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).

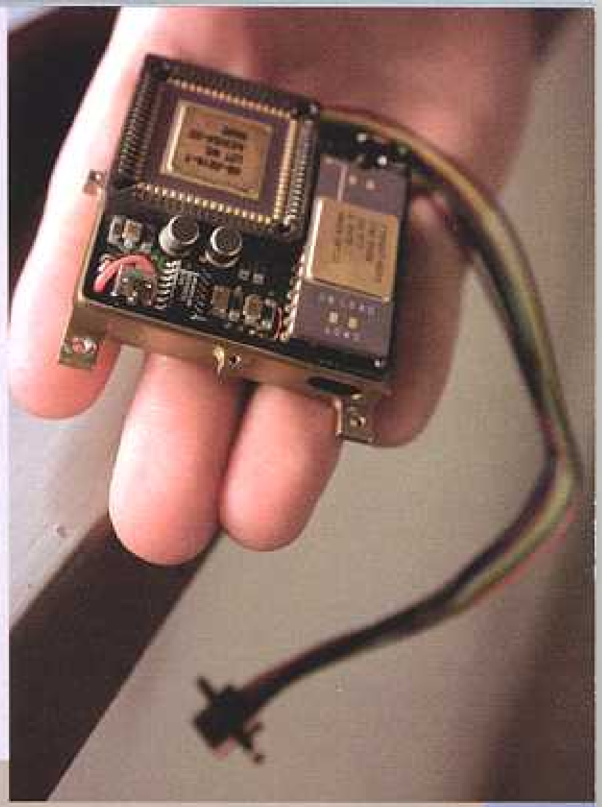
With new challenges come new opportunities. CNES officials and our European colleagues have welcomed our participation in almost every facet of the design and implementation of the *NetLander* mission, thus allowing us to optimally accommodate the microphone instruments on nearly every level. This is 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

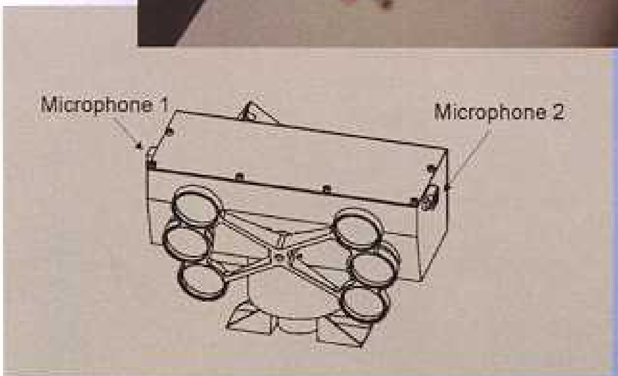
Including two microphones on each *NetLander* more than simply doubles the amount of data that will be returned from the experiment. In the same way that stereo cameras can produce three-dimensional (3-D) images using binocular vision, stereo microphones will add a depth to sound sources that simulates 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



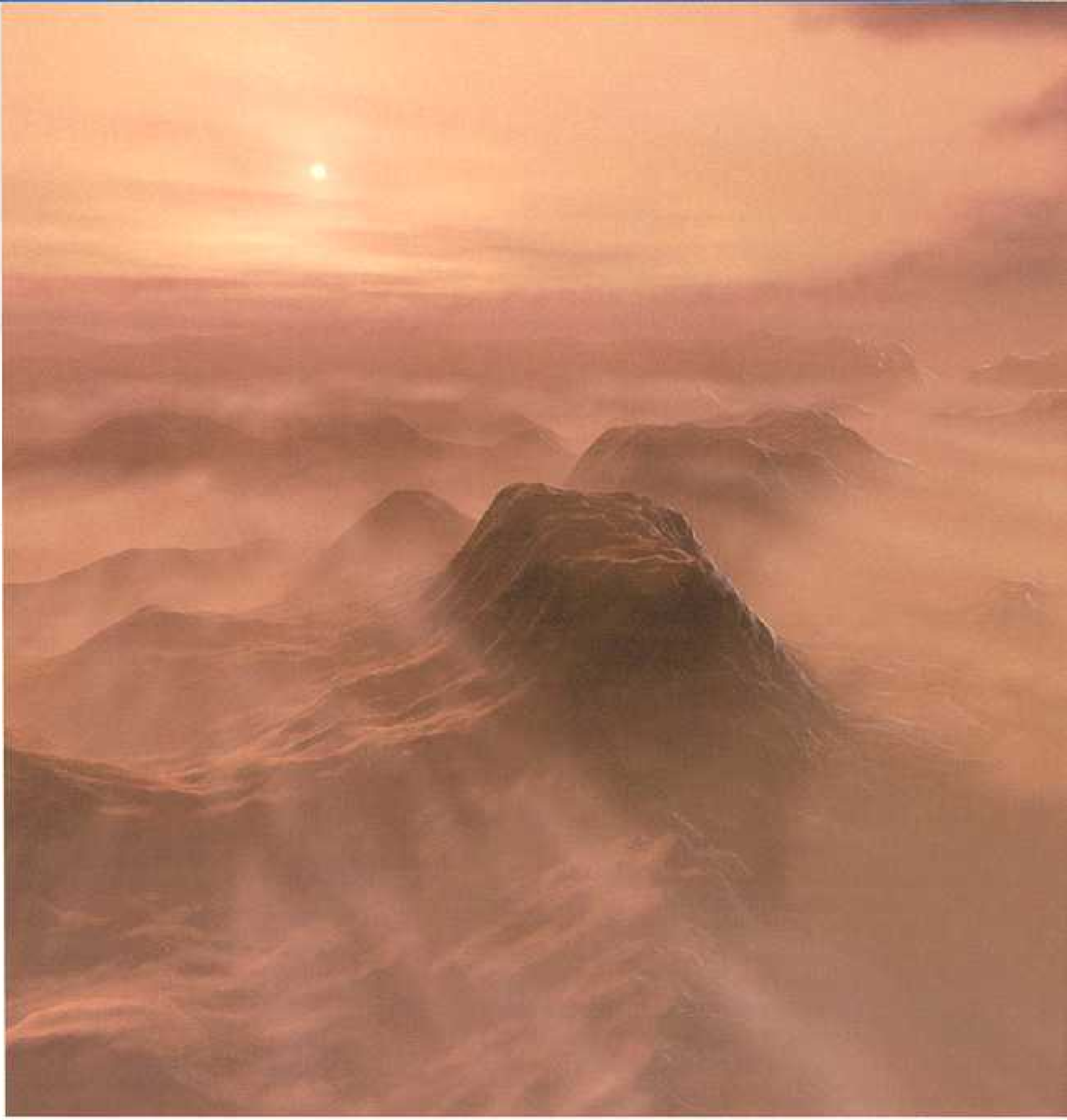
The Mars Microphone is built mostly from off-the-shelf parts, including a microphone similar to those used in hearing aids and a microprocessor chip used in speech recognition devices. This engineering marvel descends from a long line of robust miniaturized devices, several of which were used for astronaut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

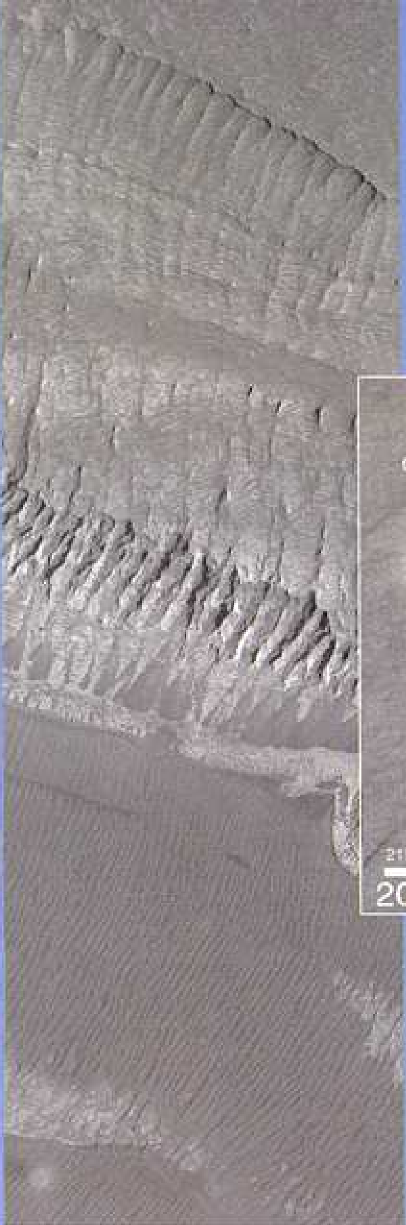
For these low frequencies, another mechanism is necessary. In fact, researchers have determined that the brain uses a time delay between sounds received by each ear as an indicator. Because sound waves travel at definite speeds, there is a small time delay as sounds arrive at one ear and then the other. 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.

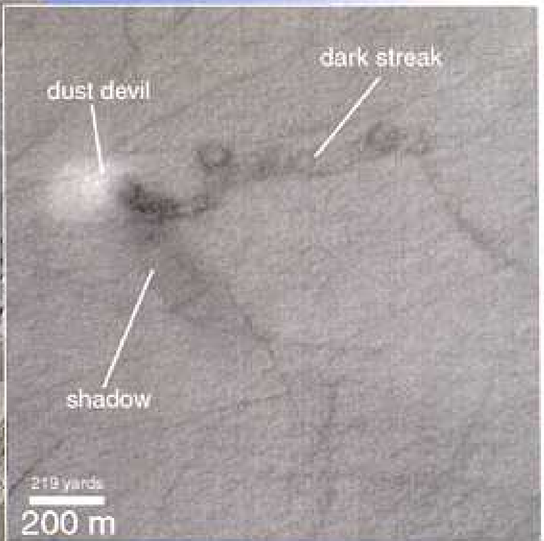
Enter the Anatomical Transfer Function (ATF), a fancy mathematical term for the effect of the ears, head, and shoulders on incoming sounds, particularly for higher frequencies. It turns out that the anatomical structure of these features in humans modifies incoming sound waves depending on the direction 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.



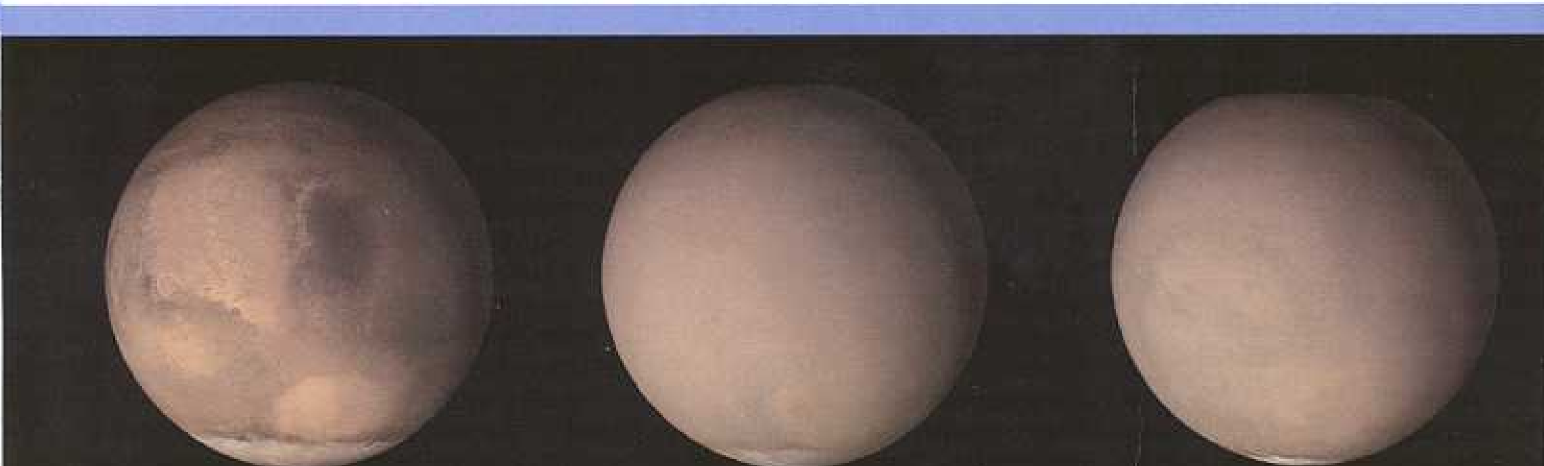
Above: Would hearing an approaching dust devil warn future explorers to move out of its disruptive path? Researchers and students from a new field of study called extraterrestrial acoustics are investigating the way sound moves through Mars' cold, rarefied atmosphere. Mars Global Surveyor caught this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



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