

The **PLANETARY REPORT**

Volume X

Number 4

July/August 1990

Look Homeward, Voyager



A Publication of
THE PLANETARY SOCIETY



Board of Directors

- | | |
|---|--|
| CARL SAGAN
President
Director, Laboratory for Planetary Studies, Cornell University | BRUCE MURRAY
Vice President
Professor of Planetary Science, California Institute of Technology |
| LOUIS FRIEDMAN
Executive Director | JOSEPH RYAN
O'Melveny & Myers |
| MICHAEL COLLINS
Apollo 11 astronaut | STEVEN SPIELBERG
director and producer |
| THOMAS O. PAINE
former Administrator, NASA
Chairman, National Commission on Space | HENRY J. TANNER
financial consultant |

Board of Advisors

- | | |
|--|--|
| DIANE ACKERMAN
poet and author | JOHN M. LOGSDON
Director, Space Policy Institute, George Washington University |
| ISAAC ASIMOV
author | HANS MARK
Chancellor, University of Texas System |
| RICHARD BERENDZEN
educator and astrophysicist | JAMES MICHENER
author |
| JACQUES BLAMONT
Chief Scientist, Centre National d'Etudes Spatiales, France | MARVIN MINSKY
Toshiba Professor of Media Arts and Sciences, Massachusetts Institute of Technology |
| RAY BRADBURY
poet and author | PHILIP MORRISON
Institute Professor, Massachusetts Institute of Technology |
| ARTHUR C. CLARKE
author | PAUL NEWMAN
actor |
| CORMELIS DE JAGER
Professor of Space Research, The Astronomical Institute at Utrecht, The Netherlands | JUN NISHIMURA
Director-General, Institute of Space and Astronautical Sciences, Japan |
| FRANK DRAKE
Professor of Astronomy and Astrophysics, University of California at Santa Cruz | BERNARD M. OLIVER
Chief, SETI Program, NASA/Ames Research Center |
| LEE A. DUBRIDGE
former presidential science advisor | SALLY RIDE
Director, California Space Institute, University of California, San Diego and former astronaut |
| JOHN GARDNER
founder, Common Cause | ROALD Z. SAGDEEV
former Director, Institute for Space Research, Academy of Sciences of the USSR |
| MARC GARNEAU
Canadian astronaut | HARRISON H. SCHMITT
former US Senator, NM and Apollo 17 astronaut |
| GEORGIY GOLITSYN
Institute of Atmospheric Physics, Academy of Sciences of the USSR | S. ROSS TAYLOR
Professional Fellow, Australian National University, Canberra |
| THEODORE M. HESBURGH
President Emeritus, University of Notre Dame | LEWIS THOMAS
Chancellor, Memorial Sloan Kettering Cancer Center |
| SHIRLEY M. HUFSTEDLER
educator and jurist | JAMES VAN ALLEN
Professor of Physics, University of Iowa |
| GARRY E. HUNT
space scientist, United Kingdom | |
| SERGEI KAPITSA
Institute for Physical Problems, Academy of Sciences of the USSR | |

The Planetary Report (ISSN 0736-3680) is published six times yearly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, (818) 793-5100. It is available to members of The Planetary Society. Annual dues in the US or Canada are \$25 US dollars or \$30 Canadian. Dues outside the US or Canada are \$30 (US).

Editor, CHARLENE M. ANDERSON
 Technical Editor, JAMES D. BURKE
 Assistant Editor, DONNA STEVENS
 Copy Editor, MARY ELIZABETH WILLIAMS
 Art Director, BARBARA SMITH

Viewpoints expressed in columns or editorials are those of the authors and do not necessarily represent positions of The Planetary Society, its officers or advisors. © 1990 by The Planetary Society.
 131 Canada, Second Class Mail Registration Number 9567

COVER: From this early portrait of Earth and its Moon together; to thousands of images of the outer planets, their rings and satellites; to the family gallery of Sun and planets that closed out its imaging mission, Voyager has done more than any other spacecraft to show us our place in the solar system. Voyager 1 took this image on September 18, 1977, 13 days after it was launched. Nearly 13 years later, on February 14, 1990, it looked back toward Earth again, and returned a series of images of the planets that we feature in this issue. Image: JPL/NASA

FROM THE EDITOR

A rover from Earth has landed on Mars! In this issue of *The Planetary Report*, we reveal for the first time in print that the Soviet Union landed a roving vehicle on Mars during their 1971 *Mars 3* mission. (A sister craft, *Mars 2*, crash-landed on the planet.) This news is exciting, because for many years Mars rovers have been on the wish-lists of planetary scientists. Both the Soviet Union and the United States have been studying such missions for the late 1990s or early 2000s. Until now no one outside of the Soviet Union knew that a rover was already on Mars. For this exclusive story, turn to page 4.

Page 3—Members' Dialogue—In our March/April issue, a member suggested that Mars exploration can wait until we solve difficult problems facing humanity here on Earth. This suggestion triggered a flurry of letters; we print here two representative responses. The Search for Extraterrestrial Intelligence and a correction to a photo caption round out this column.

Page 4—From the Moon Rover to the Mars Rover—The Soviet Union has been building planetary rovers since the late 1960s and continues a vigorous program that may well lead to another Mars rover mission by the end of the century. Author Alexander Kermurjian has worked in the Soviet rover program since its inception. Here he shares reminiscences of the *Lunokhod* programs and describes designs for the *Marsokhods* yet to be launched.

Page 12—The Family Gallery—After taking humanity on an astounding journey to Jupiter, Saturn, Uranus and Neptune, the *Voyager* project undertook one last challenge: to image our family of planets arrayed about the Sun. No other spacecraft now flying could have accomplished this mission; no spacecraft now planned will be able to do it in the future. Here are the images and the story behind them.

Page 18—Pushing Back the Frontier:

A Mission to the Pluto-Charon System—Many of you have asked us: "What about a mission to Pluto? How soon can we complete our reconnaissance of the solar system?" From Mercury out to Neptune, our spacecraft have visited every planet but Pluto, and now missions to this distant world are on the drawing boards. This article enumerates the questions Pluto poses to us and describes a possible mission to answer them.

Page 24—World Watch—Momentum toward Mars is building in the Soviet Union and in the American administration, but progress is not equal on every front. In this column we report on a few steps forward and one step back.

Page 25—Society Notes—We've truncated this edition of "Society Notes" to bring you more news in "World Watch," but check out this column for announcements of some exciting and fast-approaching events.

Page 26—Spark Matsunaga, 1916-1990—We don't often run obituaries in *The Planetary Report*, but when someone dies who has played a major role in the exploration of our solar system, we feel it fitting to remember him or her. Spark Matsunaga was a politician, not an aerospace engineer or a planetary scientist, yet his contributions to international cooperation in space were crucial.

Page 27—News & Reviews—Titan is tantalizing us again with radar echoes that seem to contradict theories that scientists have been building over the past few years about this large moon of Saturn. Pluto as well is posing questions we can answer only with spacecraft investigations.

Page 28—Q & A—And what have you been wondering about lately? Hot spots in the solar system? Ways to die in space? The dangers of meteorite impacts on the moon? Find the answers in this column.

—Charlene M. Anderson, Editor

Members' Dialogue

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

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

Regarding the letter by Margaret S. Hunt in the March/April *Planetary Report*: The only means now available for finding extraterrestrial civilizations involves searching for artificially produced radio signals. Any society that cannot produce radio signals, however interesting they may be, will simply "fall through the holes in our net." Thus, the methods available to us limit the kinds of societies we might contact to those that have at least minimal technology. This is why many people believe we will share at least some mathematics and some science with any society we contact.

I have co-authored a paper with Dr. R. T. Oehrle of the Department of Linguistics where we constructed a language with which we might communicate with an alien society. We considered many possible approaches, but we soon found that since we and our contactees share only the physical universe, our language had to be based on our respective precise descriptions of this universe; i.e., our respective sciences and their associated mathematics.
—CARL L. DeVITO, *Department of Mathematics, University of Arizona, Tucson*

The caption accompanying the cover photo of the March/April 1990 *Planetary Report* is not entirely correct. The launch of *Apollo 17* was the last piloted *Saturn 5*, but not the actual last launch of that class of launch vehicle. That distinction belongs to the April 14, 1973 crewless launch by a *Saturn 5* of the Skylab Orbital Workshop.
—ARTHUR J. STOPPE, *Moorestown, New Jersey*

I cannot resist commenting on Bruce Woollatt's letter in the March/April issue of *The Planetary Report*. While his charitable sentiment is admirable [before we attempt a Mars mission we should take care of the basic needs of everyone on Earth], he makes two seriously wrong assumptions: First, that the problems he describes would be ameliorated or solved more quickly if the resources spent on space exploration were diverted to their solutions. Their solutions are not in throwing more money or talent at them, but in attacking them properly.

Second, he apparently assumes that space exploration is simply frivolous self-gratification. Much of what we have gained from space exploration, such as improved weather forecasting, global communication, life-support systems and the lessons of comparative planetology, have already had a direct impact on worldly problems of hunger, education, water quality and disaster preparation.

Carrying his reasoning to its logical conclusion, we should not hold the Olympic Games again until we've found cures for all forms of paralysis or debilitation, or grant college degrees until we have cures for all forms of mental retardation.

Rather than advancing the stragglers by holding back the leaders, our brightest hope is in the advance of the vanguard of ability and knowledge. One can see the direction we ought to go simply by juxtaposing his letter and the article on the very next page after it, on The Planetary Society's participation in Earth Day celebrations.

—W. VAN SNYDER, *La Crescenta, California*

Some people seem to have forgotten (or have never heard) that the first human expedition to Mars has already been postponed for about 30 years! NASA originally proposed a lunar base for 1979, a human landing on Mars before 1985 and a semi-permanent Mars base before 1990! All of this was scrapped, including plans for a space station and a fully reusable space shuttle. Billions of dollars have been saved by squeezing the life out of the space program for two decades. Has a single cent saved from the space program been used to feed the hungry of the world? Rather, hasn't the effect been a dampening of the spirit of the United States, endangering its leading role in technology, weakening its ability to effectively assist poorer nations?

A healthy, strong nation has to be active in all worthwhile areas—including the fight against hunger and a vigorous space program. Waiting until all problems on Earth have been solved before we go to Mars is a naive and unrealistic proposal which only leads to stagnation and doesn't help solve anything.

—JOHANNES KOCH, *Hong Kong, China*

On June 27 NASA engineers reported a major flaw in the main light-gathering mirrors of the Hubble Space Telescope. The flaw is likely to cripple its ability to see the depths of the universe for several years.

The engineers stated at a news conference that there was a distortion in one of the two mirrors used to focus light. Jean Olivier, deputy project manager said, "We don't know if it's on the primary or secondary mirror yet, but it looks like a textbook-perfect aberration that is perfectly symmetrical." The distortion, called a spherical aberration, prevents the telescope from finely focusing the light it gathers. Because of this, the instrument loses the ability to separate very close objects or to see very faint ones, they said.

Some of the instruments on the spacecraft will be unaffected by the problem. But the wide-field planetary camera that was to perform 40 percent of the scientific work will be unusable [until fixed, which some scientists think possible with correcting optics brought up from Earth]. Also, the camera for making extremely precise images of faint objects won't work as designers planned.

Although there may be ways for ground controllers to compensate for some of the problems caused by the distortion, a permanent correction will probably have to wait two or three years for astronauts to visit the craft and replace some parts, NASA said. Ed Weiler, a principal NASA program scientist for Hubble, said, "We can still do important and unique science" until the problems are solved. "We are deferring some of the science. We are not losing science."
—from Warren E. Leary
in *The New York Times*



Japan's space scientists have lost track of *Hagoromo*, their miniature Moon satellite fired into lunar orbit on March 19 of this year. Contact with the probe was lost, it seems, because of a broken transistor in the radio. Japan launched the mother ship, *Muses-A*, on January 24 (see News Briefs for March/April 1990). The ship was then renamed *Hiten*, or Spaceflyer, in orbit.

Kuninori Uesugi, chief scientist at Japan's Institute of Space and Astronautical Science, said the *Muses-A* project met its main goal of giving Japanese engineers experience in targeting the flight of a spacecraft to a distant solar system body.
—from *Space Today*

From the Moon Rover to the Mars Rover

by Alexander Kermurjian

This spring The Planetary Society hosted Drs. Alexander Kermurjian and Valery Gromov of the Soviet Union's Industrial Transport Institute of the Ministry of Defense Industries during their visit to Pasadena, the home of the California Institute of Technology (Caltech), the Jet Propulsion Laboratory (JPL) and The Planetary Society. Although the name of their institute scarcely betrays it, these two men are instrumental in the Soviet Union's planetary rover program. We invited them to the United States to meet their counterparts in the American Mars rover program.

Dr. Kermurjian is the Chief Designer of the Industrial Transport Institute. In that position, he is in charge of building the mobility systems for roving vehicles that the Soviet Union is planning to send to Mars, perhaps before the end of this century. Dr. Kermurjian has worked in the space program since 1963, when his institute was assigned the task of building the chassis for the *Lunokhods*, the robotic rovers that explored the Moon during the early 1970s.

These extraordinary robots traversed the lunar terrain performing many experiments, and their success is rivaled only by the *Lunas* that returned samples from the Moon. Dr. Kermurjian's group was in charge of the parts that provided motion—the wheels, motors, transmissions and steering. The Lavochkin Association oversaw the entire design, while the Institute for Space Research supplied most of the scientific experiments.

Dr. Gromov has spent 25 years in the space program, specializing in the physical and mechanical properties of soil. His experiments began with the *Luna 13* mission in 1966 and continued with the *Lunokhods*. He studied Venus' soil through data returned by the *Venera* and *Vega* landers, and was an experimenter on the *Phobos* mission that unfortunately failed before it could place a lander on that martian moon.

While visiting Planetary Society headquarters in Pasadena, Dr. Kermurjian submitted the accompanying paper to *The Planetary Report* and revealed to us exclusively that the Soviet Union has already landed small rovers on Mars—during the *Mars 2* and *3* missions of 1971. Both landers failed before the rovers were deployed; nevertheless, they were the first rovers to reach the surface of the Red Planet—a task both the United States and the Soviet Union are now working on.

Drs. Kermurjian and Gromov also presented a seminar at Caltech and showed a video of their experimental vehicles. They toured JPL to meet their American colleagues and to see the equipment developed so far. The American team is concentrating on artificial intelligence to enable a rover to take care of itself on Mars, while the Soviets have concentrated on building a vehicle able to overcome obstacles likely to lie in its path. The two approaches are complementary, and if the two leading spacefaring nations were to pool their resources and work together, the timetable for putting roving robots on Mars could be reduced by several years.

—Charlene M. Anderson, Director of Publications

In 1990 the *Lunokhod* or Moon Rover is 20 years old. This paper commemorates its anniversary. [*Lunokhod 1* landed on the Moon November 17, 1970; its mission lasted 11 months.]

The *Lunokhod* was made up of an air-tight compartment containing equipment and a self-propelled undercarriage. It had a temperature-control system with an isotope heat source, a radio and television transmitter, a command receiver, a power plant with solar and back-up storage batteries, a remote control, a small-

The *Lunokhod*'s total mass was 750 kilograms [1,650 pounds], with the undercarriage weighing 105 kilograms [230 pounds]. Its speed was 0.8 to 2 kilometers per hour [0.5 to 1.2 miles per hour].

As part of the undercarriage, the *Lunokhod* (Figure 1) carried the PROP (a Russian acronym for Surface Evaluation Instrument). Although it was a scientific instrument, the PROP (Figure 2) was also used as part of the safety system to determine the degree of wheel slippage and to forecast further motion [in response to com-

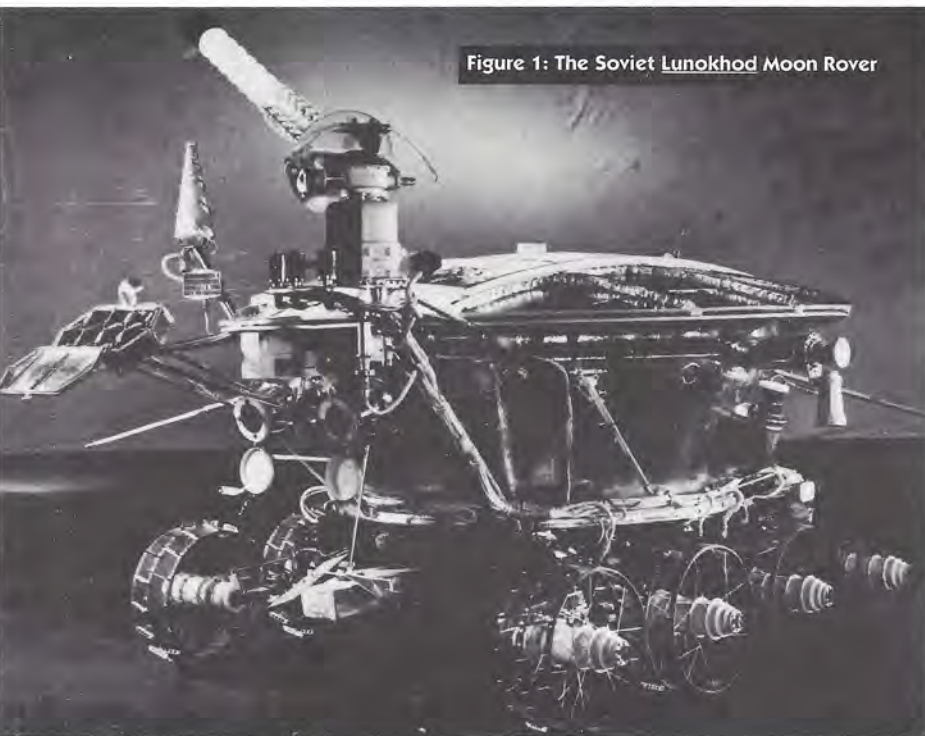


Figure 1: The Soviet *Lunokhod* Moon Rover

frame television, panoramic telephotometers [facsimile cameras, which compile an image by scanning back and forth] and a complex of scientific instruments.

The self-propelled undercarriage gave mobility to this planetary rover. This undercarriage consisted of wheels, electric motors, suspension, automatic motion-control, a complex of onboard sensors to monitor the assemblies and systems, and a device to transfer data to the telemetry system.

The undercarriage had eight rigid drive-wheels with perforated, cleated rims. The wheels did not swivel, so the rover was turned by imparting different velocities to the left or right side.

mands]. The PROP system consisted of a free-rolling wheel (the "ninth wheel") and a penetrometer.

The ninth wheel had spikes on its rim so that it could roll without slipping. The number of its revolutions provided information on the distance traveled. This wheel was attached to a lever so it could move up and down freely. Its vertical movement provided information on the unevenness of the terrain that the *Lunokhod* covered.

Comparing the number of revolutions of the ninth wheel and the drive wheels (which were also counted) made it possible to calculate how much the rover slipped. Measuring simultaneously the slippage, the forces acting on the wheels and the average



Figure 2: Close-up of the *Lunokhod* and PROP system

angle of the surface slope made it possible to determine the characteristics of the soil along *Lunokhod*'s route.

The penetrometer had a conical pressure-tool. During a measurement, the tool was implanted in the soil and turned 180 degrees. At the same time, the forces needed to penetrate the surface and to turn the instrument were measured.

Lunokhod 2 landed on the Moon on January 16, 1973. The two *Lunokhods* operated for a total of 414 days, logged about 50 kilometers [30 miles], took several hundred panoramas and over 100,000 photographs of the Moon using the small-frame television.

The special equipment on the self-propelled undercarriage, which itself acted as an independent scientific instrument, provided scientific and engineering data. For example, it has helped determine:

- The temperature of the Moon's surface and how it varied in relation to the Sun, as well as the temperature of the [wheel-driving] electromechanical transmission;
- The topography and crater distribution along the *Lunokhods*' route;



Figure 3: Trail of the Lunokhod's ninth wheel

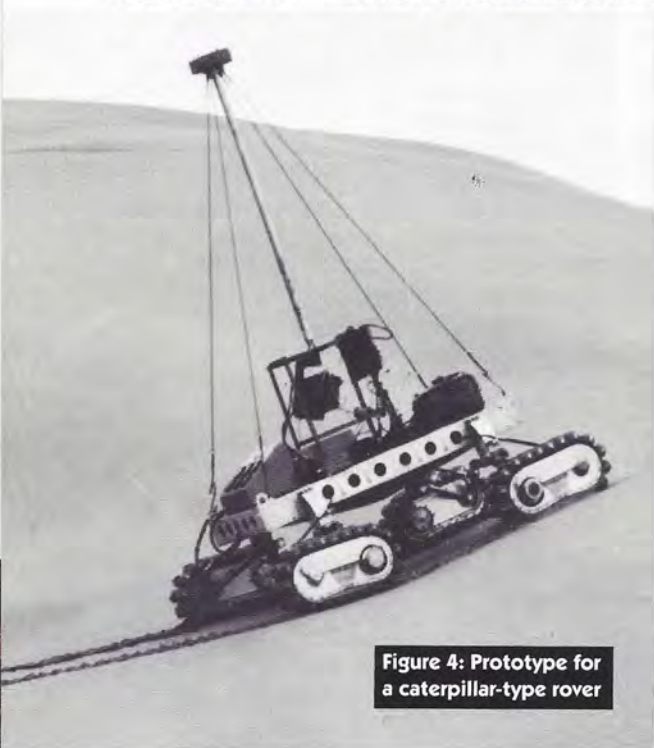


Figure 4: Prototype for a caterpillar-type rover

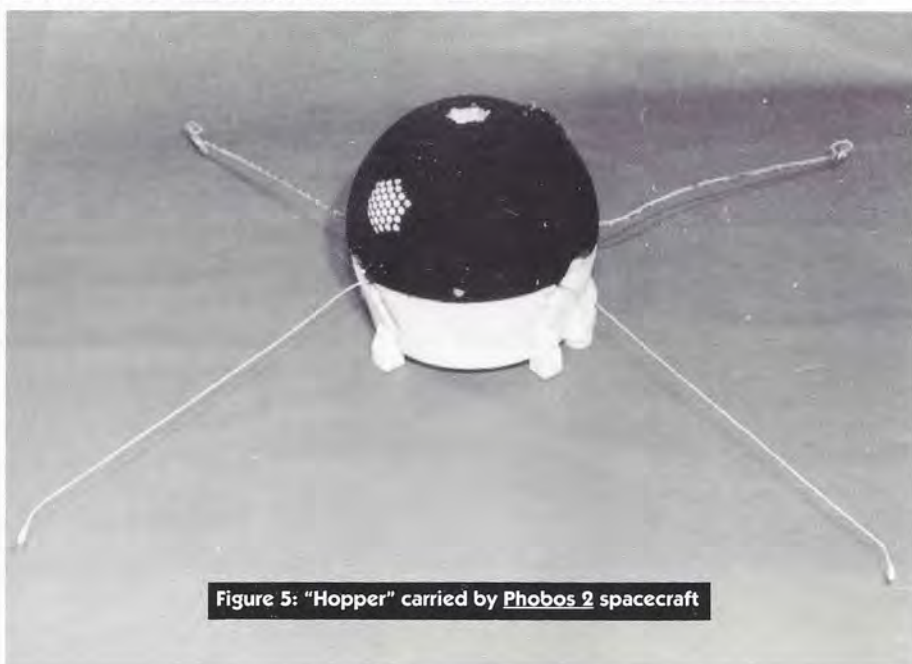


Figure 5: "Hopper" carried by Phobos 2 spacecraft

- The physical and mechanical properties of the soil, such as the bearing strength and rotational shearing strength (*Lunokhod 1* took measurements at 500 points);
- The specific power losses for soil deformation as a function of tractive force;
- The existence of a thin dust layer on the Moon's surface. The trace of the ninth wheel, as seen in **Figure 3**, is between 10 and 15 millimeters deep [about half an inch]. Its weight

on the Moon was about 200 grams [about half a pound].

Creating the Lunokhod

In creating the *Lunokhod*, many difficult scientific and technological problems had to be overcome. They must also be dealt with in developing the *Marsokhod*, or Mars Rover.

There was no reliable information about the lunar surface until the Soviet *Luna 9* made the first soft landing on the Moon on February 3, 1966.

This showed that the soil on the surface is sufficiently firm to support a spacecraft. The first panoramas made it possible for the soil structure and the distribution of small stones to be evaluated.

Special instruments on *Luna 13* (a soil penetrometer and a radiation densimeter) measured the bearing strength and density of the lunar soil.

After that, designing the *Lunokhod* took a surer course and lunar-soil models were used for tests on Earth.

First Rover on Mars—Soviets Did It in 1971

For the *Marsokhod* the problem differs. The martian surface is known to have rock outcrops and soft sands.

Gravity substantially affects the rover's cross-country capability and the stability and lubrication of its parts. This creates a problem in testing equipment on Earth since it is necessary to preserve the relationship between the mass and weight of the planetary rover. [On the Moon, a rover weighs only one-sixth as much as on Earth; on Mars it weighs a bit more than one-third.]

In tests, terrains were chosen that mimicked the surfaces of the Moon and Mars. The equipment was built to allow simulation of the gravity of various planets and celestial bodies.

Closely associated with the problems of soil and gravity is the problem of choosing a means of locomotion. Experience in operating the *Lunokhods*, as well as differences in the conditions among the planets and their satellites, necessitated a search for better means of motion.

The searches proceeded in the direction of improving the wheels (their shapes, dimensions, tread patterns and rigidity), trying a caterpillar-type mover (**Figure 4**) and trying other configurations.

For [the martian moon] Phobos, because of its ultralow gravity (one two-thousandth that of Earth), hopping was found to be the best means of movement. **Figure 5** shows the PROP-F (the Russian acronym for Mobile Robot for Evaluation of the Surface of Phobos) robotic spacecraft designed to travel over Phobos' surface. This "hopper" was installed on the *Phobos 2* spacecraft.

The spacecraft mass was 40 kilograms [90 pounds]. It was completely self-sufficient with its own power supply, radio transmitter and receiver, event programmer [a timer that turns components on and off], and an array of scientific instruments.

The spacecraft was to move by hops 10 to 40 meters long. After each hop it would roll over into its operating position and perform its experiments. Data were to be transmitted to the *Phobos 2* space-

Two robotic rovers reached the surface of Mars in 1971 during the Soviet *Mars 2* and *3* missions. Dr. Alexander Kermurjian has revealed exclusively to *The Planetary Report*. Neither vehicle completed its mission: *Mars 2* crash-landed on the planet and *Mars 3* ceased transmissions 20 seconds after landing.

The presence of mobile vehicles on these missions had not been revealed for nearly 20 years. Previous descriptions of *Mars 2* and *3* omitted mention of the small vehicles that were attached to the main landers by tethers. Their range was to be 15 meters from the lander.

The rovers moved by using skis set on either side (see photograph). The two thin bars at the front of the lander (if you look closely at the photograph, you'll see the division between them) are sensors to detect obstacles in the rover's path. The vehicle could determine on which side the obstacle lay, step back, change direction and try to go around it. This rudimentary artificial intelligence was necessary for these martian rovers; signals from Earth to Mars can take between 4 and 20 minutes to reach their destination (see box, page 9) — too long for a walking robot to wait for commands from Earth. By the time an obstacle had been recognized by mission controllers and commands transmitted from Earth, a rover could have already fallen to its demise.

The Soviet rovers each carried two scientific instruments: a dynamic penetrometer and a densitometer. They were to measure the bearing strength and density of the soil.

Although the *Mars 2* and *3* landers failed, their accompanying orbiters both successfully completed their missions and returned useful data to Earth. *Mars 2*, although it crashed, holds the distinction of being the first human-made object to reach the surface of Mars. The landers had the misfortune to arrive during one of the greatest martian dust storms in recorded history. A prevalent explanation for the sudden loss of contact with *Mars 3* is that the lander was

blown over by the fierce martian wind.

Mars 2 was launched May 19, 1971 and reached the Red Planet on November 27. *Mars 3* followed a few days later, launching on May 28 and landing on December 2. The orbiters continued their work until August 1972, when the Soviets declared the missions completed.

The United States' *Mariner 9* spacecraft had taken advantage of the same launch window (when the relative positions of Earth and Mars allow the quickest route between them). It launched on May 30 and entered orbit about Mars on November 14. Since its mission was strictly an orbital one, *Mariner 9* was able to wait out the dust storm. When the dust cleared, it discovered the great volcanos of Tharsis, the layered polar terrain, ancient river valleys, the nature of seasonal change, and Valles Marineris, the mighty canyon complex now named for its robotic discoverer.

With *Lunokhod 1* in 1970, the Soviet Union had become the first nation to land a rover on another world. In 1971 they almost succeeded in repeating their triumph with *Mars 3*. The distinction of successfully operating the first rover on Mars is still to be won. The changing relationships among the spacefaring nations of the world make it possible that that prize will not be won by any single country. It may well be that the first spacecraft to "walk" on the surface of Mars will be built and operated by the Soviet Union, the United States and other nations working together to explore the Red Planet. —CMA



Figure 7: Rover that landed on Mars in 1971

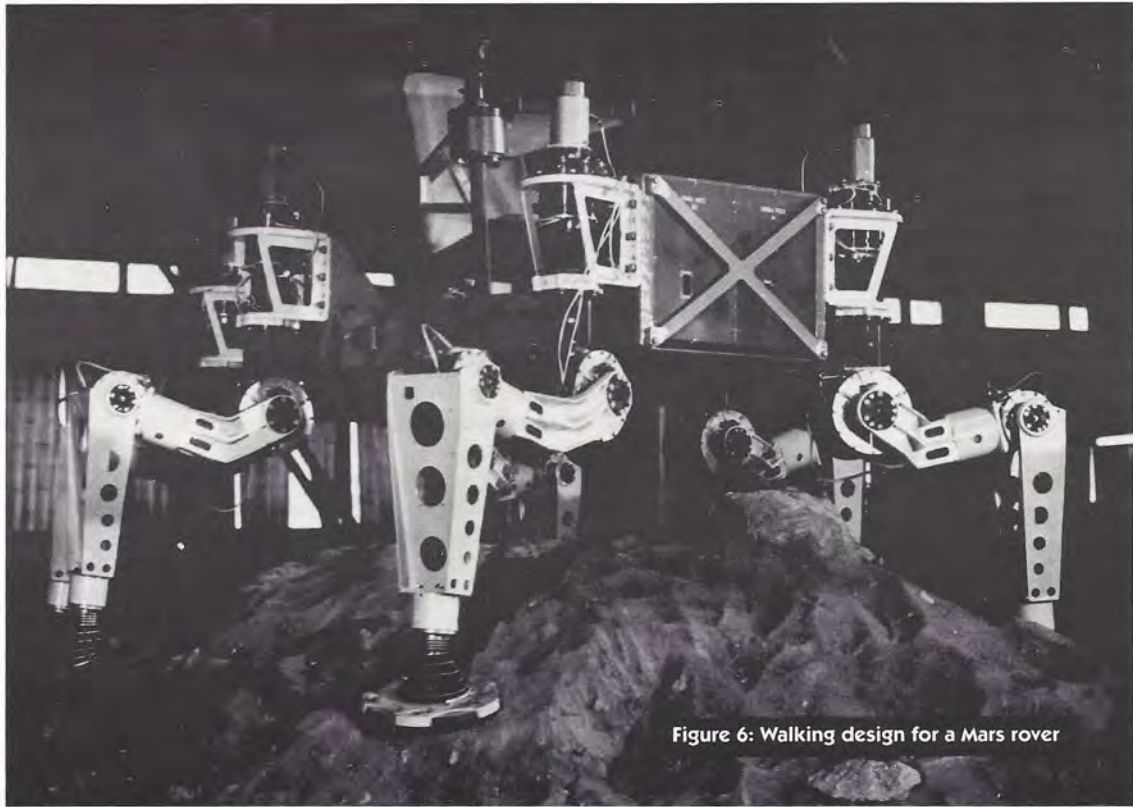


Figure 6: Walking design for a Mars rover

craft for return to Earth. Unfortunately, the PROP-F hopper was not destined to operate on Phobos. [Contact with *Phobos 2* was lost March 27, 1989 after it had reached the neighborhood of Phobos but before it had deployed the PROP-F. *Phobos 1* had failed en route to Mars.] The search continues toward

creating a walking rover for Mars. **Figure 6** shows one of the mockups of a robot that walks.

An apparatus that was to walk using skis (**Figure 7**, previous page) has been on the surface of Mars since 1971. This small rover was delivered to Mars by the *Mars 2* and *3* spacecraft. [*Mars 2*

crash-landed on the planet on November 27, 1971. On December 2, *Mars 3* was successfully deployed on the surface, but after 20 seconds of communications, transmissions ceased.]

Installed on these walkers were dynamic penetrometers and radiation densimeters. They were to communicate via cable with the landing station. The walkers' distance traveled was intended to be 15 meters. They carried sensors and an automatic control system to enable them to move around objects.

For the conditions on Mars, the "wheel-walking" mode of motion provides the best cross-country capability. A distinguishing feature of this mode is that the wheel can both roll and walk at the same time.

Figure 8 shows the first mock-up of a wheel-walking robot. This vehicle is capable of going up a friable soil slope of 30 to 32 degrees, which would be inaccessible for a wheeled or tracked vehicle. When moving along a hillside, this vehicle will not slip as much



Figure 8: Mock-up of a wheel-walking rover

as other types. A Mars rover of this design is also capable of changing the position of its body to accommodate the relief of the terrain (Figure 9).

Control is one of the main problems in creating a *Marsokhod*.

The problem of remote control also existed for the *Lunokhods*. A delay of

three seconds [the round-trip light time between Earth and the Moon, see box below] in transmitting commands and receiving a response, in addition to the complexity of determining the sizes of surface features and distances to them, required nonstandard modes of driving. The "crew" [that was to

control the *Lunokhods* from Earth] had to acquire new habits. The *Lunokhod* crew was carefully trained in simulated conditions, which took account of the psychological and physiological characteristics of every member. As a result, the crew was able to remotely control the *Luno-*

Light-Time and Robots: Communication Across the Solar System

Lunar rovers can be and have been driven by remote control from Earth. Why then do we conclude that such driving is completely out of the question for Mars? The answer is that Mars is far away and even at the speed of light, our radio commands and the responses to them are delayed.

Here are the relevant numbers: Light and radio waves travel at nearly 300,000 kilometers per second in the vacuum of space. The Moon is about 400,000 kilometers from Earth. Thus what we call the one-way light time to the Moon is about 1 1/3 seconds. As the driver commands the rover he can never observe its response any sooner than 2 2/3 seconds later. Many Earth-based experiments and the actual *Lunokhod* experience show that, though demanding of good on-board vision and hazard sensing, operator skill, and patience, such driving is indeed practical — so long as the rover travels so slowly that the driver's delayed reactions can keep up with it.

Now how about a rover on Mars? As an example of the numbers in that situation we can examine the light times for a typical martian mission, the *Mars Observer* to be launched in 1992. As Mars makes its way around the Sun

during its 687-day year and Earth circles faster, going around in only 365 days, the distance between the planets varies widely. During the flight of *Mars Observer*, Earth and Mars will come within 102,000,000 kilometers of each other when both are on the same side of the Sun, and the distance will stretch to 367,500,000 kilometers when we and Mars are on opposite sides of the Sun. Dividing these figures by lightspeed, 300,000 km/s, we find the one-way light times to vary from 5 minutes and 40 seconds to 20 minutes and 25 seconds.

Obviously nobody wants to leave a dumb rover to its own devices for nearly 41 minutes! It could drive right off an unseen cliff. No, the martian rover absolutely has to be smart. If it were not, its progress would be glacial, and even with considerable on-board intelligence it does not dare go faster than a human walking pace. The compromise among high mobility and hazard tolerance, travel speed, quality of vision and other on-board sensing, and human control demands is one of the most interesting challenges facing the engineers who are now preparing for the mobile robotic exploration of Mars.

—James D. Burke, Technical Editor



Sitting on Earth, a Soviet operator controls *Lunokhod* on the Moon.



Figure 9: Wheel-walker that can change body to accommodate relief

range and dimensional fidelity.] The robot also has an information and control complex built around a two-processor computer, a course-indication system and a displacement meter [odometer]. In motion tests, the robot traveled from a start point to a finish point. Motion was planned by processing the information from the LTVS to determine a possible path. The shortest paths were chosen.

The control problem is closely related to that of the cross-country capability. A large safety margin in the rover's cross-country capability enhances the reliability of motion in severe conditions. This may decrease the number of maneuvers while reducing demands on the required resolution of the technical vision.

Important to the efficient control of the rover's motion is its ability to maneuver. A possible configuration for a self-propelled undercarriage is one in which all wheels turn together at a specified angle. In this case, the rover may move transversely at an angle to its initial course without changing its body orientation.

There are other problems, such as the wind, temperature, composition of the atmosphere and its low density.

khods, and they avoided accidents.

For Mars, this problem of delay between sending commands and receiving responses greatly increases. A signal can take 5 to 40 minutes to travel to and from Mars. [Distances between Earth and Mars change as the planets travel their different orbits about the Sun.] So it is not possible to control a Mars rover in the same manner that the Moon rovers were controlled. A Mars rover must be more independent.

Controlling a robotic Mars rover presents difficulties, the principal one being limited or nonexistent information on the rover's situation.

In this connection, the capabilities of the *Marsokhod's* information system are increasingly important. It must also be able to determine distance and to sense its surroundings by "touch."

It is probable that the *Marsokhod* will be capable of independent motion and also of being remotely controlled from Earth by specifying a path over a certain time and distance. The navigation system has to be able to hold a heading to a finish point.

Obviously, the *Marsokhod* must have a sufficiently developed onboard "brain" for data processing, decision making and command transfer in accordance with specific programs.

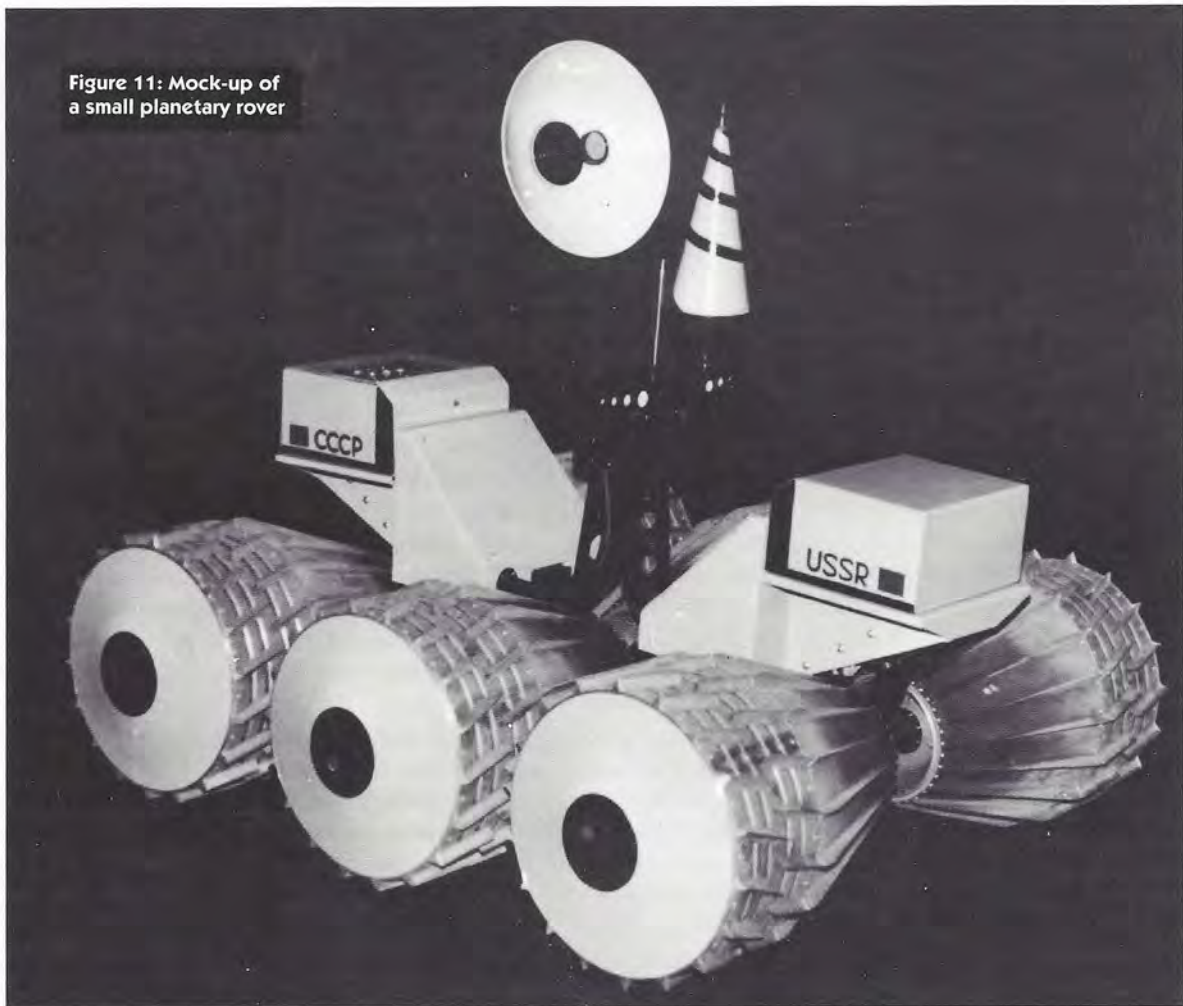
To test these abilities an experimental prototype of a planetary roving robot has been developed and tested.

It carries a laser-rangefinder technical-vision system (LTVS). [Technical vision produces an image that includes



Figure 10: Prototype rover with conical wheels

Figure 11: Mock-up of a small planetary rover



Modern Concept of the Marsokhod

The greatest cross-country capability can be ensured if the rover is a wheel-walker with a three-part configuration and a hinged frame. Such a rover has practically no road clearance. This is achieved by using conical wheels (Figure 10) that provide a continuous supporting surface for the rover, thus ensuring a cross-country capability for terrains full of obstacles and ruling out the rover's getting stuck on a high center obstacle. The hinged frame and a special drive for folding or raising the sections enable it to overcome obstacles whose height is twice the wheels' diameter.

For overcoming small crevasses, the sections can clamp together to form a rigid frame. The sections can move alternately to enable the wheel-walker to creep up friable soil slopes with angles of 33 to 35 degrees. Such a Mars rover might have the specifications listed in Table A.

The many problems that might be solved using automated rovers as well

as the inevitable restrictions [size, mass, power] on their placement on an interplanetary spacecraft suggest that it is expedient to create small mobile apparatuses (SMA). Such apparatuses may be used for the study of planetary surfaces with scientific instruments and for reconnaissance of landing sites. An SMA could also be used as a mobile radio beacon for landing the principal descent capsule and for exploration of hard-to-reach spots, where it could sample the soil and deliver the samples to a rocket for return to Earth.

As an example, Figure 11 shows a full-scale mock-up created from the concepts for the planetary rover described above. Table B gives its possi-

Table A Specifications for Prototype Marsokhod

Mass	360 to 450 kilograms [800 to 1,000 pounds]
Wheel diameter	500 millimeters [20 inches]
Maximum height of obstacle to be overcome	1 meter
Maximum angle of soil slope to be ascended	33 to 35 degrees

Table B Specifications for a Small Mobile Apparatus

Mass	70 kilograms [150 pounds]
Wheel diameter	350 millimeters [14 inches]
Maximum height of obstacle to be overcome	750 millimeters [30 inches]
Maximum angle of soil slope to be ascended	33 to 35 degrees

ble specifications.

Human thought cannot stop.
New thoughts, new ideas arise.

Therefore, it would be no surprise if the Mars rover that ultimately appears bears little resemblance to what is presented in this paper. But today, we see it this way. □

The Family

Home. Family. This will be *Voyager's* enduring legacy: It has changed forever the feelings raised by those words. Through its robotic eyes we have learned to see the solar system as our home. Through its portraits of the planets we know that they are part of our family.

Apollo astronauts showed us a tiny Earth alone in the blackness of space. Now, with these images, *Voyager* has shown us that Earth is not really alone. Around our parent Sun orbit sibling worlds, companions as we travel through the Galaxy.

These family portraits of the Sun and planets were *Voyager's* final photographic assignment. Planetary Society President and *Voyager* Imaging Team member Carl Sagan worked for a decade to get these pictures taken. Between the two *Voyager* spacecraft, they returned some 67,000 images of the four outer planets and their 56 known moons. *Voyager 1* had the slightly easier assignment: It encountered Jupiter in March 1979 and swung by Saturn in November 1980. Then it headed out in search of the heliopause, the edge of our Sun's sphere of magnetic influence, and where the solar wind gives way to the wind from the stars. In August 1989 *Voyager 2* flew by Neptune, completing its reconnaissance mission, having visited Jupiter in 1979, Saturn in 1981 and Uranus in 1986. After passing Neptune, *Voyager 2* joined its twin on the way to interstellar space.

The *Voyagers* had been launched in 1977 to take advantage of a planetary alignment that occurs only once every 176 years. The outer planets were lined up so that a spacecraft could swing from one to another, threading its way past the 4 gas giants in only 12 years. Mission planners at the Jet Propulsion Laboratory could select their paths from among many possible trajectories and targets.

For *Voyager 1*, they chose to send the spacecraft close by Titan's south pole to obtain close-up data on Saturn's largest moon. Titan's thick nitrogen atmosphere proved to be heavy with complex, carbon-rich organic molecules, and its surface is possibly dotted with lakes of liquid hydrocarbons. For carbon-based lifeforms living in a primarily nitrogen atmosphere—such as ourselves—a world like Titan is well worth a close look.

But to fly close to Titan, the project team had to sacrifice *Voyager 1's* encounters with Uranus and Neptune or a close-up look at Pluto. Its path around Saturn swung the spacecraft up and out of the ecliptic, the plane defined by Earth's orbit about the Sun.

Looking from its Pasadena home on Earth's northern hemisphere, the spacecraft now appears to be coasting above our solar system.

Voyager 1 was chosen to take the family portrait because fewer instruments might be damaged by looking back toward the Sun. And, to *Voyager 2*, now beyond Neptune and traveling much closer to the ecliptic, Jupiter was too close to the Sun to be picked up by the spacecraft's cameras.

So on February 14—Valentine's Day 1990—*Voyager 1* aimed its cameras at a string of small colored dots clustered just to the right of the constellation Orion—the Hunter. The spacecraft was then 32 degrees above the ecliptic and nearly 6 billion kilometers (3.7 billion miles) from the Sun. It took 39 wide-angle views and 21 narrow-angle images. The narrow-angle camera, with a lens resembling a telephoto, took three consecutive images through colored filters of seven of the nine planets. This enabled image processors at the Jet Propulsion Laboratory to construct the colored portraits of the planets seen on pages 16 and 17. The Multi-Mission Image Processing Laboratory then pasted together the wide-angle images into the mosaic on the next page.

Voyager had produced the first portrait ever of our Sun and planets together.

But like shy family members at a holiday gathering, the smallest planets avoided having their pictures taken. Mars and Mercury were lost in the glare of the Sun. The outermost planet, Pluto, was too tiny and far away. So this family portrait is incomplete.

The next generation of spacecraft will be unable to take another family portrait. *Magellan* and *Galileo*, and the planned missions, such as the Soviets' *Mars '94* and NASA's *Mars Observer* and Comet Rendezvous/Asteroid Flyby, plus the joint NASA/European Space Agency *Cassini* mission, will all be locked in orbit about their target planets. None of these will ever gain a perspective from which they could see the solar system as *Voyager* did.

Voyager alone could look homeward and capture our family of planets as they looked on February 14, 1990. *Voyager* alone could so graphically show us how Earth and the planets are inextricably linked to our parent Sun.

Home is now a corner of space brightened by a small yellow star. Family is now a company of planets circling that star together. Our home and family now encompass an entire solar system.

Thank you, *Voyager*. —Charlene M. Anderson

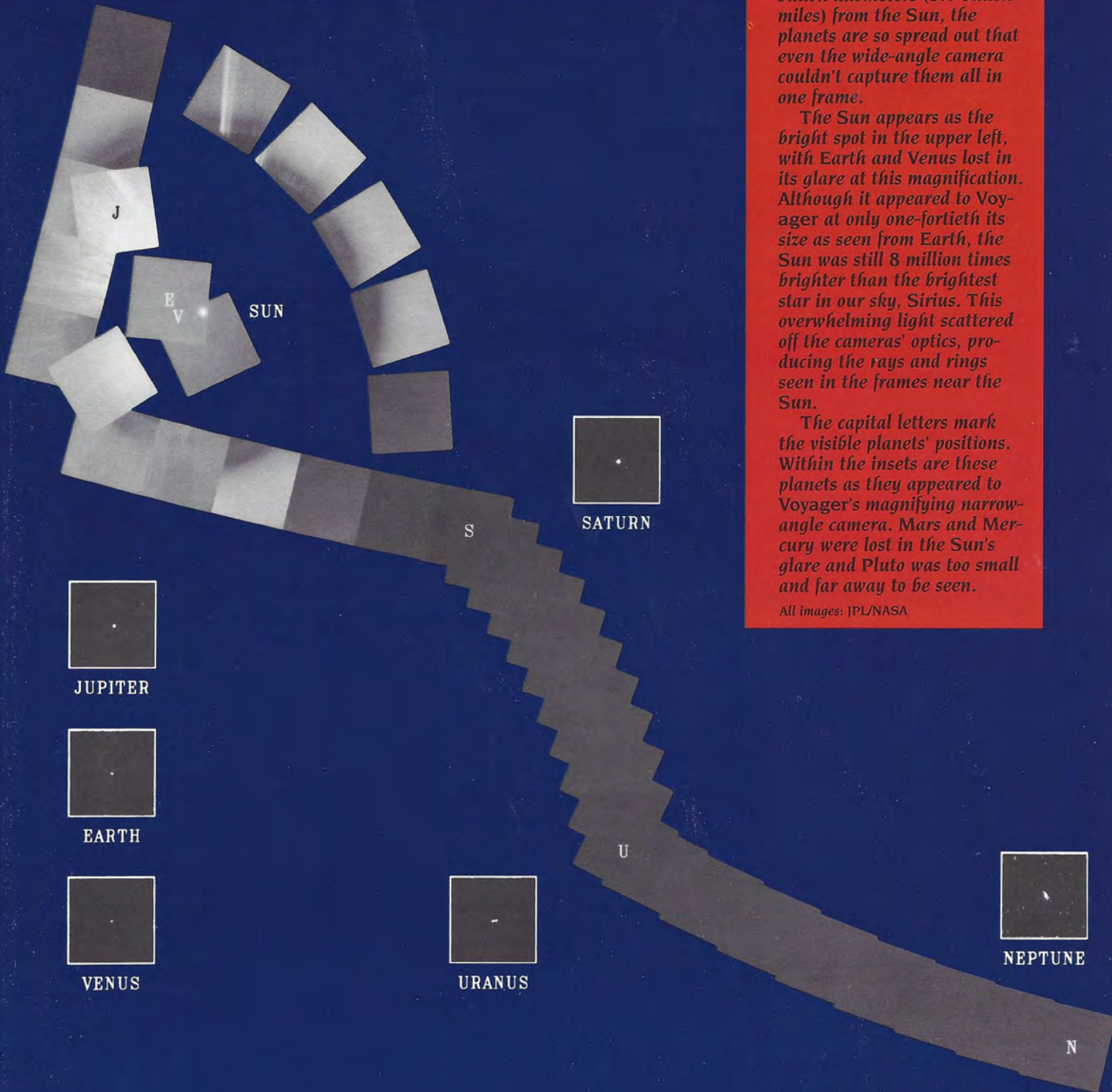
Gallery

For a family portrait, it's a little oddly shaped, but this mosaic of 60 images taken by Voyager 1 on February 14, 1990 constitutes the first picture of our Sun, Earth and planets together. At nearly 6 billion kilometers (3.7 billion miles) from the Sun, the planets are so spread out that even the wide-angle camera couldn't capture them all in one frame.

The Sun appears as the bright spot in the upper left, with Earth and Venus lost in its glare at this magnification. Although it appeared to Voyager at only one-fortieth its size as seen from Earth, the Sun was still 8 million times brighter than the brightest star in our sky, Sirius. This overwhelming light scattered off the cameras' optics, producing the rays and rings seen in the frames near the Sun.

The capital letters mark the visible planets' positions. Within the insets are these planets as they appeared to Voyager's magnifying narrow-angle camera. Mars and Mercury were lost in the Sun's glare and Pluto was too small and far away to be seen.

All images: JPL/NASA



JUPITER



EARTH



VENUS



SATURN



URANUS



NEPTUNE

Earth and Venus (right) are mere specks of light when seen from the outskirts of our solar system, as Voyager 1 did from nearly 6 billion kilometers (3.7 billion miles) from the Sun. In this mosaic, they appear at their appropriate scales relative to the Sun.

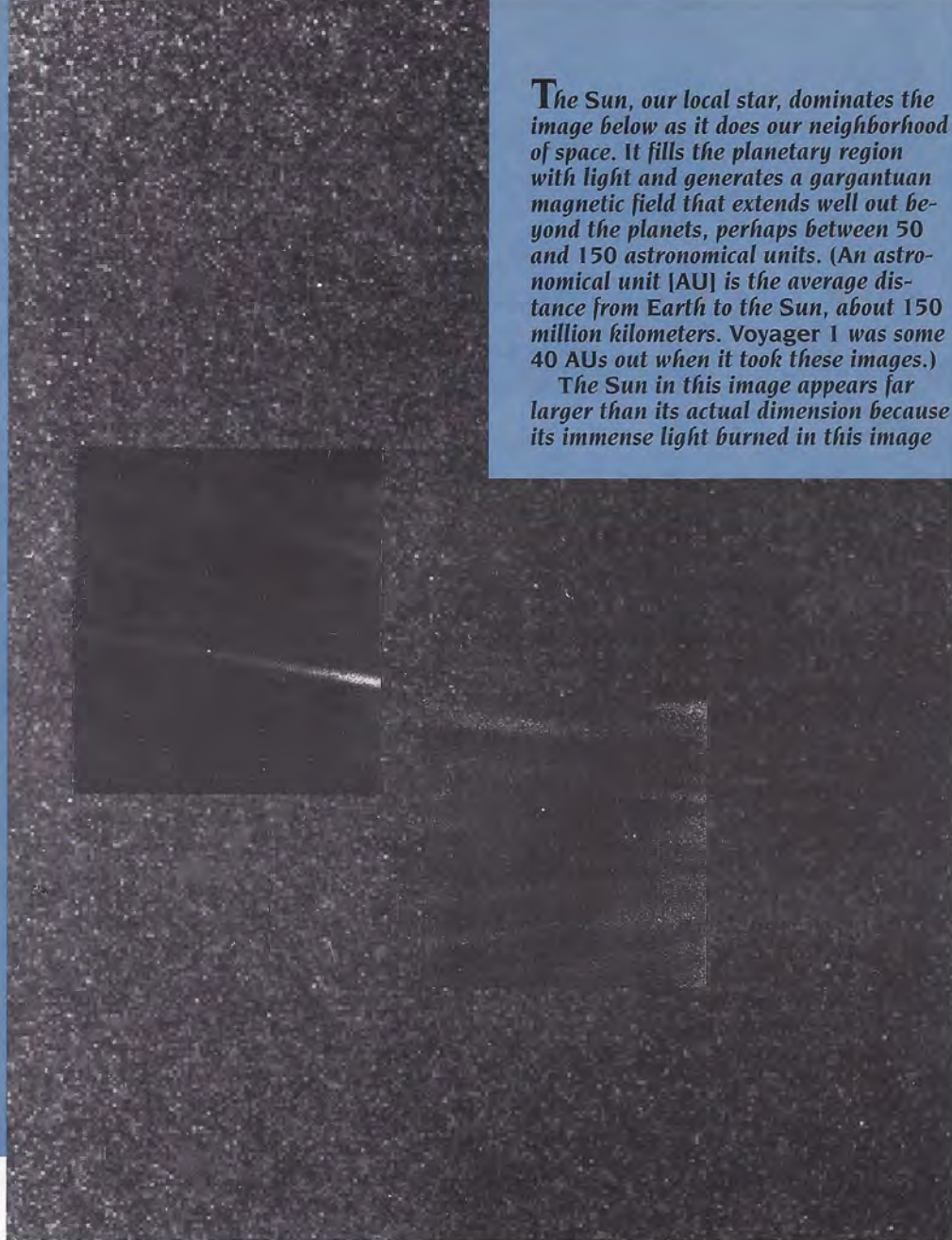
The usually glimmering Venus is a tiny dot within the frame near the center of the mosaic. Our Earth, a mote floating in a sunbeam, sits in the lefthand frame. The sunbeam is actually an artifact of sunlight reflected off Voyager's optics and not an actual phenomenon appearing in space.

A Voyager imaging frame is made up of 800 by 800 picture elements, or pixels. Even through the narrow-angle telephoto lens, our Earth is only 0.12 pixel in size; Venus is 0.11 pixel big. This humbling perspective prompted Carl Sagan, at the NASA press conference that released these images, to remark:

"That blue dot, that's where everyone you ever heard of—and every human being who ever lived—lived out their lives. It's a very small stage in a great cosmic arena, and the only home we have. This picture underscores our responsibilities to preserve and cherish that pale blue dot."

The Sun, our local star, dominates the image below as it does our neighborhood of space. It fills the planetary region with light and generates a gargantuan magnetic field that extends well out beyond the planets, perhaps between 50 and 150 astronomical units. (An astronomical unit [AU] is the average distance from Earth to the Sun, about 150 million kilometers. Voyager 1 was some 40 AUs out when it took these images.)

The Sun in this image appears far larger than its actual dimension because its immense light burned in this image



Center Spread:

We've taken the liberty of arraying Voyager's last color images of the planets into the family gallery on the following pages. The Sun and planets' positions are plotted relative to each other as Voyager saw them from the outskirts of our solar system. Even at this great distance, the members of our solar system family display distinct personalities.

Venus is the brightest planet visible in Earth's sky, but here it shows its true standing among the other planets, filling only 0.11 pixel in a frame in Voyager's narrow-angle camera. Venus orbits the Sun closest to Earth and is about the same size as our planet; for these reasons they are often called sister worlds. But they have followed entirely different evolutionary

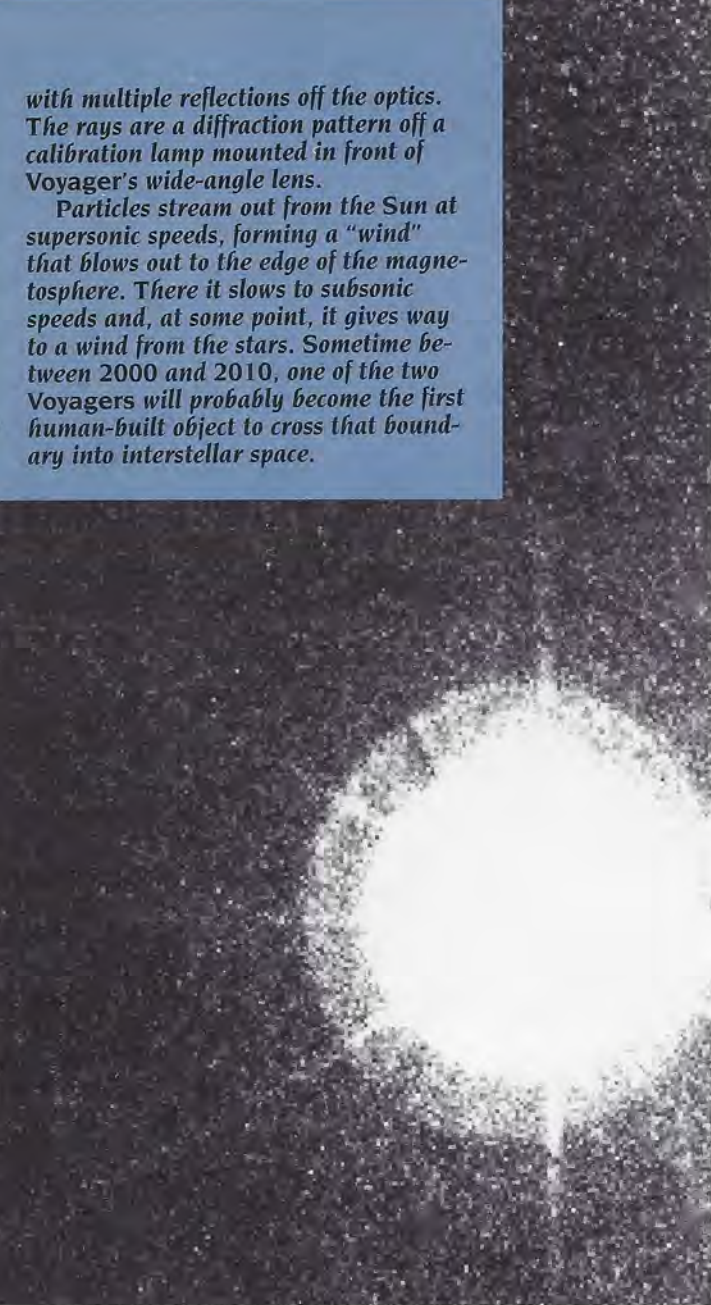
paths.

Venus shines with an opalescent glow from the sulfuric acid clouds that enshroud it. A crushingly thick carbon-dioxide atmosphere has raised surface temperatures to some 480 degrees Celsius (900 degrees Fahrenheit) through a runaway greenhouse effect. On Earth liquid water makes life possible; any liquid water that Venus may once have had has long since vanished. The sister worlds have grown to be different as heaven and hell. But at Voyager's distance, it is impossible to tell them apart.

Earth, the only life-bearing planet we know, is a tiny blue dot only 0.12 pixel across in this image. In just the last three decades, we have gotten used to images of our home planet taken

with multiple reflections off the optics. The rays are a diffraction pattern off a calibration lamp mounted in front of Voyager's wide-angle lens.

Particles stream out from the Sun at supersonic speeds, forming a "wind" that blows out to the edge of the magnetosphere. There it slows to subsonic speeds and, at some point, it gives way to a wind from the stars. Sometime between 2000 and 2010, one of the two Voyagers will probably become the first human-built object to cross that boundary into interstellar space.



from space. The blue nitrogen-oxygen atmosphere tinged with white water clouds; the bright, familiar continental landforms; the dark, world-girdling ocean—all these have long since shrunk to insignificance in Voyager's cameras.

Of all the worlds imaged by the Voyagers, only Earth seems to have managed to produce a multiplying, changing, thriving veneer of living matter. Sitting on Earth, surrounded as we are by a warm, nurturing atmosphere, friends and other living things, it's hard to conceive of how tiny, rare and fragile our world actually is. As Dr. Sagan envisioned, the preeminent value of an image like this is that it can take us out of ourselves and show us a truer perspective of our place in the universe.

Jupiter managed to fill four pixels in Voyager's camera. Its distinctive orange color registers clearly, but the banded atmosphere, including the Great Red Spot that could swallow three Earths, is impossible to see at this distance.

Jupiter's was the first planetary system visited by Voyager, and here the spacecraft made some of its most startling discoveries: the tenuous ring around Jupiter; the erupting volcanoes of Io; the smooth, icy surface of Europa that may conceal an underground ocean; the tectonically active surface of Ganymede; and the ancient, cratered face of Callisto.

Saturn with its rings was the loveliest planet that Voyager saw, and even at this distance, its slightly oblong shape suggests an enigmatic personality.

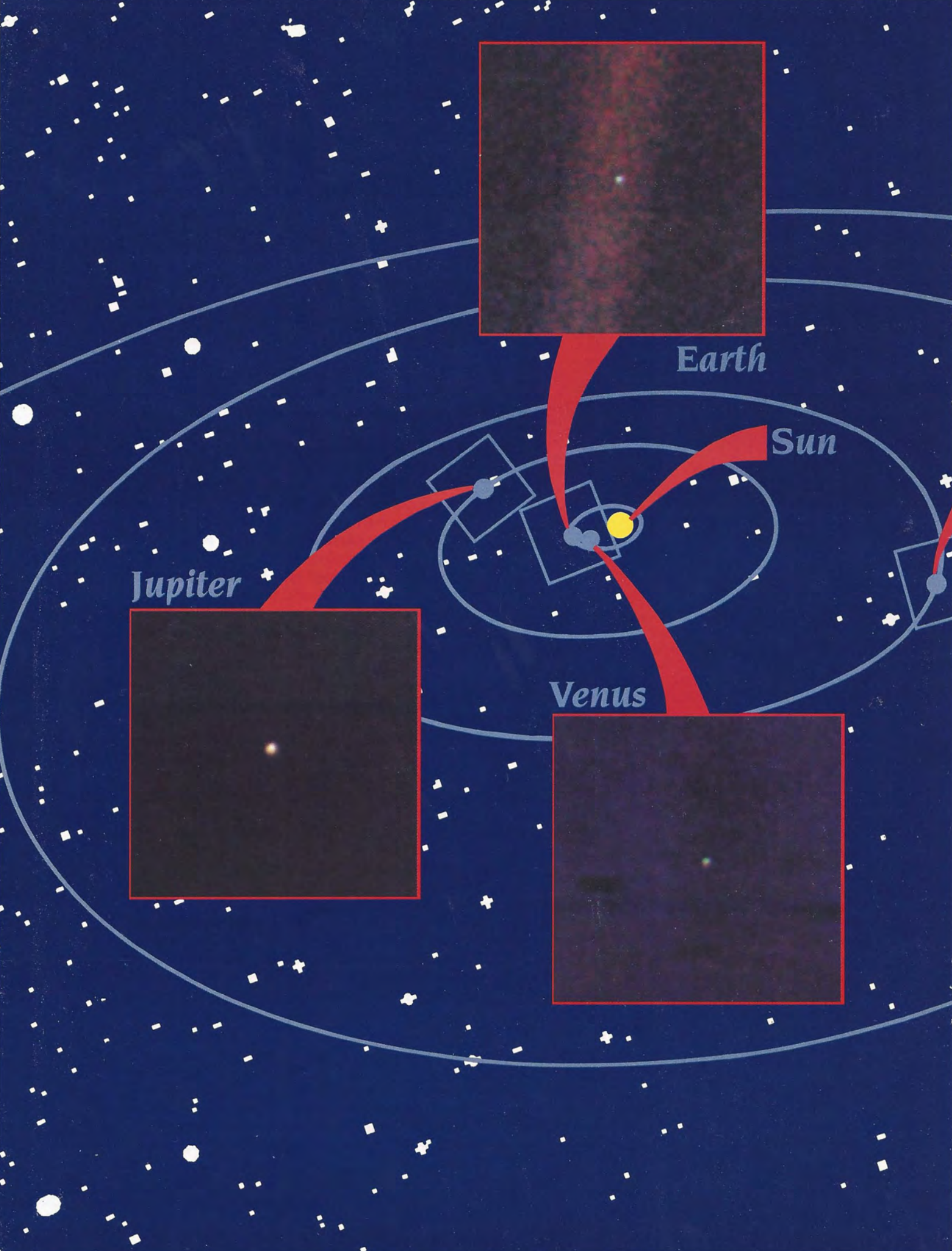
Voyager discovered that the great, classical rings are really made of thousands of tiny ringlets, with "spokes" of charged particles rotating around them. Saturn is orbited by Titan, a world wrapped in hydrocarbon haze, with a thick nitrogen atmosphere colored orange by an assortment of organic molecules.

Uranus was a bland blue ball to Voyager 2's cameras as it flew through the system in 1986. In this image (and in that of Neptune), the planet appears as a smear because the spacecraft was moving during the long 15-second exposure.

At Uranus Voyager found a corkscrewing magnetic field tilted nearly 60 degrees from the planet's axis, which is itself tipped 98 degrees from its plane of revolution about the Sun. The planet is circled by narrow, coal-black rings that contrast starkly with Saturn's bright ice rings. The star of the show turned out to be the tiny moon, Miranda, only 480 kilometers (300 miles) across. What it lacked in size, it made up in strangeness, displaying the most varied terrain seen by Voyager.

Neptune was Voyager's last planetary encounter, and it is still fresh in our minds. Its cool blue disk displayed a Great Dark Spot remarkably similar to Jupiter's Great Red Spot. The perplexing ring arcs detected from Earth turned out to be thicker segments of complete rings. Voyager thus discovered that all of the giant outer planets are surrounded by ring systems. Neptune's largest moon, Triton, provided a last planetary surprise when Voyager caught geysers erupting from its icy surface.

Many members of the Voyager team played parts in the conception of these images. Among those contributing their ideas and energy were: Candice Hansen, Charles Kohlhase, William Kosmann, Steve Matousek, Carolyn Porco, Carl Sagan and Brad Smith.



Earth

Sun

Jupiter



Venus





Saturn

Neptune

Uranus

Pushing Back the Frontier: A Mission to the Pluto-Charon System

by Robert Farquhar and S. Alan Stern

In the past three decades humanity has sent spacecraft to all the planets in our system except Pluto. In the early 1970s, when mission planners first began considering the epic *Voyager* reconnaissance, they investigated sending the *Voyager 1* spacecraft on to Pluto. At that time, scientists thought that Saturn's moon Titan, Neptune's moon Triton and Pluto—all small, organic-rich bodies traveling in the deep freeze of the outer solar system—were very similar worlds. To examine one or two close up would be enough to understand their common nature.

Voyager 1 mission planners chose to send the spacecraft in for a close look at Titan, which they knew from telescopic studies to have a thick, intriguing atmosphere containing the organic molecule methane (CH₄). *Voyager 2* would investigate Triton, and Pluto would be left for another generation of spacecraft and explorers.

But since the *Voyagers* were launched, our knowledge about Pluto has changed markedly. Indeed, even the existence of Pluto's moon, Charon, was unknown when *Voyager* was launched. Discoveries reported in the late 1980s have indicated that

Pluto is distinctive in several respects, and not a twin world to Titan or Triton. The Pluto system has a unique tale to tell us about the formation of the outer solar system and about several physical processes yet to be investigated by any planetary mission.

We've now learned just how different Pluto is. It is the smallest planet, only some 2,300 kilometers in diameter; its single, large moon, Charon, has a diameter of 1,200 kilometers. It follows the most distant and most eccentric orbit of any known planet, ranging from within 4.5 to over 7 billion kilometers from the Sun. Pluto's orbit is tilted 17 degrees—far more than any other planet's—from the ecliptic plane described by Earth's orbit about the Sun. And there is new evidence that Pluto's orbit may vary chaotically over astronomical timescales. (See "The Solar System in Chaos," in the May/June 1989 *Planetary Report*.)

Many scientists believe that a population of comets, called the Kuiper Disk, orbits the Sun between 30 and 50 astronomical units (one AU equals the average distance between Earth and the Sun, about 150 million kilometers). Since its orbit carries Pluto

through this region—untraveled by other planets—the surfaces of Pluto and Charon may preserve the best record of the flux of comets through the edge of our planetary system.

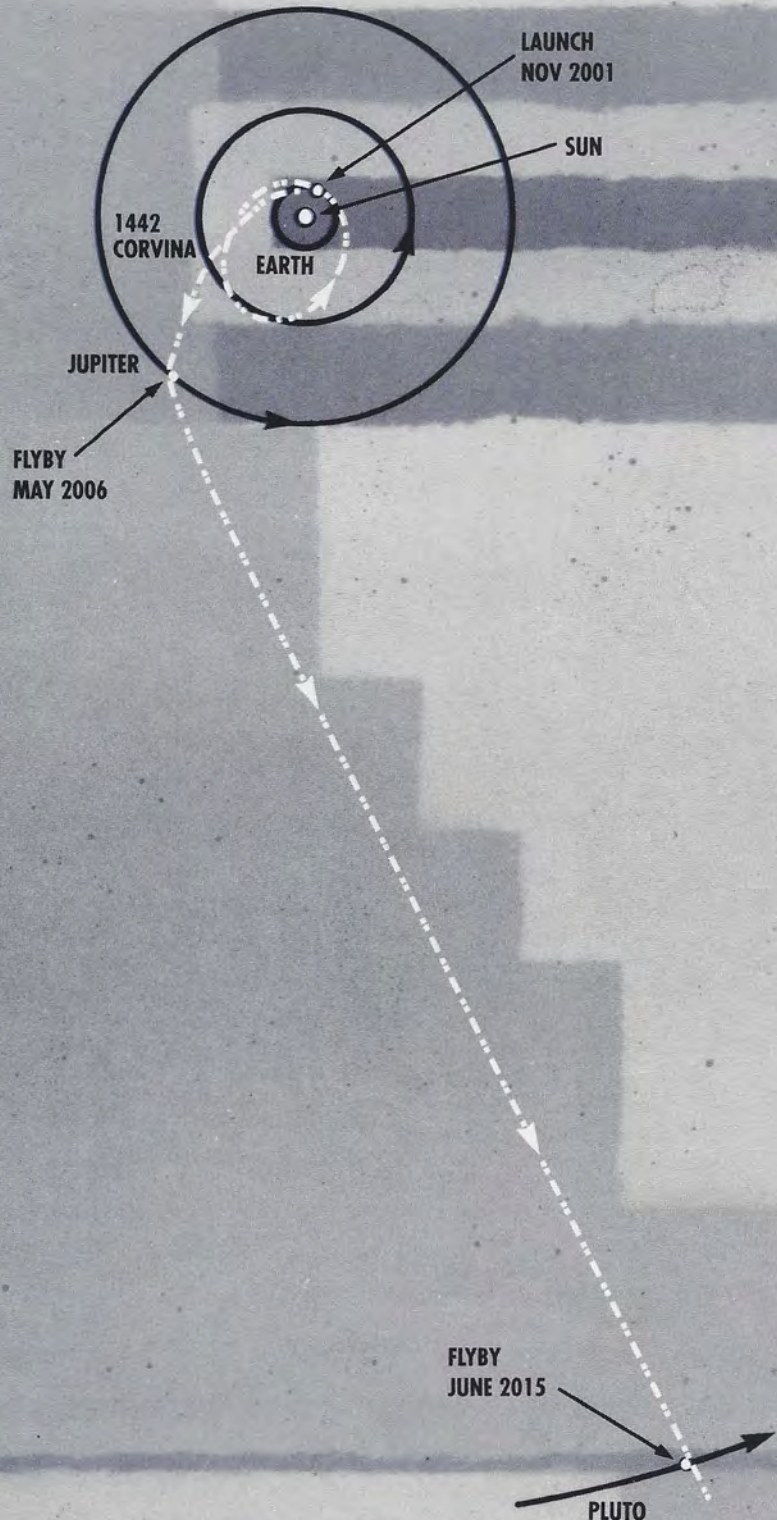
An Eccentric Planet

Because of its orbital eccentricity, Pluto experiences strongly varying solar heating during each 248-Earth-year orbit. During its passes within Neptune's orbit (the current phase lasting from 1979 to 1999), Pluto receives much more sunlight than it does in the farthest reaches of its orbit. The changing heat reaching its surface causes Pluto to be the only planet with an atmosphere that forms and decays during each orbit. This atmosphere is also more extended compared to the planet's size than the atmosphere of any other known world (in comparison, Earth's atmosphere is a thin, gaseous film).

Pluto seems also to be the rockiest planetary body in the outer solar system; yet it contains a substantial supply of volatile ices, including water and methane. The fact that Pluto is so much rockier than the giant planets or the small, icy comets is telling us something important about its formation. We think the Sun and planets

Complete Trajectory to Pluto Ecliptic Plane View

It's a long way out to Pluto, as you can see in this trajectory plot of a possible mission to this farthest known planet in our solar system. Illustration: S. A. Smith



condensed from a swirling cloud of gas and dust called the solar nebula. Around the larger planets "subnebulae" formed, from which their rock-and-ice moons then condensed. Rockier Pluto probably condensed on its own, and therefore it offers a better sample of the original solar nebula than do the outer planets' satellites. It has a unique tale to tell about the outer part of our parent nebula.

Earth and its large, single Moon are sometimes called a double-planet system. However, with Charon, Pluto is a much more extreme double-planet system. The Pluto-Charon mass ratio is 6 to 1; for Earth and its Moon, the ratio is 81 to 1. The strong gravitational interactions between Pluto and Charon are unique, and probably produce strong tides in Pluto's outer atmosphere. One particularly fascinating possibility is that Pluto's tenuous outer atmosphere may even envelop Charon, leading to mass transfer between the two. (This would be analogous to the physics of some binary star systems where matter flows between the stars.)

Like Uranus, Pluto is tipped on its side; Uranus is off 98 degrees, while Pluto tilts 108 degrees from the ecliptic. This orientation may be the result

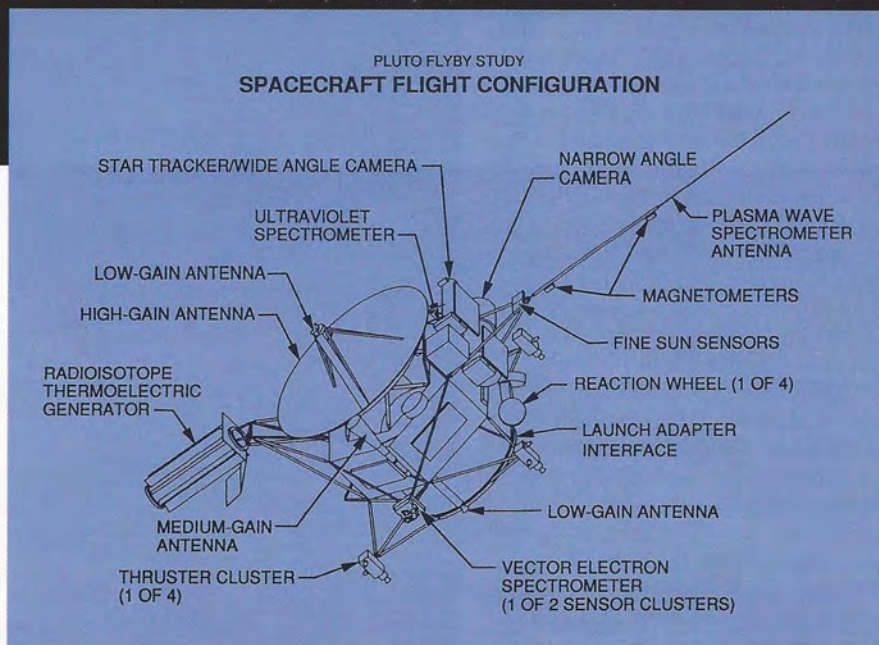


ABOVE: Pluto is the only planet in our solar system not yet visited by an exploring spacecraft. It's so far out that even the Hubble Space Telescope at its best would be unable to pick out features on its surface. The reconnaissance of the nine primary planets in our solar system will remain incomplete until a spacecraft studies Pluto and Charon.

Painting: JPL/NASA

RIGHT: This is a possible configuration for a Pluto-exploring vehicle. Mission designers at the Jet Propulsion Laboratory are working on spacecraft that can be built inexpensively yet carry a powerful array of scientific instruments.

Illustration: JPL/NASA



of an ancient giant impact. The currently leading theory for the formation of Earth and its satellite holds that a collision with a Mars-sized intruder splashed from Earth's mantle the debris that would become the Moon. If the same is true for Pluto and Charon, then they may constitute an excellent analog to the formation of our own double planet.

Taken together, this abundance of peculiarities shows that the Pluto-Charon system offers us new perspectives of planetary processes. And yet our present knowledge of them is comparable to what we knew of volcanic Io and hydrocarbon-rich Titan before *Voyager*.

Like Io and Titan, Pluto appears complex and enigmatic from afar. Given humankind's long history of misconception and mistake about planets explored only from Earth, it is unlikely that we can understand Pluto without inspecting it close up. Fortunately, NASA is now studying how it might conduct a mission to fly through the Pluto-Charon system.

Why Go Now?

Interest in a Pluto mission has been growing since the recognition that Pluto might hold the answers to important questions about the history of our solar system. The spectacular *Voyager* images of Triton, a body roughly similar to Pluto and about the same distance from the Sun, further excited scientists by demonstrating how complex and active Pluto may be. Most immediate, however, is our realization that Pluto mission opportunities with reasonable (11-14 year) flight times are infrequent.

Because of the energy needed to send a spacecraft to Pluto, gravitational assists from Jupiter (see box, next page) are a required part of the trajectory design. Unfortunately, Jupiter-Pluto transfers are only available every 13 years. One such opportunity is just ending. The next one will be between 2001-2004, with the spacecraft arriving about 2015. After that, we must wait until 2014 to launch, and that spacecraft would not arrive at Pluto until 2028. If the project started now, by 2028 the taxpayers who financed the mission, and the scientists and engineers who planned it, would be mostly gone.

More important though, as Pluto recedes from the Sun and cools, its atmosphere may collapse. This process could be over by 2025. To watch a planetary atmosphere collapse, possi-

ble with a 2001-2004 launch, would be an opportunity that cannot be repeated until the 23rd century.

In 1990, study of a low-cost Pluto flyby mission began at the Jet Propulsion Laboratory. To keep the cost under

a ceiling of \$300 million, many guidelines and constraints were applied. The most important was a directive to use a relatively inexpensive (about \$50 million) *Delta 2* rocket. Although its performance is modest by planetary stan-

The Pluto/Charon System

Physical Properties

	Pluto	Charon
<i>Radius</i>	1,150 kilometers	600 kilometers
<i>Visual color</i>	reddish	gray
<i>Rotation period (Earth days)</i>	6.39	6.39
<i>Known surface ices</i>	Methane, no water	Water, no methane
<i>Atmospheric composition</i>	Methane, other gases?	none
<i>Tilt of equator to Pluto's orbit about the Sun</i>	122.5 degrees	122.5 degrees

Orbit of Charon around Pluto

<i>Mean distance</i>	19,500 kilometers (nearly circular)
<i>Tilt to Pluto's equator</i>	0 degrees
<i>Period</i>	6.39 days

Orbit of Pluto/Charon about the Sun

<i>Perihelion distance (Closest point to the Sun)</i>	29.6 astronomical units *
<i>Perihelion date</i>	September 5, 1989
<i>Aphelion distance (Farthest point from the Sun)</i>	49.3 astronomical units
<i>Mean distance</i>	39.5 astronomical units
<i>Inclination (Tilt from ecliptic plane defined by Earth's orbit about the Sun)</i>	17.2 degrees

* One astronomical unit equals the mean distance between Earth and the Sun, about 150 million kilometers.

How Gravity Assist Works

We can change the trajectory of a spacecraft in orbit about the Sun by sending it close by a planet. With such a planetary “gravitational assist,” we can increase the energy of its solar, or heliocentric, orbit and change the orbit’s size and direction. The diagram shows the trajectory of a spacecraft near a planet. In deep space, the spacecraft follows an elliptical orbit about the Sun, and the relatively weak gravity of the planets has little effect. But if the spacecraft passes close to a planet, to within a few dozen to a few hundred times its radius, the effect of the planet’s gravity increases. This happens because although the planet’s mass is much less than the Sun’s, it is much closer to the spacecraft and so exerts a greater force upon it. This region of dominant planetary gravity is called the planet’s gravitational sphere of influence.

Inside the sphere of influence, the spacecraft follows a curved path around the planet, altered insignificantly by the Sun’s gravity. The spacecraft’s velocity increases as it approaches the planet, then decreases as it moves away. Its speed is the same at entry to and exit

from the sphere of influence.

The spacecraft’s direction has changed by an amount called the bend angle. The bend angle will be larger if the planet is more massive, if the spacecraft passes more closely or if it approaches more slowly. Since the spacecraft’s speed has not changed, its orbital energy relative to the planet remains the same.

However, its orbital energy relative to the Sun *has* changed. The planet’s velocity has been added to that of the spacecraft, and the spacecraft is now moving much faster relative to the Sun. We’ve sent it into a larger orbit that will take it to much greater distances from the Sun.

By changing the aim point, and so the encounter geometry between the spacecraft, planet and the Sun, we can send our interplanetary explorers on myriad different orbits, even on to an additional gravitational assist from another planet. *Galileo* is using this technique by encountering Venus once and Earth twice on its way out to Jupiter. By using the most massive planet, Jupiter, to slingshot our Pluto spacecraft on its way, we can reach the outermost planet in 11 to 14 years. —RF

dards, a *Delta 2* can launch a 500 kilogram (1,100 pound) spacecraft into the desired trajectory. JPL engineers succeeded in designing a “mini-*Voyager*” that could do the job.

This spacecraft would carry a multispectral wide- and narrow-angle imaging system similar to the one that will fly on the Comet Rendezvous/Asteroid Flyby (CRAF) and the *Cassini* mission to the Saturn system. The other half of the payload might consist of an ultraviolet spectrometer to study Pluto’s atmosphere and a plasma physics package to investigate the interactions of Pluto and Charon with the solar wind of ionized particles blowing out from the Sun.

Although this payload contains relatively few instruments, it strikes a balance between scientific completeness and cost. It can carry out a very exciting initial reconnaissance of the Pluto/Charon system.

You can follow the spacecraft’s circuitous path to Pluto in **Figure 1** (see page 19). With a launch in November

2001, the spacecraft travels a heliocentric trajectory out about 3.2 Astronomical Units (AUs) from the Sun. Then, in January 2005, the spacecraft swings back by Earth and slingshots out to Jupiter. There another gravity assist sends it on to Pluto by June 2015.

Building Up Benefits

A benefit of this indirect trajectory is that the spacecraft would fly by the asteroid 1442 Corvina on December 14, 2002. In addition to its scientific value, adding a closeup of another in the zoo of small bodies orbiting between Mars and Jupiter, this encounter will be an excellent opportunity to calibrate the spacecraft’s imaging system. Plus, the Jupiter flyby would be an opportunity to follow-up on *Galileo*’s orbital mission, which will end sometime in 1997.

A major advantage of a planetary flyby over ground-based observations is its inherently finer imaging capability. Even at its best resolution, the

Hubble Space Telescope (HST) will barely be able to tell how large Pluto’s polar caps are. It will see about as much detail as an amateur telescope can see on Mars. Detecting geologic features or counting craters are beyond the HST’s capability. The mission we describe will be able to do that and more. And it can make measurements that are impossible by remote sensing, such as the composition of a planet’s ionosphere or the strength of its magnetic field.

Some of the questions to be answered by a Pluto/Charon flyby include: How varied are their surfaces? What atoms and molecules make up the atmosphere? How does the varying solar heat over each orbit affect the surfaces and atmosphere? How do Pluto and Charon interact? Does the atmosphere evaporate and re-condense every day or only seasonally? Is Pluto geologically active? What does the cratering record tell us about comets in Pluto’s neighborhood? What was the origin of this double-

Trajectory Around a Planet

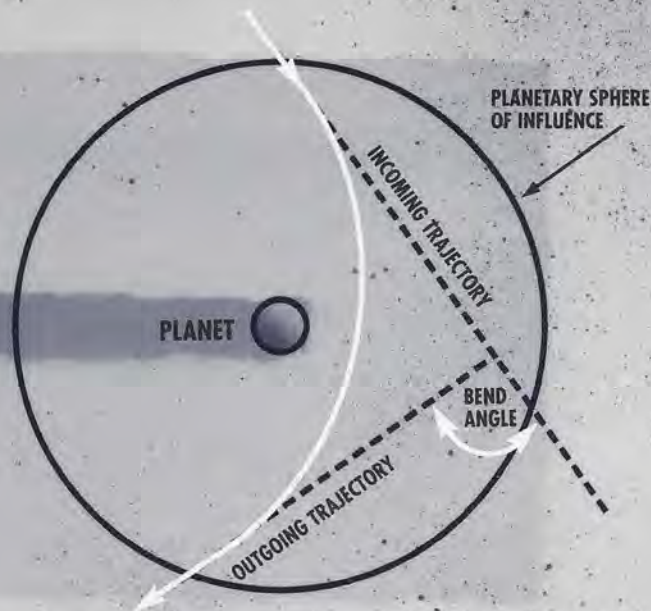


Illustration: S. A. Smith

planet system? What can Pluto and Charon tell us about the evolution of our solar system?

We consider the imaging system to be the highest-priority experiment for the Pluto flyby. Just think of what images of the planets have taught us about dynamic, changing bodies like Mars, Io and Triton. Consider that *Voyager's* amazing, high-resolution map of Triton, in which scientists discovered polar caps, atmospheric hazes and erupting geysers, consists of less than one dozen images!

Even if a camera were the only instrument flown, we could learn about the geologic history of Pluto/Charon, obtain crater counts to date the surface, perhaps map the distribution of volatiles, search for atmospheric hazes, volcanoes and geysers, and look for tenuous rings or small satellites orbiting Pluto. These answers alone would revolutionize our knowledge.

A Wish List of Instruments

Next on our list is a plasma science

package, consisting of a magnetometer and several small detectors to measure the properties of the particles streaming from the Sun and flowing around planets. This will teach us about Pluto's interaction with the solar wind, help determine the influence of Charon on Pluto's outer atmosphere, and search for magnetic fields in both Pluto and Charon.

We've included an ultraviolet spectrometer (UVS) to study Pluto's atmosphere. It would search for gases, including hydrogen, argon, carbon, nitrogen, oxygen, sulfur and carbon monoxide. It will also measure the temperature and pressure of the atmosphere and determine how it changes with altitude. The UVS would also search for a weak aurora or electroglow and determine if the atmosphere does indeed flow between Pluto and Charon.

Another strong candidate instrument would be a thermal mapper to detect heat from Pluto and Charon. Designing and fabricating an instrument capable

of measuring radiated heat from these two worlds is clearly a technological challenge because they are so cold. However, such an investigation could tell us much about their surfaces and atmospheres.

To top off the scientific measurements, the spacecraft's radio could help refine measurements of Pluto and Charon's mass and probe the atmospheric and ionospheric structure.

This payload, possible on a flyby mission of moderate cost, can answer a wide range of questions about the Pluto/Charon system that cannot be answered from Earth or even from Earth orbit.

Doubling the Return

Because the upcoming Pluto mission opportunity is unique, we might consider sending two spacecraft. If they are identical, the cost of the second spacecraft would be between 50 and 80 percent of the cost of the original. If an international partner could launch the second one, NASA's share of the cost would be modest. Candidates for a second launch are Japan's H-2, the European *Ariane 4*, and the Soviet Union's *Proton*.

A dual launch offers two advantages: redundancy and increased science return. Because both Pluto and Charon rotate slowly (about every 6.4 days), we can obtain images of only one hemisphere of each object during a single flyby. Two flybys could provide global coverage. If we separated the encounters by about one year, we could observe changes in Pluto's atmosphere and surface.

Time and again planetary scientists have been astonished by the variety nature presents in our solar system. A Pluto mission would continue the tradition of discovery begun by *Ranger*, *Mariner*, *Viking* and our other robot explorers. Until we send a spacecraft to the Pluto/Charon system, our reconnaissance of the solar system will be unfinished. Whether humankind is willing to devote the resources to explore this fascinating pair of worlds is unknown—it is something we must decide.

Robert Farquhar is the Senior Scientist and Chief of Advanced Programs in the Space Physics Division at NASA Headquarters. S. Alan Stern is a planetary scientist at the University of Colorado, Boulder and a Principal Investigator on a Hubble Space Telescope program to image Pluto.

by Louis D. Friedman

MOSCOW—The *Mars '94* mission received final approval and full funding in May 1990 from the Soviet government. The Academy of Sciences had already received its funding, but until now engineering work and industry contracts had been delayed.

The Lavochkin Association is responsible for the development of the two spacecraft, which will be launched on *Proton* boosters in October 1994. (The Soviets routinely send twin spacecraft on planetary missions.) The *Mars '94* mission includes an orbiter, the Mars Balloon (with an instrument-carrying guide-rope designed by The Planetary Society), surface penetrators and small meteorological stations.

A preliminary plan for missions to follow *Mars '94* was also approved, but it is a plan with options, owing to an as-yet-unresolved debate between the Institute for Space Research (IKI) and the Vernadsky Institute of Geochemistry and Analytical Chemistry. IKI argues for a Mars rover mission in 1998, followed by a Mars sample-return mission in 2001.

Vernadsky wants to do a sample return from the martian moon Phobos in 1996, using little new instrumentation and including a repeat of the partially failed *Phobos* mission of 1988. The mission would be a step toward a Mars sample return, which Vernadsky proposes for 1998.

Another ambitious mission receiving study-only approval is *Tsiolkovsky*, a solar probe that would go first to Saturn and drop off a small probe at Titan.

Several Soviet officials, both in the science and engineering programs, reiterated that lunar missions are receiving very little attention in the USSR.

WASHINGTON—President Bush called for Americans to set foot on Mars by 2019, the 50th anniversary of the first *Apollo* Moon landing. In a commencement speech at Texas A & I University, he set the target date for the culmination of the Space Exploration Initiative first proposed in July 1989 on

the 20th anniversary of *Apollo*.

This spring the White House directed that talks begin with European nations, Canada, Japan and the USSR to make the initiative international. This step was a major change of policy in that it set international involvement and included the USSR before the program was even defined. This administration policy, calling for landing humans on Mars early in the next century, is just what The Planetary Society has been advocating since 1984.

Space 90 Held in Albuquerque

Serious space enthusiasts gathered at a large five-day meeting called Space 90, sponsored by the American Society of Civil Engineers, the Space Studies Institute, The Planetary Society and thirteen other organizations. With the theme of construction and operations on the Moon and Mars supported by *in situ* resources, the meeting called forth all leaders in fields related to large-scale lunar development and martian exploration. Papers, posters and exhibits gave evidence of the strength and variety of research. Extracting oxygen, metals, hydrogen and helium 3 from lunar materials; building habitats; supplying power; growing food; and providing the necessities for sage and productive settlement—these and many other subjects were treated, not just as proposals but as subjects for current commitment and achievement.

The Space 90 conference demonstrated the worldwide vigor of a community of people thinking seriously about very ambitious ventures on the Moon and Mars. —James D. Burke, Technical Editor

Now needed is congressional support to define the program, develop precursor missions, and study propulsion systems and technology for long-duration life support.

LENINSK, USSR—A group of American engineers visited several space facilities in the Soviet Union during a tour organized by The Planetary Society and the USSR's Institute for Space Research. They returned with new insights into the USSR's human spaceflight program. The engineers were members of the Space Systems Technical Committee of the American Institute of Aeronautics and Astronautics. Several Planetary Society members also participated in the meetings at the facilities in Moscow, Star City and Baikonur (the main Soviet launch site, near the town of Leninsk in Kazakhstan). We are now planning future tours for Planetary Society members.

We learned that the Soviet space program is alive and healthy and that reports of its death were premature. We saw two *Energia* heavy-lift launch vehicles and a *Buran* shuttle under construction. We also saw several modules for the *Mir* space station: *Soyuz* (for crew replacement), *Progress* (for supplies), *Kvant* and *Kristall* (science stations). We were shown a docking module for coupling the *Buran* and *Mir*, which means that a fully developed space-station complex, built around the station already in orbit, could be operational by the end of 1991. Soviet officials also told us a *Mir 2* is under development for 1994 orbital insertion.

A flight of the *Buran* is planned for mid-1991, though it is uncertain whether the mission will carry humans or not. (The maiden flight of *Buran*, in late 1988, was uncrewed.) Tom Heinsheimer, a member of the Planetary Society delegation, speculated that a mission in both modes would be logical: *Buran 2* might fly to *Mir* under automatic control and dock; the crew already in the space station would board the shuttle and return to Earth.

WASHINGTON—NASA has terminated its portion of a project with the French space agency to develop an infrared mapping spectrometer for the *Mars '94* mission. The Centre National d'Études Spatiales (CNES) was notified of NASA's action in a letter from Lennard Fisk, Associate Administrator for Space Science and Applications to Jacques Breton, CNES's science director.

The move shocked those working on the international *Mars '94* mission, which is being managed by the Soviet Institute for Space Research (IKI) and includes participants from many countries, including The Planetary Society. We are designing the SNAKE guide-rope for the Mars Balloon being built by CNES. (See the May/June 1989 *Planetary Report*.)

The spectrometer would have mapped the distribution of minerals on Mars. CNES had originally planned to build an instrument, called Omega, alone. But when VIMS (Visible-Infrared Mapping Spectrometer) was dropped from the American *Mars Observer* spacecraft, NASA suggested to IKI that VIMS fly

instead on *Mars '94*. The Soviets persuaded the French to combine their instrument with the American one in an experiment to be called Omega-VIMS.

Now that NASA has backed out, CNES is faced with the task of developing the instrument alone. This has left a bitter taste among the French experimenters and Soviet mission planners. The situation was not helped when, in his letter, Fisk said that NASA might reconsider cooperating if the Soviets delayed the Mars mission from 1994 to 1996.

Fisk cited proposed cuts to the fiscal year 1991 budget, then before Congress, as the reason for the termination. The project would have required \$20 million in 1991.

NASA's decision to back out of a cooperative program is inconsistent with recent pronouncements from President Bush. On March 31, the White House issued a statement calling for greater cooperation among the spacefaring nations. The staff of the National Space Council, which is studying space policy for the President, was surprised by NASA's ac-

tion. It illuminates the low priority that middle-level NASA management places on international cooperation.

The Planetary Society vigorously protested NASA's termination of Omega-VIMS development. One of our primary goals is to see the nations of Earth explore the planets together, and this cancellation strikes at the heart of our program. Fortunately, our actions have helped reopen the question.

NASA is now reconsidering the cancellation and is exploring compromises. One possibility is that American electronic equipment—spare parts from another planetary spacecraft—might be made available to the French if they decide to continue building an infrared instrument for *Mars '94*.

The French space agency, however, faces its own budgetary problems, and may not be able to find the additional funds to continue the project.

We will keep you informed as this situation develops.

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

SOCIETY

Notes

CONTEST WINNER DELIVERS PAPER AT CASE FOR MARS

Ryan Shepperd, winner of The Planetary Society's 1990 Mars Institute Contest, delivered his report at the Case for Mars IV conference, held this June in Boulder, Colorado.

With his paper, "No Lunar Detour," the high-school student from Fort Collins, Colorado beat an impressive field of contestants from around the world. This year's entrants were asked to consider the role of the Moon in the human exploration of Mars.

PROGRESS TOWARD MARS—BALLOON TEAM TO GIVE TALK

On September 22, Louis Friedman of The Planetary Society and Frank Redd of Utah State University will report the progress of the Mars Balloon Team. The talk will be held at Hansen Planetarium in Salt Lake City.

In a Planetary Society-supported project, the team is designing an instrumented guide-rope for the French balloon probe that will fly on the Soviet Union's *Mars '94* mission.

SAGAN TO ADDRESS PLANETARY SCIENTISTS

Carl Sagan will present a lecture open to Planetary Society members during the October meeting of the Division for Planetary Sciences of the American Astronomical Soci-

ety. This year the scientists will meet in Charlottesville, Virginia during the last full week in October. Call our information lines for more details.

"THE BLUE PLANET" SCHEDULED FOR NATIONAL AIR AND SPACE MUSEUM

This fall, The Planetary Society, in cooperation with the National Air and Space Museum, is sponsoring a special free showing of the new IMAX film "The Blue Planet." NASA scientist Wes Huntress will discuss our own Earth and its sister world, Venus, in an accompanying lecture.

Our mailing address:

The Planetary Society, 65 N. Catalina Avenue
Pasadena, CA 91106

Call for an updated events calendar:

(818) 793-4328 east of the Mississippi
(818) 793-4294 west of the Mississippi

Spark Matsunaga

1916 - 1990

by Harvey Meyerson

When Senator Spark Matsunaga (D-HI) died on April 15, 1990, The Planetary Society lost one of its friends. On the floor of the United States Senate, he had championed a human landing on Mars as an international endeavor whose challenge could pull the nations of Earth toward their common destiny: He foresaw an Earth-born humanity moving out into the solar system. In 1984 he introduced a resolution that renewed US-USSR cooperation in space. The next year, he introduced another resolution calling for the joint exploration of Mars. These resolutions added political substance to Planetary Society proposals, and brought our vision of international space exploration much closer to accomplishment. We will miss him greatly.
—Charlene M. Anderson, Editor

Spark Matsunaga loved bringing people together. In politics, relationships are as important as arguments, he always said, because a winning argument has no enduring effect if the winner doesn't inspire respect and affection. Spark Matsunaga's efforts toward space cooperation were a cumulative example of that axiom. When he and Roald Sagdeev met, they didn't shake hands. They embraced—and it was spontaneous on both sides.

Matsunaga's successful two-year campaign to renew the US-Soviet space cooperation agreement was filled with festive dinners and lunches for scientists, space officials and politicians from both countries. When he introduced the congressional resolution for an International Space Year (ISY), the astronauts and cosmonauts from the epoch-marking *Apollo-Soyuz* docking were in the Senate gallery, by special arrangement. Afterward he brought them down to the floor to meet his Senate colleagues.

Matsunaga was a combat veteran of World War II who attended Harvard Law School on the G. I. Bill of Rights. He was first elected to Congress in 1962, barely three years after Hawaii won statehood. He served continuously thereafter, gaining election to the Senate in 1976.

I remember first discussing space cooperation with him in the spring of 1982. Congress was in recess. We were sitting in his regional office in Honolulu.

"This issue is important," Matsunaga said. "I want you to take all the time you need in pursuing it."

The words are still vivid because, by prevailing congressional standards, they made no sense. Senior congressional staffers are rarely told to take all the time they need on anything. Rushing from topic to topic is a necessary way of life on the Hill. Moreover,

Matsunaga served on none of the relevant committees for space. Nor was space cooperation a significant national or local issue at the time.

Why then did Matsunaga take up the issue of international space cooperation and pursue it tenaciously for the rest of his life?

Because that's the way Sparky was, and why it was such a pleasure to work for him.

Cooperation on the space frontier fit into his own unique political paradigm. It offered a nonconfrontational vision of the future. It required moral conviction. Its pursuit benefited most from imaginative ideas with universal appeal.

It also drew on two of his favorite themes, science and poetry. As Chairman of the Senate's Energy R & D subcommittee, he authored more renewable-energy legislation than any other member of Congress. Visitors to his office on any subject usually received lectures on photovoltaics, ocean thermal energy, fuel cells—replete with such props as a solar-powered music box. He might wind up the lecture with a plug for his 20-year campaign, ultimately successful, to establish a national poet laureate. When asked to contribute combat mementos to a World War II museum, Matsunaga sent copies of poems he wrote during the siege of Cassino.

His distaste for confrontational debate was, I think, essentially aesthetic. He regarded it as a failure in composition, as if the harmonious tableau he was trying to create had suddenly gone jagged. He knew the political process inside out—he even wrote a textbook on the arcane procedures of the powerful House Rules Committee, to which he once belonged. At the time of his death he was Vice-Chairman of the even more powerful and byzantine Senate Finance Committee—but he always kept his balance.

In remarks on the Senate floor when introducing his ISY resolution, Matsunaga said: "The unity of planet Earth so evident from space is undermined daily by human conflict, but it survives in our aspirations. The lingering memory of *Apollo-Soyuz* demonstrates its persistency and hints at an awaiting fulfillment. It probably won't happen in our lifetime. But what has proved impossible on Earth will, I am convinced, eventually prove necessary and unavoidable if humanity is to realize its destiny in the cosmic immensity of the heavens. Meanwhile, governments have an obligation to respond to the deepest aspirations of their citizens in ways that do not conflict with national interest."

It's all there: an encompassing vision, compassion, an obligation to aspirations, an appreciation of interests and above all a modest sense of contributing to a process larger than himself. No, it didn't happen in his lifetime. No, his contributions weren't recognized as they might have been in his lifetime. But those weren't the scales on which Matsunaga measured achievement.

If he could have chosen any words for his epitaph from the eulogies in the Senate that fill 15 pages of the Congressional Record, I suspect they would be these, from James Exon of Nebraska:

"Spark Matsunaga was a truly loving and caring person, the likes of which the US Senate may never have seen before and may never see again."

Harvey Meyerson was Spark Matsunaga's legislative counselor from 1980 to 1987.

News & Reviews

by Clark R. Chapman

Voyager taught us that planetary beauty is not a function of size. That small is beautiful—or fascinating—became clear from the first images of Jupiter's moon Io over a decade ago. *Voyager* gave us clear views of most of the moderately small objects in the outer solar system, setting aside for the moment the swarms of still smaller asteroids and comets that remain unexplored even in the inner solar system.

Two intriguing worlds were not snared in *Voyager's* net: Titan and Pluto. *Voyager 1* actually passed very near to Saturn's giant moon Titan, just 4,000 kilometers (2,500 miles) above its clouds. But Titan's smoggy haze totally hid its surface from view. All we really know about Titan concerns its atmosphere. But intricate theories and speculations about that world include the notion that Titan's surface is a frigid laboratory for studying primordial processes that, on Earth, might have led to life.

As for Pluto, when the original Grand Tour concept was "descoped" in the early 1970s and a pared-down *Voyager* emerged, a Pluto flyby was one of the casualties. From Earth, Pluto can be studied only with powerful instruments and—soon—with the Earth-orbiting Hubble Space Telescope. But ground-based astronomers grow ever more resourceful. Recently they have made strides in studying both Titan and Pluto.

Penetrating Titan's Smog Layer

The *Cassini* mission, now on NASA's drawing boards, would use radar to peer through Titan's hazes and map its hidden surface. Yet, just as for Venus (see the September/October 1986 and 1989 issues of *The Planetary Report*), radar astronomers are doing what they can from Earth. Their radio-telescopes are much larger and more powerful than *Cassini* could ever carry toward Titan. But the strength of radar echoes is exceptionally dependent on the target's distance—and Titan is very far away, much farther than Venus.

That didn't keep Duane Muhleman of the California Institute of Technology and his colleagues from trying, however. They transmitted radio waves with the Jet Propulsion Laboratory's Goldstone radar in the California desert, and then listened for echoes with the 27 telescopes of the Very Large Array in New Mexico. They succeeded not only in detecting Titan's surface, but in scuttling some cherished theories. Naturally their historic data (reported in the May 25 issue of *Science*) are a little "noisy" and there are some problems of interpretation, but Titan's surface has been revealed.

Titan's hazy atmosphere is thick with smog particles made of such hydrocarbons as ethane (C₂H₆) and acetylene (C₂H₂). Theorists confidently predicted, from *Voyager's* data on Titan's atmosphere, that the hydrocarbons should rain out onto Titan's icy surface, forming a frigid ethane ocean up to a kilometer deep. But Muhleman's radar echoes reveal Titan to be extremely reflective at the radar's 3.5 centimeter wavelength. That is inconsistent with liquid and seems to require an icy surface, with puddles of ethane at most. There are hints in the data that Titan is geographically diverse, with the radar reflectivity varying widely from place to place. Let's hope that Muhleman's team keeps tuned in on Titan.

A Small, Double Planet

In the June *Scientific American*, the Massachusetts Institute of Technology's Richard Binzel treats the smallest and usually farthest out planet in our solar system. Astronomers have learned much about Pluto. As Binzel chronicles, the 1978 discovery of Pluto's large moon, Charon, came just in time for the once-in-a-century chance to study its "eclipses." These occultations and transits of Charon behind and in front of Pluto began in early 1985 and have just ended. They have helped astronomers map Pluto's surface with far greater clarity than is possible by direct inspection of Pluto's tiny, fuzzy image in a ground-based telescope. Unfortunately, the resulting map of Pluto's surface, still being refined, is not shown in Binzel's article.

He does describe the relative sizes, masses, densities, colors, reflectivities and compositions of Pluto and Charon. They are not at all alike, yet another manifestation of the wondrous complexity of our solar system.

Binzel thinks that Pluto is the "spittin' image" of Neptune's Triton, recently unveiled by *Voyager 2*. While Triton orbits a planet and Charon orbits tiny Pluto, the comparison seems otherwise apt. But just a quarter century ago, Pluto was thought to be an Earth-sized body, stuck in a faraway orbit. Size estimates for Pluto dwindled so fast in the 1970s that some scientists joked that Pluto would vanish altogether before the end of the century! Now Pluto's size seems secure, about two-thirds that of our Moon. Charon is just half Pluto's diameter, a bit bigger than the asteroid Ceres.

Binzel argues for a spacecraft mission to Pluto, which could "complete...the preliminary reconnaissance of all the major bodies in the solar system." How soon he forgets! With the large asteroids Ceres and Vesta, and the as-yet-undiscovered comets of the outer solar system still ignored by NASA mission planners, the arbitrariness of the word "major" seems stark. Just a few paragraphs earlier, Binzel had lamented "preconceptions" that Pluto might be "uninteresting." While we await missions to the smaller and more distant bodies of our planetary system, we can rely on diligent astronomers, equipped with the latest instruments, to keep probing the mysteries of the heavens.

Clark R. Chapman is leading the Galileo Imaging Team's efforts to take pictures of Earth during its flyby this December.

Questions

&

Answers

If a person stepped out of a spacecraft on Mars wearing an oxygen mask and tank but no space suit, what would kill him or her first? How long would it take?

—Virginia Saucedo, San Gabriel, CA

This question addresses a serious concern for practitioners of aerospace medicine because such hazards endanger an astronaut working outside a protective spacecraft or space station or, to a lesser degree, crew members of high altitude aircraft that undergo a rapid decompression. Sudden exposure to a near or total vacuum would quickly be fatal (probably 1-2 minutes), with the cause of death being multiple physiologic disruptions.

That is, exposing a body to a vacu-

um would allow gases that are normally dissolved in fluids (such as the oxygen and nitrogen in blood) to come out of solution, disrupting normal circulation through small blood vessels. The effects of tissue water vaporizing, which occurs at or below a pressure of 47 millimeters of mercury (0.9 pounds per square inch), would be even more dramatic. (Normal atmospheric pressure is approximately 760 millimeters of mercury). This process is called embolism and would cause tissues to swell markedly. Circulation in the large blood vessels would be blocked by bubbles. The actual cause of death here would be asphyxiation. A person experiencing these conditions would lose consciousness in 10 to 15 seconds. In addition to these effects, gases

trapped in body cavities, such as the lungs, would expand, rupturing a lung or forcing gases into the circulatory system.

A person can survive a decompression to vacuum if he or she is brought back to higher pressures relatively rapidly—within 60 seconds or so. Thus the dramatic scene in the film *2001: A Space Odyssey*, where the astronaut Dave Bowman, shut out of the pod by HAL, the insane computer, comes in through an open airlock is technically possible.

—DON STEWART, M.D., NASA Aerospace Medicine Programs Office

After some thought on impact craters, I was wondering about the safety of a Moon base. What precautions are possible to prevent a meteor shower from destroying everything?

—William H. Matzke, St. Paul, Minnesota

A meteor shower won't damage a lunar habitat. The reason is that on the Moon living spaces will have to be buried to protect people, animals and plants from solar flare particles and cosmic rays, and the overburden (a meter or more of lunar soil) will easily stop the tiny particles that show as meteors in Earth's atmosphere. People and equipment out on the lunar surface, on the other hand, are at some slight risk; however, data from *Surveyor*, *Apollo* and other lunar missions show the meteorite danger to be negligible in comparison to the other hazards of such missions.

Of course there is always the even more remote possibility of a large meteorite hit—as is the case on Earth. On



A person exploring the surface of Mars would have about 60 seconds to make it back to the safety of the base before a broken face mask became a fatal accident. Painting: Pam Lee

This four-minute photo of Comet Austin was taken on April 28, 1990 while it was about 98 million kilometers (about 61 million miles) from Earth. The Planet-Crossing Asteroid Survey (PCAS), led by Eleanor Helin, used the half-meter (18-inch) Schmidt telescope at the Palomar Observatory to take this picture. Austin came closest to Earth in late May at a distance of 35.2 million kilometers (22 million miles). The PCAS is partly supported by The Planetary Society.

Photo: Eleanor F. Helin, Brian P. Roman and Kenneth J. Lawrence assisted by Wayne Johnson



two separate occasions (1971 and 1982) small meteorites crashed through the roofs of houses in Weathersfield, Connecticut! A similar event on the Moon would trigger the closing of pressure-isolation doors in the base complex and the quick installation of a patch at the damage-site.

—JAMES D. BURKE, *Jet Propulsion Laboratory*

Is it true that Voyager 2 found gases near Saturn that were hundreds of times hotter than the Sun's corona?

—Joe Bohnert, Festus, Missouri

Yes. *Voyager 2* discovered a cloud of electrified gases around Saturn that is one of the hottest spots ever observed in the solar system—300 times hotter than the Sun's outer regions. Temperatures in this area ranged from 300 to 600 million degrees Celsius. *Voyager 2* was able to take the heat because the gases were tenuous, only 1,000 particles per cubic meter (30 particles per cubic foot). This means that very few gas ions actually hit the spacecraft and thus very little heat was transferred to it.

These hot gases orbit Saturn in a doughnut-shaped cloud, or torus, near the planet's two icy moons, Rhea and Dione. The gases are made up of electrified ions and electrons; in such a form, scientists call them a plasma. On the day side of Saturn, the plasma torus orbits about 700,000 kilometers (450,000 miles) from the planet's

cloud tops; on the night side it's about 270,000 kilometers out (170,000 miles).

Voyager team members had earlier found a relatively cold and dense plasma torus in the region of the moons Rhea and Tethys. They thought that perhaps the electrified gases originated on the two moons. Bombardment of the moons' icy surfaces by charged particles could be stripping oxygen out of their water ice and filling the region with energetic oxygen ions, which seem to be the main ingredient of the cold torus.

We haven't determined the composition of the hot torus yet, but one possibility is that the ionized gases are protons, or hydrogen ions, which could also be byproducts of the solar particle bombardments of the moons' water ice. Interactions between the cold and hot torus could be producing instabilities that are the mechanism generating the extreme heat.

The data on the hot gases were collected by the low-energy charged particle instrument on *Voyager 2* as it flew through the saturnian system on August 26, 1981. *Voyager 1* had found evidence of the hot torus when it visited Saturn in November 1980, but the temperatures were not as hot then, only as high as about 400 million degrees Celsius. Why there would be such a difference is another aspect of the puzzle.

—S. M. KRIMIGIS, *Johns Hopkins University*

FACTINOS

Scientists at the University of Arizona in Tucson believe they've located the crater left by the 10-kilometer-wide (about 6 miles) comet that hit Earth 65 million years ago. Many scientists believe that such an impact contributed to the demise of the dinosaurs.

Using seismic imaging, Alan R. Hildebrand and William V. Boynton have identified a 300-kilometer-wide (about 180 miles) undersea depression that may be the impact site. The researchers reported in *Science* that thick layers of mud and debris on Cuba and Haiti indicate that a comet struck somewhere in the Colombian Basin of the Caribbean Sea, between North and South America.

Hildebrand and Boynton say they haven't yet proved that this crater is the impact site, but they're confident that they've at least targeted the region where the comet hit. "Now that we have a small part of the world to focus on, given five years we'll be able to map out the locations of other debris ejected by the impact and know where it [the impact] had to be," said Hildebrand.

—from Thomas Maugh II
in the *Los Angeles Times*

Walter Munk of the Scripps Institution of Oceanography in La Jolla, California has come up with what some call a "mad scheme" to measure global warming. Early next year, a team of oceanographers plans to sail to a remote island in the Indian Ocean. There they will lower a complex piece of equipment 150 meters (about 150 yards) beneath the sea and fire a "shot" that may be heard halfway around the world—underwater. If the sound waves are detected off Bermuda and northern California, this test will herald a decade-long attempt to measure global warming in Earth's oceans.

The technique they will use, called acoustic tomography (pioneered by Munk and Carl Wunsch of the Massachusetts Institute of Technology), has been used to study local ocean regions, but this would be the first test across five oceans at once.

Measuring the speed of sound waves underwater can indicate global warming because sound travels faster in warm water than in cold water. So the speed of sound waves traveling through the ocean can provide a temperature gauge. A lot of data on ocean temperatures already exists, but these temperatures are notoriously tricky to measure. Munk and his team hope that this initial test of tomography will provide the first reliable baseline—a baseline that could later be used to check temperature increases.

—from Ann Gibbons in *Science*

Summer Special! Travel the Solar System at Reduced Rates

#328

SEDS Poster

The Students for the Exploration and Development of Space (SEDS) present this whimsical view of space exploration.

Dimensions 18" x 24".

Originally \$6.00, **now \$4.00**



#346

Shuttle in Space

Astronauts working in orbit add a new dimension to space activities.

16" x 20" laser print.

Originally \$8.00, **now \$6.00**



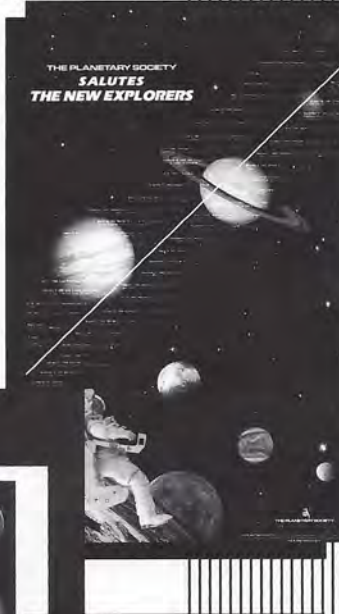
#324

The New Explorers

This informative and colorful poster presents a time-line of international achievements in space.

Dimensions 22" x 34".

Originally \$7.00, **now \$4.00**



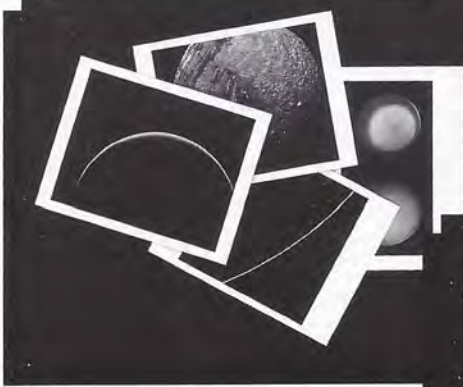
#321

Uranus Encounter

4 pictures of Uranus and its moons.

Dimensions 8" x 10".

Originally \$4.50, **now \$3.50**



#210

Remember Halley's Comet

This is the best view of the famous comet's 1985-86 visit. 20 slides with description.

Originally \$10.00, **now \$7.00**

#674

Glitter Pencils in a Tube

TPS Logo

Originally \$5.00, **now \$3.00**



Exploring Earth from Space

Jon Erickson



#121

Exploring Earth from Space

by Jon Erickson.

This basic, easy to understand book examines the many ways remote sensing devices are used to learn about Earth.

192 pages, soft cover.

Originally \$14.00, **now \$11.00**

#123

Humans in Space

by Harry L. Shipman.

Look into the future and examine the possible opportunities and problems for the human exploration of space. 351 pages.

Originally \$20.00, **now \$16.00**



HUMANS IN SPACE

#132

Life in the Universe

by Francis Jackson and Patrick Moore.

This book provides an up-to-date account of the ideas on the origins of life and the possibility of life on other worlds. 162 pages.

Originally \$17.00, **now \$15.00**

Francis Jackson and Patrick Moore LIFE IN THE UNIVERSE



#148

Planets Beyond: Discovering the Outer Solar System

by Mark Littmann.

Planets Beyond presents the stories of the outermost planets from their dramatic discoveries to the most recent findings about them. These farflung worlds are teaching us about the origin of our solar system. 286 pages.

Originally \$20.50, **now \$16.00**

PLANETS BEYOND

DISCOVERING THE OUTER SOLAR SYSTEM



MARK LITTMANN

The Solar System in Pictures and Books

ORDER NUMBER	Books	PRICE (IN US DOLLARS)
114	Cosmic Catastrophes by Clark R. Chapman and David Morrison. 302 pages	\$ 20.50
121	Exploring Earth from Space by Jon Erickson. 192 pages (soft cover) DISCOUNT	\$ 14.00 \$ 11.00
123	Humans in Space by Harry L. Shipman. 351 pages DISCOUNT	\$ 20.00 \$ 16.00
125	Journey into Space: The First Thirty Years of Space Exploration by Bruce Murray. 381 pages	\$ 18.00
129	Living in Space — A Manual for Space Travellers by Peter Smolders. 160 pages (soft cover)	\$ 13.50
132	Life in the Universe by Francis Jackson and Patrick Moore. 162 pages DISCOUNT	\$ 17.00 \$ 15.00
133	Mirror Matter: Pioneering Antimatter Physics by Robert L. Forward and Joel Davis. 262 pages	\$ 17.00
140	Out of the Cradle: Exploring the Frontiers Beyond Earth by William K. Hartmann, Ron Miller and Pamela Lee. 190 pages (soft cover)	\$ 11.00
148	Planets Beyond: Discovering the Outer Solar System by Mark Litmann. 286 pages DISCOUNT	\$ 20.50 \$ 16.00
157	Starsailing: Solar Sails and Interstellar Travel by Louis D. Friedman. 146 pages (soft cover)	\$ 9.00
161	The Case for Mars III, Strategies for Exploration Volume I — general interest & overview 750 pages (soft cover)	\$ 34.00
162	The Case for Mars III, Strategies for Exploration Volume II — technical 650 pages (soft cover)	\$ 31.00
165	The Grand Tour: A Traveler's Guide to the Solar System by Ron Miller and William K. Hartmann. 192 pages (soft cover)	\$ 10.00
170	The Home Planet edited by Kevin W. Kelley. 256 pages	\$ 30.00
184	The Search for Extraterrestrial Intelligence: Listening for Life in the Cosmos by Thomas R. McDonough. 256 pages (soft cover)	\$ 13.50
185	The Surface of Mars by Michael Carr. 232 pages (soft cover)	\$ 20.00
186	The Starflight Handbook: A Pioneer's Guide to Interstellar Travel by Eugene Mallove and Gregory Matloff. 274 pages	\$ 18.00
ORDER NUMBER	35mm Slide Sets	PRICE (IN US DOLLARS)
205	Chesley Bonestell's Vision of Space (40 slides with sound cassette)	\$ 15.00
210	Remember Halley's Comet (20 slides with description) DISCOUNT	\$ 10.00 \$ 7.00
213	Mars (20 slides with description)	\$ 10.00
220	Viking 1 & 2 at Mars (40 slides with sound cassette)	\$ 15.00
225	Voyager 1 & 2 at Jupiter (40 slides with sound cassette)	\$ 15.00

230	Voyager 1 Saturn Encounter (40 slides with sound cassette)	\$ 15.00
231	Voyager 2 Saturn Encounter (40 slides with sound cassette)	\$ 15.00
234	Voyager Mission to Neptune (20 slides plus fact sheet)	\$ 10.00
235	Voyager Mission to Uranus (20 slides with description)	\$ 7.00
ORDER NUMBER	Color Reproductions	PRICE (IN US DOLLARS)
305	Apollo — photograph of Earth full disk (16" x 20" laser print)	\$ 8.00
308	Earth at Night (23" x 35" poster)	\$ 6.00
310	Earthprint — photograph of North America (8" x 10" laser print)	\$ 4.00
315	Earthrise — photograph of Earth from the Moon (16" x 20" laser print)	\$ 8.00
321	Uranus Encounter — 4 pictures of Uranus and its moons (8" x 10") DISCOUNT	\$ 4.50 \$ 3.50
322	Jupiter — photograph of southern hemisphere (16" x 20" laser print)	\$ 8.00
323	Mars — landscape from <i>Viking Orbiter</i> (16" x 20" laser print)	\$ 8.00
324	The New Explorers (22" x 34" poster) DISCOUNT	\$ 7.00 \$ 4.00
325	Other Worlds (23" x 35" poster)	\$ 7.00
328	SEDS Poster — (Students for the Exploration and Development of Space) Dimensions 18" x 24" DISCOUNT	\$ 6.00 \$ 4.00
333	Saturn — full view photograph (16" x 20" laser print)	\$ 8.00
334	Solar System Exploration (30" x 35" map with booklet)	\$ 9.00
335	Voyager 1 at Saturn (Set of five 24" x 36" posters)	\$ 16.00
336	Solar System in Pictures — 9 pictures (8" x 10")	\$ 10.00
337	Uranus — sunlit crescent (16" x 20" laser print)	\$ 8.00
346	Shuttle in Space — Unique perspective offered of those working in space (16" x 20" laser print) DISCOUNT	\$ 8.00 \$ 6.00
347	Shuttle Ascent — Atlantis moments after liftoff (16" x 20" laser print)	\$ 8.00
348	Shuttle on Launch Pad — Columbia prepares for launch (16" x 20" laser print)	\$ 8.00
350	Shuttle Prints — nine wonderful views of the shuttle (8" x 10" laser prints)	\$ 10.00
ORDER NUMBER	Videotapes	PRICE (IN US DOLLARS)
415	VHS Jupiter, Saturn & Uranus	
416	BETA The Voyager Missions	
417	PAL (VHS) (60 Min. videotape)	\$ 30.00
425	VHS Mars & Mercury	
426	BETA (60 Min. videotape)	
427	PAL (VHS)	\$ 30.00
440	VHS Universe	
441	BETA (30 Min. Videotape)	
442	PAL (VHS)	\$ 30.00
460	VHS Together to Mars?	
461	BETA (60 min. Videotape)	
462	PAL (VHS)	\$ 15.00

ORDER NUMBER	Sportswear	PRICE (IN US DOLLARS)
523	Galileo T-Shirt — 100% cotton S M L XL	\$ 14.00
537	Magellan T-Shirt — 100% cotton S M L XL	\$ 14.00
540	Men's T-Shirt — white with blue TPS logo S M L XL DISCOUNT	\$ 9.00 \$ 6.00
557	TPS Sweatshirt — silver 50% polyester/50% cotton blend S M L XL DISCOUNT	\$ 21.00 \$ 15.00
558	TPS Sweatshirt — navy blue 50% polyester/50% cotton blend S M L XL DISCOUNT	\$ 21.00 \$ 15.00
561	Voyager 2 Sportshirt — navy blue 100% cotton S M L XL DISCOUNT	\$ 28.00 \$ 21.00
562	Voyager 2 Sportshirt — berry 100% cotton S M L XL DISCOUNT	\$ 28.00 \$ 21.00
ORDER NUMBER	Other Items	PRICE (IN US DOLLARS)
505	An Explorer's Guide to Mars (color map of Mars — 26" x 40")	\$ 5.00
516	We're Saving Space for You bookmark (6" x 2") DISCOUNT	\$ 1.00 \$ 0.50
524	Galileo Space Craft Science Kit — paper model	\$ 14.00
526	Hugg-A-Planet Earth — 14" diameter pillow	\$ 15.00
528	Hugg-A-Planet Mars — 8" diameter pillow	\$ 13.50
542	Voyager Medallion	\$ 20.00
543	Mission Stamps — 10 sets (4 stamps per set)	\$ 1.00
544	Note Cards — Set of 16 cards features 4 views from space	\$ 15.00
545	Planetary Report Binder — blue with gold lettering (2 for \$18.00)	\$ 10.00
560	The Voyager Space Craft Science Kit — paper model	\$ 14.00
565	Coffee Mug — The Planetary Society - dark blue + light blue + white (each) (specify color) (set of 3)	\$ 8.00 \$ 21.00
670	The Planetary Society Cloisone Pin — gold lettering on black background	\$ 4.00
674	Glitter Pencils in a Tube The Planetary Society logo DISCOUNT	\$ 5.00 \$ 3.00
675	Glitter Pencils — different colors (10 for \$4.00)	\$ 0.50
676	Key Ring — The Planetary Society logo	\$ 5.00
ORDER NUMBER	Pamphlet Series	PRICE (IN US DOLLARS)
700	Planets and Politics: Reflections on the Presidential Moon-Mars Initiative by Carl Sagan, 32 pages	\$ 3.00
701	Mission to Planet Earth by John L. McLucas, 32 pages	\$ 3.00
All merchandise is subject to availability		
ORDER NUMBER	Membership	PRICE (IN US DOLLARS)
003	Membership U.S. & Canadian	\$ 25.00
004	Gift Membership All other countries	\$ 35.00

IF YOU NEED MORE ROOM, JUST ATTACH ANOTHER SHEET OF PAPER

NAME _____

ADDRESS _____

CITY/STATE/ZIP _____

COUNTRY _____

DAYTIME TELEPHONE NUMBER (____) _____

CHECK OR MONEY ORDER FOR \$ _____ (Sorry, no C.O.D.'s)

VISA MC AM EXP EXPIRATION DATE _____

COMPLETE ACCOUNT NO. _____

SIGNATURE _____

ITEM NUMBER	QUANTITY	DESCRIPTION	PRICE EACH	PRICE TOTAL

For faster service on credit card orders you can NOW FAX your order to:
FAX 1-818-793-5528
 Sales Only **1-818-793-1675**

Sales Tax:
 California residents add 6.25%.
 Los Angeles County residents add an additional 1/2% transit tax.

Shipping and Handling:
 All orders add 10% (maximum \$10.00).
 Non-US add an additional \$4.00.
 Extra charge for Air Mail. Call for Prices.

Officers of The Planetary Society contribute to the Society the royalties due them as authors of the books advertised in these pages.

Total Order:

MAIL ORDER AND PAYMENT TO: THE PLANETARY SOCIETY, 65 N. CATALINA AVENUE, PASADENA, CA 91106



SATURN PROBE ENTRY—An atmospheric probe streaks down to penetrate Saturn's cloud-tops, on its way to investigate the composition and structure of this giant gas planet. Artist Ron Miller here imagines a mission not yet on the drawing boards of Earth's space agencies. However, the probe now being carried by Galileo will perform a similar mission when it arrives at Jupiter in 1995. Saturn's banded atmosphere is about 94 percent hydrogen and 6 percent helium, with cloud systems that persist for years.

Ron Miller is a space artist and writer who lives and works in Fredericksburg, Virginia. He is currently working on In the Stream of Stars, a collection of US and Soviet art celebrating the international space artists' exchange partly funded by The Planetary Society. (See the March/April 1990 Planetary Report.) The book is due out this winter from Workman Publishing.

THE PLANETARY SOCIETY
65 North Catalina Avenue
Pasadena, CA 91106

NONPROFIT ORG.
U.S. POSTAGE
PAID
THE PLANETARY
SOCIETY