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Scar on the Earth

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COVER: Scars like this are rare on Earth's face. Our home planet constantly resurfaces itself, eventually wiping clean the evidence that, over the aeons, it has been struck repeatedly by objects from space. Meteor Crater in Arizona, pictured here, was once thought to be the remains of a volcanic eruption. A young planetary scientist named Eugene Shoemaker was the first to demonstrate that this crater was blasted out by an impacting asteroid. Shoemaker went on to illuminate the role of asteroids and comets in the history of our solar system. **Photo: United States Geological Survey**

FROM THE EDITOR

The last few months have been amazingly eventful for planetary exploration, with politics, not scientists or spacecraft, seizing the central role. In the Soviet Union, economic uncertainty has forced the postponement of missions. The United States apparently must choose between the space station and planetary exploration. The situation changes daily, and at The Planetary Society we are scrambling like logrollers to stay on top of things. In this issue, we update you on the changing situation while covering the past and present in planetary research.

 —*Charlene M. Anderson*

Recycling: The Experimental Results

The results of our recycling experiment are in—as are your reactions to it. We printed our May/June issue on recycled paper as a test of both the quality of the result and our members' reaction to it.

Regarding the print quality, I must admit to being disappointed. Having been trained for years to regard sharpness and brightness as benchmarks of quality, I found the color images to be lacking on both counts.

However, there is more involved in the decision to use recycled paper, as you reminded us over and over again in your letters. The reactions are running over 12 to 1 in favor of recycled paper, and it is abundantly clear that most of our members regard the stewardship of the planet as more important than the quality of printed images.

So, this issue of *The Planetary Report* is also printed on recycled paper. Our staff is diligently seeking ways to maintain the high standard for which we are known, while doing our part to preserve Earth's resources.

We do appreciate your contributions to the decision to switch to recycled paper. —*CMA*

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.

I believe that those enlightened enough to share in the appreciation of discovery in planetary research have, or at least should have, a heightened appreciation of the complexity and delicacy of our own environment. It is for this reason that I was so alarmed to discover that the ozone-depleting agents released during a single launch of the space shuttle can equal many times the yearly output of a chlorofluorocarbon-producing plant. I refer to the figures cited by a Soviet research team which state that it would take only 330 launches of the shuttle to *completely destroy* our planet's protective ozone layer. As far as I know, the data have not been contested. Why has no one spoken up?

I urge The Planetary Society to address this issue whatever the cost to the space program—whether it means a reformulation of booster rocket design or (and I hope it doesn't come to this) a cancellation of the program entirely. I'm sure any conscientious planetary enthusiast will agree that no amount of low-orbit data can justify the wholesale destruction of the planet below.

—STEPHAN VERNIER, *Ann Arbor, Michigan*

The environmental danger from solid rocket propellants is real, although that particular statement by Soviet researchers appears to greatly overstate the risk. It assumes that all *of the rocket exhaust (and the chlorine and metallic molecules emitted) reaches the stratosphere. This is an exaggeration. The Soviets use liquid propellant rockets almost exclusively, and their comment may have been aimed at promoting their launch vehicles as well as dealing with environmental concerns. However, the propellants from solid rockets do contain particles that are harmful to the ozone layer and, in some cases, to the area near the launch site, producing such local effects as acid rain.*

A recent study by the Federation of American Scientists concluded that "the environmental impacts of solid rocket propellants should not be exaggerated." The propellants add very little ozone-depleting chlorine above that from industrial chlorofluorocarbons. Nonetheless, a shuttle launch is a pollution source and, while we are (sadly) many years away from hundreds of such launches, it seems certain that solid rocket propellants will raise environmental concerns in the future.

Thus, while it is not an immediate problem, it is one that we should be concerned about and one that The Planetary Society includes in its overall concern about environmental ethics in solar system exploration.—Louis D. Friedman, Executive Director

In last issue's Members' Dialogue you published a letter by Jim V. McAdams, who (in response to my article, "Eureka! The Recovery of 1982DB" in the January/February issue of *The Planetary Report*) questioned whether 1982DB [now known as 4660] was really the best asteroid mission candidate. The answer is yes, even though there are potentially slightly better ones, once they are observed well enough to be appropriately ranked. He mentioned 1989ML as a better candidate. Certainly, 1989ML and the recently found 1991JW, both discoveries of our Planet-Crossing Asteroid Survey, may be better candidates when their orbits are confirmed from observations made during their next apparitions. Aten asteroid 1989UQ, discovered by my French colleague, Alain Maury, is considered another excellent candidate for future missions.

—ELEANOR HELIN, *Pasadena, California*

I appreciate your use of recycled paper in *The Planetary Report*. The most obvious thing I notice is the lack of glare. I cannot say the pictures look any less bright or distinct. The grayish tinge is acceptable and overall it is an improvement.

Once again, I find *The Planetary Report* to be right where I expect it to be—in the forefront. Not only in the quality and timeliness of your articles, but even in your commitment to planet Earth, you lead the way.

Thank you and keep up the good work.

—EDWARD M. SHAFER, *Shawnee, Kansas*

NEWS BRIEFS

Despite skepticism in some Western quarters, plans continue in the Soviet Union to replace the *Mir* space station by 1994. A five-year plan for Soviet space programs calls for *Mir 2* to enter service in 1994 and remain in operation through 2000, said Grigorii Cherniavsky, chief of the Center Institute for Machinery Research of the USSR's Ministry of General Machine Building. The ministry builds virtually all Soviet spacecraft and launch vehicles, including *Mir*.

—from *Spacewatch*

An extended mission has been approved for the European Space Agency's probe *Giotto*, which will make it the first spacecraft to visit two comets. *Giotto* flew past Halley's Comet in 1986 and was put in hibernation until March 1990, when it was reactivated. *Giotto* will be reactivated again in May 1992 to encounter Comet Grigg-Skjellerup on July 10, 1992, about 3 pm Greenwich Mean Time.

—from the European Space Agency

A team of radar astronomers who have been observing asteroids from the giant Arecibo radar/radio telescope have identified a metallic near-Earth asteroid for the first time. The 2-kilometer- (1.2-mile-) wide object, called 1986DA, shows a radar brightness "far greater than any of the five dozen asteroids we have observed before or since," according to Steven Ostro of the Jet Propulsion Laboratory, leader of the team. "This supports the hypothesis that it is a large lump of iron, nickel and other metals."

Study of this asteroid may shed light on the early history of the solar system. 1986DA may be a relic of a larger body which melted, separated into layers of heavy metal and light rock, cooled, and then was smashed into fragments in a catastrophic collision with another large asteroid.

—from the Jet Propulsion Laboratory

What Now With the Soviets?

by Louis D. Friedman

Since 1984 the Directors of The Planetary Society have urged that the human exploration of Mars become the goal of an international space program, to be led by the United States and the Soviet Union. Time and time again we have argued that this goal could serve the overall interests of both nations, and that it could revitalize the American space program.

In this campaign we have, at various times, been supported by one or both houses of the US Congress, the American public, Soviet President Mikhail Gorbachev and US President George Bush.

But many who have been urging Soviet-American space cooperation are being influenced by the tone of headlines about the Soviet Union, with words like *dissension, turmoil, dissolution, collapse, repression, militarism, chaos* and *dictatorship* freely used. Recent events have compelled us to reconsider our position and tackle some serious questions: Is the Soviet Union still relevant to plans for future space missions? Should The Planetary Society continue to advocate cooperative programs?

We have at this time a variety of evidence that suggests some answers.

First, during a membership recruitment campaign in January we conducted an informal opinion survey among people we believed to be interested in planetary exploration. Of those who joined the Society, 95 percent favored general international cooperation in space, and 92 percent favored working with the Soviets in particular. Even among those who did not join, 92 percent favored cooperation, and 81 percent wanted joint efforts with the Soviets.

These numbers were even more remarkable considering the timing: The poll was conducted during the beginning of the war with Iraq and the Soviet crackdown in Lithuania. This supports our belief that, on the issue of international cooperation in planetary exploration, the Society's Directors are in touch with our constituency.

Soviet Program Still Moving Toward Mars

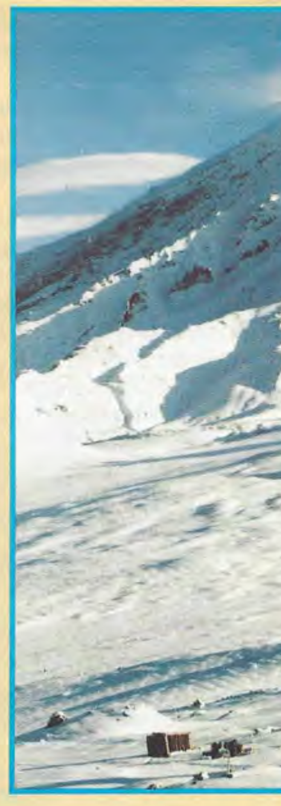
We add to our considerations the fact that, at this moment, no matter how chaotic the USSR appears to be, there is still a higher probability that the Soviets will land on the surface of Mars within this decade than there is that the US will do it. NASA has definite plans for only one Mars mission in the 1990s: the *Mars Observer*, which will orbit the planet.

Society Director in the Soviet Union for Rover Talks

As we were preparing this issue, our Executive Director, Louis Friedman, returned from the Soviet Union and a series of meetings on The Planetary Society's continuing design work on the Mars Balloon and a new role in testing the Mars Rover.

With our members' support, we have been able to accept enthusiastically the Soviet invitation to join the Mars Rover team. The Planetary Society is now cooperating with the Space Research Institute, the Babakin Center and the Transport Engineering Institute (the group is known under the acronym VNIITRANSMASH) in planning tests this year in the Kamchatka Peninsula and next year in the Mojave Desert.

ABOVE: Dr. Friedman (fifth from left) toured the Transport Engineering Institute's facilities in Leningrad and examined the minirover test models being developed for Mars exploration. To his left are Alexander Kermurjian, Chief Designer for the Institute and the moving force behind the Mars Rover, and Valery Gromov, designer of the rover's surface sampling device. Photos: VNIITRANSMASH



As I write this, the Soviets have just decided to split the *Mars '94* mission into two parts: an orbiter to launch in 1994 carrying small meteorological stations and penetrators to investigate the surface; and an orbiter and descent module to launch in 1996 carrying the Mars Balloon and Rover. As explained to us, the change was made because there were simply not enough funds available to test the descent module adequately in the time remaining before launch. The 1996 mission has uncertainties, and problems in its design. We are disappointed by this development, but despite the delay, this split mission remains the only landing on Mars scheduled for this decade.

We are trying to turn this setback into an opportunity.

The Planetary Society's contributions to this mission have been significant, and the Soviets have asked us to expand our involvement. With members of the French national space agency, the Centre National d'Études Spatiales (CNES), we are continuing our design work on the SNAKE guide-rope for the Mars Balloon (see the January/February 1991 *Planetary Report*), and we have accepted the Soviets' invitation to participate in testing their rovers. Our members' support has been extremely important to this mission.

As for landing humans on Mars, the USSR is still the only nation seriously studying the effects of long-duration spaceflight on humans in preparation for the long journey to the Red Planet. The space station *Mir* continues to orbit Earth, with cosmonauts logging extended flight times. The human flight program of the USSR has been scaled back, but it will not be ended. In several internal meetings of the Soviet Academy of Sciences, the "national Mars program" priority has been supported.

The space industry is one of the few peaceful and exportable successes of the Soviet economy. The Supreme Soviet has thus far supported space missions, albeit with increasing questioning. The program has served its country, and indeed the world, through the times of Khrushchev, Kosygin, Brezhnev, Andropov, Chernenko and Gorbachev. Although changes in the country's political organization are likely, the infrastructure of defense, space and other technological enterprises will probably survive.

For all these reasons, the Soviet space program looks as if it will endure, albeit with some uncertainties. There will undoubtedly be delays, questioning, and lessening of ambitions, but space science and human flight will, we think, continue.

The Mars program in the US, like that in the USSR, is uncertain—except for an excellent *Mars Observer* mission plan. With no surface missions now under development, the earliest one could fly is 1998, but it is more likely to be 2001 or 2003. Surface reconnaissance to prepare for a human landing will have to wait until then.

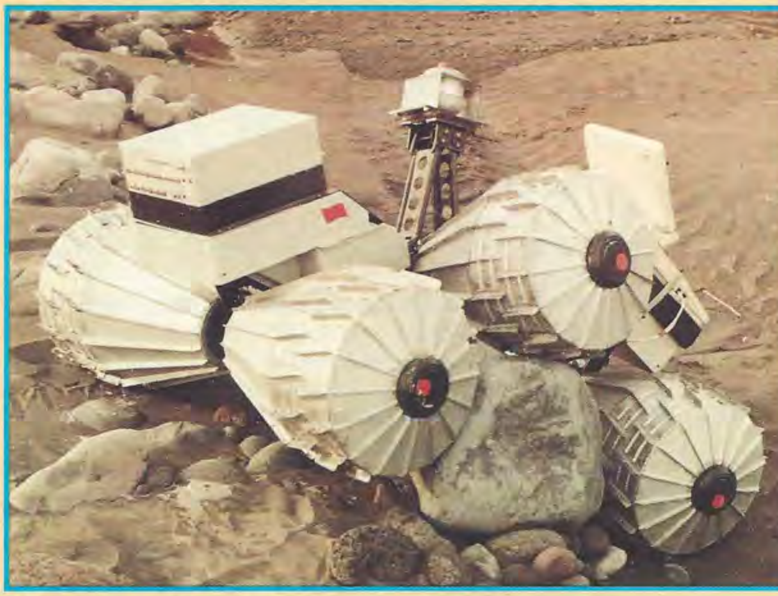
The US studies of the effects of the space environment on humans must also wait. The earliest space station *Freedom* could become operational is 1999, and it is even now being descoped, reconfigured and reconsidered. It will be a long time before Americans will fly in orbit for periods of over a month—unless they fly on *Mir.*

Although it has not, to date, been formally confirmed, officials in both the US and the USSR have told us that a cosmonaut will soon fly on the American shuttle, and an astronaut will fly on *Mir* for at least four months—an exchange we have been advocating for years.

This possibility is significant on three fronts:

- It could revitalize NASA's life science program and improve medical knowledge of the effects of long-duration spaceflight.
- It demonstrates that the Bush administration considers the Soviet space program still relevant, and that President Bush wants to work with the Soviets.

LEFT: This is the test facility on the Kamchatka Peninsula where the rover test will take place this fall. By putting the minirover through its paces in this forbidding, Mars-like terrain, and then testing an advanced prototype in the Mojave Desert, we hope to prove the rover's durability and reliability in harsh environments before sending it on to Mars.



ABOVE: The minirover proves that small boulders are no problem as it steps and rolls over this obstacle. This design is a "wheel-walker" and has six conical wheels capable of moving independently in a sort of crawling motion, thus combining elements of both walker and wheeled rover designs.

• It is a statement by the Gorbachev administration that it plans to keep the Soviet human flight program vigorous.

The US Will Not Go Alone to Mars

The final point that supports our view on international cooperation is the cold reception that the Space Exploration Initiative (SEI) proposed by President Bush has been given thus far by both the public and the politicians. In the current economic climate, even the relatively low costs of robotic precursor missions to Mars or the development of closed-loop life-support systems are considered prohibitively high for one nation.

My personal view—similar to that of Society President Carl Sagan—is that SEI will go nowhere as a nationalistic program of the US alone. If the dream of humans walking on Mars is to be achieved in our lifetimes, it must be done as a mission of the spacefaring nations of Earth together. Only if SEI involves a community of nations can it find its political *raison d'être*.

In considering this issue, we must ask one more question: Is this view of the future of planetary exploration shared by our counterparts in the USSR?

In March we took advantage of an unusual confluence of visiting Soviet officials and organized several meetings to probe this question further. We present here some of the views we solicited from leaders of the Soviet space program, which we hope will provide some insight into the state of that program and the possibility of American-Soviet cooperation.

Yuri Ryzhov is a member of the Soviet Academy of Sciences and of the Supreme Soviet, Chairman of its Science and Education Committee and President of the Moscow Aviation Institute. He is also a Deputy Chairman of the Russian Republic and the principal science advisor to Boris Yeltsin. He spoke about the need to encourage young people to remain in science.

Ryzhov: The USSR is going through an intellectual crisis as great as its economic crisis. We are experiencing a brain drain *inside* the country, as well as from those leaving it. Too many young people are opting to make money in less productive areas, forsaking science and technology. Support for the space program and other areas of science and technology is necessary. So is international cooperation, because it provides an appealing opportunity for young people.

The fruits of the intellect should be used for the benefit of the whole world. Contacts and cooperation are especially important now, and we need to come up with an innovative way to support and to provide funds to such people during this transition to continue their work and to forestall their leaving science and engineering.

Friedman: Will the Soviet Union need to focus now on shorter-term, economically productive areas instead of areas like space cooperation?

Ryzhov: There is a transition period when we will not be able to support as much in the way of space science missions as we used to, but international cooperation with Western support for new arrangements, such as barter, joint appointments, travel, joint projects, contracting, and so on, is needed.

Friedman: You are Chairman of the Science and Education Committee of the Supreme Soviet—is the budget for space missions going down?

Ryzhov: The Supreme Soviet has no power over the budget. Thus, despite our support, it is hard to carry out supervision over programs. I think we will be doing less.

Roald Sagdeev is a member of the Soviet Congress of Deputies and of the Soviet Academy of Sciences, former Director of the Space Research Institute (IKI) and a former science advisor to President Gorbachev. He is now a professor of physics at the University of Maryland and an Advisor to The Planetary Society. I asked him if financial support for the space program would decrease.

Sagdeev: Definitely, yes. There are many pressures to decrease it, and there is public questioning of its benefit. There will be cutbacks. But it will not stop. It is one of the things the Soviet Union does well, and it is a model for other areas of our economy. Science missions will be cut less than manned missions.

Friedman: What are the prospects for international ventures?

Sagdeev: Certainly less in the short term, but much better in the long term. There may be some hiatus.

Alec Galeev succeeded Sagdeev as Director of IKI. His institute is now preparing for the *Mars '94/'96* mission. I asked him also if support for planetary programs in the USSR is declining.

Galeev: Certainly there are many more pressures to decrease the budget, but the country is very big and things will not change overnight. The Mars program is actually in good shape. But we may see more difficulties in keeping our funding and meeting our schedule, as you have, even in the United States. This is to be expected.

Alexander Kermurjian is the Chief Designer for the Transport Engineering Institute of the Ministry of Defense Industries of the USSR. In that position, he is responsible for designing the mobility systems of Soviet planetary rovers. Dr. Kermurjian reported to Society members on his work in our July/August 1990 issue. I asked him if support for his work on planetary rovers is decreasing.

Kermurjian: No, we have full funding. We expect to have the small rover [described in the *Planetary Report* article] ready for *Mars '94* [now *'96*], and bigger ones will come later. But I'm not a politician.

Friedman: The Planetary Society has suggested that an innovative American microrover might be incorporated in the *Mars '94* [*'96*] rover as a sort of mobile hand. Do you think this is feasible?

Kermurjian: It is possible and interesting to plan and study it. We hope you can test it soon, together with our minirover.

Friedman: Your institute is also responsible for tank development; is conversion from military to civilian production a big factor?

Kermurjian: Yes, about 30 percent, perhaps 50 percent, of our work is undergoing that conversion.

Yuri Labutin works for the Energia Corporation, which builds the largest Soviet rockets, including the *Energia* heavy-lift launch vehicle. I asked him how much of his organization's work is being diverted from space and military systems.

Labutin: About 20 percent of our work is now for commercial and civil areas. Half of this is in artificial limbs and prosthesis devices. We expect our conversion work to grow to perhaps 30 percent.

Georgi Grechko is a three-time cosmonaut who now works in the Laboratory for Atmospheric Physics of the Soviet Academy of Sciences. I asked for his opinion of the future of the Soviet space program.

Grechko: It will continue, although we expect the budget to decrease. It is important for the Soviet Union to have such accomplishments and achievements. International cooperation is especially important and will receive financial support.

Friedman: I've heard about exchange flights on the US shuttle and on *Mir*. Is this likely, and is it valuable?

Grechko: Yes, we have been discussing it for two years, and I'm glad it is finally being planned. Although it is not financially profitable [for us]—after all, we will fly for one week on the shuttle and you will fly for months on *Mir*—it is very good for both countries. Gorbachev has many problems on Earth, but that may make it a good time to do things in space. Certainly cooperation in space enhances cooperation on Earth.

Valeriy Barsukov is Director of the Vernadsky Institute of Analytical Chemistry and Geochemistry, and Co-Chairman of the US-USSR Planetary Exploration Working Group. I asked him how he thought the Soviet political situation will affect space science in the 1990s.

Barsukov: The political and economic situations are intertwined. For the first time we have our funding being critically examined. As a result, there have been delays in receiving our budget, which may make it hard to meet our schedule. The Supreme Soviet, the Congress of Deputies and the Science and Education Committee have been helpful, as has Academician Yuri Ossipiyan, who is head of the Mars program. But it is now hard to predict one to three years ahead.

Karoly Szego is a leading scientist at the Hungarian Central Research Institute and a frequent participant in Soviet planetary science missions. Considering the great changes in his country, I asked him if Hungary will continue to participate in the Soviet space program.

Szego: Yes, it is both an economical and intellectual necessity for us to continue. We need some small fraction of effort on these creative scientific projects. It benefits our whole science and technology program. We also have a new agreement with the European Space Agency for additional cooperation.

Friedman: Do you think there will be new opportunities for Soviet-American space cooperation?

Szego: There is no doubt that it will continue and expand. But at what speed is the question. Soviet space projects will probably be scaled down and stretched out to reduce yearly costs. Current mission commitments will be met, but there may be delays in future programs. This is not unlike the US experience.

Friedman: What about a Soviet Mars sample return?

Szego: Absolutely as solid as the US plans [of which there are none—Ed.].

Stanislav Shatalin had been economic advisor to Gorbachev until his 500-day plan for conversion to a market economy was rejected. He had just given a short talk in which he announced that he had quit the Communist Party and wished that he and other reformers had banded together a year or two ago to form an opposition party. He was extremely pessimistic about the situation in the USSR, but he concluded optimistically that, although they had a long struggle ahead of them, he expected a freer and stable market-economy Soviet Union to emerge. I asked him about the Soviet military-industrial complex, and whether it is participating in the move toward economic reform and privatization.

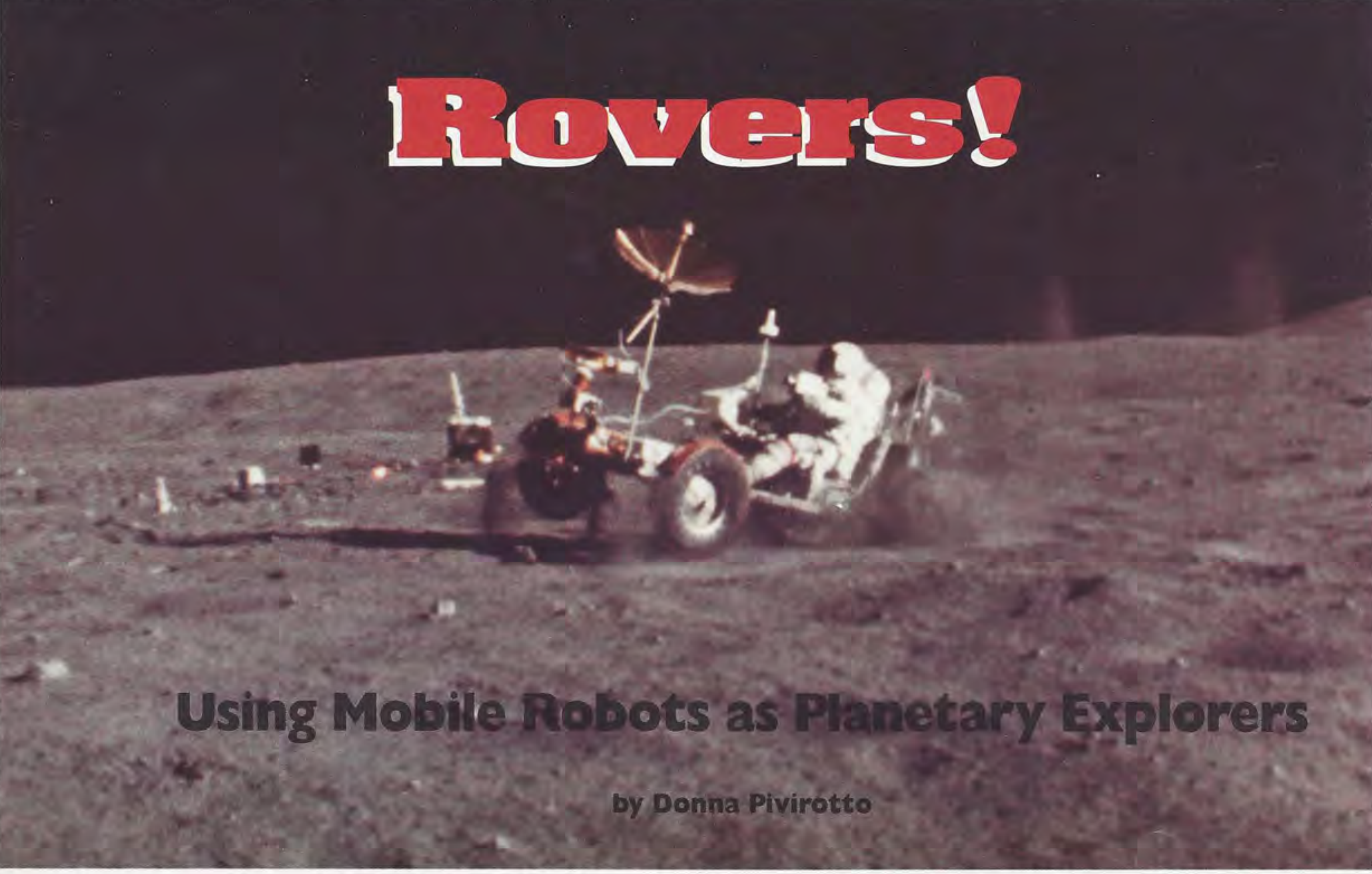
Shatalin: This is the fundamental question. The military-industrial complex, which includes the space industry, has the best resources and the best talent in our economy. Without their participation, conversion will become a bazaar. But it has to be done intelligently. We had one example of converting a rocket manufacturer to making toilet hardware. To put that talent on that problem was a disaster. There was great loss of morale and poor production, low interest and bad quality. Worse, however, is that it turned good professional people against the processes of conversion, privatization and demilitarization. We need challenging, creative projects, and we need Western participation in them to help, but even more so we need them as an incentive for professionals.

* * *

This is an extraordinary time for the USSR as it struggles toward its future. It is also a critical time for space exploration. Frank Press, President of the US National Academy of Sciences, recently noted that the Soviet Union is rich in new technologies and capabilities, as well as in resources. He believes that the US should cooperate in ventures that satisfy mutual interests and where the scope of the projects is large enough to strain one country undertaking them alone. Such projects include space exploration, particle accelerators and human genome mapping. It is his belief that the accomplishment of these ambitious projects is possible and could provide tangible symbols that the two nations can work together—one optimistic note among many pessimistic predictions.

Putting together all these comments, and being hopeful, realistic, optimistic, pessimistic and still, at heart, a space buff, I conclude that working with the Soviets is nevertheless the best bet for bettering the odds of sending robots to land on Mars in this decade, and for humans to walk on Mars in the next.

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



Rovers!

Using Mobile Robots as Planetary Explorers

by Donna Pivirotto

***ABOVE:* Astronaut John M. Young kicked up a little dust as he gave the Lunar Roving Vehicle a speed workout during the Apollo 16 Moon mission.**

***Photo:* Johnson Space Center/NASA**

Spacecraft have flown by every solar planet but Pluto. They have even landed on the Moon, Mars and Venus, but few have been able to move over the surface. We can explore only so far with a spacecraft flying high above a planetary surface or stuck stolidly in one place. On Earth, mobility has been the key to exploration, and even a cursory reading of history reveals how important such roving tools as horses have been to human development.

Mechanical rovers are seen by many as the best way to explore planetary surfaces, whether people actually drive the rovers or operate them remotely—or the vehicles think for themselves.

As humans contemplate expeditions to Mars, the planet whose surface conditions are most like Earth's, it's natural to consider sending robotic precursors to scout the alien terrain for us. We've had experience with both robots and humans moving about on the Moon, and as we prepare for Mars we can learn from that experience.

The First Steps, Remotely

In the early 1970s, the Soviets sent two *Lunokhod* vehicles to the Moon. Operated from Earth, these bathtub-shaped rovers moved around on eight metal wheels, viewing the surface and making simple scientific observations. Powered by solar energy, they operated during the lunar day and sealed themselves up at night, using radioactive heaters to protect themselves from the minus 163 degrees Celsius (minus 260 degrees Fahrenheit) cold. One managed to move 7 kilometers (4 miles) over the surface before failing. The other traveled 37 kilometers (23 miles), surviving several lunar day/night cycles.

The Soviet operators learned a great deal about how to drive lunar vehicles remotely. Glare from the Sun, black shadows and lack of depth perception all created difficulties for them. They also had to deal with sheer boredom, in part because of the need to compensate for a 2¾-second communications delay—that's how long it takes radio waves, which travel at the speed of light, to make the round trip. Rather than "driving" the *Lunokhods*, the operators commanded their simple onboard computers, which then translated the commands into wheel rotations and steering movements. The *Lunokhods* moved slowly and stopped between commands so they wouldn't get into trouble.

Hot-Rodding in Low Gravity

In about the same time frame, the *Apollo* astronauts actually drove a small, four-wheeled "dune buggy" from landing sites to points of interest a few kilometers distant. A lesson learned from this vehicle is that low gravity creates problems with high-speed driving. As a rule of thumb, the apparent speed and handling characteristics of a planetary rover are proportional to the square root of the difference in gravity between the planet and Earth. Gravity on the Moon's surface is only one-sixth that of Earth. So the *Apollo* lunar rover traveling at 10 kilometers (6 miles) per hour handled as though it were being driven at 24.5 kilometers (15 miles) per hour on Earth. Pictures clearly show the rooster tail generated by Dave Scott of *Apollo 15*, who was driving at what looked like very high speed but was actually about 15 kilometers (9 miles) per hour.

Since those days the Moon has stood unoccupied; the *Surveyor* landers, *Lunokhod* rovers and the *Apollo* dune buggies are now just debris from fitful past exploration. And on Mars, only the *Viking* landers have touched the surface and operated successfully from that vantage point. When one looks at the martian landscape shown by *Viking*'s cameras, a desire to see over the horizon is natural. To extend the reach of the *Surveyor* and *Viking* cameras and sampling arms—to see over that horizon—the Jet Propulsion Laboratory and others began addressing how to build automated rovers.

CARD Tricks

For the Moon, a natural extension of the *Lunokhod* control scheme might be appropriate. That is, the operator sits on Earth and watches a television monitor. On the monitor are projected stereo images that the lunar rover sees with its cameras. The operator designates a path in the stereo image using a light pen or joystick—just as in an arcade game. This path is transmitted to the rover in the form of directional commands, which the rover's onboard computer translates into steering angles and wheel turns. This is known as Computer-Aided Remote Driving, or CARD.

With the relatively short Earth-Moon light-time delay, the CARD rover should get in no trouble if it's traveling slowly enough. Slow travel also means low power consumption, so the rover will have to carry only a relatively small power source. This in turn means the rover will have a relatively low mass to launch to the Moon. So slow travel is good from several points of view.

On the other hand, slow travel with operator intervention every few minutes is very boring for the operator. Even a scientist watching intently for interesting rock formations may get bored as the rover creeps across the surface at a few meters per hour. And there are ways of producing faster travel.

A Roving Eye

One way is to automate the rover more fully so that a long path—perhaps several kilometers long—can be stored in its onboard memory and automatically executed. To do this, the rover must be able to recognize landmarks along the path and avoid potentially fatal hazards. Recognition involves sensing (for example, imaging or laser ranging), the ability to build a computer-recognizable representation of objects in the path, and the ability to determine the actions required to traverse the path while avoiding obstacles. Researchers have developed various schemes to do this "local navigation," some under funding by the Defense Advanced Research Projects Agency (DARPA) as part of its now defunct Autonomous Land Vehicle program. The JPL local navigation scheme, developed primarily with NASA funding, uses stereo vision and the ability to identify slopes as its principal navigation technique. Once the scene is "understood" in comparison with the rover's onboard reference map or instruction set, a path-planning algorithm—a set of rules for solving a problem—is invoked to send the rover on a safe and low-energy traverse.

This type of "semi-autonomous" navigation may be just what we need for Mars rovers. After all, Earth operators can always be rotated if they get bored navigating a lunar rover, but from Earth to Mars the round-trip communications delay is anywhere from 5 to 40 minutes, depending on the distance between the planets at the time. Calculations have shown that the progress of a rover driven by the CARD scheme is painfully slow, and the distance covered is minimal. A semi-autonomous rover, however, can

LEFT: The Martin Marietta Corporation has developed this one-quarter-scale model of the seven-legged "walking beam" to test this rover's ability to climb over obstacles. The model has a four-legged inner platform and a three-legged outer platform. As one platform moves forward, the other remains stationary. Then the moving platform's legs are planted on the ground while the other platform moves forward.
Photo: Martin Marietta Corporation

RIGHT: Carnegie-Mellon University's "Ambler" has six rotating legs that walk in an eggbeater fashion. Nearly 6 meters (19 feet) high, the Ambler can step over obstacles almost 2 meters in height. It has laser scanners, cameras and enough intelligence to walk across rugged terrain. The Ambler is being developed by Carnegie-Mellon's Field Robotics Center with a grant from NASA.
Photo: Carnegie-Mellon University

move steadily, at a rate limited only by its onboard power and computing speed, and by the ruggedness of the terrain. If we had high-resolution images from Mars orbit that would give us surface details at least down to the size of the rover itself, operating the rover would be greatly enhanced. Then, we could preprogram the rover's path to some extent, leaving the rover's onboard intelligence with the task of avoiding surprises on a smaller scale.

Wheels or Legs?

The rover would need to be big enough for an orbiter to detect hazards to its mobility, yet within reasonable limits for launching—about the size of a small car, with a weight of 600 to 1,000 kilograms (1,300 to 2,200 pounds).We have investigated various ways for a rover of this size to move. Early studies by the FMC Corporation, Martin Marietta Corporation and JPL discarded tank-type tracks and many more exotic concepts for reasons of mobility and reliability in rough terrain, combined with instrument/payload carrying power. Wheeled versus legged designs have continued to be studied.

Both wheeled and legged designs appear to need more than four appendages, with six being the number usually chosen. Wheeled vehicles offer relative simplicity but tend to be less stable platforms. Legged designs may be more adaptable to rugged terrain but are generally more complex, both mechanically and computationally. They must carefully plan where to put each foot to avoid jamming, and they tend to require more sensing and computing than wheeled designs. Although there are many examples of both wheeled and legged vehicles, no program has yet brought them together in a runoff so that the issue of wheels versus legs can be resolved. JPL has proposed such a program to NASA, but funding is not yet forthcoming.

This semi-autonomous, automobile-sized technical solution to the problem of roving on Mars was the basis for the Mars Rover Sample Return (MRSR) Project (see the September/October 1989 *Planetary Report*). In this case the site reconnaissance orbiter would collect a global map at about the same detail as the best *Viking* orbital images, in which objects the size of buildings would be visible. This map would provide not only geologic information but also context for nested sets of very high resolution images (each smaller one within the next larger one) that could see objects as small as 1 meter. We would use these images to select safe landing sites for rover and sample return vehicles, as well as to plan safe and effective paths for the rovers.

Early scenarios envisioned either very large landers (requiring launch by a heavy-lift launch vehicle), which would carry a rover and a sample return vehicle, or separate launches of rovers and sample return missions. To optimize their scientific missions, rovers would be landed at places where differing types of geologic units meet. In this case, the rovers would have a range of 100 kilometers (60 miles) or so and could collect a range of geologically diverse samples. Two rover/sample return missions could be expected to return as many as six samples of different martian terrains. However, there are problems with this MRSR approach.

The first problem is cost. The total MRSR mission set (orbiters, rovers, sample returns) was determined to be expensive (somewhere in the range of $10 billion; by comparison, the *Viking* missions in today's dollars would be about $3 billion). A second problem is that the contexts and histories of samples collected where geologic units come together could be confusing, although the context of samples collected in the middle of a lava field or a dune field, for example, would be relatively unambiguous. Third, robotic missions to Mars have begun to be seen as possible precursors for human flights,

For Fun and Science

The Uses of Rovers

There's no question that operating a rover on Mars will be fun. It will appeal to that part of humans that gleefully plays with radio-controlled toys, watches with fascination as an "intelligent" robot tries to deal with its environment, and dreams of driving dune buggies across the sands of Mars. But is there scientific justification for the effort and expense of sending mobile landers to that distant planet?

Although we have mapped the planet at the scale of a football field, we still know little about Mars' surface at smaller scales, such as a human might experience in walking across its landscape. The stationary *Viking* landers together examined less than one square kilometer of surface, although Mars has a surface area roughly equal to the dry land of Earth. How thoroughly would we understand Earth if we were confined to only a square kilometer?

To compound our problem, the *Viking* landing sites were chosen for their safety; that is, the project managers chose the smoothest places they could find. Still they were surprised by the roughness of the boulder-strewn sites. As Society Vice President Bruce Murray (then Director of the Jet Propulsion Laboratory) recalls, "There was no way to predict the nature of the landing sites from the *Viking* orbiter images. They looked like lunar maria [smooth lava plains] from orbit, but they were not!"

Safe and Boring

In geology, smooth often equates with boring—an adjective frequently applied to the *Viking* sites. Even in the coarse detail of orbiter images, we can identify many other types of terrain: canyons, channels, craters, polar caps and volcanoes, to name a few. This diversity of features indicates that a variety of processes operate on Mars. To sample just the features we see from orbit, we would need a horde of stationary landers—or a traveling robot carrying cameras and other instruments.

The situation is different for the Moon. We know the lunar surface better than any planet except Earth, and one process has dominated its evolution: impact. "The effects of impacts dominate at all scales, from the telescopic down to the microscopic," Dr. Murray points out. Even from as far away as Earth's surface, we can see the craters and basins blasted out by colliding bodies. Microscopic analysis of the lunar regolith, or soil, reveals that it was ground up from rocks repeatedly pummeled over the aeons by impacts. Knowing this, he concludes, "We can predict the surface of the Moon at any scale."

This is not the case for Mars. "There are a lot of different surface processes that can't be predicted from low-resolution orbiter pictures," Dr. Murray explains. "We have to see the planet at the best possible scale to figure out what's going on." And we have to look in many different places.

Peering in Hidden Places

This is the value of rovers. They can look beneath, beside and around interesting things. They can peer down crevasses, clamber up hills and poke about the debris from steep cliffs and scarps. They would be robotic approximations of field geologists, examining a boulder from every angle, snooping underneath it, investigating its surroundings and helping geologists back on Earth figure out where it came from and how it got there.

Some experiments require a mobile platform if they are to be carried out at all. To determine the location of water on Mars is a prime objective for future missions. If Mars has retained large amounts of water, it would most likely be held as permafrost, frozen into subsurface soil. A good way to locate such deposits is to do electromagnetic sounding, which means something will have to drag an antenna across the martian surface—just the sort of task at which a rover would excel.

Rovers could drill below the surface at many different sites. They could probe scarps where faulting or erosion has exposed sedimentary layers. From these formations geologists can read the history of a planet. And within such layers may be deposited the fossilized remains of martian life—if it ever existed.

Of course, a rover's ability to investigate the surface will be determined by the capability of its engineering. A minirover such as a "brilliant ant" would be little more than a moving finger to poke at things. In its most ambitious incarnation, a large rover would be a mobile laboratory able to analyze the samples it collects. The smallish rover being planned for the Soviet *Mars '96* mission—which The Planetary Society is helping to test—will carry a camera and an instrument to measure the bearing strength and cohesion of martian soil. Other instruments will be added.

But whatever its scientific mission, the rover will have the ability to capture the interest of humans. We will follow its mission with anticipation. As it creeps across Mars, many of us will come to see it as a sort of creature, a surrogate explorer reconnoitering the place for us. With their cousins, the Mars Balloons, the rovers are the next steps in the progression that will someday see humans walk on Mars. And we will have fun preparing the way.

—*Charlene M. Anderson*

adding a new layer of political concerns and scientific demands to our planning.

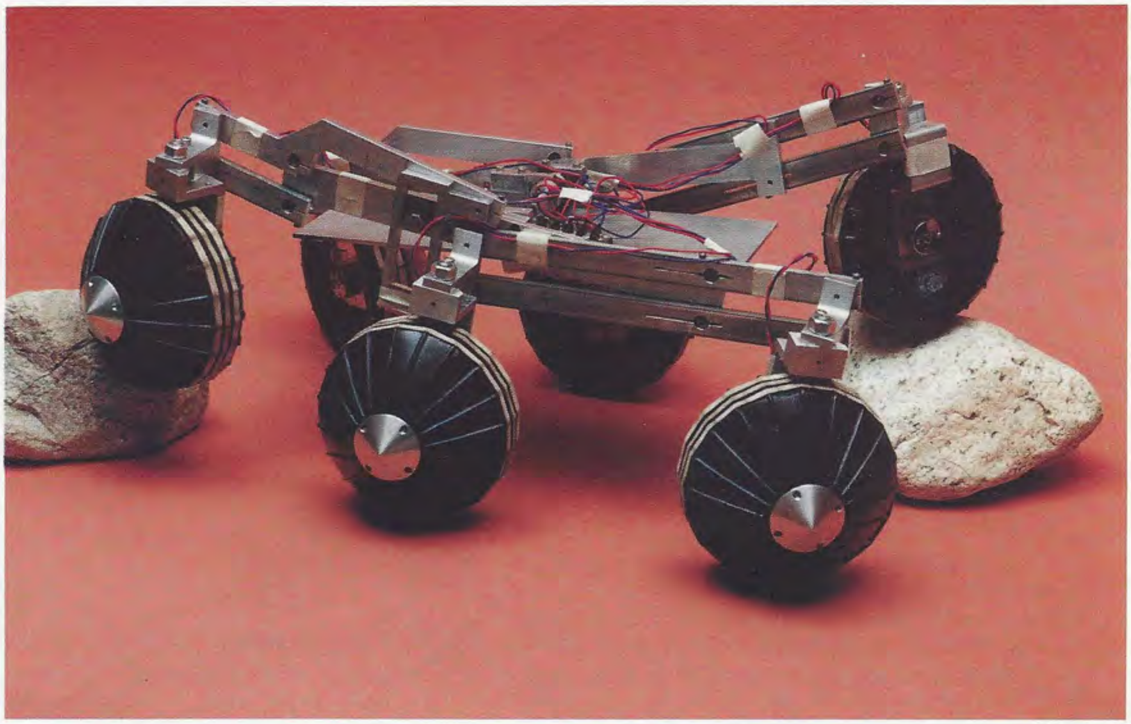
A Networked Approach

Because of these factors we have worked out a new, "evolutionary" approach to roving and sample return from Mars. A network of simple surface stations would be emplaced over time by small launch vehicles (such as *Deltas*). This network would follow the United States *Mars Observer* orbital mission in 1992 and the Soviet *Mars '94* and *'96* landed payloads (balloons, surface stations and experimental rovers). It would provide up to 10 years of seismic and atmospheric "weather" information. The network might also be able to get "snapshots" of the surface by taking pictures as the station payloads descend on their parachutes.

The systems used for the network might also be used to fly other types of small payloads—for example, minirovers. An upgrading of these entry and landing systems might even be suitable for small sample return missions. A team from JPL, NASA Johnson Space Center, NASA Ames Research Center, and Science Applications International Corporation has been studying various approaches to Mars science and engineering data collection using small payloads. Small rovers are a focus of this approach.

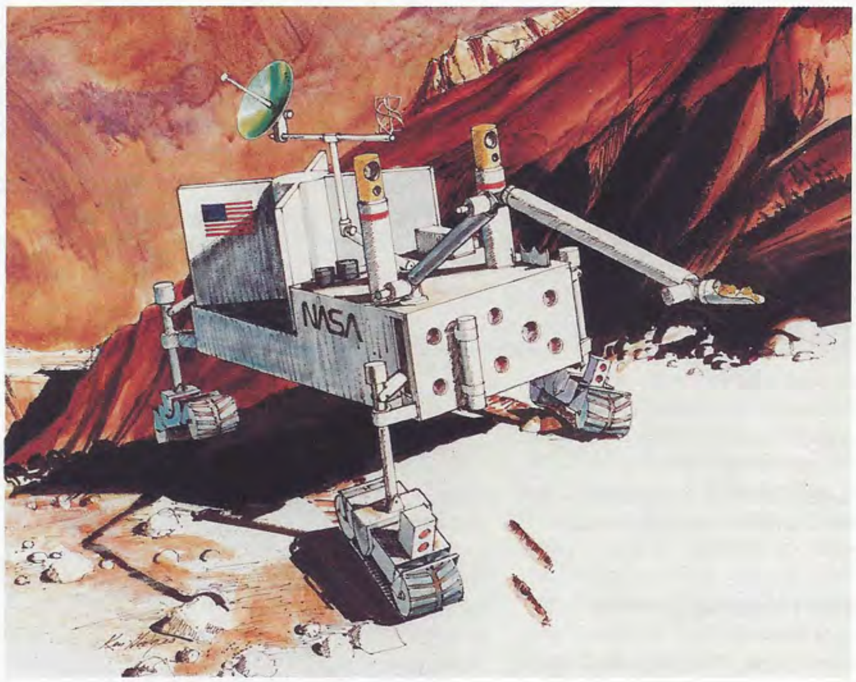
Concepts for microrovers—less than 5 kilograms (11 pounds)—or minirovers—5 to 20 kilograms (44 pounds) — that could deploy instruments, survey sites and collect samples have been developed. And some small test vehicles have been built to test mobility and control. Small rovers could use CARD or the semi-autonomous control scheme. CARD might be a viable mechanism for controlling small Mars rovers that would not travel very far from a parent lander, with the lander providing communications between Earth and the little rover. However, a mini- or microrover's view of the scene will be limited, just because of its size. In addition, providing a semi-autonomous minirover with the ability to carry its own semi-intelligent "brain" might be a problem.

An alternative may be to rely on programmed "behaviors" for the minirovers. Rodney Brooks and his



***RIGHT:* This is a one-eighth-scale model of a mobility design for a large vehicle that might be used in a Mars Rover Sample Return mission. Scaled up, this "Bickler pantograph" would have 1-meter-diameter wheels and be able to surmount 1-meter-size obstacles. However, our tests with this design showed that it might get rocks jammed between the front and middle wheels—and so get stuck.**

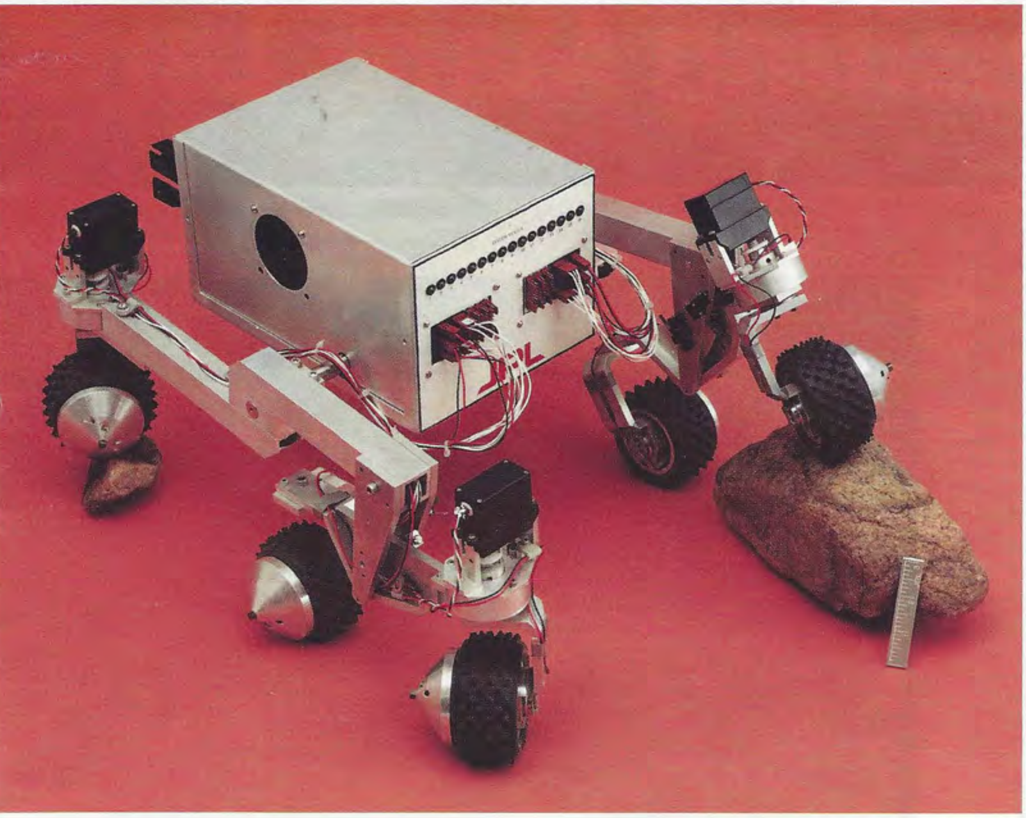
Photos: JPL/NASA



***RIGHT:* In this 1970s design, tank-like treads were used for mobility. This design type has been discarded for wheeled or legged rovers because the treads wear out quickly.**

students at the Massachusetts Institute of Technology have pioneered research into insect-like behaviors that might be used to guide and control small rovers. Brooks has programmed small, legged "ants" with a variety of hierarchical actions to enable them to walk, surmount obstacles and seek certain stimuli (e.g., light). David Miller and a team at JPL have applied similar concepts to wheeled vehicles, integrating insectile intelligences with the competent six-wheeled mobility systems developed by Don Bickler, Howard Eisen and Randel Lindemann, also of JPL.

Miller and Brooks believe that by applying these "subsumption control architecture" concepts to small rovers with good mobility, we can build vehicles that will obtain information and can be flown at low cost with small launchers. A JPL team led by Francis Sturms is developing concepts for rovers to carry small, simple instruments, such as spectrometers and cameras. For example, a 3-kilogram (7-pound) microrover might land with a simple network payload, and move away from the lander to bury a seismometer and/or place a simple spectrometer against a nearby rock to get geologic information. Alan Delamere



LEFT: The prototype Rocker Bogie is able to scale obstacles more than twice a wheel diameter in size (its wheels are five-eighths the size of the Bickler pantograph's). "Rocky" has had a computer brain added and is now being used in field tests as a minirover.

LEFT: This is an artist's conception of a full-scale Mars rover developed by FMC Corporation for NASA. Powered by the radioisotope thermoelectric generators in the rear, it has 1-meter-diameter, cone-shaped wheels, three bodies, and a robotic sampling arm on the front. The domed structure is a high-gain antenna for communicating with Earth.

of Ball Aerospace has studied an alternative concept, in which a minirover with a simple camera constantly scans the horizon and moves to the highest elevation it sees, repeating this action until it reaches a vantage point suitable for a panoramic view. Minirovers obtaining such panoramic views might compete with large, high-resolution imagers or even large multipurpose rovers for surveying possible human landing sites.

If small rovers, large rovers or a combination of the two do function as precursors, and human exploration of the Moon and Mars does take place, these humans also will need ways to get around on the surface. Human transport rovers can be *Apollo*-type dune buggies for short distances. For longer, exploratory travel, the rovers might have to be pressurized "RVs." Or perhaps "hoppers," propelled by locally produced fuels, might be used for astronaut surface travel (see the May/June 1990 issue of *The Planetary Report*). Human transport, like remotely operated "telerobotic" rovers, will have to operate in harsh conditions and mysterious landscapes. Like the horse, the rover will be the predecessor and the companion of human explorers.

Donna Pivirotto, formerly Manager of Rover Studies at JPL, is now Project Engineer for CRAF/Cassini.

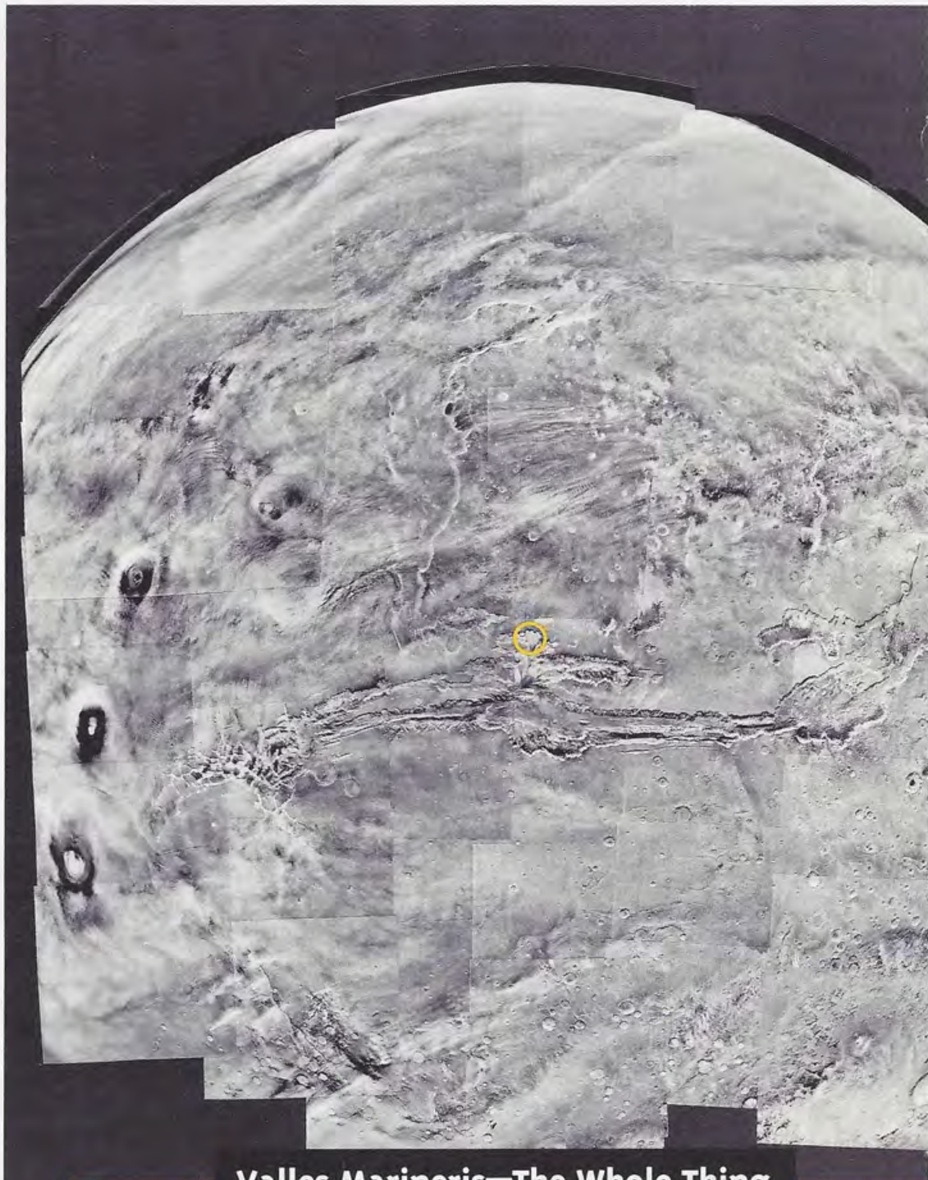
Revisiting Mars: Land

A planetary mission is expensive and difficult, and before it is over it will probably demand extraordinarily creative solutions to previously unimagined problems. It is understandable—if regrettable—that these missions are few and far between. Even the nearby planets, Venus and Mars, receive earthly visitors only infrequently.

So, if you are a planetary scientist, what do you do between missions? You can refine your technique, analyze your data in greater depth and massage your results to see if you can squeeze out anything more.

At the United States Geological Survey's Branch of Astrogeology in Flagstaff, planetary scientists continue to improve maps of the planets, and these tools help deepen our understanding of other worlds. (See the November/December 1990 *Planetary Report* for a discussion of planetary maps.) On these pages we illustrate how data from the *Viking* orbiters, which stopped operating over a decade ago, can still be used to give us new perspectives on Mars.

—*Charlene M. Anderson*



Valles Marineris—The Whole Thing

This mosaic of images taken by *Viking* Orbiter 1 on February 22, 1980, covers nearly an entire hemisphere of Mars. (An enhanced color version appeared on the cover of our May/June 1987 *Planetary Report*.) The three monumental volcanoes of the Tharsis Ridge appear at the left of the mosaic. The huge rift in Mars, running across the center, is Valles Marineris, often called "the Grand Canyon of Mars," although that appellation is misleading. Valles Marineris stretches over 4,000 kilometers (2,400 miles) around the planet. On Earth it would traverse the entire North American continent. Arizona's Grand Canyon would be swallowed up by one of its side canyons.

One of those northerly tributaries is Ophir Chasma (circled). With the low resolution of the images that make up this mosaic, it is possible, but not easy, to pick out a feature that could be a landslide at its northern edge.

Mosaic: USGS Flagstaff

slide in Ophir Chasma

Ophir Chasma—A Detailed View

This is a mosaic produced in 1983 using high-resolution *Viking* orbiter images. Now details of Ophir Chasma become visible. We see jumbled terrain on the canyon floor, tongues of material that seems to have flowed in the distant past, and the debris from a massive landslide (circled). With a map like this, we can imagine that we are closing in on the planet, seeing more and more of its secrets. Mosaic: USGS Flagstaff

Landslide in Ophir Chasma

This is what you can see with the help of a computer and advanced mapping techniques. We appear to have zoomed in as if we were flying over the surface of Mars. Below us are the remains of the immense landslide we could just pick out on the first mosaic. This breathtaking image, created by Alfred McEwen at the USGS in Flagstaff, shows how far researchers have come in their studies of Mars.

To construct this view, Sherman Wu's group at USGS Flagstaff first produced a high-resolution topographic map from the *Viking* data. Then spacecraft images of the area were pieced together and reprojected to register with the topographic map. The computer program then read the altimetry file (the digital data used to create the topographic map) and computed how a corresponding image would appear from different viewing angles. The computer then reprojected the data to produce what appears to be a three-dimensional image.

The View on Approach

The three arc-shaped slump scarps are about 25 kilometers (16 miles) wide and 4 kilometers (2 miles) high. The landslide debris flowed about 65 kilometers (40 miles) toward the observer. To give you an idea of the size of this slide, the amount of debris is about 9,000 cubic kilometers (2,200 cubic miles), or three orders of magnitude more than the debris from the 1980 eruption of Mount St. Helens. The curvature of the long grooves in the foreground indicates that the material flowed at about 77 meters (250 feet) per second. It would not have been easy to outrun this landslide.

Researchers like Dr. McEwen will continue to bring us closer and closer to knowing Mars. Fortunately, NASA's *Mars Observer* and the Soviet *Mars '94* and *'96* missions will soon be providing more data on the Red Planet. We are slowly getting to know our neighbor better and can look forward to even more spectacular views of Mars. Image: Alfred McEwen, USGS Flagstaff

Eugene Merle Shoemaker
A Pioneer of Planetary Science

by Bettyann Kevles

The* Apollo *landings on the Moon were missions more of politics than of science. Nevertheless, in his work at NASA Shoemaker succeeded in increasing their scientific return, and he taught the astronauts (mostly test pilots) a bit about geology. He is seen here during a 1965 training trip. ***Photo courtesy of Eugene Shoemaker***

Moon mapping was once the domain of astronomy, but by the late 1940s most astronomers had abandoned the study of the solar system for the exotic reaches of deep space suddenly visible through new, more powerful telescopes. Some still dismiss planets as the slag-heaps of the universe. Geologists, however, do not hear that word in a pejorative tone. Geologists, after all, make a living exploring "slag-heaps," concentrations of rocks and debris. They happily embraced the study of the solar system—planets, satellites and debris—and took on the appellation *planetary scientists.*

From the time when he began collecting rocks and fossils during frequent childhood moves—from California, where he was born in 1928, to Wyoming and New York—Eugene Merle Shoemaker wanted to be a geologist. He entered the California Institute of Technology in 1944, and three years later had a bachelor of science degree along with a scholarship to remain at Caltech for an additional year to earn a master's degree.

But while at the Caltech campus in Pasadena, Shoemaker became aware of the development of rocketry nearby at the new Jet Propulsion Laboratory. Rocket technology, he realized, would soon enable ships to reach the Moon. His ambitions shifted from Earth to space, and he set about to become the best lunar geologist, so he could be "at the head of the line" when selection time came for that first crew.

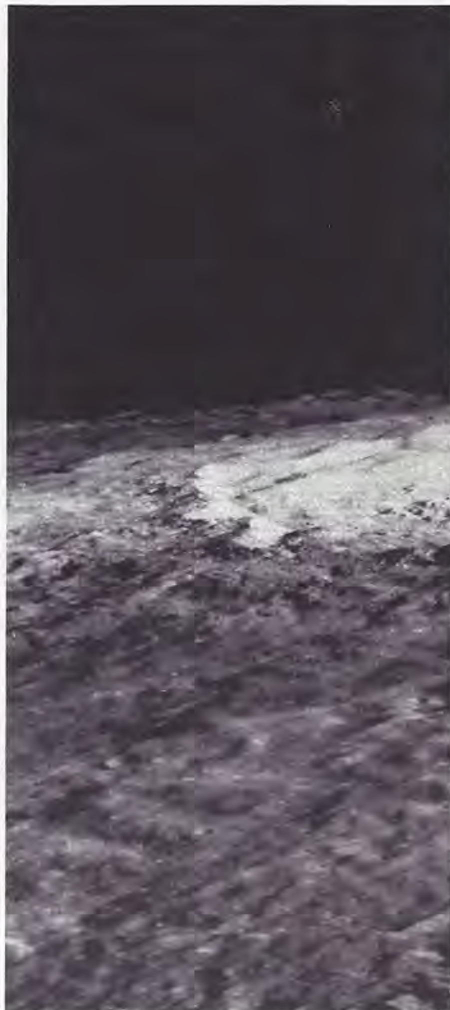
Shoemaker left Caltech in 1948 to join the United States Geological Survey, a bureau of the Department of the Interior, to which he has been attached, on and off, ever since. As a junior geologist stationed at first in Grand Junction, Colorado, he was assigned the tasks of uranium prospecting with a diamond bit drill, and the geologic mapping of the volcanoes and craters of the Hopi Buttes in Arizona. Somewhat later, the USGS decided that the Moon fell within its purview. In 1960, at the urging of Shoemaker, the USGS inaugurated a program in astrogeology and charged him with mapping the stratigraphy of the lunar crust. The job of mapping the Moon by telescope was carried out at a scale of one to a million, in quadrangles each about the size of Arizona.

By that time he had a good idea of what the geology of the Moon might be like, largely as a result of the work he had completed for his PhD thesis at Princeton University. This was a resolution of the half-century-old debate about the origin of Meteor Crater near Flagstaff in Coconino County, Arizona.

A Fingerprint in Star Dust

Meteor Crater, once known locally as Coon Mountain, is an earthwork about 180 meters (600 feet) deep and 1,200 meters (4,000 feet) in diameter with an earth collar rising about 45 meters (150 feet) around it. Until 1906, when the engineer Daniel Barringer suggested that the crater had been formed by a meteorite, it had been considered the explosion pit of a violent volcanic eruption. Throughout the early 20th century, geologists had taken positions for and against Barringer's explanation.

Shoemaker began to figure in the history of Meteor Crater as early as 1956, when he was examining craters left by nuclear tests. A fellow Caltech graduate, Ted Taylor, who had gone to work making bombs at Los Alamos, was exploring ways to retrieve plutonium from nuclear devices. One of Taylor's solutions was to explode a nuclear



device underground in salt. Shoemaker investigated craters left by small, shallow underground nuclear tests, then visited Meteor Crater and saw at once that it was geologically an enlargement of the nuclear explosion crater.

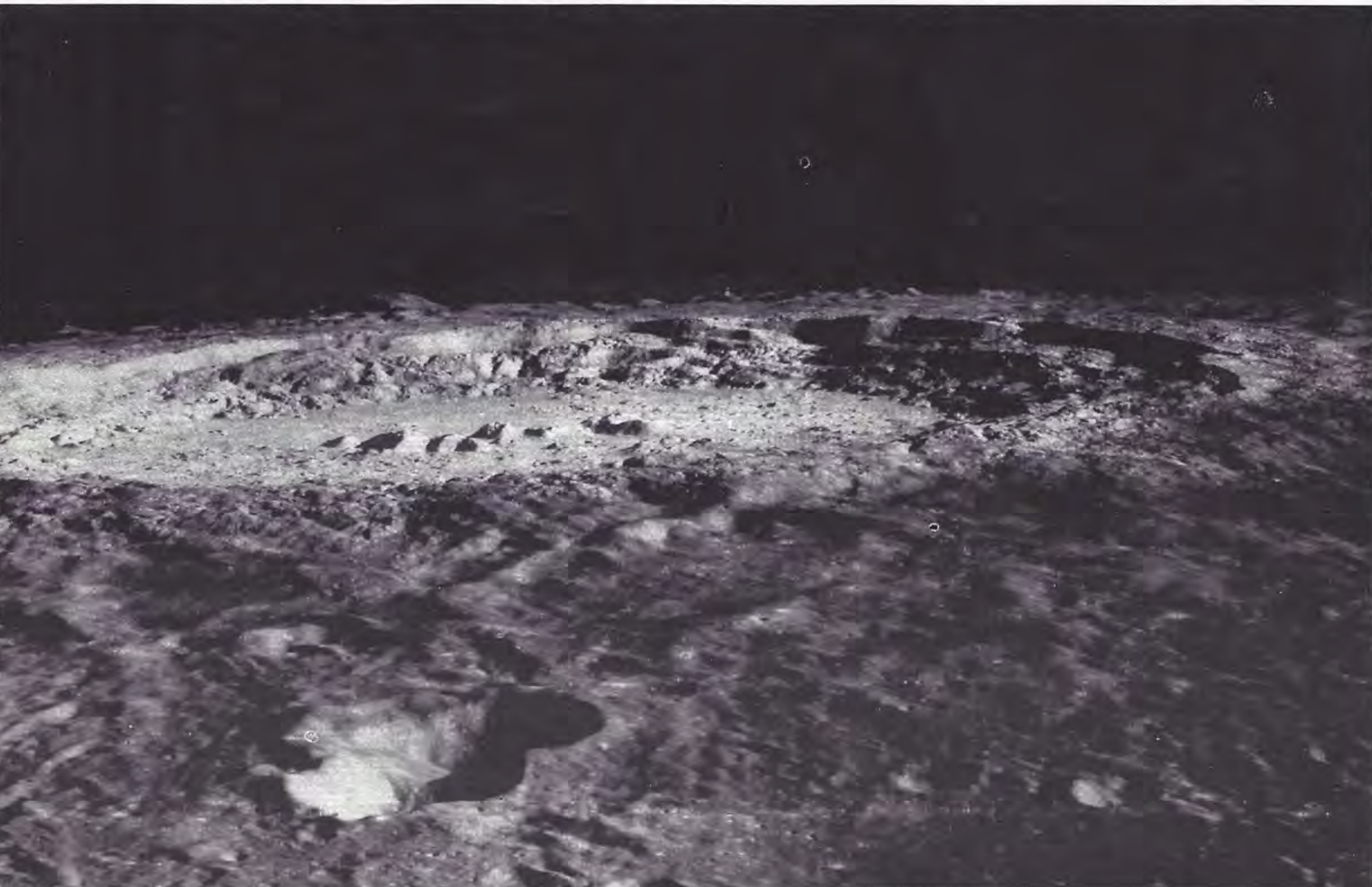
Shoemaker had taken two leaves from the USGS in the early 1950s to go to Princeton. His thesis, written after he left Princeton, proved that Meteor Crater had been created by the impact of a meteorite. (This validated the claims of a mining company that had leased part of the rim of the crater in 1932 and marketed a scouring powder they excavated as "star dust.") Shoemaker's initial conclusions were based on geologic field observations. The matter was settled forever when, together with Edward C.T. Chao, Shoemaker discovered the mineral coesite—a form of silica that can only come into being under enormous pressure—in shocked fragments of sandstone in and around the crater. Coesite cannot be explained by any other known geologic process. Shoemaker sums up the significance of his research: "We had discovered a fingerprint for impact."

Before delivering a paper about Meteor Crater at the International Geological Congress in Copenhagen in 1960, Shoemaker investigated a large eroded and degraded crater, the Ries Crater not far away in Bavaria. He declared it akin to Meteor Crater. Since then the number of meteorite craters identified by geologists has mounted to over a hundred, including impact craters in Ghana, Canada, France and Australia. The result, Shoemaker wrote recently, was "a major new paradigm . . . concerning the impact origin of craters found on the Earth, the Moon, and the other solid bodies in the solar system. This paradigm is the primary empirical support for the prevailing cosmogonic view that the Earth and the other terrestrial planets, as well as Uranus, Neptune, and the cores of Jupiter and Saturn, were formed by accretion of smaller solid bodies."

"Johnny at the Rat Hole"

Shoemaker's interest in Meteor Crater was in no small way whetted by its similarity to craters on the Moon. He had not been alone in recognizing the accessibility of the Moon by rockets. In 1956, the Air Force believed that the Moon had military potential, and under its aegis Gerard P. Kuiper directed a major photographic project. A year later, when Sputnik threatened our national scientific ego, acquiring knowledge of the Moon took on urgency. NASA was founded in 1958, and in 1960 the USGS organized its astrogeological unit with NASA support. It would soon become a branch headquartered at Flagstaff under Shoemaker's leadership.

Even seen from Earth, Copernicus is an impressive sight, but seen from just above the Moon's surface, this giant lunar crater is awesome. The crater itself is about 95 kilometers (60 miles) across; in depth, it approaches 3 kilometers (2 miles). Individual cliffs rise almost 1 kilometer (0.6 mile). Many impact craters are distinguished by a central peak formed by material rebounding after the initial shock. The central peaks here form a mountain range some 16 kilometers (10 miles) long and 600 meters (2,000 feet) high. Before the Space Age, geologists debated whether impacts or volcanism created such features. After spacecraft examination of the Moon—and Eugene Shoemaker's pioneering work—the question was settled. *Image:* Lunar Orbiter 2, *reprocessed by Jody Swann, USGS*



Being creatures of little brain, the dinosaurs had no idea of what hit them—if they were, indeed, wiped out by a giant asteroid impact. Collisions with asteroids and comets are an inevitable fact of life in our solar system. An estimated 1,500 travel in orbits that take them close to our own planet. If humans are to avoid a fate similar to that of the dinosaurs, it behooves us to find and track these objects. Shoemaker and his wife, Carolyn, along with Eleanor Helin (whose work is partly supported by The Planetary Society), are pioneers in the search for near-Earth asteroids. Painting: Don Davis

A year later, in 1961, President John F. Kennedy announced that Americans would land men on the Moon before the end of the decade. Shoemaker was ready. Manfred Eimer and Al Hibbs at JPL knew he was "keen to be Johnny at the rat hole" and got him, together with Harold Urey and Gerard Kuiper, on the *Ranger* scientific team, which was to image parts of the Moon on a much finer scale than looking through a telescope. Later he was involved with *Surveyor,* which made five soft landings on the Moon and, with television cameras, took pictures from the vantage point of a human being. These pictures convinced Shoemaker that the surface of the Moon would resemble a desert on Earth. He predicted that an astronaut's footsteps would sink only inches down. He also predicted that the craters on the Moon, considered by some theorists to be volcanic evidence that the Moon's interior was still molten and active, would be for the most part impact craters like Meteor Crater. Later he concluded, "From our knowledge of these terrestrial impact structures and craters, we have been able to establish with confidence the impact origin of most large lunar craters. From the combined evidence from the Earth and Moon we have learned to recognize impact craters on such diverse celestial bodies as Mercury, Mars and the icy satellites of Jupiter and Saturn. The record of impacts on the Moon and on Phobos and Deimos, the moons of Mars and the scars on the surfaces of

Jupiter's and Saturn's moons tell . . . the 4.5 billion year history of bombardment of the solar system."

In 1962, the USGS detailed Shoemaker to NASA, in Washington, DC, where he helped Oran Nicks, director of the Lunar and Planetary Programs Division, plan the exploration of the Moon. In 1963 he became acting director of a new NASA division of Manned Space Science. His priority—to get some science into the planned landing of astronauts.

Squeezing Science Into Apollo

The presidential directive had said that men would go to the Moon and return. There was no mention of doing anything while they were there. Shoemaker explains: "There was no science plan at all. Zero. Nothing. They didn't think the mission was for science. They didn't think the Moon was interesting. The program was being run by engineers" who, he explains, resented the intrusion of scientists. "NASA was like a feudal system with a weak king and strong dukes and I was a go-between among dukedoms."

An exception was Max Faget, at NASA's Houston Manned Spaceflight Center. Faget was the man who had helped sell the idea of a lunar mission to Kennedy and designed the lunar spacecraft. Said Shoemaker, "He had thought about compartments in the lunar landing modules for scientific equipment, but he didn't know what equipment."

Shoemaker hoped to be part of the *Apollo* crew, to collect lunar samples and do geologic field studies on the Moon. But an ongoing "rotten feeling" in 1962 was diagnosed as Addison's disease, a failure of the adrenal glands, and although cortisone allows him to live comfortably the condition disqualified him for space travel. Instead he was the Principal Investigator for geologic field investigations for the first three *Apollo* missions, and he helped select another Caltech graduate, Harrison "Jack" Schmitt, as the first geologist on the Moon.

A Moon Man

A whole generation has gone by since people stepped on the Moon, and Shoemaker is eager for scientists to return. There are lots of experiments waiting to be done, as well as a detailed examination of the lunar soil with its "3-billion-year history of radiation, bombardment, supernovae and the energetic processes of the Sun." Were he to go, he says, he would "take a shovel and a brush and dig several trenches in places that would have good layering, and dig down to bedrock with a small drill-rig." And what would he do on Mars? Nothing. That doesn't really interest him. "I'm a Moon man." And there's plenty more to learn there.

Having returned to the USGS in 1963, Shoemaker left again in 1969, to chair Caltech's Division of Geology and Planetary Sciences. He spent three and a half years as chairman recovering from the emotional stress of *Apollo*, including the fiery deaths of the *Apollo 1* crew, and going into "de-orbit." His research shifted from craters to the objects that make craters, especially asteroids whose orbits cross those of the planets.

Conveniently, Caltech operates the Palomar Mountain Observatory, which

As a geologist, Shoemaker dreamed of someday doing fieldwork on the Moon, but a medical condition prevented him from going himself. Instead, his fellow Caltech graduate Harrison H. "Jack" Schmitt became the first scientist to walk on the Moon during Apollo 17, *the last of the lunar missions.*

Photo: Johnson Space Center/NASA

Impact craters display certain traits that distinguish them from volcanic features. The lunar crater Alphonsus, some 130 kilometers (80 miles) across, is typical. A distinct rim, uplifted and overturned by the force of impact, delineates the crater. Within the crater walls lies a jumble of material that slumped inward as it settled back down. In large craters, a central peak or peaks often form as material rebounds after the impact. Scientists can estimate the age and history of a crater by how these features have softened or degraded over time. Alphonsus does show some signs of age.

Image: Ranger 9, *JPL/NASA*

boasts, in addition to the famous 200-inch telescope, an 18-inch Schmidt telescope with a wide field of view perfect for an asteroid search. For over a decade, Shoemaker worked with Eleanor "Glo" Helin, who is now at the Jet Propulsion Laboratory as Principal Investigator for the Planet-Crossing Asteroid Survey (PCAS), funded in part, in later years, by The Planetary Society (see page 23). Using the data available at the start of the program, they predicted that they'd find one or two new objects per year and were encouraged when Glo found the first, 1973NA, after six months. As they introduced new equipment, film and techniques, the rate of discoveries increased. In 1980 Shoemaker's wife, Carolyn, who had a flair for scanning the films, joined the search. Two years later, he began a separate program, the Palomar Asteroid and Comet Survey (PACS). The Shoemakers now work at the USGS in Flagstaff, and the two programs alternate observing runs at Palomar Mountain.

Target Terra

Meteor Crater alone is naked proof of the damage a meteorite can wreak. Shoemaker recalls that Earth is under constant bombardment from space-born projectiles in the form of comets, asteroids and meteorites. Usually, they have to be more than 150 meters (500 feet) in diameter "to make a crater-forming zing," Shoemaker acknowledges. Millions of the tiniest ones never make it to Earth's surface.

What interests him especially these days are the Trojan asteroids, swarms that cluster in two clouds near Jupiter. He believes that the Trojans are evidence of a violent time in the early days of the solar system, when a rain of planetesimals cratered the surfaces of the Moon and the satellites of the outer planets and collided with one another, sending some of these asteroids into eccentric orbits.

Asteroids hit Earth frequently. Shoemaker is a strong supporter of the theory posited by the late Nobel laureate Luis Alvarez that a collision of a body from space brought an abrupt end to the age of dinosaurs. Studies of comets, made largely of water ice, and meteorites, some containing amino acids, have convinced Shoemaker that Earth received its original water supply, and probably also the amino acids that combined to form the first life, from space. Referring to a scientist who has speculated that life bubbled out of a primordial soup, he says that "we don't need Stanley Miller's theories. It is clear that abundant organic chemicals came from space."

The flotsam and jetsam he studies, the by-products of planetary formation, may hold the secret of the origins of our solar system. His examination of these objects and his extrapolations of impact geology from Earth to the morphology of the Moon, the planets and their moons identify Eugene Shoemaker as one of the great pioneers of planetary science.

Bettyann Kevles is a science writer based in Pasadena.

By studying impact craters, scientists can learn much about the bodies on which they form. The force of the impact excavates material from beneath the surface, blasting it out into an ejecta blanket surrounding the crater. On the Moon, most ejecta seem to be simply material thrown out by the impact. On Mars, something else appears to have happened. Martian "splosh" craters are encircled by lobes of material that flowed out of the crater. Many scientists think that liquid water or water ice was responsible for this distinctive form.

Image: JPL/NASA

And the Discoveries Continue . . .

Asteroid Project Finds Six New Objects

by Charlene M. Anderson

Sometimes it can be hard to keep up with Glo. While we were finishing up this issue of *The Planetary Report,* Eleanor Helin (known to most of us as "Glo") of the Jet Propulsion Laboratory discovered three more near-Earth asteroids and a comet as part of the Planet-Crossing Asteroid Survey supported by members of The Planetary Society. In the first six months of 1991, Glo and her team (Ken Lawrence and Perry Rose, with occasional help from Jeff Alu and Chris Brewer) discovered a total of four asteroids and two comets, averaging one new object per month.

Two of Glo's discoveries, 1991AQ and 1991JW, are Apollo asteroids with orbits crossing that of Earth. (For an explanation of how asteroids are given numbers and named, see the January/February 1991 *Planetary Report.*) 1991JW is particularly interesting because its orbit is very similar to Earth's. A quick analysis of its orbit suggests that it is one of the best candidates yet found for a spacecraft mission. We will be keeping a close eye on this asteroid as researchers refine its orbit and investigate possible spacecraft trajectories to it.

The two other asteroids, 1991JG1 and 1991JX, are both Amors, traveling in orbits that do not cross Earth's but are still relatively close to us—within 1.3 Astronomical Units (an AU is equal to the average distance from Earth to the Sun, about 150 million kilometers or 93 million miles). Glo found 1991JX over a month before its closest approach to Earth, so she could alert other observers that the asteroid was coming by.

Astronomers from Arizona, Hawaii, Massachusetts and New Zealand were then able to make extremely precise astrometric measurements of the asteroid's position and so refine its orbit. These measurements enabled Steve Ostro of JPL and his team to point the giant Arecibo radar at 1991JX and obtain some "excellent radar data sets."

"These radar-ranging observations of 1991JX done at Arecibo, in terms of precision, are the same as if you measured the distance to a golf ball in New York City with a radar in Los Angeles having an error about the size of the golf ball," Ostro commented. The orbit of 1991JX is now pinned down precisely, and we know that the body itself is less than a kilometer across.

The two new comets, Helin-Lawrence (1991l) and Helin-Alu (1991r), both appear to be very large objects. Observers are still tracking them and refining their orbits.

Why Study Asteroids?

Asteroids are small bodies that may be debris left over from the formation of the solar system. Each of the nine large planets accreted when smaller bodies, perhaps similar to today's asteroids and comets, banged together as they traveled in intersecting orbits about our Sun. Some researchers believe that by studying the remaining small bodies close up we will come as near as possible to primordial solar system material. However, there is also evidence that asteroids and comets have evolved considerably since they formed, perhaps altering any surviving clues to our system's birth. The purpose of NASA's Comet Rendezvous Asteroid Flyby mission is to investigate these bodies close up and help determine their true natures.

Near-Earth asteroids have received a lot of media attention lately with the announcements of several types of complementary evidence that Mexico's Yucatan Peninsula was the site of a giant impact 65 million years ago—at the same time the dinosaurs disappeared. The now-leading theory for their demise is that an asteroid or cometary nucleus some 10 kilometers (6 miles) across collided with Earth at that time, altering our planet's climate and killing most living things. Many species, including all the dinosaurs, became extinct.

Separate research groups working in the Yucatan have uncovered evidence of a 65-million-year-old crater of the size—180 to 200 kilometers (110 to 125 miles) across—predicted by the impact theory. Scientists from the University of Arizona have found sedimentary deposits that look as if they were laid down after a giant impact. Another team, from NASA's Ames Research Center and JPL (including Planetary Society Special Consultant Adriana Ocampo), has discovered a ring of sinkholes that may have formed around the rim of a huge crater. Supporting evidence includes tektites (glass blobs melted by an impact) and debris washed ashore by tremendous tsunamis (tidal waves).

If an impact large enough to wipe out most of life on Earth occurred once, it could happen again. It is definitely in humanity's interest to discover and track as many of these objects as possible.

The clues they hold to our solar system's formation and the danger they pose to earthly life are compelling reasons to give more attention to near-Earth asteroids. The Planetary Society is also interested in these small, close-by bodies because they would be easy targets for spacecraft missions. These asteroid missions could serve as practice shots for much more ambitious human missions to Mars.

Continuing Our Support

For all these reasons, and because of her ever-lengthening string of successes, The Planetary Society is continuing to fund Glo Helin's discovery project as the centerpiece of our asteroid research program. We are now setting up an Asteroid Exploration and Discovery Fund to support Glo's work at Palomar Mountain, as well as Jeremy Tatum and David Balam's astrometry research at the University of Victoria in British Columbia.

Sometimes the keys to unlocking the greatest mysteries are found in the tiniest details. Although they are relatively small, asteroids have much to tell us about the evolution of the solar system and of life on Earth. At The Planetary Society we are working to help unravel those mysteries. And we are struggling to keep up with Glo.

Charlene M. Anderson is Director of Publications for The Planetary Society.

World Watch

by Louis D. Friedman

MOSCOW—The Soviet *Mars '94* mission, which was to have carried the Mars Balloon to the planet's surface, has been split into two parts, one to launch in 1994, the other in 1996.

Faced with budgetary problems, Soviet space industry officials decided that they could not satisfactorily test the planned descent module in time for the 1994 launch date. That module, which will carry the French-Soviet-Planetary Society Mars Balloon and the Mars Rover to the surface, has been delayed until 1996.

Mars '94 will now consist of a large orbiter with penetrators and small meteorological stations that will "hard-land" (as opposed to the "soft-landing" possible with the descent module) on the surface.

When word of this delay reached the offices of The Planetary Society, we sent a letter to the Soviets expressing great concern about the new plan. We noted that the international partnerships upon which this mission depends might be damaged by the postponement.

Many European nations are participating in the Soviet mission. As our members know, The Planetary Society is under contract to the French space agency to design the SNAKE guide-rope for the Mars Balloon. NASA is involved through the Mars Balloon Relay (see the May/June 1990 *Planetary Report*), which will fly on the United States' *Mars Observer*, scheduled for launch in 1992.

Soviet industry officials explained to us that there had been too many delays in receiving funds to ensure adequate testing of the descent module before launch. The balloon, the rover and the orbiter were all funded, but their "taxi" to the surface needed intensive, full-scale testing before it could be certified for spaceflight.

The split into two launch years will necessitate changes in the mission design. These are still being studied. The developments so far include:

- French space officials have said that they can accept the delay and will plan a new balloon development schedule. As a first step, they have renewed The Planetary Society's contract to design the SNAKE guide-rope for the balloon. They have even recommended that *Mars '96* carry two balloons instead of one.
- NASA officials have told the Soviets they cannot guarantee that the Mars Balloon Relay will still be operational in 1996. A new data return plan will have to be worked out.

UPDATE: THE NASA BUDGET

In late May we sent an urgent letter to our members in the United States, asking them to take action and write their congressional representatives in support of space science and exploration. NASA's budget for 1992 was then before the Appropriations Committee of the House of Representatives. We were concerned about the major cuts then being contemplated for space science, planetary missions and programs to prepare for the human exploration of space.

Our concerns were well founded. On June 6, the entire House of Representatives debated the US space program for a full day. Given current budgetary priorities and constraints, the issue boiled down to a stark choice: Cut either space station *Freedom* or nearly every other NASA program.

Our position was clear: The Planetary Society has strongly supported and, indeed, has led the popular advocacy for human space exploration. We have fought for precursor robotic missions to the Moon and to Mars, and for research into the effects of long-duration spaceflight on humans.

To study the latter, a space station is necessary. However, *as it is now designed*, space station *Freedom* is not that station. *Freedom*'s design has been widely criticized by the very community it is supposed to serve. The Space Studies Board of the National Research Council, the White House Office of Science and Technology Policy, the Congressional Budget Office, the Office of Technology Assessment, the American Physical Society, the American Geophysical Union and other scientific groups have concluded that this space station will not fulfill either of the stated purposes of its builders: research into microgravity materials processing and study of the effects of long-duration spaceflight on humans.

To be an effective platform to prepare for human interplanetary flight, a space station should enable things such as development of closed-loop life-support systems, astronaut stay-times exceeding 60 days, and a centrifuge to simulate variable gravity. Space station *Freedom*'s supporters maintain that it will someday be able to support these functions. But they are not in the current plan or budget.

If the US space program were robust, other elements could take up the slack in the space station plan. But the new, constrained NASA budget severely cripples all other projects, particularly those involving space sci-

• The Soviet rover team is actually more comfortable with the 1996 launch. At their request, The Planetary Society has agreed to participate in their testing program.

• The Soviets will have to build another spacecraft to carry the 1996 descent module. The payload of this spacecraft, if any besides the descent module, will have to be decided.

• Because of the weight freed up by the removal of the descent module, the orbit of the *Mars '94* spacecraft could be changed. This might make it possible for it to achieve a lower orbit, thus improving the quality of its data.

Although we were disappointed by the delay of the descent module, it was not entirely a surprise. Both the Soviet and American Mars programs have been affected by economic problems. The launch of the *Mars Observer* had previously been pushed back from 1990 to 1992. NASA had also cut its participation in the Visible/Infrared Mapping Spectrometer (VIMS), an instrument being developed with the French for inclusion on *Mars '94*.

We will keep you informed of further developments.

PASADENA—In a severe blow to the *Galileo* mission now en route to Jupiter, the main communications antenna has failed to deploy properly. If it remains stuck, the scientific return from the mission could be seriously degraded.

The antenna, which is about 5 meters (16 feet) in diameter, is similar to that successfully deployed several times on the Tracking and Data Relay System Satellites (TDRSS).

Looking like a furled umbrella, the antenna had been closed to help protect it from the heat of the Sun as the spacecraft made its earlier pass by Venus. In early April, mission controllers at the Jet Propulsion Laboratory commanded the antenna to deploy, but it seems to have opened unevenly, rather like an umbrella with some of its ribs stuck together. Since the antenna must achieve a precise parabolic shape, it is useless unless it deploys properly.

Mission controllers have been in communication with the spacecraft through its small, low-gain antennas, but the rate at which they can send and receive data is considerably lower than that possible using the large parabolic antenna.

The goals of the *Galileo* mission are to send a probe into Jupiter's massive atmosphere and magnetosphere, and to send an orbiter repeatedly through its system of large moons. If the large antenna cannot be fully deployed, the probe's mission will be relatively unaffected, since it transmits its data at a low rate that can be accommodated by the smaller antennas.

The orbiter is designed to make close-up observations, including detailed high-resolution images, of the moons Io, Europa, Ganymede and Callisto. These data will be most seriously affected by the antenna problem.

In October of this year, *Galileo* will fly by the asteroid Gaspra. It will make its observations as planned, record them and transmit them to Earth at the slower data rate.

The spacecraft team is studying the problem and searching for solutions. Nothing yet is known for certain. Most theories center on the temperature changes that *Galileo* has experienced on its circuitous route to Jupiter. An early guess was that heat from the Sun had melted solder. A recent suggestion is that differential cooling of spacecraft parts froze some moveable parts in place.

One "rescue" possibility, albeit a last resort, is to send a small communications relay satellite on a fast trajectory to Jupiter. It could then relay *Galileo*'s data to Earth. However, this approach is not yet being officially considered.

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

ence and planetary exploration.

Thus, we felt it would be better to cut space station *Freedom* to preserve NASA's other programs. With these programs (relatively) safe, we could then advocate a redesigned station that would support human space exploration and complement, not compete with, science. This position was consistent with the recommendations of the Advisory Committee on the Future of the US Space Program (the Augustine Committee; see the March/April 1991 *Planetary Report*). The committee recommended that science should be NASA's number one priority.

But the House of Representatives saw the matter differently. They voted to keep space station *Freedom* and to cut NASA's other programs. $505 million was cut from the proposed space science and applications budget, almost certainly ensuring the end, curtailment or postponement of the Comet Rendezvous Asteroid Flyby and *Cassini* missions, the Advanced X-Ray Astrophysical Facility, the Earth Observing System, the Search for Extraterrestrial Intelligence and many life sciences programs.

In addition, with over $600 million cut from space transportation and $160 million cut from aeronautics and space technology, all work on the Space Exploration Initiative (SEI) was eliminated, so the preparation for human missions to the Moon and Mars will cease. This will also eliminate the *Lunar Observer*, Mars rovers and other robotic precursor missions, as well as a new heavy-lift launch vehicle for the US—which, ironically, the Augustine Committee had noted would greatly help NASA's space station effort.

The week following the House vote, the Synthesis Group, chaired by Thomas Stafford for the White House National Space Council, released its report on the future of human space exploration. The group proposed four scenarios that could take us back to the Moon and on to Mars—the goals of the Space Exploration Initiative. Space station *Freedom* played only a minor role in their report, although it will have a major, and negative, effect on the realization of the group's proposals. With all studies of SEI stopped by the House vote, the report of the Synthesis Group was rendered moot.

As we go to press, the Senate has yet to act on the NASA budget. There will be differences between the House and Senate versions, which will be resolved in the Conference Committee. We will keep you informed as the situation develops. *—LDF*

News & Reviews

by Clark R. Chapman

There was widespread popular support for the space program in the 1960s, despite some skeptics who thought *Apollo* was a "moondoggle." During the 1970s, NASA's ambitious plans were descoped by budget cuts that were an economic consequence of earlier guns 'n' butter policies and were ratified by a decline in public support, which coincided with the inward-turning malaise in the national psyche. Despite renewed public interest in space, NASA has been suffering of late from the national budgetary crisis, which can be blamed in large part on the deregulated giveaway of hundreds of billions of dollars to the speculators and financial manipulators who went hog-wild in the 1980s. On top of that, we had the setbacks associated with the *Challenger* tragedy. Now, in the 1990s, the nation and the international community of spacefaring nations are making the choices that will determine the future of space exploration for the next generation.

If you want to tune in to the debates about goals and means among the most enthusiastic supporters of space—both the dreamers and the pragmatists—try reading *Ad Astra*, the magazine of the National Space Society (NSS). This glossy monthly magazine, which runs about 50 pages an issue, serves the members of NSS the way *The Planetary Report* serves members of The Planetary Society, but there are more differences than similarities. For one thing, *Ad Astra* carries advertising, and it is now being sold at specialty newsstands and museum stores, not just to NSS members. Let's glance through the June issue.

The articles conform to the interests of the majority of NSS members, who—according to a survey discussed in the issue—put space station *Freedom* at the top of their list of priorities and robotic programs toward the bottom. The anonymous writer of this article interprets the poll as showing that NSS members want, among other things, to defer exploration of the near-Earth asteroids (one of my own pet interests), so the "near-Earth asteroids will have to wait to receive major NSS support."

Ad Astra's editors are open-minded about a free and wide-ranging debate within its pages. Space is given to views as disparate as Admiral Truly's stout defense of the space station and one letter writer's preference for robotic missions (he calls the shuttle "a leech on the space program"). Mention of robotic spacecraft abounds, with pictures of the *Cassini* probe, reports about *Galileo* and the Gamma Ray Observatory, and even feature stories about the Kuiper Airborne Observatory and the Comet Rendezvous Asteroid Flyby (CRAF) mission. Pictures from *Landsat*, *Voyager* and the Hubble Space Telescope grace *Ad Astra*'s pages.

Being a Bird on Titan

A closer look, however, reveals that the feature articles are slanted toward human interest and technology rather than toward the scientific and intellectual goals of NASA's projects and missions. What little science is presented is often oversimplified or downright wrong. (For example, few comets, if any, "zoom inward" toward the Sun because of collisions with another comet in the Oort Cloud.) There is little awe about the universe expressed in the pages of *Ad Astra*. Scientific knowledge about the solar system is valued chiefly for its potential application to human exploration. For example, *Cassini*'s projected studies of the Saturn system are reported only in the context of a fantastical, far-future mission to Titan that would pave the way for colonization of that frigid world, where human beings would use strap-on wings as "an easy and pleasant form of personal locomotion."

In contrast to NASA's plodding, bureaucratic course, I applaud the optimistic spirit and creative speculations of *Ad Astra*'s writers. One of them thinks that the SETI program (Search for Extraterrestrial Intelligence) should concentrate on looking for alien artifacts, especially alien probes left in stable orbits near Earth. Hans Mark would have people landing on Mars by the year 2003. Unfortunately, the dreams are belied by economic and political realities.

The *real* side of NSS is its political advocacy for one or another version of the space station and for the entrepreneurial commercialization of space. As for the space station, it looks (as I write) as if the United States House of Representatives has heeded the call of the NSS (not to mention the lobbying of the aerospace industry and the Bush administration) and saved *this* leech of the 1990s at the expense of space science. NASA's Office of Space Science and Applications, already strapped for funds, will probably lose half a billion dollars. *Ad Astra* need spend few pages in its future issues on such likely-to-be-canceled missions as CRAF.

Space Commerce

Things aren't going so well for the NSS version of the space program, either. An undercurrent of resentment about NASA's stodgy ways runs through many of *Ad Astra*'s articles. And the economic consequences of the savings-and-loan scandal are preventing NSS' legislative victories from bearing fruit in the commercial arena. One article in the June issue, for example, chronicles Geostar Corporation's filing for Chapter 11 reorganization.

In short, *Ad Astra* mirrors both the wild hopes and bitter disappointments of space activists. Whatever its leanings, *Ad Astra* is developing into an important forum for popular discussion of the space program.

Clark R. Chapman is editor of a new section of the American Geophysical Union's flagship technical journal, the Journal of Geophysical Research—Planets.

SOCIETY *Notes*

A THANK YOU TO OUR MEMBERS

Planetary Society members' response to the Mars Rover test and development project has been outstanding. The money already raised (final figures are not yet in) exceeded our goal. Many thanks to all of you for so generously providing the funds to make the rover project happen.

With these funds, the Society has been able to accept the Soviet invitation to work with them in testing the Mars Rover for what will now be the *Mars '96* mission. We will also be able to expand our promotion and development of Mars surface exploration.

Testing of the current prototype will take place in September in Siberia. The next stage will be tested early next year in the Mojave Desert in California. As soon as the dates for the Mojave tests are set, members will be informed. *—Louis D. Friedman, Executive Director*

MORE ROVER NEWS

We are working with the Smithsonian Institution's National Air and Space Museum and the NASA Office of Exploration on a rover exposition to be held in 1992. The expo will showcase the mobile robots now being developed to explore planetary surfaces.

We have also established contact with most of the rover groups in the United States and in Europe and will work to stimulate international development of rovers. *—Susan Lendroth, Manager of Events and Communications*

MARS BALLOON WORK CONTINUES

Our Mars Balloon and guiderope (SNAKE) project is moving along. Balloon engineering team member James Cantrell, who started out as a Utah State student and Society volunteer and went on to become the chief designer of the SNAKE, is working on the project in Toulouse, France, on a two-year appointment for the Society (but paid for by the French space agency, the Centre National d'Études Spatiales). In the US, we continue system design, testing and risk assessment. *—LDF*

NEW AFFINITY CARDS TO BENEFIT SOCIETY PROGRAMS

The Planetary Society will soon be offering its members a credit card—in fact, two of them, a Designer Visa® Gold Card and a Designer Visa Classic Card.

Called *affinity cards*, the credit cards permit members to promote the Society by using (and showing) them. Each time the card is used, a percentage of the sale is contributed to Planetary Society projects.

The cards offer members the same or better benefits at the same or lower interest rate as other bank cards. But this one helps support our projects. You will be getting a letter about the affinity cards. *—LDF*

SOCIETY HOSTS EVENT IN JAPAN

The Planetary Society helped launch Japan's program for International Space Year (ISY) 1992 with a standing-room-only event in Tokyo on May 11. Co-sponsors were Japan's Institute of Space and Astronautical Sciences (ISAS), the Foundation of Space Science Promotion, the Japanese Rocket Society and the University of the Air Foundation.

Speakers included Dr. Jun Nishimura, Director-General of ISAS and a member of the Society's Board of Advisors; Professor Hitoshi Mizutani and Dr. Yasunori Matogawa of ISAS; Dr. Keiji Nitta of Japan's National Aerospace Laboratory; and Society representative Susan Lendroth. The event was the first of many the Society will hold to celebrate ISY around the world. *—SL*

IT'S OFFICIAL

We're happy to report that The Planetary Society has become more directly involved in the world community, thanks to our new status as a non-governmental organization (NGO) having consultative status with the Economic and Social Council of the United Nations.

Although the UN is not involved in space exploration per se, it is a major force in space education, sponsoring such programs as educator workshops. It also provides a useful forum on the development of international space policy in its Committee on the Peaceful Uses of Outer Space (COPUOS).

We have now started a cooperative project with COPUOS sponsoring workshops for educators on planetary sciences. Building on our success in Mexico (see the May/June 1988 *Planetary Report*), we are planning other workshops in Latin America in the next two years. *—LDF*

SPACE ART AT THE SMITHSONIAN

"Art of the Cosmic Age" is the title of a new exhibit now at the Smithsonian Institution's National Air and Space Museum in Washington, DC. More than 70 works by noted space artists from around the world are being displayed.

The exhibit is part of an international tour put together, with Planetary Society assistance, by the International Association for the Astronomical Arts, an organization of Western artists, and their Soviet counterparts, the USSR's Union of Artists.

You've seen the paintings of many of these artists in the pages of *The Planetary Report*. The exhibit, which opened in May and will close in December, is well worth a look. *—Charlene M. Anderson, Director of Publications*

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Questions & Answers

Does lightning on other planets produce thunder as we know it on Earth, considering the differences in atmospheric density and composition?
—Leo J. Tellier, Jr., Temple, Texas

Lightning has been detected in planetary atmospheres by a variety of different sensors, including optical and radio, but never acoustically. The Soviet *Venera 11* and *12* landers included acoustic sensors, but the noise of the air rushing by the spacecraft on descent apparently saturated these sensors.

Lightning produces thunder in Earth's atmosphere by creating a hot, ionized channel that collapses rapidly after the electrical discharge has ceased. The sparse evidence we have on the intensity of lightning in the atmospheres of other planets indicates that it is similar to or greater than that of terrestrial lightning. Thus, even given the different electric charge carriers that probably exist in the atmospheres of other planets and the different compositions of these atmospheres, we expect that electrical discharges will produce hot, ionized columns and the consequent thunder, just as on Earth.
—CHRIS RUSSELL, *University of California, Los Angeles*

If a planet's greenhouse gases won't let its radiated heat escape into space, how does the Sun's heat get past them in the first place?
—Iva Svitek, Centreville, Virginia

Part of the key to your question is that the Sun's heat is concentrated at visible and near-infrared wavelengths of the electromagnetic spectrum but Earth radiates this energy back at much longer wavelengths, the so-called "thermal infrared." There is almost no overlap between the wavelength of the incoming sunlight and the wavelength of the heat radiated back by Earth.

Ordinary window glass is designed to be very transparent to sunlight, and by chance is opaque to the thermal infrared radiation coming from objects on the other side of the pane from the Sun. The interior of a greenhouse made of such glass can become very warm indeed.

A greenhouse also takes advantage of the lack of cooling winds. Early in this century, the importance of the winds was emphasized by the imaginative Johns Hopkins physicist, Robert W. Wood. He made a model greenhouse with windows of rock salt, which does not block the thermal infrared. It still got hot in the sunlight, although not as hot as a glass one. So greenhouses don't necessarily operate entirely by the greenhouse effect, but some planets do.

Earth is the best example of a greenhouse planet in which most of the sunlight does get to the ground, unless it is intercepted by clouds. There are small percentages of "greenhouse gases," such as carbon dioxide (CO_2) and water (H_2O), in our atmosphere that are opaque to thermal infrared. These gases trap enough sunlight to keep our planet's surface temperature cozy enough to allow water to exist in its liquid state, and so make Earth the haven for life that it is.

However, all that is really needed to create greenhouse warming is a few percent of the total incoming sunlight, as long as the blanketing of the thermal in-

As lightning cuts its narrow path through the air, the temperature rises almost instantaneously to about 15,000 degrees Celsius, causing the air in the channel to expand explosively. These thunderbolts were photographed over Colorado Springs on what must have been a less than peaceful night.
Photo: Roy Johnson/ Tom Stack and Associates

frared by greenhouse gases is thorough enough. This is the situation on Venus, where the greenhouse generates a temperature of hundreds of degrees. Saturn's moon Titan experiences similar but much less spectacular effects. Mars illustrates the opposite extreme, where a large fraction of the sunlight reaches the surface but there is not enough greenhouse blanketing to have much warming effect at all.

—D.M. HUNTEN, *Lunar and Planetary Laboratory, University of Arizona*

If our Moon were in the outer solar system, would it be able to retain an atmosphere there, where it is much colder?

—William Biewener, Burbank, California

This is an interesting question because it incorporates many ramifications of modern science. Atmospheres are held down by gravity. The atoms and molecules of gas are in constant motion, and if one is directed upward from a layer in the upper atmosphere high enough that it doesn't hit another atom, then it will travel out into space. If it is moving fast enough, it will escape from the planet. This is how atmospheres, given enough time, leak off planets.

The outermost atmosphere layer where atoms have a realistic chance of not hitting still higher atoms is called the *exosphere*. The higher the temperature, the faster atoms move, and the faster the rate of gas escape from the exosphere. Therefore, scientists usually say that the rate of a planet's atmosphere escape is controlled by the exosphere's temperature.

You are right in suggesting that in the cold outer solar system escape rates are usually slower, and the chances of a given body retaining an atmosphere are generally greater at larger distances from the Sun. However, if the temperature is too cold, many gases may freeze and form an ice layer instead of an atmosphere.

As for the Moon, let's divide this into two questions. One, if the present Moon were moved out there, would it have an atmosphere; and two, if it formed out there, would it have an atmosphere?

The answer to the first question is no, because the Moon has no volatile compounds—the kind that give rise to gases when heated. The Moon apparently formed from very hot debris blown out of Earth's mantle by the giant impact of a Mars-sized body 4.4 billion years ago, and so all of its water and other volatiles were driven off into space by the heat of that event. Also, it has too little gravity to attract an atmosphere from the thin interplanetary gas of the outer solar system.

Now, if the Moon had formed in the outer solar system, it probably would be composed of a mix of ice and carbon-rich soil. In this case, it probably would have an atmosphere, because any episodes of heating, such as large impact, internal radioactivity, or tidal forces (as on Io), would change the ice to gas.

We can test this idea by looking at real moons in the outer solar system. Remember that our moon is 3,476 kilometers (2,160 miles) in diameter. The largest satellites of Jupiter, Ganymede (5,262 kilometers or 3,270 miles) and Callisto (4,800 kilometers or 2,980 miles) have negligible atmospheres, being the closest outer-planet moons to the Sun, though Ganymede has polar frost caps, testifying to some vapor activity. In contrast, Saturn's moon Titan (5,150 kilometers or 3,200 miles) has an atmosphere thicker than Earth's.

One satellite almost the same size as our Moon has atmospheric traces. Jupiter's Io (3,630 kilometers or 2,260 miles) sustains a very thin volcano-derived atmosphere and even a torus—a doughnut-shaped cloud—of thin gas in its orbit, because it is being heated by tidal forces.

One satellite even smaller than our Moon has a bona fide atmosphere; Neptune's Triton (2,705 kilometers or 1,680 miles) amazed *Voyager* scientists by having haze layers, clouds and spouting geysers, though the atmospheric pressure is only 15 millionths that of Earth. Its heat source is somewhat mysterious, but may involve tidal forces.

Most moons of still smaller sizes are too small to retain gas or be geologically active, but there is at least one enigma: One of *Voyager*'s parting shots of Saturn's moon Enceladus (500 kilometers or 310 miles) showed a hint of an eruptive plume. Enceladus also seems to be the source of a torus of particles around Saturn. Tidal heating may produce occasional eruptions and gas even on such a small world.

—WILLIAM K. HARTMANN, *Planetary Science Institute*

FACTINOS

Antarctica was once connected to the western coast of North America, according to geologists Eldridge M. Moores of the University of California at Davis and Ian W.D. Dalziel of the University of Texas at Austin.

They said several clues led them to their conclusion. The strongest is a rock formation, the Grenville Front, that runs from Quebec through the Adirondack and Appalachian Mountains and cuts through central Texas and California. A range of Grenville-like rock that would fit with the front was found in eastern Antarctica, the researchers said.

Their theory holds that Earth's land masses were once arranged so differently that North America looked like a slice of pizza between Antarctica and South America. The geologists say the single continent was near the equator. Earth's appearance changed in the late Precambrian era—about a billion to half a billion years ago—before life emerged from the sea.

—from the Associated Press in *The New York Times*

NASA researchers believe they've found the first surface evidence marking the buried impact crater formed by the comet or asteroid impact that may have caused the extinction of the dinosaurs. They say a ring of sinkholes in the northeastern corner of Mexico's Yucatan Peninsula outlines the largest known impact crater on Earth.

Charles Duller of NASA's Ames Research Center discovered the ring formation. Two other members of the research team are Kevin Pope, formerly of Ames, and Adriana Ocampo of the Jet Propulsion Lab. "The apparent age, location and size of the proposed Yucatan impact make it one of the best candidates for the global catastrophic event, although multiple impacts remain a possibility. Regardless, the Yucatan impact alone would have had a devastating impact on the climate, animals and plant life of the Earth," Pope said.

—from NASA's Ames Research Center

All the other planets in our solar system could be placed inside the planet Jupiter.

—from the *Weekly Reader*

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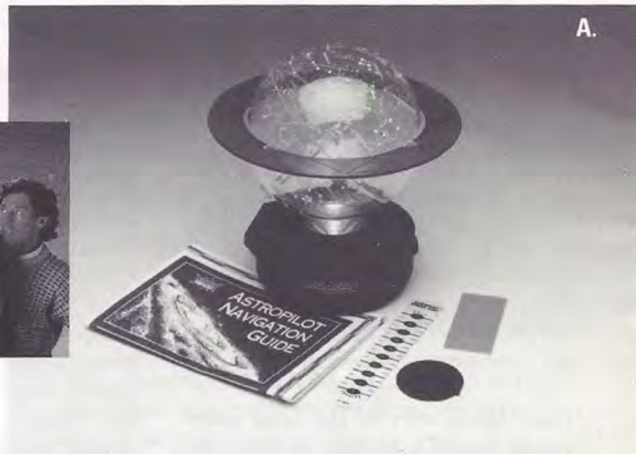

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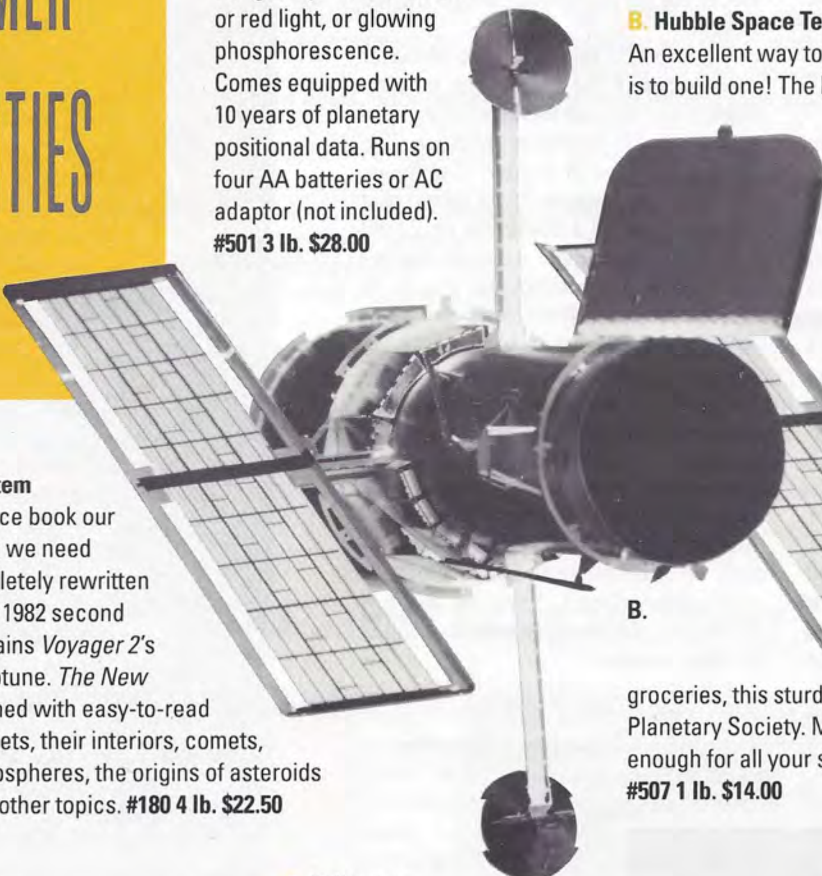

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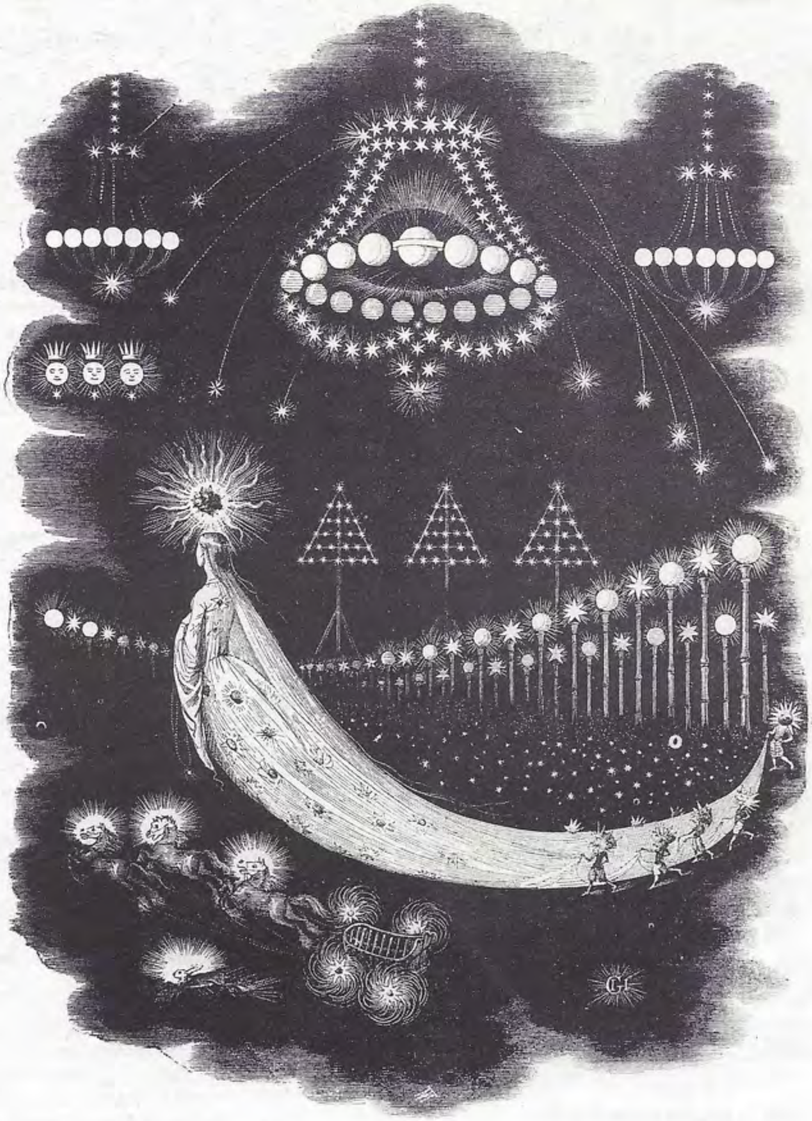

The nineteenth century French illustrator Grandville was highly celebrated in his day for his perceptive caricatures of what he called "the comedy of life." In his satires people usually took the guise of animals, although he did produce a variety of nonanthropomorphic illustrations.

"The Passage of a Comet Across the Sky" appeared originally in his illustration series Un Autre Monde *(Another World). Below her is the Big Dipper.*

From Fantastic Illustrations of Grandville, *Dover Publications, Inc., New York, 1974.*

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