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Climbing Toward Mars

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Editor, CHARLENE M. ANDERSON
Technical Editor, JAMES D. BURKE
Assistant Editor, DONNA ESCANDON STEVENS
Copy Editor, GLORIA JOYCE
Production Editor, MITCHELL BIRD
Art Director, BARBARA S. SMITH

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COVER: The Mars Rover reaches the boulder-strewn summit of Mars Hill—in Death Valley, California. The 1992 Planetary Society test program brought together Russian, American, French and Hungarian engineers and scientists who matched the little robot explorer against some of the most Mars-like terrain on Earth. The program marked the first time a private space organization involved the public in the actual tests of a craft designed to explore another world.

Photograph: Charlene M. Anderson

FROM THE EDITOR

"Making Less Do More at NASA" was the title of a recent article in *Science* (October 2, 1992) describing the new NASA administrator's attempts to reform the way the space agency does business. Daniel Goldin's initiatives have been described as revolutionary by some, but, at The Planetary Society, doing creative and innovative things with a very little bit of money is business as usual.

It's not as if we had much choice in the matter. As a nonprofit membership organization, The Planetary Society has never had access to the once seemingly bottomless wells of government money. To conduct our projects to build a novel SETI receiver and signal analyzer, to design the SNAKE guide-rope for the Mars Balloon and to test the Mars Rover in Death Valley, our 100,000 members contributed most of the needed funds. The rest came from a few special private donors.

At the Society, we like to find what we call seed projects, where a little bit of money can help an idea grow into a significant program to further planetary exploration. Two seed projects that have grown into actual flight projects are the guide-rope for the Mars Balloon and tests of the Mars Rover. Both the balloon and the rover are scheduled for launch on the Russian *Mars '96* mission.

In this issue of *The Planetary Report*, we bring our members up to date on the progress of these two projects. We also report on recent developments in the world of planetary exploration.

• **To Mars on the Back of a Giant SNAKE—Page 4** Jim Cantrell's creativity and dedication have impressed everyone working on the Mars Balloon, and the Society arranged for him to spend some time in France designing the guide-rope. In this article, he tells the story of the SNAKE guide-rope for Society members, who made it possible.

• ***Mars Observer:* On Its Way—Page 10** *Mars Observer* is finally on its way to the Red Planet, after a delay of two years and a last-minute problem of dust contamination. We are looking forward to seeing what this advanced orbiter will discover about this most Earth-like of worlds.

• **Through Teamwork to Mars: The 1992 Mars Rover Tests—Page 12** This was the biggest test program ever undertaken by The Planetary Society. Not only did we bring together experimenters from several different countries, we also invited Society members to participate in the tests. There is so much to report that, although we've devoted many pages to the tests here, we will complete our coverage in our next issue.

• **A Planetary Readers' Service—Page 22** Books published by university presses are not readily available in most bookstores, so in this issue we offer a recent title that we think you'll enjoy.

• **NASA's Search Begins—Page 23** After more than a decade of planning and building, NASA has finally begun its powerful search for extraterrestrial intelligence, now called the High-Resolution Microwave Survey.

• **World Watch—Page 24** The bureaucracies that run planetary exploration are changing fast, and we do our best to keep you informed about the latest developments.

• **Toward the Next Millennium: A Vision for Spaceship Earth—Page 25** The new NASA administrator, Daniel Goldin, is shaking things up at the space agency. Here is a bit of his vision of the future.

• **News & Reviews—Page 26** Not everyone is pleased with Dan Goldin's changes, and Clark Chapman expresses his opinion.

• **Society Notes—Page 27** We've been busy with much more than testing rovers, and here are some examples.

• **Questions & Answers—Page 28** Gas giants and their satellites, asteroidal atmospheres and SETI have raised questions in our members' minds. Here are some answers.

—Charlene M. Anderson

Members' Dialogue

As administrators of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of our Society. We encourage members to write us and create a dialogue on topics such as a space station, a lunar outpost, the exploration of Mars and the search for extraterrestrial life.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

"Doing More With Less: The New Way of Exploring the Solar System" in the July/August 1992 *Planetary Report* surely shows the way to rebuild and carry on our nation's space program. As demonstrated in *The Planetary Report*, small-scale missions are the best for exploring the solar system.

When the United States space program began in the 1960s with the *Mariner* series, the missions were double ones, with two identical craft sent. And as *Mariner 2* proved, these smaller, more economical craft could be fully built in less than one year and multiple missions sent on their way to explore the solar system.

Larger missions take decades to plan out and extensive time to be cleared by the administration, and they cost vast amounts of money. It is possible for multiple missions to require less financing than a single costly mission. Microspacecraft are definitely the way to accomplish our exploratory needs in the future. But instead of looking to the future, let's first look to the past. After all, that's when we were navigating the cosmos at an unprecedented rate. Let's bring back the simpler (yet equally rewarding) micromissions.

Many thanks to *The Planetary Report* for keeping these ideas alive and well.
—BRIAN CHIARELLA, *Wallingford, Connecticut*

If there is one hallmark that characterizes the human race and underlies its evolution from the days of its first appearance upon Earth, it is its unique ability and drive to search out its roots and seek out its future. To the extent that we deny this very essence of our humanity in favor of short-term gratification, we diminish ourselves as human beings.

The Search for Extraterrestrial Intelligence is the very epitome of noble human endeavor, testifying to our respect for ourselves as uniquely endowed beings able, prepared and obligated to reach out to any companions with whom we may share the universe.

The NASA budget item for this endeavor may well entail some small sacrifices in other areas. However, budgetary support of this modest effort will validate and confirm that in our current stage of human enlightenment we will not shrink from our heritage nor hide from our destiny, but will instead embrace this next great evolution in the unfolding saga of the human race.
—JOSEPH E. MACHUREK, *Crested Butte, Colorado*

Considering the very finite funding available for NASA and space exploration, I feel that continued funding for SETI should *not* be as high a priority as the Planet-Crossing Asteroid Survey. As much as I appreciate the eventual payoff of pure research, SETI seems to be the 20th-century equivalent of the alchemists' philosophers' stone.

A reading of Niven and Pournelle's fictional *Lucifer's Hammer* graphically points out the unimaginable disaster this planet could suffer from a hit by a comparatively small asteroid. As one who has worked on thermonuclear weapons as well as intercontinental ballistic missiles, I can only hope that some of these weapons will be kept at the ready to split or divert any asteroids heading our way, assuming they could be detected in time.
—R. LAMAR SCHEUERMAN, *Spring Valley, California*

If "telepresence" will let Mars astronauts stay in their base and "gain access to the whole planet" [see News Briefs in the July/August *Planetary Report*], why can't that base be comfortably at Ames Research Center in Mountain View, California?
—MORGAN C. LARKIN, *Salem, Oregon*

One-way light-time—the time a radio signal takes to travel from Mars to Earth—varies from 5 to 20 minutes, depending on the relative positions of Earth and Mars in their orbits about the Sun. This would make the control of a robot moving across the surface of an alien planet rather risky. With a dumb robot, by the time the operator on Earth realized that the machine was heading off a cliff it would be too late to save it. That is why martian robots need to be smart.
—James D. Burke, Technical Editor

NEWS BRIEFS

The *Pioneer 12* spacecraft, seared and pummeled as it flashed through the upper atmosphere of Venus, expired after 14 years of uncovering the mysteries of the cloud-shrouded planet.

"This has been an enormously productive mission," the project manager, Richard Fimmel, said at a combination briefing and wake held at NASA's Ames Research Center. "In spite of the fact that we are sad at the loss of an old friend," he said, "we have the satisfaction of a job well done."

Near the end, *Pioneer 12* was 128 kilometers (79.5 miles) above the planet's surface and was making history as the first orbiting spacecraft to sample the high atmosphere of any planet.

Project scientists lost radio contact with the craft at 12:22 p.m. Eastern time on October 8 and knew its mission was over when the signal did not emerge on schedule from behind the planet.
—from Warren E. Leary in the Pasadena *Star-News*

Early warning, good preparation and powerful equipment could provide the best view ever of a large asteroid as it zooms close to Earth in December, astronomers say. "This is the first time we've had something predicted ahead of time coming so close," said Brian Marsden of the International Astronomical Union in Cambridge, Massachusetts.

The asteroid, first known as 1989AC but now in the record books as 4179 Toutatis, "is quite a large object, several kilometers across. In December it will come to about 3 million kilometers (about 2 million miles) from us," Marsden said.

Steve Ostro of the Jet Propulsion Laboratory said Toutatis presents an enticing target because "it will make the closest approach of any known asteroid or comet between now and the end of this decade."
—from Robert Cooke in *Newsday*

To Mars on the Back of a

by James Cantrell

In 1996, a Russian rocket will blast off from central Asia, beginning a long-awaited mission to Mars: *Mars '96*. The spacecraft will be carrying one of the most innovative and elegant devices ever built to explore another world: the Mars Balloon. This balloon system will be the first human-made flying machine to land on and take off from an alien planet's surface.

The design of the Mars Balloon with its SNAKE guide-rope has been extremely interesting and challenging. Those of us who worked on its development have found ourselves pushing the limits of existing technology. But persistence and good, old-fashioned hard work have paid off, as we are now at a point where most of the technical problems have been solved. The hardware will soon enter the qualification phase and, if all goes as planned, a group of people will huddle around a computer screen sometime in 1997 to see the first photo of Mars taken from the balloon as the SNAKE slowly glides over the unknown martian terrain.

This is the story of the Mars Balloon, the SNAKE and the people who have worked to make this dream a reality. I have been involved in this project now for the better portion of my engineering career and have just returned from over two years in France, working directly with French and Russian scientists and engineers. For my part, I have felt fundamentally changed by the experience.

The History of the Balloon Mission

As early as 1963, a Rand Corporation study considered the possibility of ballooning on Mars. The study concluded that the idea was feasible but the enabling technology needed to mature—principally sufficiently lightweight and durable balloon materials—and mission planners would need to know much more about how the martian atmosphere behaves.

The tremendous success of the American *Viking* missions in 1976 once again ignited the fires to explore Mars. The first close-up pictures showed a planet whose desert terrain seemed not very different from Earth's—so similar that we half-expected to see some

Giant SNAKE

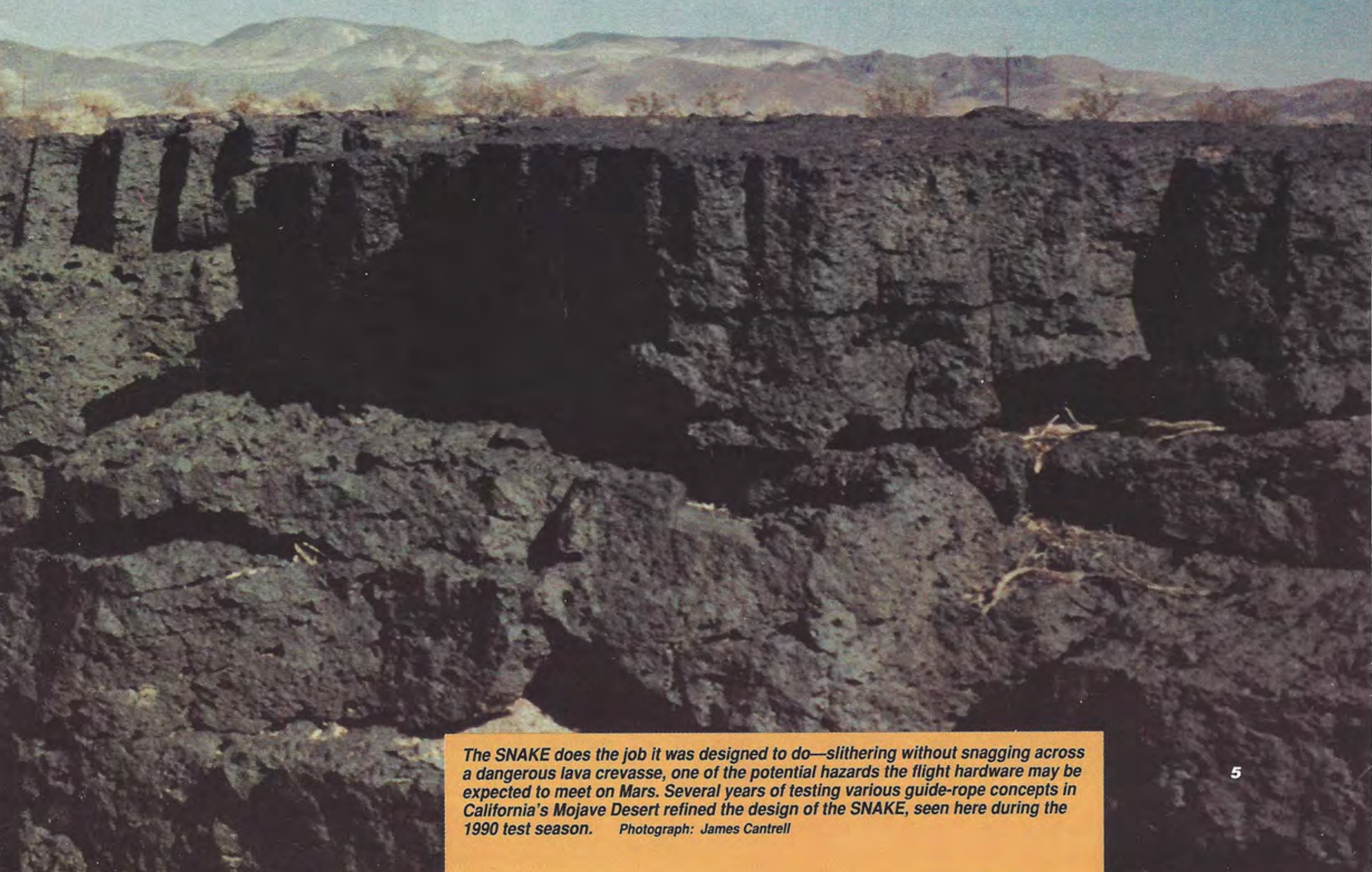
miner and his mule appear in front of *Viking*'s cameras, even though we knew that *Viking* did not detect life.

One lingering legacy of the *Viking* mission was really bittersweet: The ability to study the martian environment so well locally made us thirsty. Stuck in one place, the landers could only show us two small bits of the surface. We, as humans, wished that somehow we could move the landers around the adjacent rocks and over the hill, to see what might be there, just hidden from our view. Thus, the mobile exploration of Mars became a very hot topic, with robotic rovers the most seriously discussed candidates for "roving" missions.

The idea of martian balloons resurfaced in 1986, after the success of Soviet balloons deployed in the atmosphere of Venus during the *Vega* mission that also investigated Halley's Comet. French scientist Jacques Blamont, who had worked with the Soviets on the international Venus Balloon project, proposed the use of solar-heated *montgolfiere* balloons to explore Mars. The balloons would fly during the day and descend to the surface at night.

To Blamont, the idea of sending balloons to Mars was the perfect complement to past and future missions. The scientific community was excited by the idea of an instrument platform flying both close to and above the martian surface, able to visit many different sites over thousands of kilometers of terrain. However, there would be challenging technical problems to solve: building and handling enormous balloons made out of thin materials, inflating these balloons during descent in the martian atmosphere and ensuring that payloads would be able to contact the martian surface safely. The mission would be a huge gamble, but it would have a potential payoff worthy of the best that Las Vegas could offer.

By the end of 1986, researchers around the world were busy investigating the feasibility of sending



The SNAKE does the job it was designed to do—slithering without snagging across a dangerous lava crevasse, one of the potential hazards the flight hardware may be expected to meet on Mars. Several years of testing various guide-rope concepts in California's Mojave Desert refined the design of the SNAKE, seen here during the 1990 test season. ***Photograph: James Cantrell***

balloons to Mars. The group from the French space agency (the Centre National d'Études Spatiales, or CNES), led by Venus Balloon veterans Jacques Blamont, Christien Tarrieu and Josette Runavot, was looking at a dual-balloon configuration (a *montgolfiere* and a helium balloon) that would make nightly landings. They focused on developing extremely thin and rugged balloon materials, and on fabricating and handling the very large balloons that Mars demanded. In the Soviet Union, scientists led by Venus Balloon veterans Viktor Kerzhanovich and Raould Kremnev concentrated on a nonlanding balloon configuration.

In the United States, independent teams at the Jet Propulsion Laboratory, Utah State University and the California Institute of Technology began to study balloon aerodynamics and the problem known as ground contact (that is, the balloon payload contacting and dragging on the surface). The work at JPL was led by Jim Burke, who had earlier raced the Soviets to the Moon as the project manager of *Ranger*. The group at USU was headed by Frank Redd, who had directed the development of the Inertial Upper Stage for the Air Force. Planetary Society Vice President Bruce Murray, a Mars expert and former director of JPL, led the work at Caltech.

The Planetary Society closely followed and supported the work being done by the various groups. It contracted with aerospace consultant and longtime balloonist Tom Heinsheimer and space veterans Harris M. "Bud" Schurmeier and Jim French to conduct studies, and worked to facilitate cooperation between the different groups for testing and scientific exchanges. In 1987, anxious to advance this new technology, the Society sponsored tests to address the problem of ground contact.

Two concepts were investigated: "point mass" (small boxes) and distributed mass, which evolved into a guide-rope similar in principle and shape to the classic hemp design used by terrestrial balloonists for nearly two hundred years. The point masses were easier to house instruments in but snagged on the surface. The distributed mass payloads were excellent dynamically and did not snag, but instrumentation was more difficult. The tests were to be pivotal in moving Mars Balloon technology closer to the realm of possibility.

Enter the SNAKE

The Planetary Society's tests clearly demonstrated that any Mars Balloon design that is to fly near the surface needs to be equipped with a guide-rope. The guide-rope's primary role is to enable the balloon to fly close to the surface without touching it while acting as an automatic ballast for the balloon's buoyancy variation, as the heat from the Sun causes it to rise and nighttime cooling causes it to descend. If the guide-rope were to snag on the surface, the wind would blow the delicate balloon to the ground and it would be destroyed. Thus the guide-rope is, in this sense, an extremely critical component of the mission. It must reliably and stably drag across unknown and rough surfaces without snagging. As a bonus, it could carry scientific instruments to study the martian surface.

At Caltech, Bruce Murray had been thinking about the problem of ground contact and what instruments might be housed in a guide-rope. Jim Burke at JPL came up with an idea for a design based on overlapping cones. His original model consisted of taped 3-by-5-inch index cards attached to a central string. He dragged it over office obstacles to demonstrate the concept, then asked me to come up with a more practical mechanical design.

After several long afternoons staring at Jim's original model, and late-night discussions with my wife, Ellen, about emulating nature, I came up with a simple mechanical design.

The new concept was the SNAKE. It looked like a snake when it moved, and its construction was based on the actual creature (which was Ellen's idea). It was made by joining overlapping cones made of a strong and hard material in such a way that the dragging surface would always be smooth—much like the underside of a real snake—and the structural ensemble would be flexible. Inside there would be a central attaching structure, and instrument modules could be placed inside each segment. This construction would not only be practical to manufacture, it would permit a modular approach: The guide-rope could be lengthened or shortened as needed, and the cones could be varied as called for by local design requirements.

The prototype, not much different from Jim's original index-card model, consisted of rolled and riveted sheet metal cones, 15 centimeters in diameter and 30 centimeters long, attached to a central chain. The external shells were made of aluminum, and there was ample room on the inside for instruments.

1 *The first field tests of the guide-rope idea pitted the point mass concept against the distributed mass concept. The green plastic box, seen here as it was dragged across a lava field by a helium-filled balloon, represented a point mass that would serve as ballast for the balloon while it carried instruments that could easily be fitted into its box shape. However, it snagged frequently and was easily damaged. The distributed mass concept, represented by the earliest SNAKE, won the competition.* Photograph: James D. Burke

2 *and* **3** *The 1988 tests focused on refining the SNAKE, which still needed a lot of work. Made of overlapping metallic segments, this SNAKE easily avoided hazards such as crevasses, large boulders and sand dunes, and only snagged when confronted with a bush—a hazard not anticipated on Mars. However, the thin metal of this prototype was not immune to wear and tear.* Photographs: James D. Burke

4 *By the 1990 test season, the SNAKE had been made into a hardier beast, which passed all of its snagging tests with honors. This version carried instruments to measure its performance in greater detail than before, and here the French team is preparing it for a test run across Palen Dry Lake in the Mojave Desert. A team member at right stands behind the test gondola, which in the flight model will carry sensitive instruments to measure the martian winds and weather, as well as a camera to return detailed images of the planet's surface.* Photograph: Charlene M. Anderson

I must admit that at the time I viewed this whole activity with impatience and disinterest. As a student of thermo- and fluid dynamics, I was much more interested in investigating the balloon's aerodynamics and heat-transfer mechanisms than in bolting together aluminum cans. However, my affinity for building race cars and my respect for Jim Burke kept me and fellow student Ray LeVesque working in the basement of Caltech during the week and in garages on the weekend, on a weird thing that prompted the question, "What is *that?*" from everyone who saw it.

The first tests of the SNAKE took place in the Mojave Desert in late 1987. The new configuration performed far beyond our expectations, gliding over rough lava fields, up slopes and across crevasses. Not only did it drag smoothly over the surface without snagging, it did so with astonishing ease, even on the severest surfaces. This slippery movement made the name SNAKE impossible to resist.

Why Doesn't It Snag?

Getting a guide-rope to move across a rough and rocky surface without snagging seems at first to be an impossibly complex problem. However, our tests have revealed several basic principles. A desirable guide-rope has a combination of global (or overall) flexibility and local rigidity. If the guide-rope is globally flexible (relative to the terrain's macro scale) and locally rigid (relative to the terrain's micro scale), then the combination of smooth dragging and snag-resistance is achieved.

Our final design was further enhanced by adding a wire tail at the end of the SNAKE. This prevented the SNAKE from being whiplashed when dragging across the surface at high speed, and allowed a safe landing when the balloon was coming down fast.

The SNAKE's Mission

The physical contrast between the guide-rope and the balloon is striking. Whereas the balloon is immense, made from very thin and delicate materials, and gracefully floats in the atmosphere, the guide-rope is small and built to withstand enormous amounts of punishment. On Mars, it will get plenty of that: It is expected to be dragged hundreds of kilometers in its 10-day journey, over a terrain for the most part unknown but thought to include boulder fields, sand dunes and lava flows. It will move along this surface at speeds of up to 9 meters per second, raising vast amounts of dust as it goes. Its moving parts must therefore be able to operate in the presence of dust and sand, as well as at ambient temperatures as low as minus 110 degrees Celsius.

To fulfill the mission requirements, the guide-rope must satisfy other constraints. It must have an overall length of 14 meters, a diameter sufficient to house electronic modules 40 millimeters in diameter by 200 millimeters long, and a total structural mass less than 7 kilograms; moreover, it must be able to coil into a space less than a meter in diameter—the available space on the *Mars '96* descent module.

Finally, the guide-rope must be compatible with sterilization procedures that may be necessary to ensure compliance with planetary quarantine measures. Current sterilization methods vary for different portions of the descent module. The guide-rope, however, will be sterilized either by heat or by a hydrogen peroxide gas procedure, depending on final specifications. The effect of these procedures on the guide-rope is constantly being taken into consideration.

The Home Stretch

By early 1989, the various parts of the puzzle were falling into place, largely through the efforts of The Planetary Society. While the French and the Soviets had reached a formal cooperative agreement, the US programs ran out of government funding. The Planetary Society, in a bold and decisive move, opted to lead the then-disintegrating US teams to keep alive their unique capabilities and help ensure the eventual success of this important scientific mission. In 1989 and 1990, the Space Dynamics Laboratory of USU in Logan, Utah, joined the Society in supporting developmental work on the SNAKE and balloon system performance analysis. This was part of an informal cooperative effort with CNES and the Babakin Center in Moscow. Our work centered on designing a smaller, leaner and more realistic SNAKE.

Our Mojave Desert tests convinced CNES that the SNAKE was viable, and formal cooperation between CNES and the Society ensued. As a result, I was sent to France for two years to head up the mechanical development work on the SNAKE, which had shifted to CNES in Toulouse in 1990, and to transfer our hard-earned know-how to the French.

For me personally, this was a very enriching experience, sometimes frightening, sometimes exciting, and sometimes bittersweet as well. For the French, it was equally enriching. I had to learn to read, speak and write French as quickly as possible, and the French team had to learn the secrets of the SNAKE that had been gathered over the previous four years.

The work during this period progressed smoothly at times and not so smoothly at other times. The SNAKE's design has gradually progressed, and we have overcome many technical and political hurdles, yielding what is now considered a mature mechanical design. One by one, the design's mechanical problems are being resolved in the face of difficult mass and environmental constraints.

Our confidence in the basic mechanical configuration of the SNAKE significantly increased after we tested it more thoroughly in the field. Several such tests were conducted between 1988 and 1991 using scaled balloon/guide-rope systems. By far the most interesting of these were the 1990 Mojave Desert field tests (see the January/February 1991 *Planetary Report*). A group of French, American and Soviet scientists and engineers put the balloon and its guide-rope through some intensive testing over sand dunes and lava fields very similar to those on the martian surface. Packed with measurement systems and electronics, it flew untethered for up to 8 kilometers at a time, performing exceptionally well. There was no snagging, and the dynamics of the balloon, tether and SNAKE were acceptable.

By the end of 1993, the SNAKE should be ready for qualification tests in which the whole system will be rigorously tested and punished in conditions as close as possible to those on Mars. Let's take a look at what we hope will actually happen beginning in the autumn of 1996.

Mission Preview

On Earth, the gigantic balloon, the gondola and the guide-rope are carefully placed in the small descent module in preparation for the voyage to Mars. Neatly packed away in the same descent module is a small travel companion, the Mars Rover. The two will share the same space for nearly one year. Once Mars is reached, they will part ways.

The ride to Mars begins with the launch of a Russian *Proton* rocket carrying a cargo of a *Phobos*-class orbiter and the

A test balloon is inflated at the Centre National d'Études Spatiales facility in Toulouse, France. In the thin martian atmosphere, only 1/100 as dense as that of Earth, the balloon will have to be gigantic to carry its payload on its daily trek. The flight model will be about 42 meters high and will be filled with 5,500 cubic meters of helium. It will capture infrared radiation, both from the Sun and reflected from the planet's surface. This heat will cause the helium to expand, increasing its buoyancy and enabling the balloon to fly during the day. At night, when the gas cools, the balloon will gently sink to the surface, where the automatically varying ballast of the SNAKE will, we hope, keep it safe to fly another day. Photograph: Centre National d'Études Spatiales

INSET: The flight configuration will be similar to that tested during the 1990 test season. Photograph: Charlene M. Anderson descent module. At Mars, the descent module is jettisoned from the orbiter and begins its fall toward the martian surface. At the proper altitude, the rover capsule is separated by parachute, and the descent module deploys the balloon.

The balloon inflates automatically as it descends; the filling sequence lasts about five minutes. The highly compacted balloon (1 meter in diameter by 0.5 meter high) is transformed into a gigantic floating cylinder 42 meters long by 12 meters in diameter, holding 5,500 cubic meters of helium. Hanging below the balloon is a conical shield containing the still-undeployed gondola and guide-rope.

The inflated balloon continues its descent until the shield reaches the martian surface. Then, the guide-rope is deployed from its coiled storage position, and its internal computers and instruments come to life. The balloon system has passed one of the most critical points in its mission, inflation and deployment. It is now completely free to move, and it begins its 10-day journey.

During the day, the balloon is heated directly by the Sun and indirectly by energy from sunlight re-radiated from the martian surface. The resulting increase in temperature creates a net increase in lift, and the balloon rises from the surface. As it continues to ascend, its gondola instruments take measurements of the martian atmosphere. The balloon gas expands until the maximum volume is reached and the balloon is pressurized.

The balloon now floats at a nearly constant altitude after having reached equilibrium. The gondola's cameras photograph the martian surface, now 1 to 3 kilometers distant, with stunning precision, and its instruments continue to sample the atmosphere, studying every detail. Meanwhile, winds effortlessly ferry the balloon through the sky, high above the vast expanses of martian desert.

As sunset approaches, the balloon cools, loses buoyancy and once again heads toward the surface. It is now several hundred kilometers away from its previous landing site.

The guide-rope is the first and only part of the balloon system to touch the ground. The nightly landing throws it onto the surface at speeds up to 7 meters per second. Once the system has reached equilibrium after landing, the balloon and the gondola remain some 50 meters above the ground. Roughly half of the guide-rope rests on the surface.

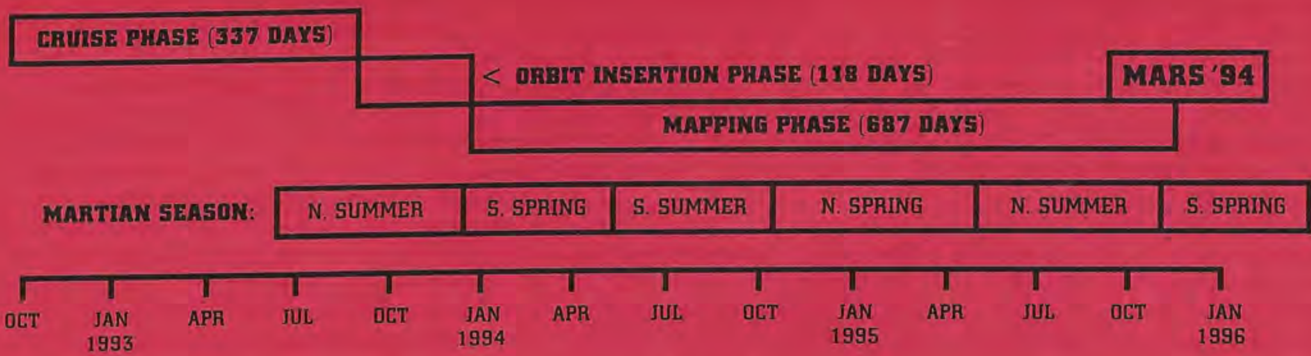
As night falls, the titanium-clad guide-rope becomes the star of the show. The evening winds carry the balloon along, dragging the guide-rope over the rough and unknown martian surface. The SNAKE slithers along the rocks and sand as its instruments take their measurements, continuing its mission well into darkness.

As the temperature drops, the guide-rope becomes colder and colder. When its internal temperature reaches minus 60 degrees Celsius, the guide-rope puts itself into a "sleeping" mode in order to conserve its precious lithium battery. During this phase, the evening's data are safely stored awaiting transmission the next day.

The guide-rope and balloon system continue dragging through the night, during which ambient temperatures can reach minus 110 degrees Celsius. As the Sun rises the next morning, the balloon warms once again and gradually ascends. When the guide-rope reaches operating temperature, it transmits its data to the gondola, which has a solid-state memory and a transmitter capable of sending the data to a spacecraft in martian orbit. The gondola waits for an overhead passage of either the *Mars '96* orbiter or the veteran *Mars Observer*, and transmits the data. The relay spacecraft in turn stores and then forwards the data to Earth. Back on Earth, many people will be anxiously waiting for their scientific booty from this strange martian explorer, the interplanetary SNAKE.

James Cantrell is a mechanical engineer at the Space Dynamics Laboratory in Logan, Utah. He continues to work closely with The Planetary Society and CNES on the SNAKE's design, testing and hardware fabrication.

Mars Observer: On Its Way



Mars Observer was launched from Cape Canaveral on September 25, 1992. It is now in the cruise phase of its mission, which will end on August 24, 1993, when the spacecraft enters a highly eccentric orbit around Mars. Over the next 118 days, gentle pushes from its thrusters will slowly lower the spacecraft to a circular orbit 378 kilometers (about 235 miles) high. The mapping phase of concentrated data-gathering will then begin. This phase will last for an entire martian year of 687 Earth days, taking *Mars Observer* through a complete seasonal cycle. At the end of this phase, the support mission for the Russian *Mars '94* mission will begin.

When Is Encounter?

With the *Voyager* mission, the greatest mission of the past decade, space scientists and the public became accustomed to speaking about "encounter," the few days surrounding a spacecraft's closest approach to its target planet. Encounters were characterized by their intensity, for the data flowed back to Earth like a flash flood, threatening to engulf the scientists who gathered at the Jet Propulsion Laboratory to receive in a torrent the planetary data that they would study for the next few years.

The press also gathered, to relay the rush of encounter news to a waiting public. Scenes of scientists and mission managers breathless with discoveries flashed across the evening news, and newspapers and magazines carried major stories about the triumphs of *Voyager*.

It will be different for *Mars Observer*—there will be no fleeting or dangerous flyby. The spacecraft will reach Mars on August 24, 1993, and begin a laborious, 118-day-long process to circularize its orbit. Although some of *Mars Observer*'s instruments, such as the gamma ray spectrometer and magnetometer, will collect data during the cruise to Mars, most of the instruments will not go into action until the circular mapping orbit is reached.

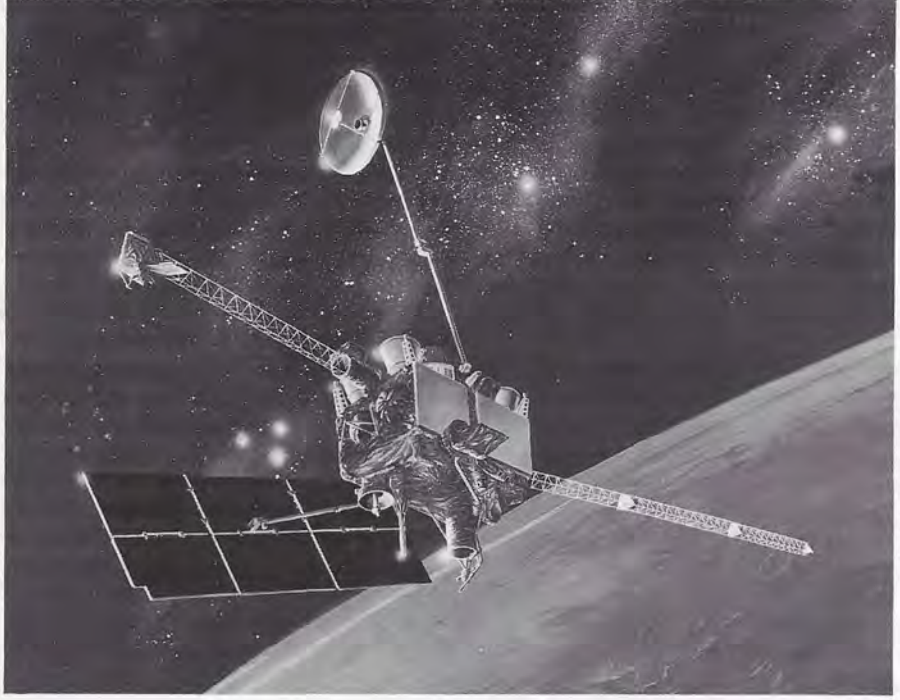
Even the achievement of the mapping orbit and the beginning of observations will be no occasion for an encounter. The telecommunications revolution of the past decade has made the encounter gathering of scientists unnecessary. Instead, *Mars Observer* researchers will sit at their home institutions and receive their long-awaited data through a computer network linked to the operations center at JPL.

All of these changes will help make *Mars Observer* a cost-effective and scientifically efficient mission. But at a price. Without an exciting, ephemeral encounter, and the intense press coverage it can generate, the public who paid for the mission will find it more difficult to share in the excitement of discovery. It will be a challenge to The Planetary Society to bring *Mars Observer*'s findings to you.

Mars Balloon Relay

Mars Observer will carry a small radio, built by the French space agency, that will receive and relay to Earth data from the Russian small stations and penetrators that will be part of the *Mars '94* mission. This radio is called the Mars Balloon Relay, for it was originally conceived by Planetary Society Advisor Jacques Blamont as a way to transmit high-resolution imaging data from the Mars Balloon back to Earth. As Society members know, the Mars Balloon was once scheduled to be launched in 1994 as part of the Soviet *Mars '94* mission. But political and economic vicissitudes took their toll, and the balloon was postponed until the 1996 launch opportunity to Mars.

If *Mars Observer* survives until 1997, when the balloon is now scheduled to arrive, the relay may still be working and could fulfill its original function. It may well be called upon to transmit data from the latest addition to this mission, the Mars Rover.



Mars Observer as it should appear in orbit around the Red Planet.

Painting: JPL/NASA

What Will *Mars Observer* Teach Us?

Mars Observer began life under a different name: Mars Geoscience/Climatology Orbiter. This much more descriptive, if unwieldy, title gives an immediate idea of the mission's purpose: to study the surface and atmosphere of Mars. The *Mars Observer* Science Working Group, a NASA committee, set out five primary objectives. In the committee's official words, the mission will:

- Determine the global elemental and mineralogical character of the surface material.
- Define globally the topography and gravitational field.
- Establish the nature of the magnetic field.
- Determine the time and space distribution, abundance, sources and sinks of volatile material and dust over a seasonal cycle.
- Explore the structure and aspects of the circulation of the atmosphere.

If a reader can penetrate this scientific jargon, one of the overarching goals of *Mars Observer* will spring into view: the search for water on Mars. *Mariner 9*, launched in 1971, surprised nearly everyone with its discovery of vast channel systems etched into the martian surface, suggesting that liquid water once flowed abundantly on Mars. Where did it go? The largest remaining water reservoir is the north polar cap, but that contains only a fraction of the water that would have been needed to carve the features discovered by *Mariner 9*. Some small amount of water vapor exists in the atmosphere, sometimes forming tenuous clouds or condensing on the surface as frost. Was the rest lost to space, or is it hidden beneath the surface, frozen as permafrost in the soil of Mars? A good portion of the scientific energy soon to be expended in the *Mars Observer* project will go toward answering such questions.

The *Mars Observer* mission is scheduled to last for one martian year, or 687 Earth days. Mars' axis is tilted 24 degrees, an obliquity almost identical to the 23.5-degree tilt of Earth. The Red Planet experiences winters, springs, summers and falls similar to our own seasons, but Mars' seasons are about twice as long. *Mars Observer*'s yearlong mission will give it time to track seasonal changes through one full cycle.

When *Mars Observer* has completed its mission, we will have learned much about the climate of Mars and its similarities to and differences from that of Earth. We will know much more about the rocks, soils and surface features of Mars, where there are good landing sites and whether or not there are usable resources for those who will eventually walk on the Red Planet.

Mars Observer is an exciting mission of scientific discovery, but it is also a precursor for missions that are sure to follow: mobile robots, then sample returns, orbital reconnaissance and—eventually—human explorers. *Mars Observer* is a very large step toward the day humans will settle another world.

—Charlene M. Anderson

SPACECRAFT EXPERIMENTS

➢ GAMMA RAY SPECTROMETER

Detects and measures gamma rays emitted by the planet's surface. These data will allow researchers to identify some of the chemical elements present and determine the amount of each.

➢ MAGNETOMETER AND ELECTRON REFLECTOMETER

Detects and measures any global or local magnetic fields. If Mars possesses a magnetic field, these instruments can study its interaction with the solar wind.

➢ *MARS OBSERVER* CAMERA

Returns detailed images of the surface and makes daily record of the martian weather. This instrument consists of one high-resolution, narrow-angle camera and two low-resolution, wide-angle cameras. The MOC will have the highest resolution, or ability to see details, of any camera ever flown on a planetary spacecraft.

➢ PRESSURE MODULATOR INFRARED RADIOMETER

Measures thermal radiation from the atmosphere. It will produce altitude profiles of temperature, water vapor, pressure, dust and cloud composition.

➢ LASER ALTIMETER

Uses infrared laser pulses to measure distance from spacecraft to surface. With these data, researchers can construct a map of the surface topography.

➢ RADIO SCIENCE

Uses the spacecraft's radio system to probe the martian gravity field and atmosphere. Researchers can translate changes in the radio signals into data about the temperature and pressure within the atmosphere.

➢ THERMAL EMISSION SPECTROMETER

Takes infrared measurements to determine surface temperature and mineral composition. This instrument will also study atmospheric dust and cloud composition.

Through Team

The 1992 Mars Rover Tests

It was a series of improbable events, leading to a moment that can never be repeated: Finding myself standing in the middle of Death Valley at the beginning of summer, watching a robot bound for Mars climb a boulder-covered hillside, in the company of Russians, Hungarians, French and Americans, all working together to turn a dream of planetary exploration into reality.

That was the essence of The Planetary Society's 1992 Mars Rover test program. From May 22 to May 25, an international team of scientists, engineers, students and volunteers strained to their limits to test the capabilities of a short, squat, six-wheeled, low-riding robot designed to explore the alien terrain of another planet.

And while the technical Mars team members sweated in the sun, pushing themselves and the equipment to the utmost, they were cheered on by a crowd of Society members who had traveled to this desolate corner of Earth to witness what could be a turning point in the history of planetary exploration.

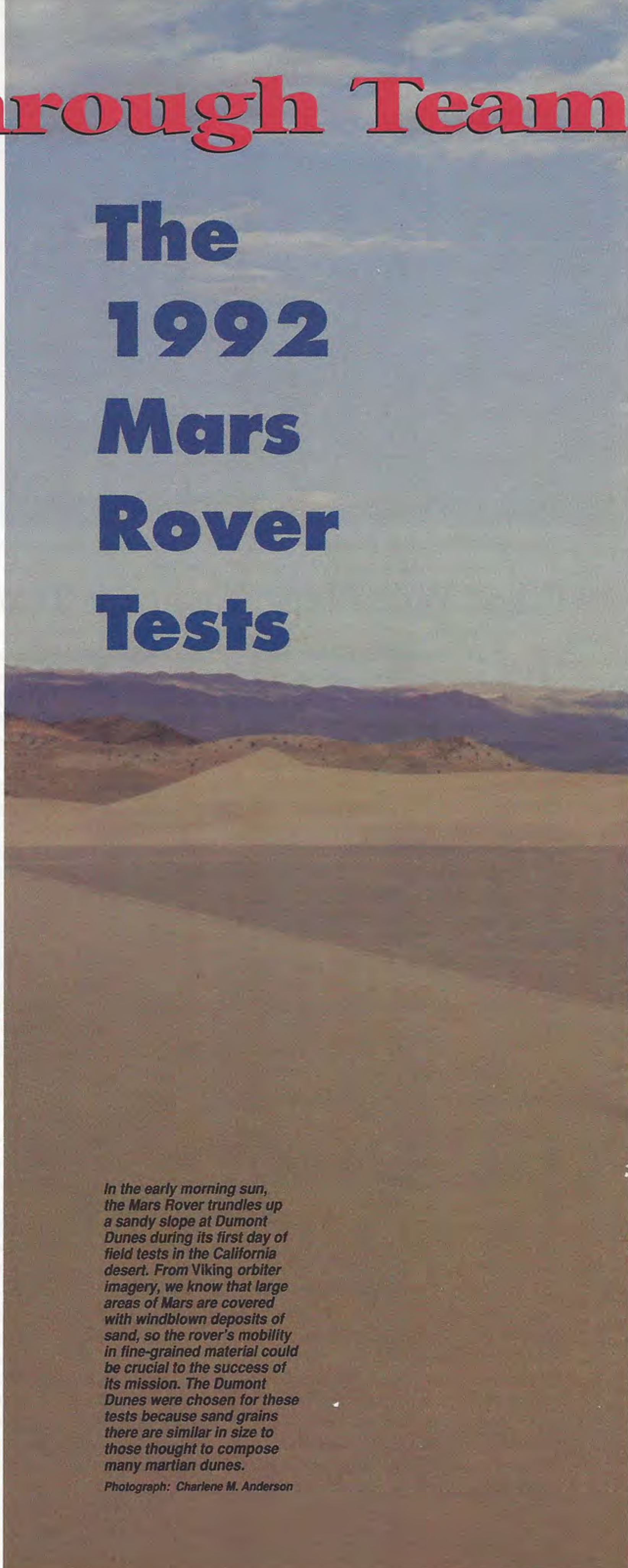
The genesis of this Mars Rover test program was in a chance meeting in 1989 between Society Executive Director Louis D. Friedman and Alexander Kemurdjian, designer of both the Lunokhod that explored the Moon in the early 1970s and the prototype of the Marsokhod that is scheduled to land on the Red Planet in 1997. They exchanged visits to each other's headquarters, and in 1991 Friedman traveled to Kamchatka to observe field tests of the Mars Rover on some of the most inhospitable terrain in Russia.

With the experience of the 1990 tests of the Mars Balloon in the Mojave Desert to draw on, Friedman suggested to the Russian rover team that they might benefit from testing their robot on some of the most inhospitable terrain that the United States has to offer: the Californiia desert. The Russians accepted the invitation, and a scouting party chose two locales as the most Mars-like sites: Dumont Dunes north of Baker and Mars Hill in Death Valley.

We realized from the beginning that this expedition would test more than equipment and algorithms. The Planetary Society's 1992 Mars Rover test program was—first and foremost—an experiment in team-building. We proved that Russian, American, French and Hungarian scientists and engineers can work together smoothly to develop an innovative vehicle to explore Mars.

And, of equal importance, we also proved that members of the general public can work with the specialists as well as cheer them on from the sidelines to enhance the success of an equipment test program.

When I listened closely, I could hear Hungarians and Russians communicating in English, Americans



In the early morning sun, the Mars Rover trundles up a sandy slope at Dumont Dunes during its first day of field tests in the California desert. From Viking orbiter imagery, we know that large areas of Mars are covered with windblown deposits of sand, so the rover's mobility in fine-grained material could be crucial to the success of its mission. The Dumont Dunes were chosen for these tests because sand grains there are similar in size to those thought to compose many martian dunes.

Photograph: Charlene M. Anderson

work to Mars:

chatting with Russians in French, and English touched with British, Italian, German and Mexican overtones. When words failed, gestures sufficed. American and Russian children, neither speaking the other's language, established friendships that have a chance of lasting long beyond the end of the desert tests. We all learned that language need not be a barrier between people.

When I looked around, I saw the most amazing and once impossible scenes: Sitting together in a precious bit of shade, casually untangling muddles of string, were Russian and American engineers who had once competed with each other in the deadly serious Space Race of the 1950s and 1960s. Toting and hauling loads of equipment from the back of a rental truck were retired project managers from the Jet Propulsion Laboratory, who had led the US from the Moon to the outer planets, along with students from UCLA, Utah State University and the California Institute of Technology. And Russian technicians from a once secret institute were patiently driving the rover up and down Mars Hill for a ponderous IMAX camera filming the scene for audiences around the world.

What made these desert tests particularly special for The Planetary Society was the ability to invite our members and the general public to witness the experiments. Despite the threat of 120-degree Fahrenheit days and the daunting remoteness of Death Valley, more than 100 spectators turned out every day to watch the little robot scratch its way up and down a rocky hill. Every morning the spectators beat the technical team out to the test site, and many stayed until the last bit of equipment was packed up for the day. The technical team was impressed. Fears that the spectators might get in the way were completely dispelled. Many team members enjoyed performing before an audience and fielded questions about the rover with delight.

With this issue of *The Planetary Report*, we want to share the experience of the 1992 test program with Society members who were unable to travel to the desert with us. We asked several members of the Mars team to contribute 500 words each on the significance of The Planetary Society test program. It was difficult to condense their experiences into so few words, and not all succeeded, so while we begin the feature in this issue, we will have to continue it in our January/February 1993 issue!

So share with us now the excitement and achievement of The Planetary Society's 1992 Mars Rover test program. And hope with us that we will be able to repeat this series of improbable events and bring the people of Earth a little bit closer to exploring the surface of Mars.

—Charlene M. Anderson

The Russian Death Valley Experience

by V.V. Gromov

Tests of the mobile mock-up of the Mars Rover for the *Mars '96* project involved specialists from Russia, the United States, Hungary and France. The engineering experience developed in the various countries was successfully combined to create a ground system and an onboard system for controlling the operation of the rover mock-up, thereby creating the necessary environment for carrying out the mobile testing for the *Mars '96* project under field conditions.

Such testing is necessary to develop methods for controlling the motion of the rover and to accumulate experience and develop driving skills, especially with the mock-up in the self-contained control mode.

The tests were generally successful and fruitful. They were an important phase in the experimental development of the rover; however, they should be treated as but the initial phase in an extensive developmental program.

The fundamental components of the technical systems required for operation on the surface of Mars were integrated for essentially the first time during the tests. The following components were included:

- Self-propelled chassis
- Onboard computer system
- Television systems (including the radio link)
- Radiotelemetry system
- Radio command system
- Onboard electric power source
- Mobile control panel

This system enabled us to carry out a wide variety of tests, especially since it was in mobile form and could be transported from site to site. Assembling and mastering the operation of the mobile control system was an important step in preparing for and carrying out the tests. During the tests, methods for organizing the work of controlling the Mars Rover were formulated, and algorithms and software were developed for data transmission and analysis, for the generation of commands and for the identification of dangerous situations and insurmountable obstacles.

One quite interesting (and characteristic) feature of the testing process was that it involved specialists working on different aspects of the mission, even though the experiments were oriented toward solving the overall problems involved in the rover's development. Every specialist was able to see his or her own contribution in the form of the final result, which enabled each one to more deeply understand the sense of the problem to be solved. In such an environment, new ideas and approaches arise especially often, and previous work is evaluated more critically. This all provides a very important stimulus for further progress.

Several such instances occurred during the testing. For example, the requirements on the location of the television cameras, the field of view of the cameras, the method to be used in rotating them, and the form in which the data were to be displayed on the monitors were formulated quite rapidly. They will most likely be used in the actual rover.

As part of the testing, the efficiency of motion on sandy soil having grades of various steepness and on stony ground with various densities of obstacles was estimated, and algorithms were developed for avoiding insurmountable objects. This was the final result of the testing. Obtaining this result required a large amount of experimentation with the data- and command-processing equipment, the onboard and ground computer systems, the onboard automated systems and the sensors. However, the limited duration of the tests did not enable us to accumulate a sufficiently large amount of statistical material. This will also require more detailed research and description of the regions where testing is to be carried out.

The Death Valley tests are, in my view, very important for future planetary research. The foundation of Mars research with the Mars Rover was essentially laid there. The areas selected were quite similar to regions on Mars, the rover mock-up was relatively similar to the real rover, and it could clearly be said that we had taken the first step in "flying to Mars together."

Among the practical applications resulting from the tests, we should note that use of the mobile control system will assist us in the development of new techniques for controlling the rover. Such a system can be used in the real-time development of programs for the operation of the Mars Rover on the surface of Mars; the test results may be used to prepare the required programs and commands.

Similar systems may also be used for training and selecting specialists in Mars Rover control and for commercial activity aimed at involving firms in space research. Moreover, carrying out such testing will enable us to evaluate the possibilities for using rovers on other planets.

One important point about these tests is that the broad scientific public, the media, various specialists from scientific and industrial organizations, space travel and technology enthusiasts, curious people and children were involved. I believe it is extremely important for the development of space research and exploration to have the worldwide public understand the goals of and the reasons for space exploration, and to have the involvement of enthusiasts, young people, entrepreneurs, politicians, sponsors and other categories of energetic, intelligent people.

Virtually anyone could have become involved in the testing of the Mars Rover in Death Valley as an observer. This is extremely important, since it means that participation in space research and exploration has become accessible to all.

The cosmos should be accessible to all, both individual countries and individual people. The significance of the tests carried out here is that it was virtually proved that it can be.

V.V. Gromov is chief designer at the Mobile Vehicle Engineering Institute (VNII Transmash) in St. Petersburg.

Translated by Paul Makinen.

Geomorphology of the 1992 Mars Rover Test Sites

by Laszlo Keszthelyi

LEFT: The starkly beautiful Dumont Dunes provided a spectacular setting for the first day of testing. These wind-sculpted formations towered 100 meters above the test crew and dwarfed the little Mars Rover, seen here on the slope just above the ring of cars and trucks. Because of the difficulty in reaching the site (even some of our four-wheel-drive trucks got stuck in the sand), we did not open these tests up to the public.

Pilot (and JPL manager) Roger Bourke provided aerial reconnaissance for the rover test program. His wife, Margaret, drew the not highly sought after assignment of hanging out of the cockpit window and photographing the activities from above.

ABOVE: Mars Hill rises like a blackened kidney from the sandy floor of Death Valley. Scientists who had worked on the Viking *project in the 1970s noticed the similarity of the lava-boulder-strewn hill to the sites where the* Viking *landers touched down. The name "Mars Hill" entered common usage in the planetary science community but does not yet appear on any official maps of the area. However, two Planetary Society members who witnessed the tests have made it a personal project to convince the United States Geological Survey to recognize the name and so memorialize the hill as a site where Mars-bound spacecraft can be tested.* Photographs: Margaret Bourke

The 1992 Mars Rover tests occurred at two sites: Dumont Dunes, located about 95 kilometers (60 miles) north of Baker, California, and Mars Hill, located inside Death Valley National Monument, just south of the exit from Artist's Drive.

The dunes are built up of windblown sand gathered from across the Mojave Desert. They are among the largest in California and move about on the surface of a playa (dry lake). The exposed playa surface gave relatively easy vehicular access to the test site. The large, active dunes provided a picturesque setting, as well as a simulation of the dune fields expected in the northern plains of Mars.

The rover tests were conducted on the slip face of a dune about 20 meters (65 feet) tall. The lower half of the dune face was at a slope of about 25 degrees, and the slope of the upper half was closer to 30 degrees, the maximum stable slope for sand dunes. The top meter or so of the dune was at a supercritical angle of 33 degrees, making the top of the dune particularly susceptible to collapse.

Mars Hill is the eroded terminus of a basaltic lava flow. Its surface is nearly identical to that observed on Mars by the two *Viking* landers, consisting of angular basaltic boulders ranging in size from a few centimeters to a few meters sitting within a coarse, sandy fill. This fill is a mix of erosion products from the lava flow and windblown sediments.

The tests were conducted primarily on the slopes of Mars Hill but also on its top and on the surface surrounding the hill. Only the top of Mars Hill matches the *Viking* sites in terms of the size distribution of boulders. However, the slopes of the hill provided a more challenging test because they have a greater density of boulders and the boulders have a larger mean size. The surface surrounding Mars Hill consists of hard-packed clays with occasional gravel- to cobble-sized clasts and a light dusting of windblown sand.

Laszlo Keszthelyi is a graduate student in geology at the California Institute of Technology.

Reasons to Be Proud

by Louis D. Friedman

TOP: Artist Michael Carroll accompanied the Mars Team to Mars Hill to capture the experience in the medium of paint. Like many of us there, he was captivated by these two Planetary Society members, who were eminently prepared for the desert conditions. Each morning they set up their matching chairs and umbrellas and set out a tempting spread of food and drink. Even in the heat and dust, they watched the rover perform in comparative luxury. Their colorful umbrellas provided a delightful splash of color for the desert test site and for this oil sketch. Painting: Michael Carroll

ABOVE: What they saw was an amazing demonstration of mobility and flexibility. The three segments of the rover chassis are independently hinged to enable the robot to navigate uneven, rocky terrain such as Mars Hill. The chassis has a very wide footprint, making it extremely difficult to tip over. The treads on the cone-shaped wheels give it traction on almost any type of surface.
Photograph: Charlene M. Anderson

The Death Valley Mars Rover tests represent one of the most significant achievements in the history of The Planetary Society. We have many reasons to be proud:

- Using our own resources—our members' donations—we brought together six space agencies to test a prototype Mars Rover.
- Scientists and engineers from many diverse sources, speaking at least four languages, worked together as a highly coordinated team, the likes of which could not have easily been created by an official government space agency.
- The mobility and control experiments conducted by our team considerably advanced the development of the rover. Flight project implementation is now closer to reality.
- The tests focused media attention around the world on continuing missions to explore Mars. IMAX, *Smithsonian*, national television news and other shows sent crews to film the tests. Many newspapers also covered it. Without the excitement generated by the Death Valley test program, the media might have overlooked this serious yet innovative project.
- Our multipartite success helped lead to official NASA participation in the *Mars '94* mission.

But we have done more: We have established a precedent for private-citizen involvement in planetary exploration.

The Society is, after all, only a collection of individuals who are interested in and willing to support planetary exploration. Most have no professional role in carrying out spacecraft missions; only a few thousand people around the world do.

The test program gave our members a chance to show that they care about the exploration of Mars. Given this chance, they seized it, and were able to influence the development of a scheduled planetary mission.

We hope that our members' enthusiasm is a microcosm of general public interest in Mars exploration. It is the first priority of the Society—by its existence—to testify to that interest.

I think there is no better way to testify to public interest than by what we did in the rover tests. Our organization made it possible for people to become part of the sometimes distant and arcane process of space science and technology development.

Many of the Russian scientists and engineers who traveled to Death Valley with us work for an organization (VNII Transmash) that only three years ago was unknown to the outside world. Its very name was a secret. In Death Valley I watched them working on their equipment less than two feet away from a crowd of citizens of half a dozen countries. I saw people tap them on the shoulder and ask questions to which they always provided courteous answers. Another image that sticks with me is that of two Russian engineers, one of our American graduate students and one of the Hungarians bent over the rover, making television system adjustments—as one team.

This was a moving experience for me. For the engineers and scientists, as well as for the public, this interaction demonstrated why the activity of space exploration transcends its status as line items on national budgets.

I will admit that opportunities like this do not come along very often and, for all the credit Planetary Society members and staff deserve in making this one happen, we have an increased responsibility to seek out more opportunities.

By their cost and ambition, large space ventures will remain the activities of governments for the time being. Citizen support and private funding will play only a limited role. It is up to The Planetary Society to leverage that role to achieve the broadest possible results.

Thus, by our success, we have set for ourselves a difficult challenge: to find new ways to involve private citizens in planetary exploration. I believe that Planetary Society members accept that challenge.

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

Lessons of the Great Rover Adventure

by Thomas Heinsheimer

The Death Valley operation was a uniquely successful activity because it proved what could be done with a small nucleus of enthusiastic people working within a relatively informal management structure. This may be the model for the future; the more elaborate development and test processes of the space agencies would have made such a field test unaffordable, unattainable on the short schedule and so beset by rules, procedures, restrictions and checklists as to become a quagmire for all concerned.

Instead of the canonical "ad hoc committee" or "working group" process, we found that a good level of international coordination was attained using e-mail and fax systems. This was a triumph of liaison by low-cost telecommunications over the old way of high-cost travel and committee meetings. The Planetary Society should get high marks for having promoted, sponsored and provided much of the communications equipment that made this liaison process not only possible but relatively painless.

By avoiding large management structures and their time-consuming internal coordination process, the needed approvals could be obtained by a few Planetary Society personnel by telephone and confirmatory letters, with a minimum of travel. Moreover, the logistics could be kept within reasonable limits. No self-appointed participants, coordinators or VIPs needed accommodations, make-work tasks or adulation at the test site. All members of the small team had constructive tasks. This left space and facilities for the invited public and the media.

The media were enchanted by the refreshing candor of the operation. Rather than facing canned briefings and being separated from the action, they were encouraged to mingle freely with the players on the field, speaking to anyone about anything, taking any pictures for any press purpose without restriction. The resulting coverage was without the cynicism often seen in the modern press. It was factual, accurate, extensive and spectacularly well placed.

The participation of an informed and enthusiastic public further enhanced the atmosphere. This had a beneficial effect on the attitude of the press and reinforced the morale of the test participants when heat, fatigue and occasional technical disappointment tended to get them down.

The success of the Death Valley rover tests was the result of a clear and supportable program objective, free access to the ongoing activities by the public and the media, and efficient management by a lean organization.

Thomas Heinsheimer is vice president and chief scientist at Steve Myers and Associates. He is not only a leader in the aerospace industry but also a balloonist of international renown who has made numerous flights using helium and hot-air balloons as research vehicles.

The Mars Rover left tracks in the sands of Dumont Dunes unlike anything this highly popular off-road recreation area had seen before. The rover's conical wheels are the result of a long process of experimentation at the Mobile Vehicle Engineering Institute (VNII Transmash) in St. Petersburg. The ancestors of this robot, the **Lunokhods** ***that explored the Moon in the early 1970s, had spoked wire wheels, and its designers have tested hoppers, skiers, walkers and vehicles with tank treads. For the varied terrain of Mars, they have settled on this six-wheeled configuration.***

INSET/TOP: Were this a normal vehicle, being up to its hubcaps in sand might prove embarrassing. But the Mars Rover was in no difficulty as some of its wheels sank in the soft sand as it neared the summit of a dune. The hinged front and rear segments are able to extend independently from the rest of the chassis, establish a foothold and pull the rest of the rover along. This motion resembles somewhat the motion of an inchworm moving along a branch.

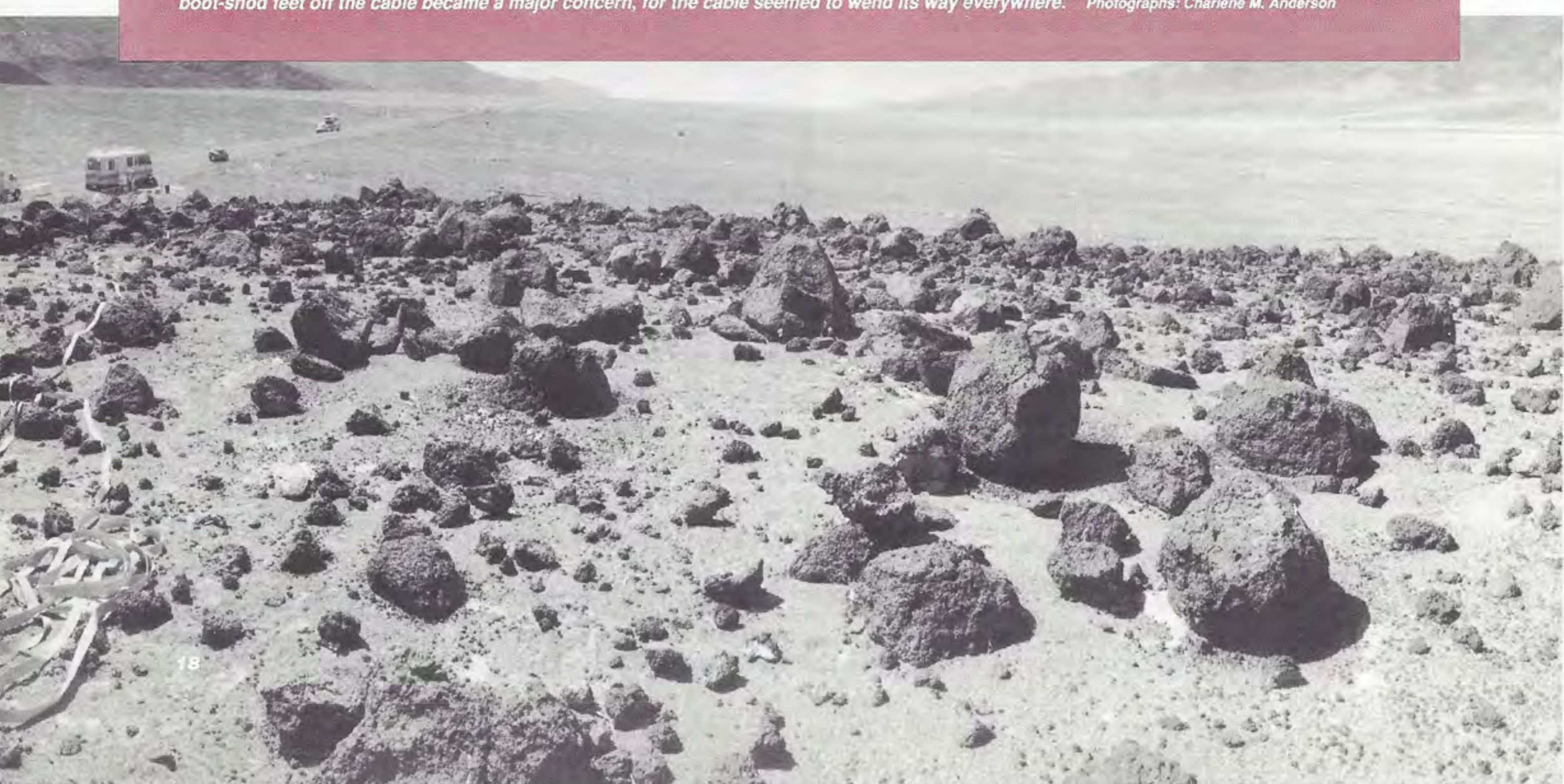
INSET/BOTTOM: Sometimes, after the rover had scraped and climbed to the top of the hill, it returned to the setup site under a different means of locomotion. Using a specially built stretcher, six team members navigated the difficult terrain themselves, and conserved the precious batteries concealed in the rover's wheels.

Photographs: Charlene M. Anderson

Seeing the Big Picture:
The Panoramic Camera

BOTTOM SPREAD: Ball Aerospace contributed a prototype panoramic camera for the Society's Mars Rover tests. A similar device may be used on landers and rovers destined for Mars. The camera's linear charge-coupled device (CCD) converts light into electric signals. As the camera slowly rotates, it scans the scene and produces a highly detailed, two-dimensional image. This image covers 225 degrees around Mars Hill from 8 degrees above to 35 degrees below the horizon. Image: Alan Delamere, Ball Aerospace

LEFT: When the panoramic camera was taking a picture, the rover stood still and everyone cleared off the hill. The slow scanning process meant that if anything moved, the image would be distorted. The camera unit is the white box sitting on the rover, with the camera itself swiveling above it. RIGHT: The long gray cable attached to the panoramic camera on the rover ran back to the control trailer, where its images were displayed on a computer monitor. (The cable was used instead of a radio link to reduce cost and save test preparation time.) Keeping hiking-boot-shod feet off the cable became a major concern, for the cable seemed to wend its way everywhere. Photographs: Charlene M. Anderson



Navigating the Rover: The French Stereo Cameras

by Marcel Lamboley

France is a major partner in the *Mars '94/'96* project headed by the Russian Space Agency. On the *Mars '96* lander, the Russians plan to include a small rover for scientific and technological purposes. In the nominal plan, this rover would be teleoperated from Earth. Thus, because of the long operational cycle of one command and response every second day, it could move only short distances at a time and its range would be very restricted.

In an attempt to improve this situation, we have worked up some concepts regarding the three-dimensional reconstruction of terrain and the generation of paths. A computer on board the Mars Rover could then recognize an obstacle in its path and plot a course around it.

There is a major constraint in implementing these concepts: The computer processor on the Mars Rover is not fast enough to run our present 3-D reconstruction or path-generation algorithms in real time. But because there will be a two-day command–response cycle, even if the onboard computer is limited to one hour of processing it will have time to compute the new path. Such algorithms can significantly improve the rover's range.

For this reason, it is worth adapting and optimizing the algorithms we have developed and assessing their performance and the required processing resources. This is now in progress at the Centre National d'Études Spatiales (CNES).

Picture-Taking Tests

The Planetary Society's Death Valley campaign of experimentation was a good opportunity for the French team to see the prototype rover operating in a realistic, Mars-like environment. Moreover, it enabled us to collect representative pictures to use as test data for our algorithms.

With two CCD (charge-coupled device) cameras mounted on the moving Mars Rover, we acquired a series of stereopair images. Calibration was done using a target, and the direction and attitude of the rover were measured for each pair of pictures. At some of the stopping points, the panoramic camera of Ball Aerospace took pictures, which should allow us to identify the largest rocks met by the rover during its motion. These rocks have been measured to check the accuracy of the 3-D reconstruction.

When the rover was unavailable, we took triplets of pictures at both the Dumont Dunes and Mars Hill sites using three CCD cameras mounted on a tripod. The landscape on Mars Hill included rocks of different sizes, some surmountable, and some not, but suitable to test both our 3-D reconstruction and the path-generation algorithms. With the panoramic photographs of the site and measurements of the largest rocks, we were able to check the accuracy of the 3-D reconstruction from these stereo cameras also.

A Worthwhile Campaign

For all the participants, the Death Valley experimentation was an opportunity to verify the remarkable locomotive properties of the Mars Rover on both sandy and rocky terrain. Furthermore, our French team brought back from Dumont Dunes and Mars Hill a large set of stereographic pictures that have proved very useful in testing our algorithms for stereovision and path generation.

We appreciated the cooperation among the different teams during this campaign, and also the efficient Planetary Society organization, which made it possible to work under the difficult conditions of Death Valley.

Marcel Lamboley, of the Centre National d'Études Spatiales in Toulouse, was in charge of the French television team for the 1992 Mars Rover tests.

Testing the Onboard Computer

by József Biró

The KFKI Research Institute for Particle and Nuclear Physics (Budapest, Hungary) is providing the onboard computer (both hardware and software) for the Mars Rover. This computer will control all the scientific and service functions and perform the task of autonomous navigation. For the tests in Death Valley, we delivered a preliminary version of the computer.

Because the tests took place at an early stage in the project, the goals were different from the final specifications. Thus the onboard computer had limited tasks as well. The first two tasks relate to remote control; the third, to autonomous movement:

- To collect data from sensors mounted on the vehicle and transmit these data back to the control van.
- To decode and execute motion-control commands received from the control van.
- To check the data from the sensors and take necessary action in an emergency.

Although the final vehicle will be able to navigate nearly autonomously, we need remote control for several reasons. It has an important role in testing different parts of the system during development, and will supplement the autonomous movement during the mission itself. And it will make it possible for us to take control of the vehicle if the navigation system should fail.

Since the safe remote control of the rover was essential for the success of the Death Valley tests, the onboard computer had to work reliably. The minimal goal of the Hungarian team members was to ensure this reliability. We have to emphasize the difficulty of this, as the whole control system had been set up in only four months.

The third task represents the first step toward autonomy. The onboard computer regularly checked the sensors that described the position and mechanical status of the rover. If the computer sensed a dangerous situation or an obstacle, it took the necessary action to avoid disaster. This action could be a simple "stop" command or a more difficult sequence of commands, depending on the conditions. This was the first time that we included any kind of autonomy in the system, so one of our most important engineering goals was to investigate how the algorithms worked.

The results of the tests were promising. The onboard computer worked flawlessly, as did the rest of the system, for the most part. This permitted us to concentrate on real technical problems.

The algorithms for emergency checking worked well. Our previous ideas about possible sources of danger (tipping over, getting stuck in soft sand) proved to be mostly correct. We fixed the problems (there were not many) easily during the tests.

The Death Valley tests gave a new momentum to the development of the Mars Rover. We answered a lot of questions, and now we can go on to work on new problems. In the near future, we will focus on two important tasks. The first is developing a new onboard computer with highly increased computing power so that it will be able to perform the image processing for autonomous navigation. The second is improving the image processing itself. During this work we will mainly use the pictures taken in Death Valley.

The tests had more than scientific and engineering profit. The participants also wanted to demonstrate their activities to the general public. As the project is really exciting and spectacular, it was easy to draw attention to it. In Hungary, articles on the Death Valley rover tests appeared not only in professional publications but also in the most popular daily newspaper.

ABOVE: At the beginning of the test program, at Dumont Dunes, the tracks of the rover seemed strange and alien, almost as if they were the marks of a robot from another world. By the end of the program, they were as familiar as our own footprints, and the tracks wending their way up Mars Hill were symbolic of the success of our tests. On this hill in Death Valley, there is also an ancient Native American site that we roped off. Both the test team and the spectators carefully avoided it.

INSET: The Mars Rover misbehaved only once during the entire test program: when NASA Administrator Daniel Goldin came to visit. At the Pasadena setup facility, the rover's handlers attempted to demonstrate how the obstacle-avoidance computer program worked by having the rover deliberately drive into a barrier. The program failed to function, and the rover twisted itself into strange positions in a vain attempt to overcome the barrier. However, this incident did demonstrate the amazing flexibility of the rover chassis.

Photographs: Charlene M. Anderson

József Biró is a member of the Hungarian team for the Mars '96 *mission.*

Thanks for the Rover Tests

by Louis D. Friedman

The 1992 Planetary Society Mars Rover Death Valley test program was an extraordinary event, made possible by a unique confluence of people from around the Earth. There may never be anything like it again, although I hope that The Planetary Society will continue to find experimental programs with which we can advance the prospects of planetary exploration. It was the people involved who made these tests special. There are far too many for me to mention each one personally here.

First and foremost I must thank the thousands of members of the Society who donated the funds to make the tests possible. Then there were more than 150 members who made the trip to Death Valley to watch the rover go through its paces. Their loyal presence cheered us on (some were always on site before the technical team arrived in the *very* early morning).

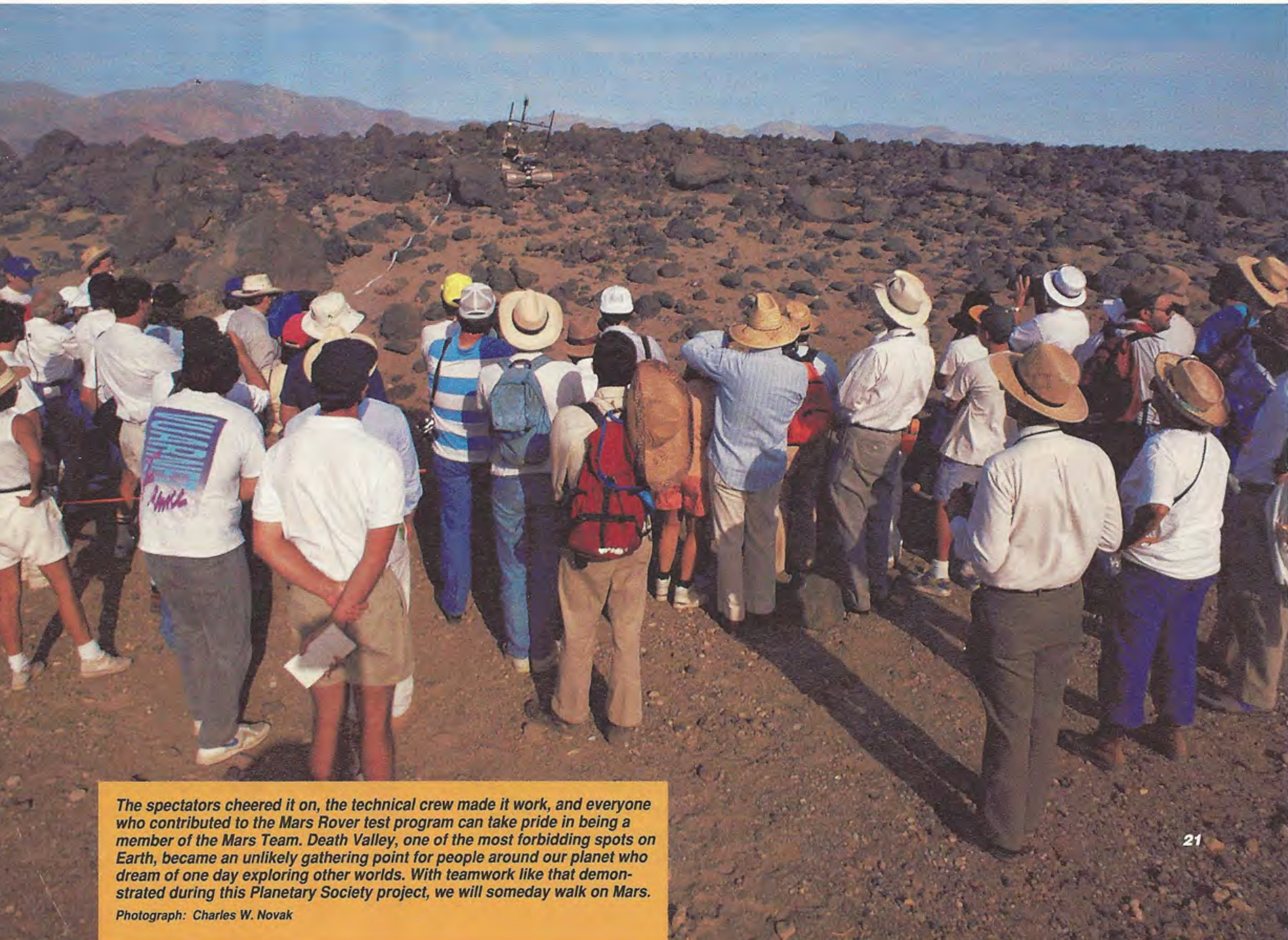
Scientists, engineers and expert technicians traveled from Russia, Hungary and France to take advantage of the harsh California desert test sites. Their dedication to the rover program may be the single most important element in making its Mars mission happen.

The Planetary Society contingent was a conglomeration of people with different backgrounds and skills. The technical team was made up of retired space program engineers and managers, Jet Propulsion Laboratory employees on vacation, graduate students from top universities and volunteers from our membership. The support crew included Society staff members, volunteers and an artist.

Representatives from American industry also made the trek to the desert to test their equipment with the Russian rover.

Of course, the tests simply would not have been possible without the enthusiasm and dedication of the staff of Death Valley National Monument and the Bureau of Land Management. We owe them a great debt of thanks.

These individuals from the corners of the globe came together to form the remarkable Mars Rover team. They established a milestone in international cooperation, and set an example of public participation in spacecraft development. To all the participants, I extend my sincere thanks. □



The spectators cheered it on, the technical crew made it work, and everyone who contributed to the Mars Rover test program can take pride in being a member of the Mars Team. Death Valley, one of the most forbidding spots on Earth, became an unlikely gathering point for people around our planet who dream of one day exploring other worlds. With teamwork like that demonstrated during this Planetary Society project, we will someday walk on Mars.

Photograph: Charles W. Novak

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Our Planetary Readers' Service is an easy way for Society members to obtain newly published books about the science and adventure of voyages to other worlds.

We make these books available at the lowest possible prices. Each title is offered for six months, or three issues of The Planetary Report. *We keep rotating our stock so that the titles we offer are always fresh.*

From Stone to Star: A View of Modern Geology

By Claude Allègre; translated by Deborah Kurmes Van Dam; Harvard University Press, Cambridge, Massachusetts, 1992, 287 pages.
Retail price: $39.95
Member price: $32.00

In 1980 the Swedish Academy rectified one of Alfred Nobel's sins of omission by announcing the lucrative Crafoord Prize for outstanding achievements in planetary science, geology and astronomy. Then, in 1986, it awarded the Crafoord jointly to Claude Allègre, professor of earth sciences at the University of Paris, and to the California Institute of Technology's Gerald Wasserburg for applying high-tech methods to determining the age and origin of planetary matter. Using what Allègre describes as "ultraprecise isotopic analysis of a few grams of rock," they were able to read the oldest message in the solar system.

In *From Stone to Star*, Allègre gracefully chronicles the relatively brief history of geology, from its beginnings during the Industrial Revolution to the examination of meteorites, reaching beyond the terrestrial crust to the formation of the planets. Shackled by religious authority to the text of Genesis, the subject of the formation of Earth was blasphemy as long as literal interpretations of the Bible denied the long periods of time implicit in a scientific explanation.

The intellectual climate began to change in the 18th century, as engineers digging canals, roads and mines began turning up fossilized plants and animals with a certain regularity. Increasingly, defenders of the faith interpreted the origin tale as metaphor. Meanwhile, the study of the layering of minerals at certain locations brought about one of geology's first subspecialties—stratigraphy, the study of Earth's layers.

Soon voyagers like the young Charles Darwin set out to map exotic places, noting as they sailed that volcanoes, sedimentation and earthquakes occur in many places, always leaving a similar record. By the end of the 19th century, seismology, another specialized approach, had become an independent discipline under the umbrella of geology.

Allègre recounts the intellectual battles as geologists moved from exploration to explanation. He presents competing theories as they were understood in their own time, from the arguments of 18th-century neptunists, who interpreted fossils as debris from the Great Flood, to those of plutonists, who believed that a great fire in Earth's core set off recurring cycles. He treats the 19th-century geologists in the same equitable manner, and he explains the 20th-century debates over the origin of the solar system by offering the logic and evidence of each view in turn.

While obviously interested in the evolution of all the planets, Allègre does not hide his terrestrial bias. The Sun, planets and meteorites, fascinating in themselves, are even more wonderful in terms of what they tell us about Earth.

Because Earth, as a living planet, long ago destroyed all evidence of its formation and early evolution, scientists sought a geologic clock. The history of Earth since the appearance of life was the first step. This was established in the 19th century by using the location of fossils as markers. Early in the 20th century, the discovery of naturally radioactive elements exhibiting predictable half-lives increased the time period that could be dated.

Then, at midcentury, Clair Patterson, a graduate student in Chicago (now at Caltech) developed a technique for analyzing the isotopic composition of microscopic quantities of lead. Patterson soon applied this analysis to meteorites, which he was able to date back 4.55 billion years to the birth of the solar system.

Much of what Allègre has to say about the formation of the planets, and how life and the presence of fresh and salt water affect geologic evolution, may be familiar. But his explanation of these events in the context of geology is both fresh and satisfying.

— Reviewed by Bettyann Kevles

Still Available:

Isaac Asimov's Guide to Earth and Space, *by Isaac Asimov. Arranged in a question-and-answer format, this book guides the reader around Earth, the solar system and the stars beyond. (Reviewed July/August 1992.)*
Retail price: $20.00
Member price: $17.95

Five Billion Vodka Bottles to the Moon: Tales of a Soviet Scientist, *by Iosif Shklovsky. Relive the exciting days of the Space Race through the eyes of one of the Soviet Union's leading astronomers, a pioneer in the Search for Extraterrestrial Intelligence. (Reviewed September/October 1992.)*
Retail price: $19.95
Member price: $17.95

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NASA's Search Begins

by Thomas R. McDonough

In the film *E.T.*, an extraterrestrial being trapped on Earth phoned home to his buddies with a jury-rigged transmitter. But suppose E.T. had stayed home. He could have let his fingers do the walking and signaled to our planet, saving the time, trouble and expense of a trip—and avoiding the risk of being caught by primitives.

That, in a nutshell, is the idea behind SETI—the Search for Extraterrestrial Intelligence. Several SETI projects around the world are now active, including those of The Planetary Society (META I at Harvard and META II in Argentina) and the University of California at Berkeley (SERENDIP III in Puerto Rico).

For over a decade, NASA has been building the next generation of SETI. The political obstacles have sometimes been worse than the technological ones. Every now and then a politician in Congress would decide that it was a waste of the taxpayers' money to search for "little green men."

The project was nearly killed on several occasions. This in fact helped inspire the Society to build its own SETI systems, largely privately funded to insulate them from Washington's budget debates, although occasionally supported by NASA. Eventually NASA, The Planetary Society and interested scientists and politicians were able to persuade Congress that there was widespread support in the scientific community for SETI.

The Rescue of NASA SETI: HRMS

This year, when NASA SETI seemed doomed once again, it was transferred into a different branch of NASA and given a new name: HRMS (High-Resolution Microwave Survey). It may not be as easy to say now, but the name emphasizes that those involved are not just searching for signals from E.T. They are also doing good astronomy—surveying the sky at microwave frequencies more thoroughly than anyone ever has. On October 12—Columbus Day—NASA at last launched its HRMS system.

When NASA switched on its new receivers, there was transcontinental jubilation. Scientists, engineers, politicians, journalists and guests had flocked to Goldstone, California, and Arecibo, Puerto Rico, to witness the event. Among the speakers were SETI pioneers Frank Drake and Philip Morrison in Puerto Rico and Planetary Society President Carl Sagan in California.

HRMS Project Manager David Brocker gave the command to start the search. The antenna feed above the Arecibo dish moved to point at its first star, and the Goldstone dish simultaneously began its systematic scan of the sky. Joyously, the audiences cheered the start of this grand quest for cosmic neighbors.

Why do SETI? One of the people best qualified to answer this is a British-born physician, John Billingham. He has helped steer the NASA program since 1969 at the Ames Research Center in northern California, where he is now chief of their SETI office.

His justification for SETI: "The world today is filled with pessimists and doomsayers who say that we will not last more than 50 years. Any civilization we detect will be much older than us, maybe millions of years." We won't hear anyone younger because they won't have radio transmitters. "So we would know that real longevity can be achieved. It would be a very significant data point for our own future."

Thus, on the 500th anniversary of Columbus' voyage, NASA embarked on its own exploration of the galaxy in search of the faint murmurs of other beings. For around $10 million a year, NASA's strategy uses two approaches. One is run by the Ames Research Center, and the other is run by the Jet Propulsion Laboratory in southern California. Assistance has also come from Stanford University, a company called Silicon Engines and the nonprofit SETI Institute, all under contract to NASA.

The Ames approach is to pick out the 1,000 closest stars that are like our own Sun. These are the ones many scientists think would be the best bets for life. The Ames people will scan the radio sky with a 14-million-channel system.

JPL, on the other hand, will systematically scan every part of the sky using a 2-million-channel system that it hopes to enlarge to 32 million. It plans to cover the microwave spectrum from 1,000 to 10,000 megahertz.

Ames has begun its observations at the huge Arecibo radio telescope in Puerto Rico, run by Cornell University for the National Science Foundation. Its dish is 305 meters (1,000 feet) in diameter and fills a valley, making it the largest such antenna in the world.

JPL uses the new 34-meter (112-foot) antenna at Goldstone in southern California; this antenna is part of the Deep Space Network used for communicating with spacecraft.

META, BETA and HRMS

The NASA systems complement our own two METAs, searching frequencies we cannot yet observe. The METAs remain more closely fine-tuned to the ultranarrowband (0.05 hertz) channels best suited for galactic communication, if we've chosen the right frequency band and the aliens are sending a steady (carrier) signal. META's designer, Harvard physicist Paul Horowitz, is working on the new BETA system, which will cover more frequencies.

The Planetary Society has long encouraged SETI. We applaud the many years of hard work that went into building the NASA HRMS system, and wish them success.

If E.T. is phoning, there's a good chance someone will hear him (or her or it) in the next decade.

Tom McDonough is the Society's SETI coordinator and the author of the novel The Missing Matter.

World Watch

by Louis D. Friedman

WASHINGTON, DC—In late summer, at the meetings of the World Space Congress and the Association of Space Explorers, NASA Administrator Daniel Goldin laid out his vision of the future of space exploration. It is a vision focused on the planets.

In these speeches, Goldin called for many more planetary missions than previously planned. Despite this, some planetary scientists worry that he is disturbing the status quo too much, both by perturbing existing plans and by calling for reduced costs. (See News & Reviews, page 26.)

Goldin has told Planetary Society officers he believes that future planetary missions will not be launched if smaller and lighter spacecraft are not used. He also argues that if planetary missions are made "smaller, cheaper and faster" a mission could be launched every year instead of once or twice a decade.

The Society's officers are gratified by his strong support for planetary missions. Goldin particularly campaigned for the *Cassini* mission during the 1993 budget battles. A vocal advocate of Mars exploration, Goldin also pushed for a United States lander to be added to the Russian *Mars '94* mission, backed plans for the Mars Environmental Survey (MESUR) mission and reiterated his long-range goal of a human mission to Mars. He has also called for a mission to Pluto (see below).

PASADENA—Proposals for missions to Pluto, the only planet in our solar system not yet visited by a spacecraft, continue to have their ups and downs. (See the July/August 1990 *Planetary Report*.) In 1991, a NASA space science advisory committee surprised the planetary exploration community by recommending an early mission to Pluto, with work to begin in 1996. This was part of its overall review of priorities for space science in the 1990s.

In the following few months, the enthusiasm of Pluto supporters diminished somewhat as the reality of the long trip time (more than 12 years in the then proposed mission) and the high launch energy required sank in. Interest in two other missions, of the Discovery class, grew as interest in Pluto faded.

Discovery missions, as they are proposed, would cost less than $150 million each and could be completed in less than three years. The first mission would be *Pathfinder*, planned for a 1996 launch to Mars. This would be a precursor mission, using a single lander, to the more ambitious MESUR. The second proposed Discovery mission would be NEAR, the Near-Earth Asteroid Rendezvous.

But NASA Administrator Daniel Goldin has become interested in a quick and cheap Pluto mission suggested to him by Jet Propulsion Laboratory engineer Robert Staehle. Its quickness—a seven-year trip time—would be achieved by launching a lightweight spacecraft—under 100 kilograms—on a very powerful rocket, such as an American *Titan 4* or a Russian *Proton*.

The payoff would be the completion of the reconnaissance of the solar system. But just the launch with a *Titan 4*, and a necessary *Centaur* upper stage, would cost over $400 million. Is the mission of a small spacecraft, carrying only a few scientific instruments, worth that cost?

An alternative is to launch using the *Proton*, which would cost less than $60 million. This may be the enabling factor.

But what of MESUR/*Pathfinder* and NEAR? Goldin has maintained his strong support for those missions also; as noted above he is urging new thinking in the planetary program for many small missions.

WASHINGTON/MOSCOW/SAN FRANCISCO—NASA and the Russian Space Agency (RKA) have agreed to an arrangement for the US to provide funds for a third small station to be added to the Russian *Mars '94* mission. Whether US instruments can be provided for the lander in time for its scheduled launch in October 1994 is still under study.

The agreement takes the form of a contract with the RKA and a grant to the Russian Academy of Sciences.

The RKA is the new authority in the Russian space industry and is in charge of government funds for space missions. NPO Lavochkin, which with its Babakin Center builds the planetary spacecraft, is the RKA center responsible for *Mars '94/'96*.

The Russian Academy of Sciences and its many institutes are separate from the RKA. The Space Research Institute (IKI) is the lead Academy center for the mission and is responsible for the scientific experiments.

Under the agreement, Russia will build an engineering model for the US to use in instrument development. Those instruments will also be relevant to MESUR mission planning. Russia will build the flight unit, and the selected American instruments will be integrated into it just before launch.

The $2 million the US is investing in *Mars '94* is important financial—as well as political— support for the Russian mission. It also opens the way for increased cooperation between the two nations in 1996 and beyond.

We expect this agreement to lead to new opportunities with MESUR, the European Marsnet and *Mars '96*. This was the topic of a special session of the Division for Planetary Sciences of the American Astronomical Society meeting in Munich on October 12, 1992.

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

NOTE: In this issue's News & Reviews, Clark Chapman criticizes Dan Goldin's call for planetary missions costing "tens of millions" of dollars. In the printed text of Goldin's speech, the amount mentioned was "hundreds of millions." We asked Goldin to clarify this discrepancy. He said that his goal was to share development costs of perhaps hundreds of millions among several missions that would cost tens of millions to complete. In the verbal shorthand of his speech, he said "tens of millions." —*LDF*

Toward the Next Millennium: A Vision for Spaceship Earth

by Daniel S. Goldin

An excerpt from a speech given before the World Space Congress on September 2, 1992

I've been NASA administrator for five months now, and I've spent most of that time listening. Tonight, I'd like to integrate what I've heard with the thoughts I wrote down the night before I was confirmed for this job. I'd like to sketch for you a vision of what I think we, as a planet, can achieve in space.

First, I believe the next international scientific research outpost beyond space station *Freedom* will be on the Moon. The best reason to go back to the lunar surface is not to look down, but to look *up*, for what we hope to find are not rocks, but planets—planets around nearby stars.

The Moon is the perfect place for astronomy. On the Moon's thermally and seismically stable surface, we can build telescopes and interferometers that are orders of magnitude beyond what's possible on Earth and in orbit. On the Moon, nighttime lasts for 14 days and there's no atmosphere to cloud the view. Super telescopes measuring every frequency —from gamma rays to radio waves—could discover a whole universe of knowledge that's invisible to us on Earth.

Another reason for going back to the Moon is that it has resources that Earth may need someday. And since the Moon is only three days away, it's an ideal place to test the space hardware we'll need for the next milestone in human spaceflight: the exploration of Mars.

We are about to take the next step along the way to the Red Planet. In three weeks, we will launch the *Mars Observer* to examine the surface characteristics, such as temperature and geology, of Mars. The Russians will send international landers in 1994 and 1996. Then NASA's MESUR, the Mars Environmental Survey, can put a series of landers [on Mars], some with microrovers, to study surface features, weather and seismic activity. These new landers will head for the more risky and challenging areas of Mars—such as the boundaries of the polar caps, hydrothermal hot spots that *Mars Observer* may find and dry river gorges where water may be present below the surface. Even if some form of life does not now exist, there may be fossilized remains.

This search for life—this urge to explore to the very limits of our technology—is not idle curiosity. It's a biological imperative—wired right into our DNA. In his book *Mission to Mars*, Mike Collins wrote, "Call it genes, character, culture, spirit, ethos: by whatever name, it is within us to look up into the night sky and be curious, [and] within us to commit our bodies to follow our eyes."

Going to the Moon and Mars is just the first step in getting to know the neighborhood that is our solar system. I believe it is possible for the people of Earth to send orbiters to map the resources of every major body in the solar system, even Pluto.

We can put landers on those planets and moons, some with microrovers. We can look for minerals on asteroids, and check comets for traces of the primordial soup from which the cosmos was formed. We can bring samples back from these bodies to Earth for study. All this can be done in just 20 years.

And I'll throw out a special challenge here. I believe we can build a spacecraft in three years weighing hundreds, not thousands, of pounds, and costing a few hundred million dollars, not billions—and have it arrive at Pluto, the last unexplored planet, in the first years of the 21st century. It *can* be done.

Because Earth is just one part of the solar system, it is through studying the rest that we can hope to fully understand Earth's environment and its future.

For instance, Venus is the same size as Earth, but with a runaway greenhouse effect. Why? Mars may have had a dense atmosphere and surface water. What happened to them?

To figure out the puzzle of global climate change, we all, including the developing nations, have a role to play. Data on the biosphere must be collected from terrestrial sites around the world. Then from the vantage point of space, dozens of spacecraft will collect complementary data on the atmosphere, oceans and land. The international cooperation necessary to explore Earth, explore the Moon, and send humans to Mars, I believe, can inspire the people of the entire planet to see what can be accomplished if we replace our habit of confrontation with cooperation.

If we intend to complete the exploratory missions I just mentioned in years rather than a good portion of a century, no nation can do it alone. But if each of us is willing to give in a little bit on what we insist on doing and share the burden, then together—as one planet, one people—we can coordinate our efforts and resources, and achieve everything I mentioned today.

Our space agency budgets will not triple to finance this new exploration. Nor should they, because our societies do have other pressing needs. We must push out beyond our comfort zone, and *make* ourselves build spacecraft smaller, faster and cheaper. Let's be bold and not be afraid. It's OK to take risks when you're pushing the frontiers of the possible.

Finally, and most important, we must remember that our space programs belong to the people of the world. And when we send someone into space, it's not one person going, but entire nations—an entire planet—that worked together to put them there.

When I moved into the administrator's office five months ago, I found a plaque in a display case—covered with dust. The plaque bore the signatures of Armstrong, Aldrin and Collins, along with the *Apollo 11* patch. On the top, it's written, "Carried to the Moon aboard *Apollo 11*. Presented to the *Mars 1* crew." As far as I'm concerned, that plaque has been gathering dust long enough. It's time for all of us to get moving and *take it to Mars*.

Is there life on Mars? Maybe not now. But there will be. ❑

News & Reviews

by Clark R. Chapman

Rarely has there been a more auspicious space exploration meeting than the World Space Congress, held earlier this year in Washington, DC, to coincide with the 500th anniversary of Columbus' voyage across the "ocean blue."

The nine-day event was organized in part by the Committee on Space Research (COSPAR). COSPAR's raison d'être used to be that it was sanctioned by the Soviet Union, so Russian scientists could attend and mingle with their American and European counterparts. It thus preserved the slender threads of international cooperation in space during the Cold War. For new economic and political reasons, space exploration is again at a crossroads. So thousands of aerospace engineers, industry executives, space buffs and scientists came.

The exhibit hall held not just displays but whole pavilions. A Canadian space arm reached over our heads. Rockets looked ready to launch. An industry devastated by military reductions, due to the Cold War's end and the rotten economy, yearns that space may be its salvation. I hope so, but I'm not so sure.

Visions, or Fantasies?

Consider the excursion into a peculiarly parsimonious never-never land by President Bush's new NASA head, Dan Goldin. His unscheduled, last-minute address was (to me) an impressive, scary example of style over substance, of fantasy displacing reality. Before a thousand aerospace engineers, Goldin never mentioned the aerospace plane and some other big-ticket items that dominate NASA's budget. Rather, he emphasized a scientific wonderland: astronomy from the Moon and a rich harvest of planetary exploration. It thrilled the space scientists in attendance, until he reached the bottom line.

Goldin's first and loudest applause came after his rhapsodic words about a fast, cheap mission to Pluto. Pluto enthusiasts (not a large demographic group!) are overjoyed. Their scientific curiosity (and my own—see my column in the September/October *Planetary Report*) about the small double world could be well satisfied. (I wonder why the aerospace community would applaud a "tens of millions of dollars" mission as the centerpiece of NASA's new vision? Goldin revised his text—see excerpt in this issue—to say the cost is "hundreds" of millions; even that used to be small potatoes to aerospace giants.)

Putting Pluto on the Fast Track

Goldin told the World Space Congress that in Hollywood he bumped into a guy who had a new dream, and it was Pluto. The guy happened to be the Jet Propulsion Laboratory's Rob Staehle, engineer for a Pluto mission study that had its day in court last year as a prospective "low-cost" Discovery mission but didn't make the cut. ("Discovery" is NASA's latest moniker for something once called "Observers," which were to be focused missions for minimal dollars but, like the Lunar Observer, were axed when they grew toward billion-dollar budgets.)

The director's whims have replaced responsible space science planning. When NASA's head repeatedly asks about progress on the Pluto mission study, his underlings can hardly dare to respond that the emperor is wearing no clothes. NASA's already decimated planetary budget must eat any unplanned costs of getting Pluto onto the fast track, before Goldin's tenure ends, which could be soon.

I admire Goldin's spirit. But when he proposes to bring back samples from most planets for tens (or even hundreds) of millions of dollars each, his "challenge" lacks credibility. His caprice undermines the loyal, dedicated work and intelligence of a generation of the nation's brightest engineers and scientists, who know that reliability, capability and crucial scientific goals would be sacrificed.

The Discovery Game

Meanwhile, NASA has most planetary scientists playing Charlie Brown to Lucy's football gambit. The community was consumed by developing nearly a hundred Discovery mission concepts, as part of a "contest." Few realized how slender is the dangled carrot that inspired the feeding frenzy. At the World Space Congress, word spread that only three mission concepts might "win" the right to divide up a mere few hundred thousand dollars next year to carry the concepts forward. There will be good new concepts, but NASA has never lacked good ideas or strategic plans. It has lacked the resolve to pursue them and persevere.

I think that the Solar System Exploration Committee in the mid-eighties laid out a responsible, cost-effective plan for future missions. The cancellation of the Comet Rendezvous Asteroid Flyby (CRAF) put that plan in the garbage. As Dan Goldin says, we are in an era of declining budgets. It feels good listening to his plea for "smaller, faster, cheaper," but not if it's by gimmickry and zero-cost mission planning, with priorities set by personal whim and by seasonal political shifts within the Washington Beltway. For me, Goldin's speech was not worthy of Columbus, who stuck to his plans. We need commitment to launches and real planetary data.

Clark R. Chapman kicked at Lucy's football, too, working on a Mercury orbiter concept and on an idea for a multiple near-Earth asteroid rendezvous mission—each would cost under $150 million.

SOCIETY *Notes*

MALAYSIA SUPPORTS MARS EXPLORATION

In July of this year, Malaysia held its first "Spaceweek" and The Planetary Society participated as a cosponsor. One of the major activities was the collection of signatures in support of the Society's 1992 Mars Affirmation.

Local press coverage of the signings led to one newspaper publishing the Mars Affirmation, with an invitation for readers to mail in their endorsements.

Almost two hundred signatures supporting Mars exploration were collected.
—Louis D. Friedman, Executive Director

JOIN THE SCIENCE ROUNDUP IN KANSAS CITY

Once again The Planetary Society will join forces with the National Science Teachers Association (NSTA) to cosponsor their national convention April 1 to 4, 1993. The convention will be held in Kansas City, Missouri.

The NSTA national convention attracts over 15,000 participants each year and features more than 1,000 intriguing workshops and sessions as well as an exhibit hall full of the latest in innovative scientific gadgetry and educational resources. Our Planetary Science Day on Saturday, April 3, will offer an array of notable speakers who will focus on topics of interest to both Society members and educators. Remember, you don't have to be a teacher to enjoy this convention! You just have to enjoy science. For registration details, please contact:

NSTA Convention, The Planetary Society,
65 North Catalina Avenue, Pasadena, CA 91106
Telephone: (800) WOW-MARS

—Susan Lendroth, Manager of Events and Communications

ROVER EXPO REPORT

Rover Expo, held in Washington, DC, on September 1 and 2, was a huge success. Some 9,000 people watched 16 planetary rover prototypes demonstrate their capabilities on the Mall in direct sight of the Capitol.

On August 31, before the expo, a parade of rovers took place. The rovers rolled across the Mall and into the special tent constructed for the expo. There, they demonstrated their capabilities on a realistic Mars-like terrain made of red clay and backed by a 40-foot blowup of a *Viking* lander image. The Planetary Society-designed SNAKE, developed for the Mars Balloon, also was put through its paces. The event was well covered by the national press.

Rover Expo was conceived by The Planetary Society, and was sponsored by the Society in conjunction with the National Air and Space Museum and NASA. The French and Russian space agencies and the American Institute of Aeronautics and Astronautics Robotics Committee also served as cosponsors. *—LDF*

UNITED NATIONS WORKSHOP TO STRENGTHEN SCIENCE

In response to the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), the UN, the European Space Agency and The Planetary Society are sponsoring a workshop on basic space sciences for the benefit of developing countries from November 1 to 14.

The three agencies will bring together scientists from the United States, Europe and Japan and scientists and educators from developing countries, for sessions in Costa Rica and Colombia. The purpose of the workshop is to strengthen basic space science in developing countries, enhance international scientific cooperation and collaboration, and explore avenues of education, training and research in this field for the benefit of developing countries.
—Carlos J. Populus, Volunteer Coordinator

SOCIETY ACTIVITIES IN DECEMBER

On December 8, nearly 30 years to the day after *Mariner 2*'s encounter with Venus, *Galileo* will fly by Earth and embark on the last leg of its voyage to Jupiter. The Planetary Society will celebrate the day with a very special program, a dialogue between NASA Administrator Daniel Goldin and Society President Carl Sagan on the future of planetary exploration.

During the same week, the Society will launch its new science curriculum reform project in conjunction with the National Science Teachers Association. The Society has been asked to develop the space science curriculum for the NSTA's Project on Scope, Sequence and Coordination of Secondary School Science.
—LDF

KEEP IN TOUCH

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Questions & Answers

Why don't gas planets have gas moons, and where did the rocky moons of the outer solar system originate?
—Enrico Pieranghetti, Dunlap, Illinois

What a great question! I liked it so much that I used it as the basis for a problem in the final examination for my planetary physics course.

Hydrogen and helium are among the most volatile of substances, and they have very low densities even in their condensed states. Even if nature could somehow discover how to create a gas moon next to a gas planet, the moon wouldn't stay there very long.

At low pressure, cold, solid hydrogen has a density only about 7 percent that of water. If nature could somehow assemble such a moon in place of the jovian satellite Callisto, say, with the same mass as Callisto, it would have a size similar to Earth's! But because of its low mass, the surface gravity would be only about 1 percent of Earth's surface gravity.

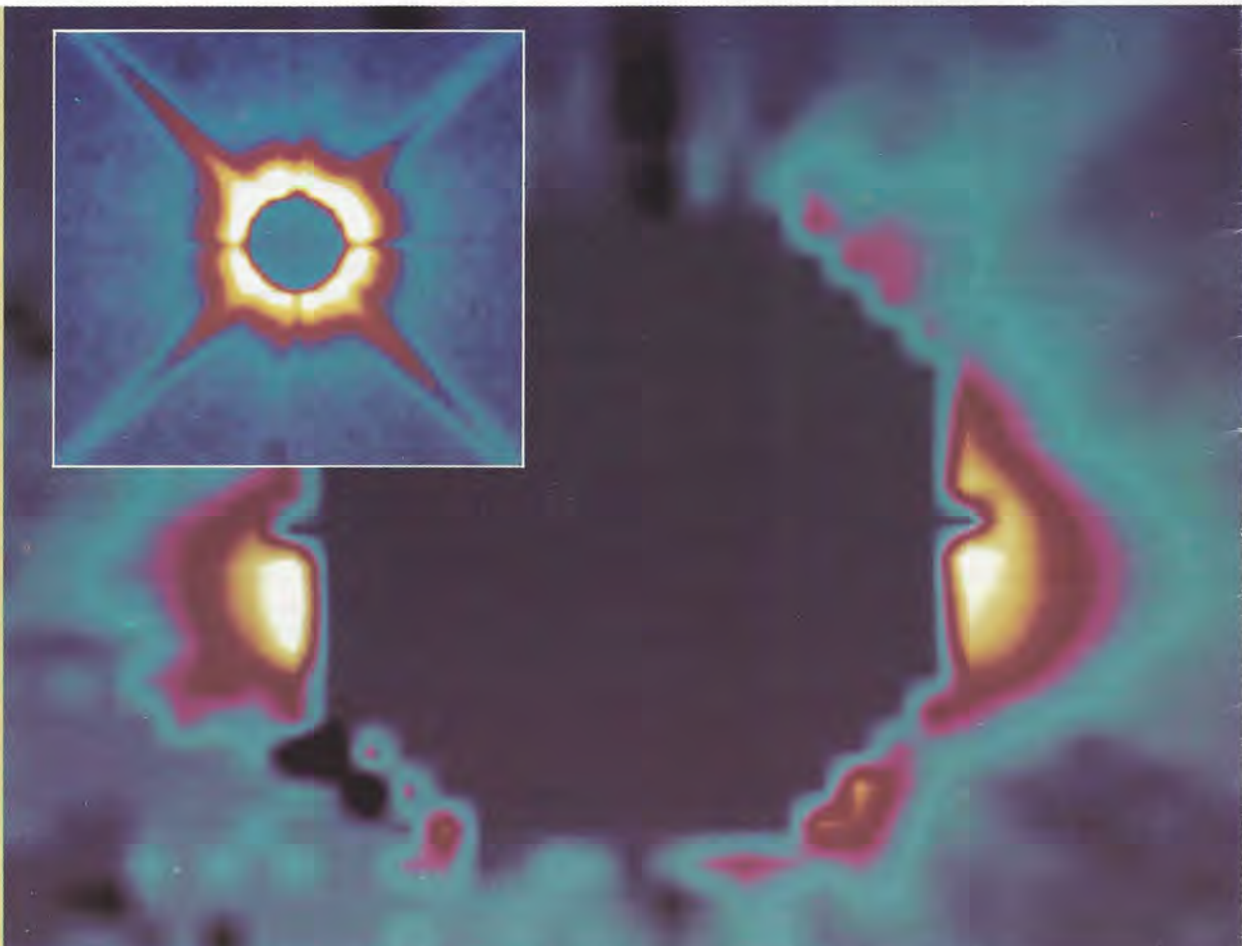
Solid hydrogen melts at minus 259 degrees Celsius. Our imaginary gas-Callisto would quickly develop a gaseous hydrogen atmosphere as it warmed in the sunlight to a balmy minus 150 degrees Celsius or so. But because of the low gravity, this atmosphere would develop a thickness comparable to the radius of the gas moon itself; it would become unbound and vanish in an astronomical instant. The moon would then replenish its atmosphere from its own mass of solid hydrogen. Very quickly, the moon would evaporate into space. Even out at Neptune, the Sun warms bodies enough to guarantee that no gas moons could be stable there.

As far as the second part of the question is concerned, rock should always be present in any part of the solar system where icy bodies form, because the original material out of which the solar system formed had comparable abundances of rock-forming and ice-forming atoms. We know, for example, that comets typically are made of "dirty snow"—that is, ices mixed with silicate dust. The icy moons, some of which may have originally formed from planetesimals similar to comets, have a lot of rock as well; they are typically about half ice and half rock. A few bodies, such as Jupiter's moon Io, have no ice, but they are atypical. Some process must have devolatilized them, either before they formed or during their subsequent evolution. In the case of Io, this process may have been extreme early heating while nearby proto-Jupiter captured its vast stores of gas from the solar nebula. Even today, Jupiter heats Io through the tidal friction that it exerts. But this tidal heating couldn't have occurred if Io were less rocky. Most likely, Io has been rocky since it was

RIGHT: The central dark region in this final version of the Beta Pictoris image was created by inserting a mask over the camera to block the light from the star. In this way the relatively faint light reflected from the debris disk (which looks like a pair of ears extending from the left and right of the dark mask) could be more easily detected. This star system is about 100 million to 200 million years old. At that age the planets of our own solar system had mostly finished forming. The material shown in this image consists of very small grains, about 1 micrometer in size.

INSET: In this raw image of Beta Pictoris, the disk is not visible due to the bright, scattered light from the star. The rays that extend diagonally from the star are diffraction spikes, an effect of the optics inside the telescope.

Photographs: Melissa L. Nischan, Dana Backman and Ben Zuckerman



formed. The same remarks apply, to a lesser degree, to Europa.
—W.B. HUBBARD, *University of Arizona*

Do asteroids have atmospheres?
—Peter P. Pruce, Northridge, California

No. The ability of any planetary body to hold an atmosphere depends on its gravity. The constantly moving atoms and molecules of a gaseous atmosphere are like little ballistic missiles. If gravity is too little, their velocities simply carry them off into space. If gravity is great, they arc upward but fall back toward the surface, although their trajectories are constantly interrupted as they collide with one another. Even the largest asteroid, 1 Ceres, is too small to retain a gaseous atmosphere over any appreciable length of geologic time. Its gaseous atoms would escape, one by one, in a few years.

One caveat to this answer is that the distinctions between comets and asteroids have become blurred; some "asteroids" may have ice deposits or other volatiles and occasionally release clouds of gas and dust. These produce a short-lived "coma," or extended very low density atmosphere, which usually dissipates in days, weeks or months. "Asteroid" 2060 Chiron, for example, has given off several bursts of gas in recent years; it is essentially a giant comet. Such temporary clouds are generally not classed as true atmospheres.
—WILLIAM K. HARTMANN, *Planetary Science Institute*

What is the definition of extraterrestrial intelligence?
—Dennis G. Dahl, Sandnes, Norway

A traditional definition of intelligence was the ability to use tools. Now, however, we know that animals such as chimpanzees can use primitive tools. Another definition involved the use of language, but there is controversial evidence of chimps and dolphins communicating in this way, and even honeybees use a language of dance to communicate.

In the Search for Extraterrestrial Intelligence (SETI), we usually avoid subtle questions of whether chimps or dolphins are intelligent by a practical consideration: Can the creatures communicate across interstellar distances? By this standard, 19th-century human civilization was "unintelligent." It was not until the maturing of radio technology in this century that we became able to communicate over distances of light-years.

There could be planets of brilliant shepherds who are far smarter than we are but who have never built radio transmitters. Unless we build interstellar spacecraft, we will never know about their dazzling philosophies. On the other hand, if there is a planet with idiot savants who have only one talent, and that talent is the building of radio transmitters, then we could perhaps detect them.

Since astronomers find that the laws of physics are the same everywhere, radio is possible everywhere. This means that SETI could be successful whether the creatures are carbon-based or not, whether they live on Earth-like planets or gas giants like Jupiter, or even if they are plasma beings in interstellar space, as long as they use radio (or some kind of electromagnetic technology such as infrared or light waves).

So SETI looks for extraterrestrial civilizations that are at least as intelligent as we are—or, more accurately, that are technologically communicative.
—TOM McDONOUGH, *SETI Coordinator*

FACTINOS

Melissa L. Nischan of Franklin and Marshall College in Lancaster, Pennsylvania, and two colleagues have taken the first infrared image of the disk of dust and debris surrounding the star Beta Pictoris (see photos at left). The researchers used the 1.5-meter telescope at the Cerro Tololo Inter-American Observatory in La Serena, Chile.

The colors and reflectivity of the light from the outer part of the disk indicate that its composition may be similar to that of the icy moons of Jupiter, Saturn and Uranus, say the researchers. Thus, the outer part of the disk may contain material left over from the creation of bodies similar to those in the outer solar system.
—from *Science News*

❖

Earth scientists have determined that Chicxulub, a large, craterlike structure in Mexico, dates from the exact time of the extinction of the dinosaurs 65 million years ago. This all but seals the case that a large comet or meteorite slammed into Earth and wrought havoc at the boundary of the Cretaceous and Tertiary periods.

"This lets us go into a new phase in the whole program of research," says Walter Alvarez, a geologist at the University of California, Berkeley, who participated in the new study and was part of the team that originally proposed the idea of an impact at the K-T boundary. "It should allow us to stop arguing about whether there was or was not an impact at precisely the time of the extinctions. This essentially ties that down."

In the August 14 issue of *Science*, geochronologist Carl C. Swisher III, of the Institute of Human Origins in Berkeley, and his colleagues reported that rocks from inside the Chicxulub circle formed exactly 65 million years ago and are the same age as impact debris found around the Caribbean/Gulf of Mexico region. To date the rocks, Swisher's group used a radiometric technique that relies on the radioactive decay of potassium-40 to argon-40 over millions of years.
—from R. Monastersky in *Science News*

❖

According to Larry Esposito and Joshua Colwell from the University of Colorado at Boulder, the ring around Neptune probably formed within the last few hundred million years when a lone wayward comet collided with a tiny moonlet orbiting the planet.

The researchers used imagery and other data gathered by *Voyager 2* when it visited Neptune in 1989 to model the formation of the ring on a computer. They found that the chances of its four separate arc segments being formed through multiple, random collisions are about 1 in 100 million.

This research adds to the prevailing theory that similar rocky rings around Saturn, Jupiter and Uranus were formed more recently than the planets they encircle, says Esposito.
—from *Space News*

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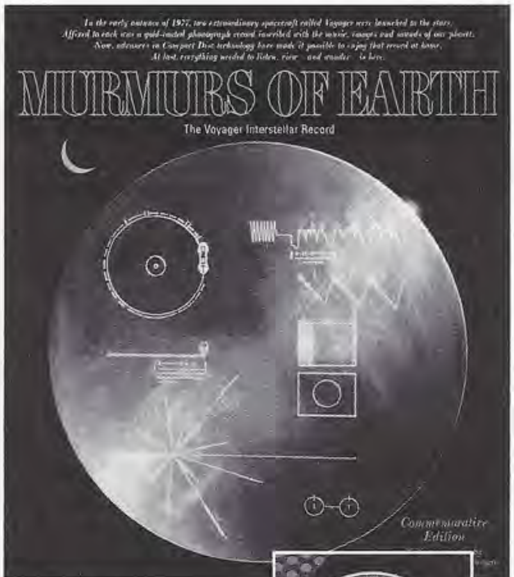

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Bob Eggleton is an astronomical artist and science fiction illustrator. His spacescapes have appeared in Astronomy, Ceil et Espace *and* Geo. *As a science fiction artist, he's done covers and illustrated books by Isaac Asimov, Arthur C. Clarke and H.G. Wells.*

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