The PLANETARY REPORT

Volume XV Number 6 November/December 1995

More Steps to Mars

On the Cover:

The hard, rocky planets lead violent lives, bombarded from space, riven by tectonic forces, beset by volcanic eruptions, and their faces bear the scars. This is the Memnonia Fossae region on Mars. Here we see impact craters that have been weathered by wind and possibly water, partly filled in by lava from the great Tharsis volcanoes, and then, for the large crater at the top, cracked apart by tectonic forces. By determining the order in which such scars form, scientists piece together the history of a planet. (This image covers an area 206 kilometers, or 128 miles, across.)

Image: Alfred McEwen, United States Geological Survey

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From The Editor

This is a time of retrenching for planetary exploration. This ambitious endeavor is facing economic and political threats from those who see no future for humanity among the planets. To counter these threats, we must understand the *why* behind humanity's exploration of the solar system. To turn our vision of the future into reality, we need a firm concept of what that future could be.

In the months and years to come we will be calling on all our members to write, call, fax, e-mail or in other ways ask space policy makers, legislators and administrators to support planetary exploration programs. In the first two articles in this issue, we've tried to provide material to help Society members focus their thoughts in preparation for the coming campaign.

We invite you to read these articles, digest them and keep them for reference. Even if current and planned planetary missions survive this year's round of budget cuts, there will be more campaigns to come. We must prepare as best we can for a very long haul.

—*Charlene M. Anderson*

Features

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The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, 818-793-5100. It is available to members of The Planetary Society. Annual dues in the US are $25 (US dollars); in Canada, $35 (Canadian dollars). Dues in other countries are $40 (US dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

A Publication of **THE PLANETARY SOCIETY**

Members' **Dialogue**

NASA Budget

As a retired aerospace engineer who has worked on the *Atlas-Centaur* and Surveyor programs and on military aircraft programs, and also as a member of The Planetary Society, I find Clark R. Chapman's comments about the recent NASA budget reductions (see the July/August 1995 *Planetary Report*) to be insensitive, naive and parochial.

Insensitive in that they support government spending for NASA without regard to the many social and economic issues facing the world today. Congress and the administration are planning severe cuts in Medicare and social services in spite of the fact that the elderly population is growing and we have crises in our inner cities that approach genocide. Does Mr. Chapman believe that NASA's programs are more important than solving these problems? Does he also believe that attracting more talented people to aerospace work should take precedence over trying to attract them to careers that could help solve our social and economic problems?

Naive in that they do not recognize that the huge reduction in military spending has ruined the careers of many aerospace workers, resulting in increased profits while these workers were put out on the streets.

Parochial in that they represent the same old attitude of "don't gore my ox," when sacrifices have to be made for the good of many, and maybe all of us.

I strongly believe in planetary exploration and scientific advancement, but also believe that everyone should share in getting our country "on track" both economically and socially.

—ROBERT R. REIMER,
Florissant, Missouri

In answer to Mr. Reimer's speculations on my beliefs: No, I do not believe that NASA's programs are "more important" than solving problems of the elderly and inner cities. No, I do not believe that talented people should be attracted away from social services and economic planning to study the stars. (I do think that those young people whose talents lie in the area of physics, mathematics and engineering, and whose inspirations come from the stars, should have the opportunity to follow careers that will benefit the country by using their talents. Those with different talents can help our society in their own individual ways.)

As a scientist in a democracy that is growing increasingly uneducated about science and technology, I think it is my responsibility to argue that these endeavors are vital to the future of our country and our civilization, which I passionately believe is true.

What I also believe is that our society requires a *balance* between caring for our urgent concerns and investing in the future. Investing in science and education will not immediately cure problems in the inner cities, but if we spend everything putting out today's fires, we will have lost the future.

Most of my column dealt not with NASA's absolute funding level (in comparison with other societal funding needs), but with current attempts to change priorities and ways of doing business with NASA. My argument was that one important element of what NASA does is in danger of being destroyed, by blunt attempts to dismantle and reorganize some of the most productive scientific research groups in the world. Science research is a delicate process of creativity, and the real insensitivity lies inside the Beltway, where ignorant people try to fix institutions that are already working well.

It is shortsighted to view scientific research as another pig at the federal trough.

—CLARK R. CHAPMAN,
Tucson, Arizona

Preserving the Moon

In response to Takao Tanikawa and Nan Y. Hiraiwa's letter in the May/June 1995 issue of *The Planetary Report*, the European Space Agency's Lunar Science Advisory Group (LSAG) has placed great emphasis on the preservation of the Moon for future scientific investigations. Preserving the Moon's environment from anthropogenic perturbations is at the center of the preoccupation of LSAG and of ESA.

We are well aware that there may be difficult conflicts to solve between the need to preserve the environment on the one hand and the potential exploitation of industrial resources and the robotic or human activities on and around the Moon on the other hand. ESA takes this issue very seriously and welcomes all initiatives and reflections on matters aimed at securing the future use of the Moon for scientific purposes.

The costs foreseen for the MORO and LEDA projects are capped at a total of $460 million US dollars each, including launch and operations costs. These two projects are presently in the study phase. If approved, LEDA would be scheduled for launch in 2001.

—R.M. BONNET, *Paris, France*

Gravity Assist

A correction, please, to your story on gravity assist in the May/June issue—the idea long predates JPL's superb 1960s explanation. The first reference I know of is "Perturbation Manoeuvres" by Derek F. Lawden in the *Journal of the British Interplanetary Society*, Volume 13, Number 5; September 1954.

—ARTHUR C. CLARKE,
Colombo, Sri Lanka

Please send your letters to Members' Dialogue, The Planetary Society, 65 North Catalina Ave., Pasadena, CA 91106-2301 or e-mail tps.des@genie.geis.com.

WHAT IS THE VALUE OF SPACE EXPLORATION?

Within The Planetary Society, we can sometimes take it for granted that everyone shares our belief that planetary exploration is inherently valuable to humanity. Once, perhaps, it was easier to argue that the future of our species lay in space. But the world has changed much since the hopefully named Space Age began nearly 40 years ago. The nations whose citizens once envisioned a future in space are now focused on economic woes, civil strife and environmental degradation. Some of us still maintain that hope, however, and it is our responsibility to see that it does not fade away.

In the next few months and years, critical decisions will be made that will determine that future. As citizens, we can make our voices heard, and we must strive to make our arguments convincing. With this in mind, we have printed here a selection of ideas presented at a symposium entitled "What Is the Value of Space Exploration?," held at the National Geographic Society headquarters in Washington, DC, on July 18 and 19, 1994. We offer these ideas in the hope that you will find them useful in framing your own ideas about the value of space exploration, and they will help you in convincing others of the value of this endeavor we support. —*Charlene M. Anderson*

Space exploration has contributed perhaps more than any other scientific venture to an increased level of scientific curiosity throughout society. Public understanding of space exploration, and of science and technology in general, will ensure that the public understands the value of investing in knowledge for the future. —*M.R.C. Greenwood, White House Office of Science and Technology Policy*

With a 1-in-1,000 chance that a comet or asteroid 1.5 kilometers in diameter could collide with Earth within the next 100 years, a significant human presence in the inner solar system beyond the Earth is mandated. It is safer for the human species if we're on many worlds than if we're on only one. —*Carl Sagan, Cornell University*

We need to build a truly commercial space infrastructure that can stand apart from the military–industrial complex. A true space exploration program is such a project: new space transportation vehicles unrelated to ballistic missiles, cargo ships from low Earth orbit to Moon orbit, housing on the Moon for hundreds of workers, astronomy centers on the far side of the Moon. A proposal this large will engage the Russians. It will allow them to further develop Western-style trade practices. It will keep a generation of American engineers employed. It allows us to dream as one people, not as a multitude of nations. It is impossible to depict the specific value of space exploration in the near term, so we must learn to accept the concept of long-term rewards. Who knows how strong the US and Russian civilian aerospace industries might be today if, instead of downsizing, they had begun the retooling for a mission to Mars years ago, and how much sooner the Cold War would have ended?
—*Jeffrey Mamber, NPO Energia Ltd.*

Those first photographs of our entire planet, the very notion of an Earthrise over the Moon, or the concept of a crescent Earth rising over the Moon provided a thrill which is still with me. But while there's thrill, there's also philosophy, and there's also scientific advance. After all, futurist Buckminster Fuller's famous metaphor of Spaceship Earth did fuel the environmentalism of the 1970s and onward. I don't mean to exaggerate the power of an icon, but I wouldn't underplay it either. This is a philosophically and intellectually transforming icon as well as an aesthetic thrill.
—*Stephen Jay Gould, Harvard University*

Space exploration and technology have been instruments which have led not only to great advances in natural science, but contributed to fundamental changes in human society; for example, space-based data gathering contributed to nuclear disarmament, European unification, and the collapse of communism. The Soviet government denied the Chernobyl nuclear accident until other nations produced satellite imagery of the damaged reactor; this incident was a final contributor to lack of confidence in a system which couldn't exist in the modern world with space technology and the diffusion of information. —*Paul Gray, European Commission*

Without a vision, the people perish. —*Charles Bolden, Jr., US Naval Academy, paraphrasing Proverbs 29:18*

According to standard econometric models, there's no good reason to argue that a dollar invested in NASA will yield anything more than a dollar of value elsewhere, in the short- or long-term. But given that economic growth depends on innovation in the long run and that our economy is increasingly dependent on knowledge, we need some way of driving innovation and expanding knowledge, and NASA seems to serve these purposes.
—*W. Bowman Cutter, National Economic Council*

People say that our space program is a luxury and that we should really be concerned about food for the hungry and medical aid for the needy, that to those whose stomachs are empty, the space program is merely a waste of money, it's

not only a waste of money but it's an insult to the human race. Well, I happen to have the good fortune to spend most of my time among people who recognize the invaluable contribution that space research has made to our daily lives. If somebody were to ask me that question, I would reply that I know of a geomorphologist who travels to Third World countries in order to maximize land use, to grow crops that will feed millions where only thousands were fed before. His tools are not the hoe and the spade; his tools are satellite transmissions from space, his knowledge comes from highly sophisticated computers perfected by NASA. The people he feeds, in fact, are fed by the space industry.
—Majel Barrett Roddenberry

The Moon landing brought us face to face with our own fragility and the fragility of our planet. The diversity of life on this planet is based on the weakly bonded but versatile chemistry of carbon in an aqueous environment. Its fragility and versatility was an essential component of evolution, but it is rapidly damaged by confrontation with the fundamental atomic forces which are loose in space. This confrontation with fragility requires humility from persons, institutions, and even nations, but from this humility can arise a great strength if we realize that the true exploration, space exploration, is a voyage of the human spirit. *—Paul Gray*

After *Sputnik*, the government provided a great infusion of money to build the infrastructure to compete with the Soviet Union in science and technology: high school curriculum development, elementary science teaching, and graduate centers of excellence, including facilities, equipment, and faculty. NASA itself financed research programs and even buildings on college campuses.

All these actions helped to expand and broaden the base, economically and strategically, of certain Americans' cooperation. As a result, the nation produced more engineers, physicists, mathematicians, and so on, creating the human capabilities required to meet the technical requirements of the emphasis to get to the Moon. Thanks to space exploration, we have moved from the industrial age to the information age. There can be no information age without space.
—Frederick Humphries, Florida A&M University

There's an increasingly high value to increasing international collaboration in space as well as in other areas, for obvious foreign policy reasons. With the end of the Cold War, we need a new kind of glue, a new basis on which to work together.
—W. Bowman Cutter

Like beauty, the value of space exploration is in the eye of the beholder. To some, the value may be intrinsic scientific merit; to others, it may be technical accomplishment. To some, it is a sense of pride, a stirring of the spirit, an opportunity for vicarious wandering, wondering, or entertainment. To yet others, maybe it's a pragmatic expectation of tangible economic gain in the quality of life or a means of attracting young people to study science or engineering. To some, it's competition. To others, it's cooperation. To many, the value is an a la carte combination of these. To others, there may be very little or no value associated with exploration. Which of these should guide federal space activities? Whose values should count? Whose should be weighted most heavily?
—Molly Macauley, Resources for the Future

There is a desperate need for a positive vision of the future. We need it for our children. What organization in the US government, in the natural course of doing business, offers a positive view of the future? What agency is future-oriented by its very nature? What agency excites the visions of young people, makes their hearts beat a little faster, makes them imagine doing exciting exploratory things when they grow up? As far as I can tell, there's only one such organization, and that's NASA. *—Carl Sagan*

What I'd like to invite you to do is look forward to a time when exploration will be the province of everyone, when it will be possible to explore by remote sensing in a way that provides the same information humans would provide. Already, we're starting to see real space discoveries being made by school kids, using Earth-based exploration technologies such as telescopes. More and more of these kinds of discoveries will be possible using those technologies that we call virtual reality. Let's take the example of Mars. We're going to need to reconnoiter the planet. In the future, geology students will be able to do real geology on Mars, in their classroom. We're going to see the potential for a greatly expanded role for exploration precisely where we need it: among young people, who traditionally have had so much to do with those roles in society that exploration fulfills. Exploration is inherently unpredictable and, as such, potentially upsetting, but it's also vitally necessary for our society.
—Timothy Ferris, University of California, Berkeley

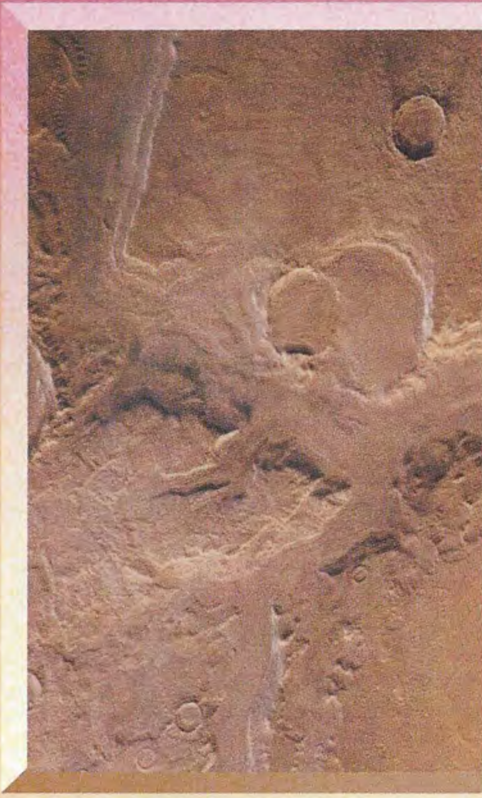
Space exploration has generally stirred a positive response among artists, affirming positive values, a sense of human potential, and of beauty, a serene cosmic consciousness, soaring inspiration and optimism. Much of the art inspired by space exploration defies the cynicism of our age. It does what the liberal arts and humanities are supposed to do: capture beauty, celebrate human achievement, lift the spirit into the realm of the universal. For this antidote to intellectual malaise and spiritual drift, space exploration has been of value in our culture.
—Valerie Neal, National Air and Space Museum

Why are we now traveling into space? Why indeed did we trouble to look past the next mountain?
—Gene Roddenberry, quoted by Majel Barrett Roddenberry

Note: This symposium was sponsored by the Mission From Planet Earth Study Office—a part of the Office of Space Science at NASA Headquarters—and the University of Maryland at College Park. It was hosted by the National Geographic Society. The Symposium Proceedings, from which the comments in this article were drawn, are available from the University of Maryland at College Park by calling 301-405-8052 or faxing a request to 301-405-9966.

STEPS TO MARS II

A CONFERENCE REPORT



***REULL VALLES:** Mars' surface is cut by channels that may have been formed by running water billions of years ago, when a denser atmosphere supported a warmer climate. This fretted channel, Reull Valles, dissects the wall of the Hellas basin, one of the largest impact scars on the planet. Nearby hills and mountains (seen at bottom right) are surrounded by debris aprons that may have been formed by the creep of rock lubricated by near-surface ice. (This image covers an area 161 kilometers, or 100 miles, across.)*

The road to Mars is long and hard, but we've made considerable progress in the short history of The Planetary Society. For us, the journey began in July 1985 in Washington, DC, at a conference that we called Steps to Mars. Then, at a time when planetary exploration was low on the agendas of most nations, United States Senator Spark Matsunaga chose to announce his plans for the International Space Year, which became a reality in 1992. When Soviet–American cooperation was a topic mostly forgotten, we honored the *Apollo–Soyuz* crew on the 10th anniversary of their groundbreaking flight. When NASA was steadfastly not studying human flight beyond Earth orbit, Carl Sagan issued a call for an international human mission to Mars.

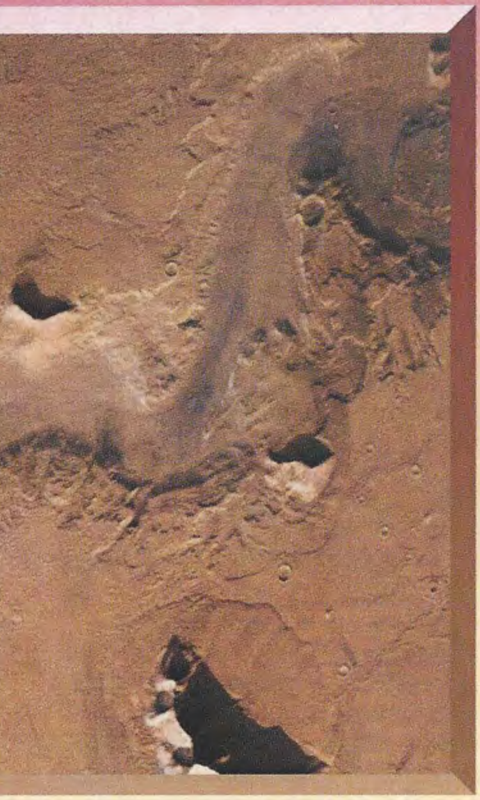
Looking back, these were real, significant steps to Mars. This past July, we again gathered the leaders of the world's space programs to discuss the next steps toward the human exploration of the Red Planet. These steps will be based on concrete achievements: Three launches are scheduled for 1996, with three more to follow in 1998. The US, Russian, Japanese and European space agencies are all developing new Mars missions. Russia and the US have merged their human spaceflight programs, and, just before the conference took place, we saw the completion of the rendezvous of the US space shuttle *Atlantis* with the Russian space station *Mir*.

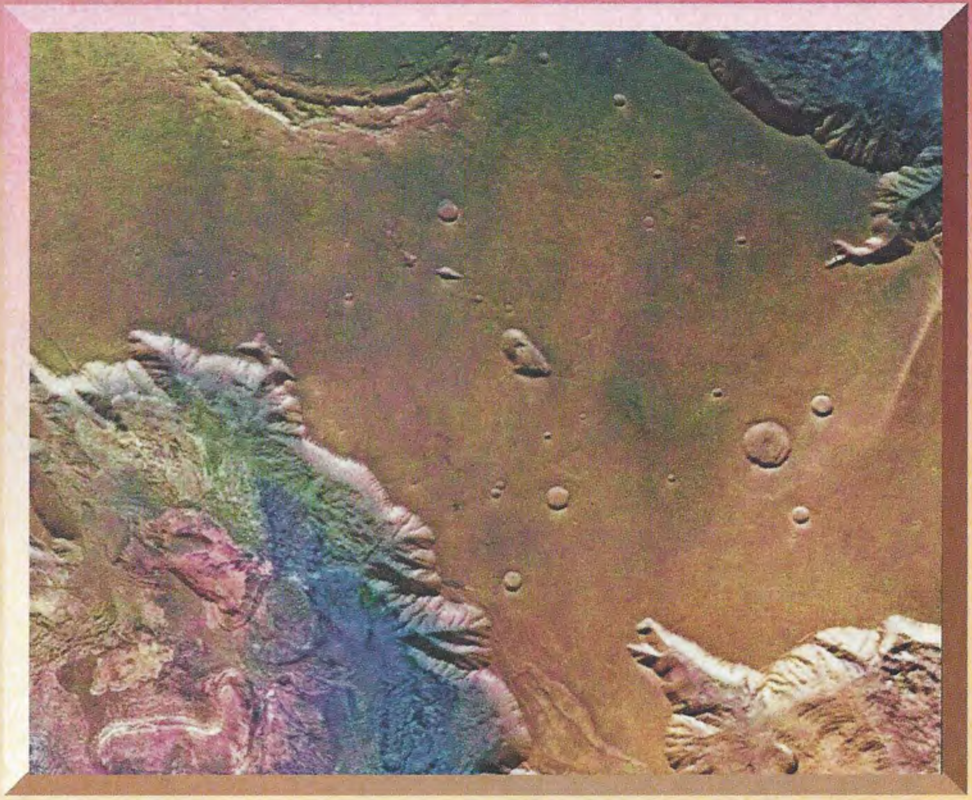
Even with all these successes, the world of 1995 is not quite ready to embrace a goal as lofty as sending humans to Mars. Space exploration budgets continue to shrink. No human Mars mission is under development. The future of Russia's space capability is in doubt. NASA and the US aerospace industry are undergoing profound changes.

Thus, we felt it was again time to consider the way to Mars. With the American Astronautical Society and the Association of Space Explorers, we organized Steps to Mars II, held at the National Academy of Sciences in Washington, DC, on the 20th anniversary of the *Apollo–Soyuz* mission. We gathered with the shuttle–*Mir* rendezvous of the previous week fresh in our minds. We were joined by astronauts Robert "Hoot" Gibson, shuttle commander, and Bonnie Dunbar, mission specialist, who shared their thoughts about space exploration from the perspective of those who had just made history. American astronaut Norm Thagard, with Vladimir Dezhurov and Gennady Stekalov, who flew with him on *Mir*, joined us by special audio link from Houston.

This generation of astronauts shared the stage with Alexei Leonov and Tom Stafford of the *Apollo–Soyuz* crew and the first generation to step off Earth. They spoke of the children of today, who will be the generation to first walk on Mars.

At the first Steps to Mars, Academician Roald Sagdeev, head of the Soviet Space Research Institute (IKI), spoke about cooperation on the way to Mars. This year, Professor Roald Sagdeev of the University of Maryland continued on this theme, joined by his successor at IKI, Alec Galeev. Academician Vladimir Utkin of the Russian Space Agency filled us in on the human spaceflight program. NASA Administrator Dan Goldin presented his vision of the future in space, while Donna Shirley, head of the Mars program at the Jet Propulsion Laboratory, detailed the robotic missions





WEST CANDOR CHASM:* *By enhancing the colors in images taken through the colored filters of spacecraft cameras, scientists can deduce quite a bit of geologic history. Here we see the parts of central Valles Marineris, the Grand Canyon of Mars. Candor Chasm is at the lower left, Ophir Chasm at the lower right and Hebes Chasm at the upper right. The complex layered terrains in these canyons may have been deposited at the bottoms of lakes, so such areas may be ripe targets for future fossil hunters. The pinkish area in Candor Chasm may be hydrothermal deposits. (This image covers an area 231 kilometers, or 143 miles, across.) *Images: Alfred McEwen, United States Geological Survey*

now being prepared. Arnauld Nicogossian, president of the American Astronautical Society, moderated the program.

We share here some selections from the conference. It is our hope that we will hold another conference in July 2005, as a rally calling for the spacefaring nations to grant a "new start" for a human mission to Mars. *—Louis D. Friedman, Executive Director*

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ARNAULD NICOGOSSIAN: This conference, Steps to Mars II, helps us sharpen our focus on human space exploration—as societies, and as informed citizens. As we celebrate the anniversary of *Apollo–Soyuz,* we have to think about all the steps that we have taken so far to explore space, and about where we are today. We have to think about accelerating these steps to explore the solar system in the 21st century.

The 1975 *Apollo–Soyuz* mission was the first international piloted mission after we visited the Moon. The crew demonstrated that the two big spacefaring nations can work together, and that their engineers and scientists can perform great deeds when they are called upon.

Today, as we attend this conference, people are working in space. The *Mir 19* crew, which was brought by the shuttle *Atlantis* to space station *Mir,* is now in orbit continuing the joint experiments that were started on *Mir 18* and the shuttle. We were also informed that *Galileo* released its probe yesterday.

So, robotic missions and human missions are taking us into the future. That's what the conference is about. And we would like you to carry this message.

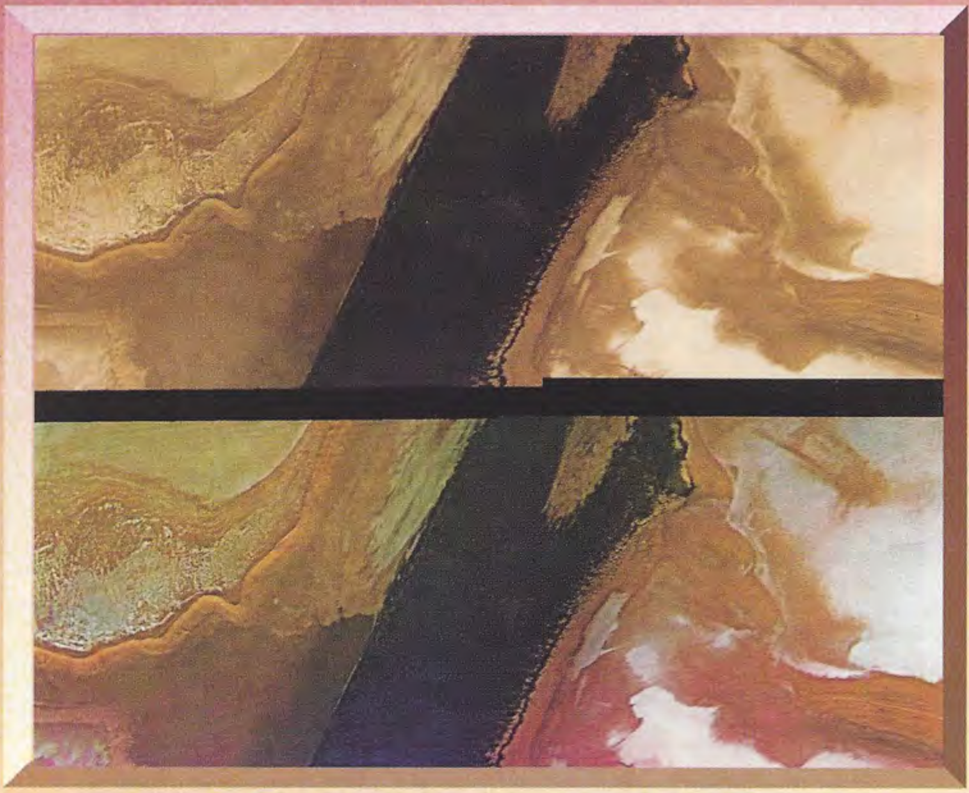
ROALD SAGDEEV: An extremely important step would be to look for primitive extraterrestrial life. Only Mars is keeping alive the hope, because there is no chance to find life on any other planet.

The *Viking* biology experiments were quite disappointing for all of us. But we shouldn't completely abandon the chance to look for extraterrestrial life on Mars.

One particular scenario which we were considering in the Soviet space program focused on the chance of there being primitive microbial life on Mars. Samples to be returned to Earth had to go through special biological screening. We had a huge debate as to how to bring about an internationally accepted planetary quarantine—so we wouldn't contaminate extraterrestrial bodies with terrestrial forms of life, and to eliminate the risk of bringing back to Earth unknown forms of microbial life.

So, in this particular mission that we were planning for Mars, we were almost ready to adopt the strategy of chemical warfare. The sample of Mars soil had to be chemically treated in order to kill any potential microbes we would bring back to Earth. Then our biologists were thinking about how they could reconstruct the idea of extraterrestrial life on Mars by studying the dead bodies of microbes.

I would like to live until the moment when we humans on this planet would be able to discover the existence of extraterrestrial life.



***NORTH POLAR CAP:** As on Earth, a residual north polar cap of water ice remains on Mars even during the summers, and that permanent ice is seen here as the brown-colored area. A seasonal frost of nearly pure ice partly blankets the permanent deposits. Linear sand dunes (the dark band) lie in a large trough, which exposes the layered deposits that record the history of Mars' weather and climate. The color of the lower half has been enhanced to bring out subtle variations. (This image covers an area 106 kilometers, or 66 miles, across.)*
Image: Alfred McEwen, United States Geological Survey

ALEXEI LEONOV: I knew Thomas Paine for many years: a very good scientist, very big organizer, a big citizen of not only the United States, but of our Earth. During the early 1970s, he was in correspondence with Academician Keldysh. [Their discussions led to the *Apollo–Soyuz* mission.] You probably remember the Cold War period. They were very courageous in their efforts. And the same applies to Mr. Kosygin and Mr. Nixon [under whose administrations the mission flew]. They knew that we came very, very close to that black hole, that canyon.

They had to come up with a great alternative—with a grand plan so that the people of the world would be able to understand that there was something else, apart from the Cold War and competition, that would work. Finally, in 1973, such an agreement [beginning the mission] was signed. For the first time, the two crews met each other.

We had a lot of problems. During the first stages of our work together, we heard one word quite a few times—incompatibility. Incompatibility of the construction, the life support systems were incompatible, the onboard atmospheres were incompatible, the communication systems were incompatible. Herbert Smith, the chief of the mixed group, said, "If you have decided to cooperate, there are absolutely no problems that cannot be solved."

As it got closer to the flight, we got rid of all the problems, and the most popular words of that period were "no problem."

We've experienced a period of incompatibility between our two countries. We understand each other now, and we want to meet each other. When I was at the Jet Propulsion Laboratory together with the shuttle–*Mir* crews, I saw a huge banner. And on that banner I saw words which surprised me with their wisdom: "Together We Are Better." Only good people could say words like that.

A few years ago, we were discussing with Tom Paine the possibility of a manned flight to Mars. When we took into consideration all of our resources, and the political situation, we decided to set a date: 2015, 2017. We could fly today, if you are talking about technology. People have been in space for a year and a half already. Life-support systems have been in orbit for 10 years, and that's enough to go to Mars and back three times.

But still the most important aspect of this flight is the crew. The day before yesterday, Tom Stafford and myself met with the NASA recruits, the youngest astronauts. Nice young people with a lot of experience as test pilots, but already they are older than 30. Absolutely the same kind of group exists in Russia. If we started training them now, aiming at 2015, 2017, not too many of them will survive to that time. Therefore the best candidates for this kind of crew are little girls and boys.

The boys and girls we saw yesterday with the Red Rover, Red Rover project amazed us with their ability to work the computers and rovers and to communicate by a computer modem with different parts of the world. But it is necessary to say that these groups have to be international. They should know a little more than 300 words [the total vocabulary the *Apollo–Soyuz* crew said they had in common]. They have to know the whole vocabulary of humanity.

DAN GOLDIN: Today, I want to paint a picture of some of the possibilities for humankind in space. I want to take you on a fantasy journey to Mars, where we'll see robots building the first cityscape on Mars and astronauts searching for signs of early life.

Our first job is to map the planet from orbit. Toward this end, we'll send small, low-cost orbiters to Mars in 1996, 1998 and 2001. The first Mars *Global Surveyor* will be launched in '96 to map the geology and topography of Mars. The second orbiting Surveyor in 1998 and the third in 2001 will fill in that map and examine the atmosphere and climate, in addition. They'll also search for water in the atmosphere, on the surface and just below the surface. These two orbiters will also complete the orbital communications network of three orbiters going around Mars. Future landed missions will use the network to communicate back to Earth.

Our second task is to scout selected areas on the martian surface with landers and rovers, using information we obtained from the orbiters. We'll need to examine the local conditions, rock and soil types, the potential for water and other resources and signs of the planet's history. We'll send a series of small, low-cost landers to many different areas of Mars. Then we'll determine the one or two sites we'll go to, to actually bring back samples.

Let me talk about the first of our landed missions. There will be a microrover to provide mobility on the surface. *Pathfinder* is only the first. We'll send similar landed missions in 1998, 2001 and 2003. (I might point out that the Russians are also sending a robot in '96. We have a payload on their lander in '96 and they may have a payload on our lander in '98.)

We'll send more landers in 2005. They'll be part of a large international effort to place a network of landers on the surface of Mars. This includes a network of seismometers to understand the interior of Mars and a network of weather stations to understand martian weather and climate. Imagine getting a weather report from the polar station on Mars on the 11 o'clock news every night.

After we finish scouting the global diversity of the Mars surface with small landers, we'll be ready for a sample-return mission. That could happen as early as 2005, maybe even as early as 2003. Also by then, we hope the Mars Surveyor program will involve other countries on planet Earth so we can all go to Mars together. A sample return is just the beginning. We'll need ways to move around on the planet. We're looking at a range of things, from microrovers like *Pathfinder*'s to larger ones built with the Russians for larger area coverage. We're looking at super-pressure balloons—the possibilities are fascinating.

As we move toward the possibility of launching the human mission in 2018, here's what we'll have accomplished. Our scientific exploration will have done detailed surveys of sites we want humans to examine for subtle, hard-to-find evidence of life. We'll have scoured the surface to find out where water and other resources are most accessible. When we've found the best sites and studied them with more robots, the world—and I emphasize the world—will send the first human beings to the planet Mars. We'll also have figured out how human beings can live and work in space for long periods. We'll learn much of this aboard the international space station. In the process, we'll benefit the people of Earth. That's part of our new way of thinking at NASA.

Let's fast-forward a little further ahead. It's 2018, just moments before *Mars 1* takes off on its two-year mission. It will take them six or seven months to get to Mars. They'll spend 30 days on the surface, and they'll take 14 or 15 months to get back. Right now, they're on the launch pad. When they get to low Earth orbit, they'll transfer to the Mars vehicle. Once they're aboard, they'll talk to Mission Control in Houston. They'll also talk to operations centers in Kaliningrad, Bavaria and Tsukuba.

Once they arrive on Mars, the astronauts have three basic missions to perform. One, they will do things connected with finding past life on Mars. Two, they'll be doing things to support life in the present. And three, they'll be doing things for life on Mars in the future.

Let's start with life in the past. Suppose that robots have located areas that appear highly probable for containing fossil cell life. The next step is for humans to confirm that revolutionary finding. They'd carefully select the most promising rocks, which they'll bring back to the base for study.

The *Mars 1* crew will also worry about life in the present. They'll need to make a place on Mars where humans can survive and grow and do research. Humans won't go to Mars alone. They'll go as a community of life-forms, bringing with them seeds and plants grown on the trip.

Photo: Margaret Bourke

Mars Hill: It's Official!

Perseverance pays off! Thanks to longtime Society member Alan Silverstein, Mars Hill in California's Death Valley National Park—the site of The Planetary Society's 1992 Mars Rover tests—has been formally named by the United States Geological Survey's Bureau of Geographic Names. Now that it's official, future maps of the area will list Mars Hill by name.

The name itself is nothing new—this boulder-strewn, kidney-shaped mound was nicknamed Mars Hill in the mid-1970s by the planetary science community because the terrain of the hilltop resembles the *Viking* mission's landing sites on Mars. Naturally, this rugged little "bit of Mars" was an excellent place to test the boulder-navigating abilities of the Russian-built robot that will explore the Red Planet in earnest a few years from now. (For a detailed report on these tests, see the November/December 1992 and January/February 1993 issues of *The Planetary Report*)

Reading about the tests inspired Alan to visit Death Valley in January 1993; during his visit he was able to find some of the spots where the published photos were taken, including those captured by the rover itself! After checking to see if a formal proposal to name the hill had been filed by anyone else (it hadn't), Alan began his mission, writing letters and making phone calls. In June of this year he finally received his answer from the USGS.

The Planetary Society plans to keep the Death Valley Visitor Center stocked with information about the rover tests and the Russian mission so that anyone who is curious will be able to learn about Mars Hill's significance to future exploration of the Red Planet. —*Donna E. Stevens*

After a year-long contest in which over 3,500 entries from around the world were submitted, the name "Sojourner" has been chosen for the microrover that will soon explore Mars. Valerie Ambroise, 13, of Bridgeport, Connecticut, submitted the winning essay, which explained why the 19th-century abolitionist and women's rights champion Sojourner Truth should be honored by having the robot named for her. Valerie received her award during the Steps to Mars II conference and was also presented with a rover T-shirt bearing the name "Sojourner" by Donna Shirley (left), head of the JPL Mars program, and Louis Friedman (right), Planetary Society Executive Director. The second-place winner was Deepti Rohatgi, 18, of Rockville, Maryland, who proposed "Marie Curie." Third place went to Adam Sheedy, 16, of Round Rock, Texas. **Sojourner** ***will be launched in December 1996 as part of the Mars*** **Pathfinder** ***mission. The*** **Pathfinder** ***lander will carry the rover to the surface, then send it off to study the chemistry of nearby rocks and other features. We hope that*** **Sojourner** ***will be the first of many intelligent, mobile robots that will aid humanity in its exploration of Mars.*** *Photo: Jim Pickerell*

The third thing our crew could do is look toward life in the future. They'll begin to assess whether local or broad-range terraforming is feasible—whether it's possible for human beings to colonize Mars. They will also push forward the search for planets around other stars. By better understanding the evolution of Mars, we'll get a better understanding of how planets in general form and evolve. This will help us in our search for planetary systems around other stars.

The next human crew will stay longer. They could stay for nearly two years. They'll develop permanent habitats and grow a lot of their own food. They'll bring "hopper" rockets that will let them get anywhere on the planet.

Someday, there will be a colony on Mars.

BONNIE DUNBAR: It's very hard to quantify the human spirit. You should never underestimate it. I remember when I was about eight or nine years old my father took me out to the haystack and we watched *Sputnik* go over. I don't know if it was the combination of *Sputnik* and writers like H.G. Wells and Jules Verne or what it was, but I was captured by this concept that there was more out there than just my immediate surroundings and that the quest for knowledge fed my human spirit.

Exploration is the pursuit of knowledge. It feeds our souls. When it ignites our human spirit, that energy is translated, not only to the task at hand—the goal we are focused on—but to the vitality of the society that it resides in—to its pride, to its purpose and, ultimately, to its productivity. The question for me is not are we going to go to Mars together someday, but how and when are we going to do it.

DONNA SHIRLEY: Believe it or not, we get very attached to the robots we build. So when we lost *Mars Observer*, it was a tragedy for everyone who worked on it. It carried eight very powerful instruments that we had worked on for about 20 years to answer questions about Mars. Everybody thought that [losing *Mars Observer*] was the end of the Mars program. Instead, Congress rallied around and allowed us to have another Mars program, not just with a single, spectacular shot like *Mars Observer,* but with a continuous, steady increment of knowledge as we go along over the next 10 years. This is called the Mars Surveyor program.

We start in 1996. The first set of missions is the Mars *Global Surveyor* orbiter and the *Pathfinder* lander. This is a cost-driven program. We say, how much money do we have? What can we do for it? Then we do the best we can in terms of all the technology and the intelligence we can bring together to get the most out of a small amount of money.

VLADIMIR UTKIN: First, we wanted to launch *Mars '94*. We had to redo *Mars '96* because Mars was not waiting for us. The [atmospheric] conditions on Mars are worse now than they were two years ago [and the planet is in a more difficult position to reach]. Fifteen international participants are working on this program for 15 different countries. (By the way, we wanted to make sure we wouldn't have 13 participants, although I like this number.) All the instruments that we would have flown in 1994 we had to take back and the scientists had to check whether we could launch in 1996 or not. If we could not launch in 1996, the next launch is not possible until 1998, and [since the relative orbital positions of the planets are worse] we would have to remove half of the equipment or we would not have enough energy [to reach the planet].

We have tried very hard to maintain our schedule. Without this we will not be able to achieve our goals at Mars. Also, we are working on the *Alpha* program [the international space station], and when we were selecting experiments for the *Alpha* and *Mir* programs, we were looking at certain experiments that could be utilized in 2018 at Mars. For example, cosmonaut Viktor Polykov was in space for more than a year. A little more time and we will have enough time to go to Mars and back. We are studying different systems, bones and muscles, the cardiovascular system, we are studying radiation in space, and all this is needed to achieve our goals to fly to Mars. We think we need to create surgical equipment for such a long-duration flight. We think we need to have a doctor on board or a doctor and engineer together.

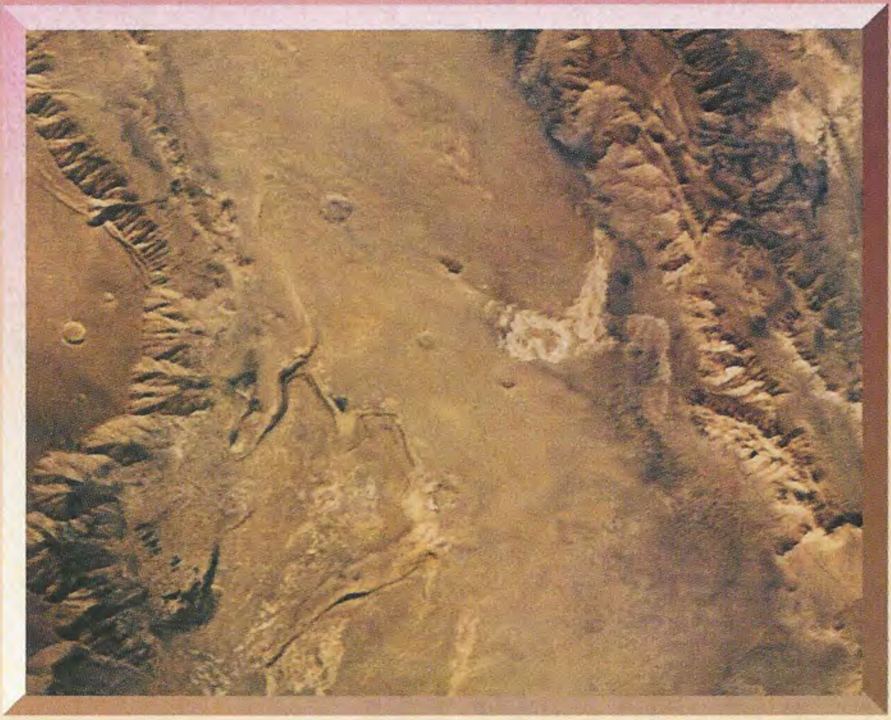
I would like to end my presentation with two thoughts: There is a saying in Russia which goes, "If you want to do something you will do it but if you don't want to do it, you will find reason not to do it." Today, there are no obstacles anymore in the way of cooperation. We don't have to look for a reason. We have to continue working. And the next thought is a little more sophisticated. We have to remember our young people, and we have to make sure that they are still interested in Mars, Venus, space and other planets.

❖ AUDIENCE QUESTIONS ❖

QUESTION: *I am very sad that so much of our scientific progress seems to depend upon political progress now. What can I do as an American citizen to stimulate our Congress to make this a human endeavor, a world endeavor, a universal endeavor instead of a political situation? Is there any way to get this out of politics and into another realm of reality where it belongs?*

Louis Friedman: Of course, we can avoid the political process. It is not the only one. There is education, influencing public opinion through newspapers and magazines, and talking to people who are decision leaders, influential leaders in communities which include business, labor and all of the other usual interest groups. Other interest groups are important. Clearly, the political one is at the center but there are many others.

Vladimir Utkin: You ask a very difficult question. First of all, you should be a real believer yourself, as a scientist, as an engineer and as a citizen. I had to go to our political organizations, too, and try to convince our politicians to continue this program. You have to go either once, twice or many times. But first of all you yourself have to believe in these programs and try to convince your colleagues. If we fly there, that is good; if not, politicians are not the problem. We ourselves are the problem.



MELAS CHASM: Future explorers of Mars will have an entire world of fascinating landforms to map and study. Here in central Valles Marineris is Melas Chasm, chock-full of interesting features. In the center right is some whitish material that may be carbonates or some other deposit laid down when the water bearing them evaporated. To the upper right is an area rich in crystalline iron oxides (rust), and in the lower left are dark sand dunes. (This image covers an area 261 kilometers, or 162 miles, across.)
Image: Alfred McEwen, United States Geological Survey

Arnauld Nicogossian: One of the issues is education: telling people what the space program is, what research and technology bring back to Earth and how this can enrich our lives. Space exploration is at the cutting edge of science and technology, and research and development are very important. They are important in preserving and advancing civilization. When we talk science and technology, we talk education.

Question: *I am wondering where the exploration of the Moon fits into all of this, in terms of both exploring the Moon and returning humans to the Moon. Is going to Mars part of the overall scheme? If it is, how do you balance the resources in terms of what is more valuable—going to Mars or going to the Moon? Can both be done?*

Tom Stafford: The goal of the Moon was set in a rapid fashion by President Kennedy. The decision was made in a couple of days. The one to go to Mars is a very prolonged decision. You have to come to a political consensus to have sustained political funding over the years. You had political consensus on *Apollo.* Occasionally, you had a few detractors, particularly after the tragic [*Apollo 1*] fire, some of the people in Congress wanted to kill it. But there was still the carry-through. But on this one, it's going to take tremendous education to outline why we need to go there and what is involved. And the consensus of many countries is going to be more difficult to achieve than the consensus of one country when you have a strong president and strong leadership in both houses. But the approach to go there in a multinational effort is really the only way to go.

Donna Shirley: I was going to say that the Moon has not been totally forgotten. There is Lunar Prospector. It is the first Discovery mission and, and if it were to find ice at the poles, for example, on the Moon, you might see renewed interest in the Moon. I think Mars is seen as a much more alive and Earth-like planet, and it is an object of more fascination than the Moon is among the science community and the general public.

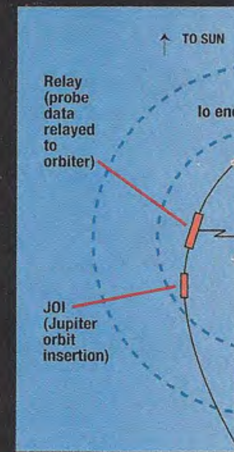
Louis Friedman: Now I am going to simplify the question and put Bonnie and Hoot on the spot: You have just one shot, you're going to the Moon or Mars, where do you want to go?

Bonnie Dunbar: There is no such thing as a simple question. I see different scenarios. My feeling is that we still have some work to do on the question of using indigenous materials. We might want to think about a preliminary test base on the Moon, where we can get back quickly if we have to. That is an option.

I don't know that we have enough information yet to make that decision. I would hope that when we make the decision on a technical basis, and in a conservative way, we will also have the resources to do it. Then it would not be just a forgotten test base. Personally, I think there are reasons to go back as well to this satellite that orbits our planet.

Hoot Gibson: In my opinion, we would garner more support and we would have an easier time of saying, "Let's go attack Mars," than we would with the Moon. That's purely a philosophical answer, saying that we are going to pull together a number of nations and put a goal in front of all of them. I think more of the world would rather be behind Mars. ❖

ON TARGET: Galileo Approaches the Jovian System



Planetfest '96 Is Coming!

Join us in Pasadena on July 5 to 7, 1996, as we celebrate the *Galileo* mission to Jupiter. We're planning a festival to share with the public the spacecraft's anticipated discoveries, along with other achievements and plans for future missions. We'll have broadcasts of spacecraft findings, films, concerts, exhibits, lectures and enough activities to fill three days of fun.

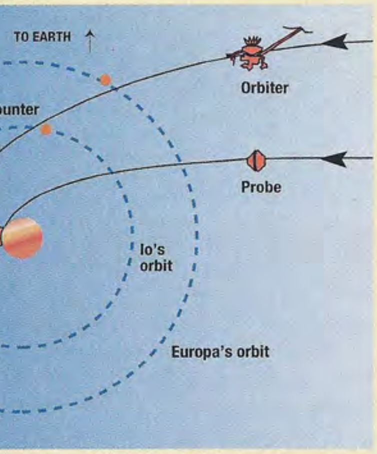
If you'd like information on how to join us, contact Susan Lendroth at 800-9WORLDS, or contact her by e-mail at tps.sl@genie.geis.com.

The spacecraft *Galileo* is now set to begin its long-awaited exploration of the jovian system. On December 7, its probe will enter Jupiter's massive atmosphere at 170,700 kilometers (106,000 miles) per hour, and for the first time humans will "touch" a gas-giant planet. The orbiter will swing by the moon Europa and fly within 1,000 kilometers (600 miles) of Io, the most volcanically active object we know of in our solar system. The spacecraft will fire its thrusters and slow down enough to be captured by Jupiter's gravity and begin a 23-month, 11-orbit tour among the planet's moons and rings. Thus will begin the most in-depth investigation of any planetary system beyond our own Earth and Moon.

This return to the jovian system calls to mind another, fondly remembered mission: the *Voyager* encounters of 1979. *Voyager* gave us the first detailed looks at jovian satellites Io, Europa, Ganymede and Callisto, the first evidence of a planet-circling ring, and awesome glimpses into Jupiter's tumultuous atmosphere. But *Voyager*'s wondrous data were gathered during only a few hours of close encounters; it was a flyby mission, quickly sweeping past the planet on its way to more distant encounters. *Galileo* will remain in the system for almost two years and will pass hundreds of times closer to the moons than *Voyager* was able to.

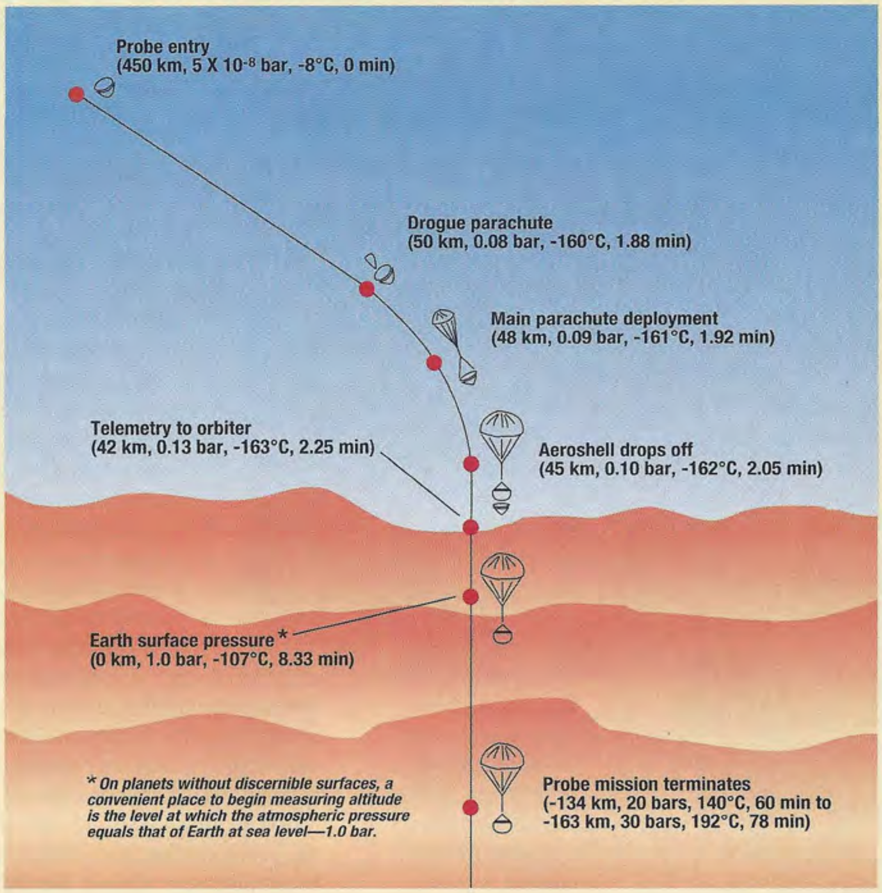
This December, the scientific focus will be on *Galileo*'s probe, which will provide the first in situ data from within the planet's swirling clouds. Our knowledge of Jupiter up to this point is based on data gathered remotely—no spacecraft has yet taken direct measurements of the planet. The probe carries instruments to record the temperature, pressure and density of the atmosphere. It can identify the chemical composition of gases and determine if the multicolored clouds are made of liquid drops or ice crystals. As it falls through the atmosphere, the probe will locate the cloud decks and give scientists a view to much greater depths than ever before.

Still, *Galileo*'s probe will penetrate only a thin skin of engulfing clouds—it will probably be destroyed 130 to 160 kilometers (80 to 100 miles) below the cloud tops. Jupiter's



***Above:** Although the* Galileo *probe and orbiter separated in July of 1995, they will arrive at Jupiter on the same day—December 7. On its way in, the orbiter will fly 32,500 kilometers (20,000 miles) above Europa and take images of this cracked, icy moon comparable to those* Voyager *gathered 16 years earlier. It will then close in on Io for its only close encounter with this moon. The orbiter will pass just 1,000 kilometers above the volcanic surface, returning the best pictures yet of this violent world. After Io, the spacecraft will receive the data transmitted from the probe as it plunges through the atmosphere. Then, as the probe dies, the orbiter's engines will burn for almost an hour to slow it for capture into orbit around Jupiter.*

Image at left: JPL/NASA



***Left:** On December 7, the* Galileo *probe will undertake its mission of no return. Protected at first by its aeroshell (so thick it makes up half the total weight of the probe), the probe will enter Jupiter at 170,700 kilometers per hour, making it the fastest projectile ever created by humans. Friction with atmospheric gases will begin to slow its descent; a parachute will then take over the braking and the aeroshell will be jettisoned. If all goes as planned, the probe will descend through the massive atmosphere, encountering ever-increasing temperatures and pressures and collecting data for about an hour. (For a glimpse of its ultimate fate, turn the page.)*

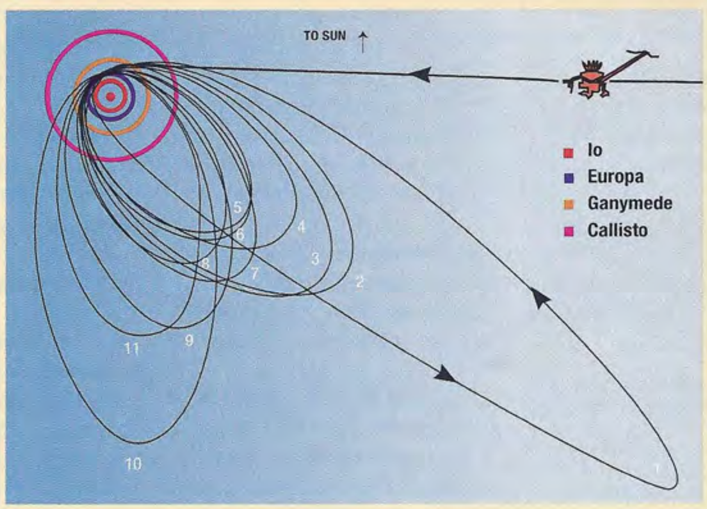
rocky core lies 60,000 kilometers (37,000 miles) deeper, at temperatures and pressures no spacecraft we know of will ever reach.

During its death plunge, the probe will transmit its data to the orbiter, which will then relay them to Earth. Despite the problem with *Galileo*'s partly opened high-gain antenna, we will receive 100 percent of the probe's data. Spacecraft engineers have been able to increase the data rate through the low-gain antenna from 16 bits per second to 160. This is still much, much less than the 134,400 bits per second the more powerful antenna could have sent, but despite the antenna's problem, the project team hopes to recover most of the orbiter science planned for the mission.

So this December, the adventure begins. Humanity will explore another planetary system. We will be enriched by our increased understanding of the nature of such systems and our planetary neighborhood.

We've designed these pages to be a brief guide to this first leg of *Galileo*'s mission, so use it, and enjoy the adventure.

—Charlene M. Anderson



***Left:** On December 7,* Galileo *will begin its 11-orbit tour of the jovian system. Over the next 23 months, it will have 10 very close encounters with the large moons of Jupiter, using the gravity of each moon to tweak its orbit enough to retarget for the following encounter. After the Io close encounter before entering jovian orbit, the next encounter will be with Ganymede on July 4, 1996. On its repeated swings through the system,* Galileo *will study the smaller moons of Jupiter, as well as Jupiter's tenuous rings, atmosphere and magnetosphere.*

All charts: JPL/NASA; redrawn by B.S. Smith

A Dusty Mystery

On its way to Jupiter, Galileo *flew through intense dust storms that appeared to be emanating from the vicinity of the gas giant. The first storm struck the craft in December 1994 and lasted about a week. Since then, storms of ever-increasing intensity have been periodically bombarding the craft with dust impacts that have exceeded the normal rate of interplanetary impacts by 10,000 times.*

The Ulysses *spacecraft discovered the jovian dust storms in 1992, but since then their intensity and periodicity have changed. The nature and behavior of the storms have created a mystery that the spacecraft team hopes to solve.*

Right now, there are many questions and few answers: Where does the dust come from? Volcanic eruptions on Io? The wispy halo outside Jupiter's rings? The remains of comet Shoemaker-Levy 9? And what accelerates the dust particles out of the jovian system? Why are the storms periodic, and why has that period changed since 1992?

These dust storms have added another dimension to the mysteries that Galileo *may solve on its mission to Jupiter.* — CMA

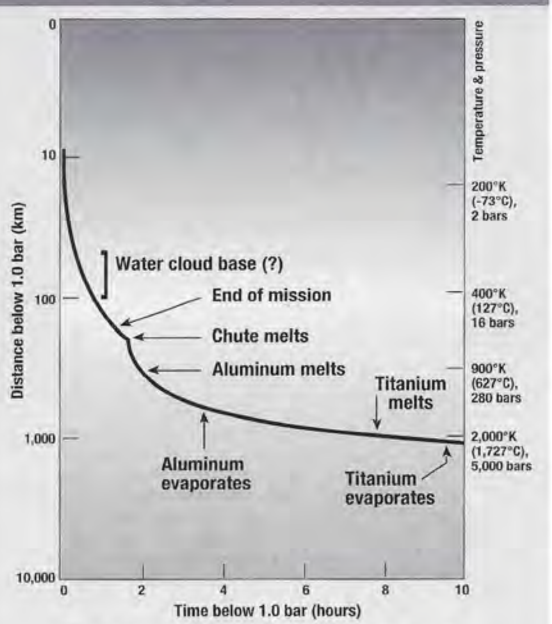
The Fate of the Galileo Probe

by Jonathan Lunine and Rich Young

On December 7, the *Galileo* probe will enter the atmosphere of Jupiter and beam back to Earth information of a sort never before obtained for the solar system's largest planet.

To understand the fate of the probe requires that we consider its design. The entry of the *Galileo* probe into Jupiter's atmosphere is the most difficult ever attempted at a planet, in terms of the velocity of entry and subsequent heating of the probe structure. The scientific instruments are housed in what is termed the descent module, which is protected during the high-speed entry by the fore and aft heat shields. Once the probe has slowed sufficiently, the heat shields separate from the descent module, which drops through the atmosphere on a parachute, taking scientific measurements.

Fate of the Galileo probe as it falls through Jupiter's atmosphere



The distance the probe has fallen, and the time it takes, are shown: the 1-bar pressure level is used as a convenient reference point, which is reached just under nine minutes from entry. Also given are temperatures (on the Kelvin scale with conversions to Celsius) and pressures at each distance.

Chart: J. Ludwinski; redrawn by B.S. Smith

The orbiter is in position as a receiving station for 75 minutes. The batteries on the probe are sized to last at most a few minutes beyond that time. Bigger batteries would yield little more data, since as the probe sinks deeper into the atmosphere radio signals become more and more attenuated by the gases and clouds overhead. The probe, bereft of an orbiter link and its batteries depleted, will continue to sink deeper into Jupiter's interior.

One fate we know the probe won't suffer is to hit a surface, because Jupiter is almost entirely gas. Furthermore, the density of the probe is greater than the density of Jupiter's gaseous interior, and the probe continues to sink after transmissions cease. The probe is vented, so the overall structure will remain intact, except for some sealed boxes (which will be crushed as the pressure increases). Thus, what ultimately will destroy the probe is the increasing temperature with depth, which will cause the probe materials to melt and vaporize.

To find out where this happens, we borrowed a model of the temperature–pressure–density structure of Jupiter's interior from Didier Saumon and Tristan Guillot of the University of Arizona. We simplified the lengthy list of probe materials to just three: Dacron for the parachute, aluminum for the inner equipment shelf and titanium for the outer aeroshell.

The first event is the melting of the Dacron parachute, at about 260 degrees Celsius (500 degrees Fahrenheit), about one half hour after the latest possible probe mission end. Parachute failure causes the probe to drop more rapidly, as shown in the diagram. Roughly 40 minutes later, at a temperature of about 660 degrees Celsius (1,200 degrees Fahrenheit) and 280 bars pressure, the aluminum portions melt. (One bar equals Earth's atmospheric pressure at sea level.) Although some interesting chemistry could take place between the molten aluminum and the titanium housing, more likely the aluminum separates from the probe in blobs or droplets, which continue to descend on their own. The titanium itself melts at a much higher temperature—about 1,680 degrees Celsius (3,100 degrees Fahrenheit)—which the probe reaches at a pressure of 2,000 bars, more than nine hours after its entry into the atmosphere. The probe housing becomes a molten mass, probably breaking up into droplets of titanium that rain down through the dense jovian gas.

The fate of these molten materials is vaporization (or evaporation, equivalently), as temperatures get so high that the liquid turns to vapor. Where this occurs turns out to be a complicated issue, depending on how much natural titanium and aluminum are in Jupiter's gaseous interior, and what chemical form they're in.

To simplify the analysis, we note that evaporation is very slow at low temperatures. However, as the probe continues to fall and the temperature goes up, the evaporation rate increases dramatically. When sufficiently high temperatures are reached—for aluminum, around 1,170 degrees Celsius or 2,150 degrees Fahrenheit; for titanium, around 1,850 degrees Celsius or 3,360 degrees Fahrenheit—the metals will evaporate within minutes. By 10 hours into the mission, the probe has been transformed into separate atoms and molecules.

So, after telling humans about the nature of Jupiter's atmosphere, the atoms of the *Galileo* probe will become a part of that giant planet. This exchange of material between one world and another is nothing new; it has been happening across the solar system from the beginning (witness Shoemaker-Levy 9). The atoms out of which the probe was fashioned were originally produced as part of the debris of nucleosynthesis in massive stars, spewed out with the rest of the stellar material to form Earth, the solar system and life. The epitaph "ashes to ashes" might be appropriate to describe the origin and fate of this product of human ingenuity.

Jonathan Lunine is a full professor at the University of Arizona, and Rich Young is a Galileo *probe scientist at NASA Ames Research Center.*

World Watch

by Louis D. Friedman

Pasadena—Launch vehicle problems abound. In August, the space shuttle was grounded due to excessive decomposition on one of the O-ring joints; the *Titan 4,* the United States' largest launch vehicle, failed an important ground test when its second-stage nozzle was destroyed.

At the other end of the size spectrum, the Orbital Sciences Corporation's small launcher, *Pegasus XL*, had to be destroyed immediately after launch in June. The Lockheed Launch Vehicle (LLV), the intended launcher for the 1997 Lunar Prospector, had to be destroyed following a launch failure in August. A competing small launcher, the *Conestoga,* had its launch indefinitely delayed.

Also in August, even the normally reliable *Delta* rocket had a mission anomaly in strap-on motor firing, which, while not catastrophic, ended up putting its payload in the wrong orbit. *Delta* is to launch both Mars *Pathfinder* and Mars *Global Surveyor* in 1996.

Launch vehicle problems are not America's alone. The Chinese *Long March* has had two major failures in launching commercial communications satellites, and in January the Japanese scientific program had its first failure with the MU-3S-II rocket, a test version of the rocket scheduled to launch Lunar-A in 1997 and Planet-B to Mars in 1998. *Ariane,* the European Space Agency launcher, had two failures last year. Even the normally reliable Russians had failure this year with an Israeli payload launched on a converted ICBM.

In short, contrary to enthusiastic hype, space is still a difficult and expensive place to get to. We are a long way from cheap or profitable access to space.

Baikonur, Kazakhstan—On the heels of the record set by Norm Thagard for the longest US mission (115 days), European Space Agency astronaut Thomas Reiter from Germany began a 135-day flight on board the *Mir* space station in early September. This will be the longest flight ever for a European, exceeded only by the Russian cosmonaut space experiences.

In addition to carrying out a number of European experiments, Reiter will get to control the *Mir* craft and perform Europe's first extravehicular activity in order to place scientific equipment on the outside of the space station.

One planetary science experiment being performed on this mission is the collection of dust and particles (left in the wake of comet Giacobini-Zinner) hitting the spacecraft as it passes through the Draconid meteor shower.

Washington, DC—The NASA budget (and almost all other budgets of the US government) were not determined in time for the new fiscal year. Eventually, differences between the House of Representatives and Senate budgets will be worked out, and the president will sign the appropriations bill. Here are some highlights of the budget activities.

The space station was debated but attempts to cancel it failed. Planetary Society support for the international plan was frequently cited in the Senate debates. The *Cassini* project remains intact, along with other planetary programs and new starts for the Lunar Prospector and the New Millennium projects. New Millennium is an advanced-technology small spacecraft development project for future planetary missions. The first flight of the project—a solar electric, low-thrust spacecraft to an asteroid and comet, set for launch in 1998—was announced.

Washington, DC—A NASA advisory committee chaired by Eugene Shoemaker recommended an increased Earth-based observation program for discovery of near-Earth objects—asteroids and comets whose orbits come close to that of Earth. The cost of such a program would be only about $4 million to $6 million per year. Despite concerns expressed by the House Science, Space and Technology Committee about the potential danger to Earth, NASA officials refused to endorse the recommendation. They were afraid to upset the delicate budget negotiations in Congress by asking for increased funds.

The Society has advocated such a program, and following our cosponsored April meeting in New York on the subject of near-Earth objects, I wrote a letter to the chairman and ranking minority leader of the House committee urging that NASA be mandated to take the lead in evaluating the threat and be given some small additional funds to conduct the astronomical search.

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

Basics of Spaceflight:

Telemetry and Command

by Dave Doody

Telemetry and command are the heartbeat of operating an interplanetary spacecraft. Telemetry is constantly flowing from the spacecraft, and commands are sent to it frequently; for some interplanetary spacecraft, commands are sent almost every day. By contrast, navigation, or tracking, data (discussed in the September/October 1995 *Planetary Report*) are also acquired routinely every day, but the opportunities to put navigation data to physical use for adjusting the spacecraft's course through the solar system, or its orbit at another planet, typically come only once in several months or years, and these processes depend on telemetry and command. They are very important processes, but they are fairly rare.

Defining the Terms

The word "telemetry," tele-metry, means "distant-measuring." It's the process of making measurements such as pressure, temperature, voltage, current, levels of light and color—all sorts of physical measurements—sending these measurements over a distance and then making sense of them when they arrive. Command is the process of sending signals that cause the spacecraft to respond in some way: turn cameras or other equipment on or off, take pictures, turn, change settings and so on.

Command is fairly simple; let's look at it first. Just as your television set is programmed to recognize various commands from your remote control, such as to turn on or off, change channels, and increase or decrease speaker volume, spacecraft are programmed to receive commands remotely and to process them. The commands you send your television set are signals modulated on an infrared wavelength, but the ones sent to a spacecraft go by modulated radio carrier. They also carry time-tags, telling the spacecraft precisely when to carry out a function.

Producing the commands to be sent to the spacecraft takes input from the scientists who use the spacecraft's instruments to make observations, and from the engineers who take care of the spacecraft itself. The process is well automated, using computer programs that set out the commands in long sequences and check for errors or potential problems.

Once the commands are prepared and checked, we send them up to the spacecraft in the solar system via the Jet Propulsion Laboratory's Deep Space Network. The spacecraft confirms its receipt of each and every command; if it ever misses one, it reports the fact, and we re-send the command.

The way the spacecraft confirms receipt of commands, and reports any problems, is via telemetry. Telemetry also provides reports on the health and status of the spacecraft systems and subsystems—on everything from the temperature of its skin to the pressure in its propellant tanks.

How the Process Works

There are thousands of different things measured and telemetered that are of interest to engineers responsible for the spacecraft. But the main purpose of an interplanetary spacecraft is to obtain scientific data about a planet or a phenomenon and to send those data to scientists. That's the objective illustrated in the diagram—sending data on a phenomenon (box A) to a science investigator (box E); that is, to the scientist who is investigating that particular phenomenon. The data are sent via telemetry; the rest of the diagram illustrates how the process works.

First, the phenomenon of interest interacts with a scientific instrument aboard the spacecraft. This can happen in different ways. A camera might receive sunlight reflected off a planet or satellite, or the spacecraft's radar instrument might bounce radio waves off an object and receive them as they reflect back. This is *remote sensing,* since the instrument is actually remote from the object it is sensing. On the other hand, a dust-particle detector may register particles of dust that enter it. That's called *direct sensing.*

In any case, the instrument acquires data about the phenomenon and, using its internal microprocessor, turns them into digital data—thousands or millions of bits, the binary digits one and zero, just like the bits manipulated by your personal computer or compact disc audio player. This appears as the first step in box B.

The spacecraft's computers can then continue to process the digital data. In some cases, the instrument's data can be compressed, to reduce the number of bits that need to be handled. As an example, one kind of compression could be used with an image of a small object against a large black background in space: Instead of transmitting each of the many bits representing the black background in the picture, the compression algorithm would analyze the image and simply report how many black bits there are in various areas of the picture. Sent along with the unaltered data representing the small object, this information would be enough to reconstitute the whole original image later on Earth. There are other, more complex compression routines that can be applied as well.

In the third step in box B, the data from each science instrument are then processed into packets for convenient handling (although older spacecraft use other techniques for handling data). A packet is a quantity of digital bits preceded by a "header" whose bits identify the source (the instrument) and provide other identifying information, including a count of the data bits contained in the packet. The spacecraft's computer collects packets from the science instruments, and also from all the engineering subsystems, such as propulsion, electrical power and attitude control, to provide information on the health and status of the spacecraft.

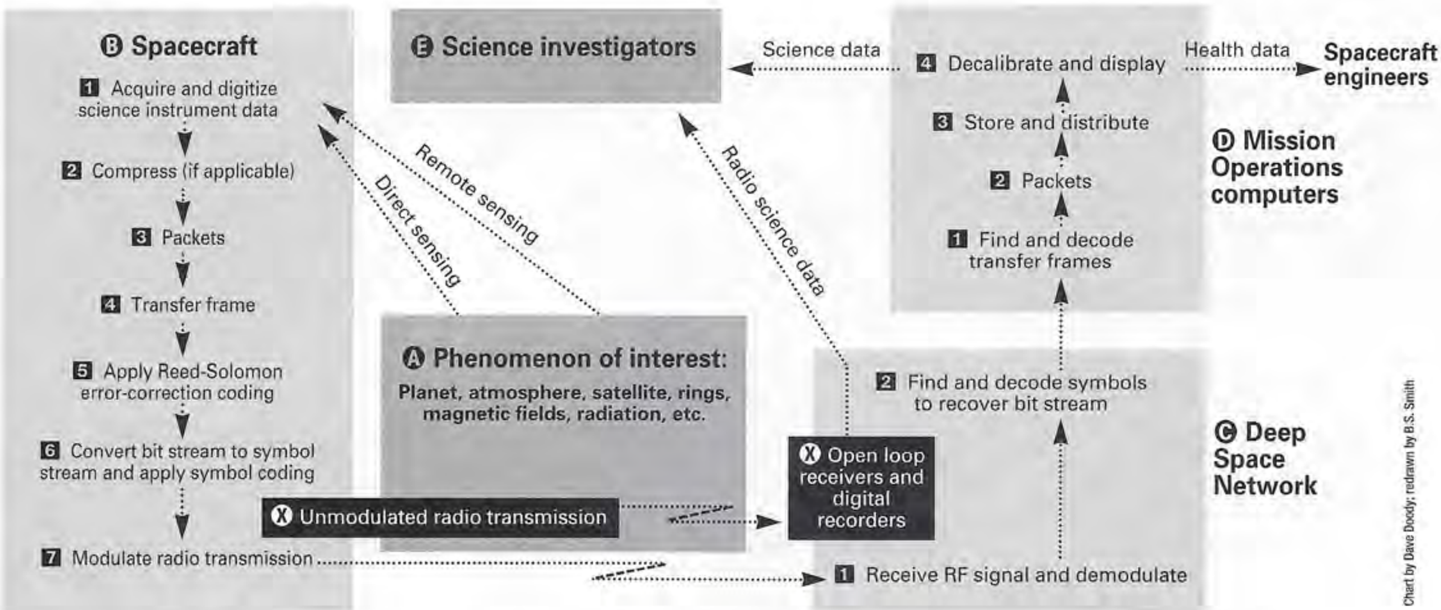


Chart by Dave Doody; redrawn by B.S. Smith

A number of packets are gathered into a transfer frame, which can be thought of as a big packet, processed to apply a special error-correction code, called Reed-Solomon for its inventors. This code permits recovery from errors that occur during transmission. Look at the technical specifications of your compact disc audio player—it probably uses the Reed-Solomon error-correction system too.

At this point, we come to the sixth step in box B. The stream of digital bits is coded into symbols that the radio frequency transmitter can use. These symbols are then modulated onto the transmitter's signal, which is called the carrier.

To understand this process, imagine singing the sound "aaaaaahhhh" as a single note. This would represent the carrier signal. Now imagine "modulating" that sound by going, "aaaaaahhh, wah, wah, wah, aaaaaahhh." This modulation would illustrate the use of symbols representing the digital data. We might decide that "aaaaaahhh" would represent a zero, and that "wah" represents a one. In reality, various symbols are used to represent different groups of bits.

If you listen to the telephone while a fax machine is transmitting, you'll get a better idea of this process. Groups of bits are being represented by symbols of tone on the telephone line—the "deedle-diddle-deedle" sounds. Your computer's modem (which stands for "modulator/demodulator") makes similar noises. With the radio signals transmitted from a spacecraft, it's a different set of symbols, but this gives a general idea of the process.

The radio signals make the journey to Earth, which can be a long distance indeed. It takes about 1.5 seconds for a radio signal to arrive from the distance of our Moon; from the distance of Saturn, the time required is around two hours. The signal is weak when it arrives. It is captured by the large reflector dishes of the Deep Space Network antennas, and then amplified. In step 1 of box C, the radio signal is demodulated to begin extracting information from it. In the next step, the symbols are recognized and converted back into digital bits, which are then passed to JPL, typically via Earth-orbiting communication satellites.

Delivering the Data

Computers in Mission Operations, box D, receive the bit stream and find the transfer frames. The error-correction coding is removed, and errors are corrected. Then the frames are split back up into their constituent packets. The packets are stored for future reference, and they are routed to appropriate destinations, mainly according to their header identification. For example, packets from the imaging instrument get delivered to the team of imaging scientists. Packets containing spacecraft health data are picked up by the spacecraft engineers. When each user receives his or her data, the process (for which the spacecraft exists) is finally complete: From the phenomenon of interest, box A, data are delivered to the science investigator, box E. The end user's computers convert the telemetry measurements into readable form—volts, amperes, degrees Celsius, images, colors and so on, to create readable displays, and to store and further process the data.

Radio Science

To stray off the subject of telemetry a bit, there's another scientific discipline, called radio science, that can obtain valuable information about a phenomenon without directly using the telemetry process discussed here. It does this by passing the spacecraft's radio signal directly through the phenomenon and then observing how that signal has been changed by the phenomenon. For example, the signal might be sent through Saturn's rings. When received on Earth, changes in the signal caused by the ring particles can be studied, and information such as the size of the particles can be determined.

Many different studies can be accomplished with radio science, ranging from searching for Einsteinian gravitational waves to probing a planet's atmosphere, even measuring the mass of a planet or satellite. In the diagram, this process starts at point X in box B, illustrating a pure, unmodulated radio signal passing through the phenomenon, and being captured and recorded at point X in box C. The signal is digitized and recorded, and then sent directly to the radio scientists for study.

Dave Doody is a member of the Jet Propulsion Laboratory's Advanced Mission Operations Section and is currently working on the Cassini *mission to Saturn.*

For more information, check out JPL's *Basics of Space Flight* on the World Wide Web at Uniform Resource Locator http://oel-www.jpl.nasa.gov/basics/bsf.htm.

News and Reviews

by Clark R. Chapman

The universe is a fantastically, unimaginably immense place. And with modern telescopes, we are beginning to probe the brightest, oldest objects in its most distant corners. Yet all that we get for our trouble are the faintest glimmers of light, hopelessly beyond the reach of our unaided, frail human eyesight. These cosmic outposts tease our minds and challenge us to ponder our origins. But they hardly exhibit the drama that grabs us viscerally, like a *Star Wars* movie.

I myself have always been more fascinated by the solar system than by the distant stars, galaxies and clusters of galaxies. Perhaps it is simply because the Moon and nearer planets are brighter than almost anything farther away, more readily watched through the small telescopes of my youth. Maybe it is because of my knowledge that, if humankind ventures anywhere beyond the Moon in my lifetime, it will surely be to destinations confined to the solar system.

There is, I've just realized, a more basic reason for my interest. Action. Dynamic activity has a fundamental attraction for us. Witness our love of action movies, of arcade games, of sports. Stasis is death. By virtue of our proximity to things that are in the solar system, we can (as the ancients did) see that planets move. Occasionally, as in July 1994 when comet Shoemaker-Levy 9 struck Jupiter, the cosmos can be dramatic indeed. But the solar system always offers evidence that things are ticking.

Dynamic activity is surely, in reality, vastly more energetic in parts of distant galaxies. But we can only infer it from our own observations. We cannot experience it. Galaxies are simply too far away. It's like the contrast between rain, hail and fog swirling around us and a distant, seemingly motionless, hovering thundercloud. Even in or near our own galaxy, motions at the speed of light take months or years to unfold in our sharpest telescopic pictures.

Hale-Bopp Is No Joke

This past summer, the solar system put on quite a show. I witnessed some of the most spectacular meteoric fireballs ever on several clear nights in July. Far beyond Jupiter, a new comet was found—Hale-Bopp. My wife and I had the good fortune to watch it through David Levy's comet-hunting telescope the night after it was discovered. About April 1, 1997, it will pass within Earth's orbit, perhaps the largest object ever to do so in modern history. And that's no April Fools' joke. Were Earth elsewhere in its orbit, Hale-Bopp would become a truly frightening object to behold, instead of just one of the brightest comets in our lifetime. Of course, we astronomers always fear that a comet might pull a Kohoutek, and turn out to be a dud.

The *Galileo* spacecraft has been plummeting through an enormous dust storm as it closes in on Jupiter. Meanwhile, the giant planet's innermost moon, volcanically active Io, has been putting on its own show. Loki, an ionian volcano first revealed by *Voyager,* has been wildly active, and hot spots at other longitudes have been acting up, too. Will Io even be recognizable when *Galileo* gets there?

Tipping Rings

Because of the rapidly changing geometries of the planets, we get different looks at them all the time. A distant galaxy's visage remains unchanged over human history. Saturn, however, goes through a cycle of tipping one side of its famous rings to Earth, then the other side, as it orbits the Sun. Every 15 years or so, the rings are briefly edge-on, and practically invisible. This past summer, the Hubble Space Telescope (HST) captured Saturn during moments when the rings seemed nearly gone. In the absence of ring-glare, numerous small moonlets of Saturn were detected, some never seen before, not even by *Voyager*.

Kuiper Belt Comets

Patient astronomers using sophisticated equipment can detect motions even in the outermost reaches of the solar system, during just a few hours. In June, Anita Cochran and her collaborators, using HST, reported evidence of moving comets, roughly the size of comet Halley, well beyond Neptune's orbit. The HST team was able to show that there were lots of familiar-sized comets out there, clinching earlier theories that the so-called Kuiper belt is the breeding ground for short-period comets.

Whether one is a professional astronomer studying the changing cloud patterns on Neptune with HST, a dedicated amateur watching the seasons evolve on Mars or a star being covered up by the Moon, or just a backyard stargazer watching for meteors and charting nightly changes in the position of the Moon or Venus, we can all appreciate that the apparently static nature of the nighttime sky and its "fixed" stars is just an illusion due to our great distance. The drama of our own solar system is but our local microcosm of forces set in motion throughout the universe during the Big Bang.

To learn about new astronomical observations that you can't make yourself, read the news-notes sections of magazines like *Astronomy, Sky & Telescope, Science News, Nature* and *Science*. Or browse Hubble pictures on the Web: http://www.stsci.edu/pubinfo.html. An access point to home pages on Hale-Bopp is http://www.eso.org/comet-hale-bopp/comet-hale-bopp.html.

Clark R. Chapman is a member of the imaging/spectroscopy team of the Near Earth Asteroid Rendezvous mission, due to be launched in February 1996.

Society News

Honoring Mars Exploration Heroes

On July 14, 1995, in Washington, DC, NASA Administrator Daniel Goldin and Planetary Society Executive Director Louis Friedman announced the winners of the Society's second Thomas O. Paine Award for the Advancement of Human Exploration of Mars: 1975 *Apollo–Soyuz* crew members Vance Brand, Valeri Kubasov, Alexei Leonov, Donald Slayton and Thomas Stafford. The winners received an honorary plaque and a Mars flag designed by Tom Paine in recognition of what they have done to bring us closer to the day when humans will walk on Mars. *—Michael Haggerty, Information Services Manager*

Next Year's Paine Award

We invite all our members to suggest nominees for the 1996 Paine Award. The honor will go to the group or individual who has done the most to advance human exploration of the Red Planet. The deadline for nominations is February 1, 1996. For a copy of the official application form, or for more information, contact Planetary Society headquarters.
—Susan Lendroth, Manager of Events and Communications

K/T Expedition News

Society members searching in Belize for evidence of the major asteroid impact believed to have occurred 65 million years ago were delighted when they found a beautifully preserved fossil crab (see story in the July/August 1995 *Planetary Report*). Now paleontologist Francisco Vera Vega has told us that the crab is a member of a new species, from the family Carcineretidae, a widely distributed family that lived exclusively during the late Cretaceous and became extinct along with the dinosaurs at the end of the Cretaceous period.

Society members are returning to Belize in January of 1996, and an expedition to a new locale—the area near Gubbio, Italy—is in the works for the fall of 1996. We estimate the cost of the trip to Italy to be $2,200 to $2,500 per person. If you'd like to join us, or if you'd like more information, please contact me at Society headquarters or send inquiries to me at my e-mail address: tps.lc@genie.geis.com. *—Lu Coffing, Financial Manager*

Calling All Volunteers: Planetfest Is Coming

In July of 1996, The Planetary Society will hold a three-day Planetfest in the Pasadena/Los Angeles area to celebrate the *Galileo* mission to Jupiter (see page 12 of this issue). This will be an event-filled celebration, and we will need a lot of help from Society volunteers. If you would like to be a part of this exciting program, please contact me at Society headquarters, or by e-mail at tps.cp@genie.geis.com.
—Carlos Populus, Volunteer Coordinator

Tell Us What You Want

Don't miss our Planetary Society Resource Center questionnaire, bound into this issue of *The Planetary Report.* Here's your chance to tell us just what kind of Resource Center you'd like to have. Just fill in the questionnaire and mail it to us. *—Kari Magee, Resource Center Manager*

We're Part of the PMIRR Team

The Planetary Society has been asked to join the Mars Surveyor PMIRR instrument team to lead public education and information. PMIRR stands for Pressure Modulator Infrared Radiometer—an instrument that measures atmospheric dust and particles, temperature and radiation to determine the presence of water. The instrument is critical to the search for water on Mars.

Water is the key to understanding how hospitable Mars was to life in the past, and to uncovering Mars' subsequent climate history. It is also the key to future Mars exploration and to whether such exploration can lead to human settlement.

PMIRR is an international experiment, with investigators from England and Russia included on the team. It is the first NASA planetary experiment to include Russian hardware: The Space Research Institute in Moscow has been invited to supply optics for the instrument. The PMIRR team leader is Dan McCleese of the Jet Propulsion Laboratory.

With PMIRR, the Society is pleased to be involved in three of its favorite things: Mars exploration, international cooperation and education.
—Louis D. Friedman, Executive Director

Visions Becomes Reality

In November 1993, we announced that a Society-created CD-ROM entitled *Visions of Mars* would be sent to Mars on a future Russian mission. This collection of science fiction and art relating to the Red Planet is a tribute from our generation of explorers to the writers and artists and engineers who have made planetary exploration their lifework.

Visions of Mars is also a gift to the future generation of Mars explorers, who, we hope, will one day retrieve it from the *Mars '96* craft. It will be their library to remind them of how humans of 20th-century Earth once envisioned Mars.

A copy of the CD is now available and is being sold at a special price to our members for a limited time. See page 23 of this issue of *The Planetary Report.* —LC

Keep in Touch

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World Wide Web Home Page:
http://planetary.org/tps/

Questions and Answers

***What is the status of the spacecraft sent to Halley's Comet? After* Giotto*'s additional encounter with comet Grigg-Skjellerup, I had heard that the probe could be retargeted to fly by yet another comet. I've also heard that Japan's* Sakigake *will encounter comet Honda-Mrkos-Pajdusakova in February 1996, and that* Suisei *may be directed to a November 1998 flyby of comet Giacobini-Zinner. And what became of Russia's two* VEGA *spacecraft and the United States'* International Cometary Explorer?**
—Jason Wentworth, Miami, Florida

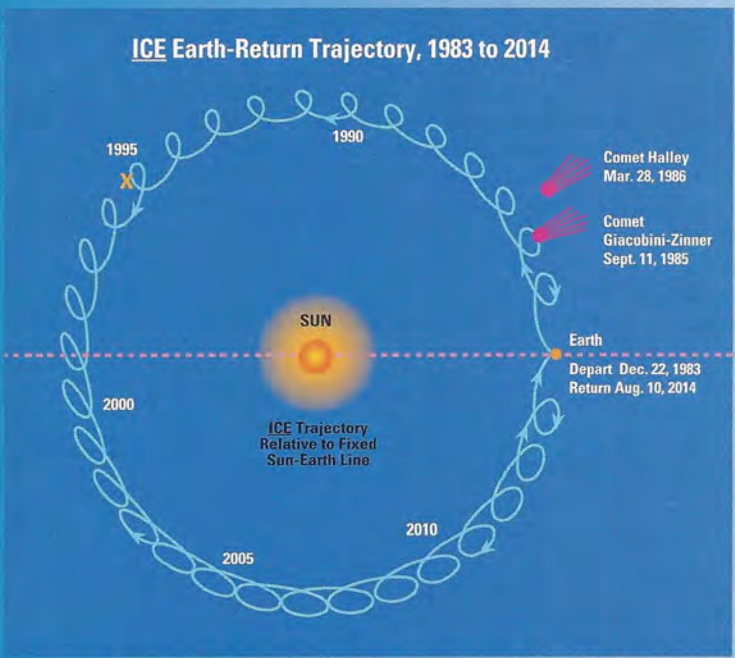
We had investigated the possibility of other cometary encounters for *Giotto* in 2005 and 2006, but it now appears that there will not be sufficient fuel. After *Giotto*'s very successful encounter with comet Grigg-Skjellerup in July 1992, almost all of the spacecraft's instruments were shut off and it was put into hibernation mode. We are taking care to preserve the spacecraft by keeping it as warm as possible within the power constraints, and by keeping it in the same configuration and at the same attitude that was successful before.

After its Grigg-Skjellerup encounter, we concluded that *Giotto* had about 15 kilograms (about 33 pounds) of fuel left. That was just enough for us to maneuver the spacecraft's orbit so that it will swing by Earth one last time in July 1999.
—MANFRED G. GRENSEMANN, *European Space Agency, the Netherlands*

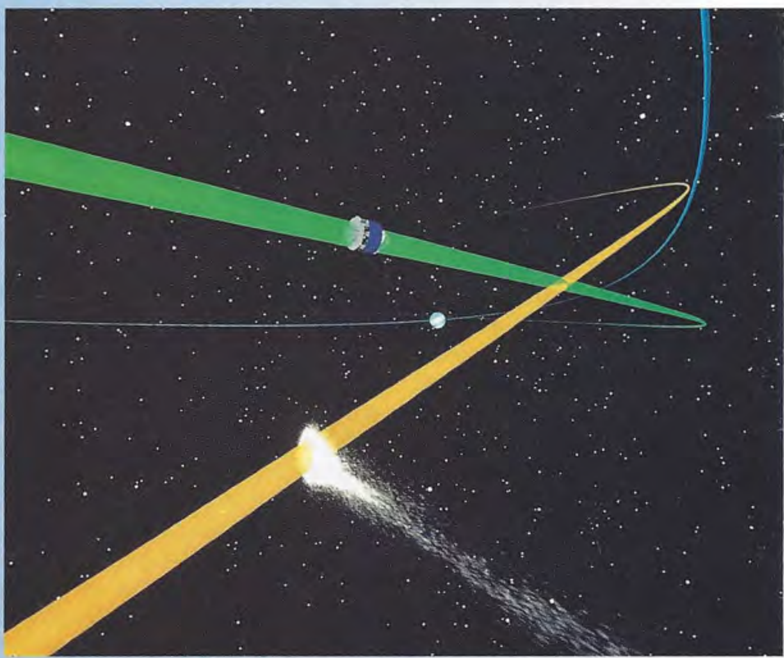
Almost no fuel remained after *Sakigake* last flew by Earth on July 3, 1995. This spacecraft will not approach Earth again. We are still contacting the spacecraft once or twice a week to retrieve stored measurements of the interplanetary magnetic field, plasma waves and the solar wind.

We had planned to send *Sakigake* to comet Giacobini-Zinner in 1998, but that is now not possible due to the lack of fuel.

Suisei flew past Halley's Comet on March 8, 1986. In 1987 the Institute of Space and Astronautical Science decided to guide the spacecraft to a November 24, 1998, encounter with comet Giacobini-Zinner (only five days before *Sakigake* was due to arrive). We had also planned for the spacecraft to fly within several million kilometers of comet Tempel-Tuttle on February 28 of that year. But the mission ended when *Suisei* ran out of fuel on February 22, 1991. The spacecraft shut itself off with a command to cut transmitter power. Since that day, nobody has known *Suisei*'s exact position.
—KUNINORI T. UESUGI, *Institute of Space and Astronautical Science, Japan*



ICE was launched in 1983 and will return home to Earth in 2014. Each of these loops represents an Earth orbit in ICE's 31-year path around the Sun. The spacecraft's position at press time is marked by an X.
Chart: Courtesy of Robert W. Farquhar, Johns Hopkins Applied Physics Lab; redrawn by B.S. Smith



Comet Grigg-Skjellerup passed through Earth's ecliptic plane (the white spot in the background is Earth) to "catch up" with Giotto for their encounter in July 1992. The comet was moving at about 38 kilometers (27 miles) per second while Giotto's speed was about 31 kilometers (19 miles) per second.
Illustration: European Space Agency

VEGA 1 and *2,* which were launched by the Soviet Union in December 1984, had their successful encounters with Halley's Comet on March 6 and 9, 1986. They were the first to fly close to a comet nucleus. The spacecraft continued to work for almost another year, but they are now dead, tumbling with no power and, of course, no communications with Earth.

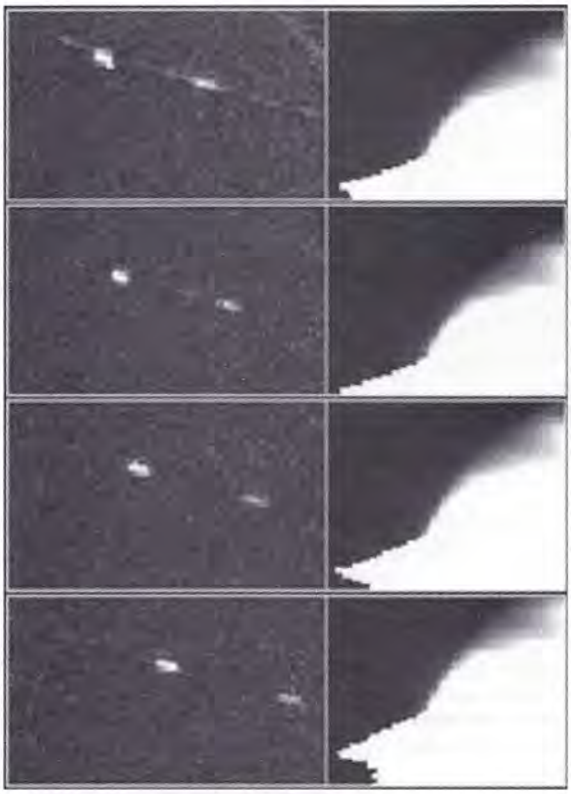
The *VEGAs* are now inside of Earth's orbit on roughly the same trajectory that they took after leaving Venus in June 1985. Their original trajectories took them from Earth to Venus (where they dropped small balloons into the atmosphere), and then on to Halley's Comet. The interplanetary trajectory that *VEGA 1* and *2* are now on is an ellipse with its perihelion (point closest to the Sun) equal to that of Venus' orbit and its aphelion (point farthest from the Sun) just outside of Earth's orbit.
—OLEG PAPKOV, *NPO Lavochkin, Russia*

The *International Cometary Explorer* (*ICE*) has not been in hibernation since its encounter with Halley's Comet. The spacecraft has been quite active doing what it was originally designed to do, which is to measure the interplanetary environment—plasma waves, the solar wind and energetic particles from the Sun.

Several years ago, *ICE* was attached to the *Ulysses* project. The *Ulysses* spacecraft is in an orbit that takes it over the Sun's poles. Over the past several years, we have gathered data simultaneously when *ICE* was at the same longitude as *Ulysses,* which was then at a higher solar latitude. One of these intervals occurred between the end of August and the beginning of October, 1995.

In the next several years, *ICE* will be passing behind the Sun as seen from Earth. Its radio signals will pass near the Sun, enabling them to probe the corona. No data will be radioed back from the *ICE* instruments, although they will be operating; the spacecraft will function simply as a radio frequency beacon.

Several years ago, an agreement was signed by NASA to recapture *ICE* after it returns to Earth in 2014 and to deliver it to the National Air and Space Museum in Washington, DC! As far as we know, there are no definite plans to accomplish this, although there is still a lot of time.
—EDWARD J. SMITH, *Jet Propulsion Laboratory,* and ROBERT W. FARQUHAR, *Johns Hopkins Applied Physics Laboratory*



Two (and maybe two more) new moons have been discovered around Saturn in images taken by the Hubble Space Telescope on May 22, 1995, when the planet's rings were tilted edge-on to Earth. Saturn ring-plane crossings like this happen only once every 15 years, and astronomers use these opportunities to discover new satellites normally lost in the glare of the planet's bright rings.

The elongated white spot near the center of the top image is one of the new moons known as S/1995 S3. It lies just outside Saturn's outermost F ring and is about 24 kilometers (15 miles) across. Epimetheus, which was discovered during the ring-plane crossing of 1966, is the brighter object at the left. Both moons change position from frame to frame because they are orbiting the planet. Saturn is the bright white disk at far right, and the edge-on rings extend diagonally to the upper left.

Each of these images (which span 30 minutes) was processed to remove residual light from the rings and accentuate any faint objects orbiting nearby. Saturn's bright, overexposed look is due to the long observing times that were necessary to detect the faint satellites.

"We were excited to see new satellites in the Hubble pictures. This was not the primary goal of our observations so we were quite surprised," said Amanda Bosh, who discovered the moons with partner Andrew S. Rivkin.

Images: Amanda S. Bosh, Lowell Observatory, and Andrew S. Rivkin, Lowell Observatory and University of Arizona/NASA

Factinos

Two new moons, and possibly two more, have been discovered in orbit around Saturn (see images at left). Amanda S. Bosh of the Lowell Observatory near Flagstaff, Arizona, and Andrew S. Rivkin of the University of Arizona announced in late July that they had spotted the new satellites in images of Saturn that they had taken using the Hubble Space Telescope.

Bosh said that the pictures were captured last May at a time when Saturn's rings, as seen from Earth, were exactly edge-on. During this rare celestial event, called Earth ring crossing, the rings nearly disappear from view, making it easier to see small objects nearby.

Two of the moons in the new images may be previously discovered satellites known as Atlas and Prometheus. Those moons were discovered by *Voyager* in 1980, but the latest sighting was in a slightly different location than where they were believed to be based on *Voyager*'s findings.
—from the Associated Press

✷

The Hubble Space Telescope has detected a previously unseen population of at least 200 million comets orbiting in a flattened ring, perhaps 149 billion kilometers (90 billion miles) in diameter, that encircles our solar system. This ring is the Kuiper belt. The scientists who announced the discovery in mid-June said it confirms decades-old theories about the origins of comets.

"For the first time, we have a direct handle on the population of comets in this outer region. We know, conclusively, that our solar system does not end at Neptune," said Anita Cochran of the University of Texas, who announced her team's finding at a June meeting of the American Astronomical Society.

"Knowing where comets come from tells us something new about where we came from," she added.

Another member of the research team, Hal Levinson of Southwest Research Institute in Colorado, said, "We believe we are seeing a region of the solar system where the accumulation of planets fizzled out."
—from Kathy Sawyer in *The Washington Post*

HOLIDAY GIFT GUIDE!

Make this holiday season fun and easy by shopping with The Planetary Society. Use this gift guide and the catalog (in the September/October 1995 issue of The Planetary Report) to make everyone happy!

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1 lb.
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Both Explorer *CD-ROMs are available for IBM or Macintosh. IBM version requires a 386 or better PC, 4 MB RAM, VGA (Super VGA recommended). Macintosh or Power Macintosh versions require system 7 or better, color monitor, 1 MB RAM. Power Macintosh version runs in native mode.*

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By William K. Hartmann and Joe Cain. Produced by The Planetary Society and the National Science Teachers Association, *Craters!* explains how comets, asteroids and volcanoes have shaped Earth's history. Includes 20 ready-to-use activities that teach key concepts in physics, astronomy, biology and Earth science. Plus, it comes with a CD-ROM (Windows- and Macintosh-compatible) filled with more than 200 images. 224 pages (soft cover).
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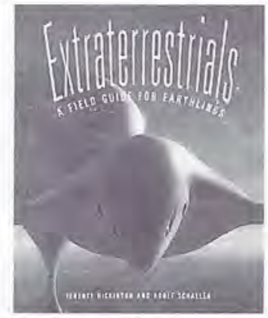

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Pasadena, CA 91106-2301

Printed in USA