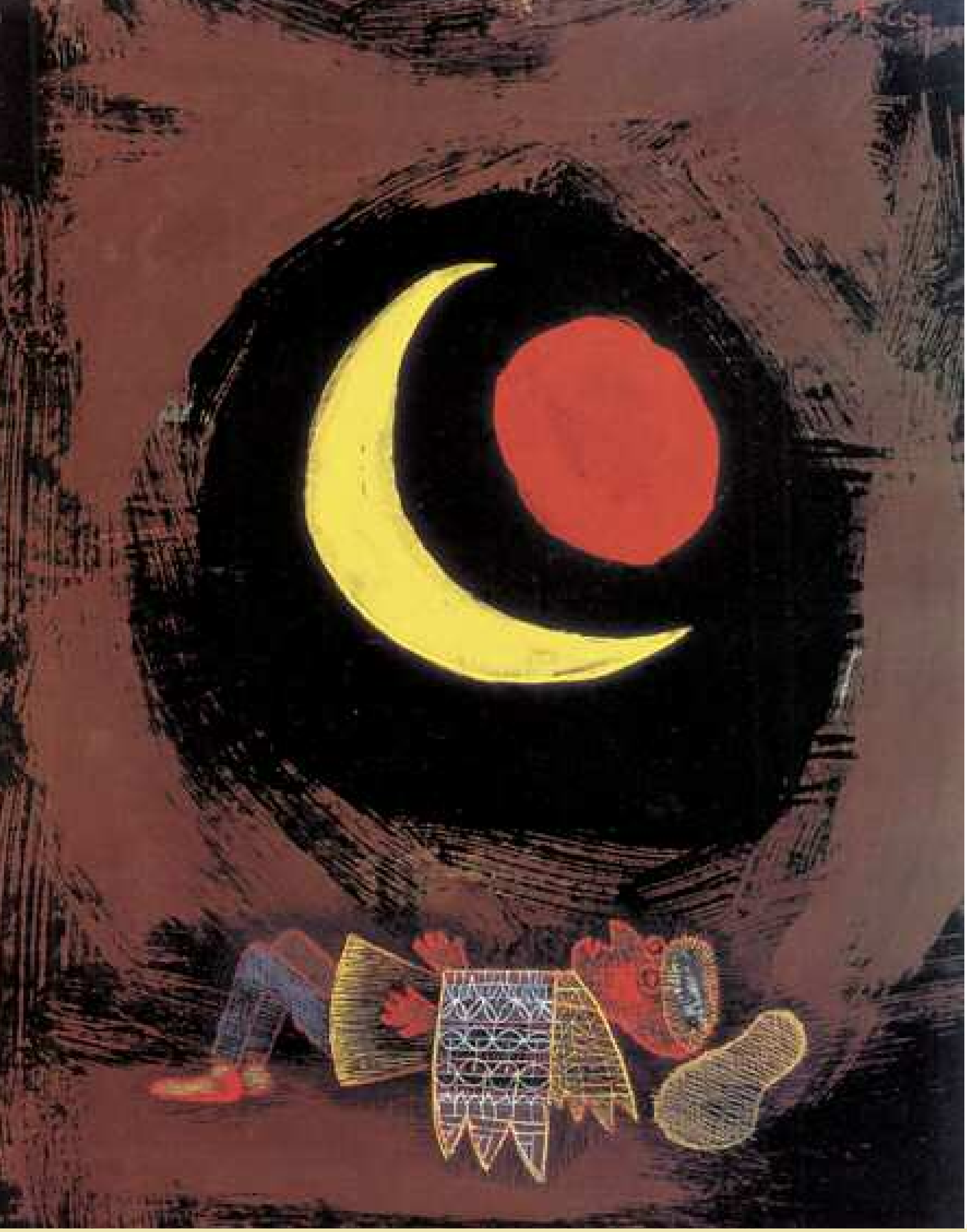

For all of us working to keep the dream of space exploration alive, Paul Klee's *Starker Traum* (A Vivid Dream) first brings to mind the Moon and Mars. In 1929, when this painting was completed, the notion of visiting these worlds was nothing more than a fantasy.

Paul Klee was born on December 18, 1879, in Münchenbuchsee, Switzerland. Although difficult to classify, his work is most often associated with the abstract, surrealist, and expressionist movements of the early 20th century. Klee's personal and often gently humorous works are filled with allusions to dreams, music, and poetry. He belonged to Der Blaue Reiter (The Blue Rider), an expressionist group that contributed much to the development of abstract art. After World War I, Klee also taught at Germany's famous Bauhaus school. He died on June 29, 1940, in Muralto-Locarno, Switzerland.

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Pasadena, CA 91106-2301

PRINTED ON RECYCLED PAPER
Printed in USA