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Galileo Encounters Earth

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COVER: How might our own planet appear to an alien spacecraft sweeping by? This mosaic of images taken by* Galileo *gives us some idea. Here the snow and ice of Antarctica, surrounded by oceans of liquid water, tell much about the unique nature of this watery planet in our solar system. But could an alien detect signs of life? Not in these images, where features smaller than 5 kilometers (3 miles) are not visible. But a spacecraft like* Galileo *carries many types of instruments, and some of these did detect evidence of life. ***Image: JPL/NASA***

FROM THE EDITOR

Planetary exploration, by its very nature, requires that we take the long view of things. Spacecraft missions can take years to plan and implement. Even while current events absorb the world's attention, those planning the future in space continue to work, mapping out ideas and testing techniques that will only mature in the decades to come. In this issue, we take a look at some of those plans and studies, and also report on recent results.

Page 3—Members' Dialogue—Did an asteroid kill off the dinosaurs or not? The sometimes vitriolic controversy over this question has spread to our membership. And an alert reader catches a mistake in our arithmetic.

Page 4—The Future of the United States Space Program—Watchers of the US planetary program know that one thing the space community (and, indeed, the scientific community) does better than almost anything else is to issue reports. Most are graciously accepted by the commissioning agent, published and allowed to slip into oblivion. This year, however, a report was issued that, if implemented by NASA, may have a chance of turning the troubled US program around. Norman Augustine, the chairman of the issuing committee, reports directly to Society members on findings and proposals.

Page 7—World Watch—Since the release of the Augustine report, the entire US space program, including planetary science, is being scrutinized by Congress, the Bush administration and the science community. The future of several programs may be determined in the next few months. In this column we review the status of planned and proposed international planetary missions.

Page 8—From Siberia to Mars—By any estimate, the human exploration of Mars is decades away, but the groundwork can still be laid now. Scientists are developing methods to address the question of whether life ever existed on Mars. The only hands-on laboratories available are remote parts of Earth that resemble Mars, such as the permafrost regions of Siberia. Last year a Soviet-American scientific team visited such a Mars-like site, and here they report on their expedition.

Page 12—*Galileo* Encounters Earth and Venus—The *Galileo* mission's story is one of perseverance unmatched in the short history of planetary exploration. Although *Galileo* was originally scheduled to travel a direct trajectory to Jupiter, arriving in 1985, space shuttle problems delayed its flight and forced it onto a loop-the-loop trip through the inner solar system, building up the velocity needed to reach its target. *Galileo* will finally begin its jovian mission in 1995, a decade late. Still, some benefits have accrued from disappointment: As it flew by them, the spacecraft tested its instruments on Venus, Earth and the Moon.

Page 16—Tracking Spacecraft: The Deep Space Network in Spain—The Soviet Union and the United States, as the first and largest spacefaring nations, usually hog the spotlight during planetary missions. But many of their triumphs have been accomplished with the participation of other nations. A good example is Spain, which provides the site and the staff for a crucial tracking station in NASA's Deep Space Network.

Page 18—News & Reviews—Our intrepid columnist has investigated Biosphere 2, the self-contained ecosystem being completed in the Arizona desert. He reviews the concept and the facility.

Page 19—Society Notes—We have major Society events coming up, so mark your calendars. And we say good-bye to one of the best friends the Society has ever had.

Page 20—Q & A—You've been asking about meteorite types, storms on gas giants and Martian babies, and we have some answers. We also have pictures of a new asteroid and Pluto.

—Charlene M. Anderson

Members' Dialogue

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

I am one of the "holdouts" Mr. Chapman denigrates in "News & Reviews" in the November/December *Planetary Report.* I used to believe the Alvarez impact theory of dinosaur extinction. It was appealing because it was a simple, dramatic and tragic explanation of the Cretaceous extinctions, which have puzzled people for several decades.

Last summer I spent two weeks in Montana excavating fossils from rock strata straddling the Cretaceous-Tertiary (K-T) boundary. The fossil evidence in the Hell Creek (Cretaceous) and Tullock (Tertiary) formations shows a decline in dinosaur populations and diversity at the end of the Cretaceous. Thirty-three dinosaur species present 100 million years ago gradually decline to 13 species just below the iridium layer. Contrary to the predictions of the impact theory, 13 dinosaur species appear just *above* the layer. They gradually disappear over the next 500,000 years. The fossil record shows that no dinosaur species goes extinct across the boundary. It takes another 500,000 years until dinosaur fossils are absent from the Tertiary strata. The fossils we uncovered were not abraded, which rules out the possibility of Tertiary erosion and redeposit of Cretaceous fossils.

The outpouring of massive amounts of mantle material from the Deccan Traps eruptions in India over a period of 500,000 years injected large amounts of sulfur aerosols into the atmosphere. On a large enough scale, these emissions would cause acid rain, reduction in pH of the ocean surface, global atmospheric temperature changes and ozone layer depletion. The Deccan Traps eruptions, as Alvarez notes in the *Scientific American* article, "represent the greatest outpouring of lava on land in the past quarter of a billion years." In addition to the flood basalt volcanism in India, there is evidence of substantial explosive volcanism at the K-T boundary over an extensive area from the South Atlantic to the Antarctic.

The iridium layer is most often cited as evidence of an extraterrestrial body. Although iridium is rare in Earth's crust, it is more plentiful in the mantle. Modern samples taken from the Kilauea volcano in Hawaii show an enormous iridium enrichment in deep-mantle lavas (about 100,000 times) over other Hawaiian lavas.

Contrary to Mr. Chapman's assertion that we "know what caused most K-T extinctions: an impact," the paleontological record is ambiguous. The controversy over the impact versus eruption theories is science at its best. It has stimulated the close examination and interpretation of the geological record from a variety of disciplines. Although chastised by Chapman, *Scientific American* did its readers a service by presenting both sides of the debate and letting readers draw their own conclusions.

I challenge Mr. Chapman to get out and dig (literally) into the fossil record in Montana (or anyplace else where the K-T boundary is exposed). Although lacking in drama, terrestrial volcanism lasting over several hundred thousand years is a more probable cause of the Cretaceous extinctions.

—CAROL A. SCHNEIER, *Marietta, Georgia*

As I said in my column, the dinosaur fossil evidence (a topic on which Dr. Schneier is expert) is one of the few areas where legitimate disputes remain about the K-T extinctions. Even there, recent evidence on thousands of dinosaur bones collected by the Milwaukee Museum at the Hell Creek Formation is looking good for the hypothesis of sudden obliteration by an impact event. The other topics she raises—which echo the traditionalist litany—are further from her paleontological expertise, and I fear that she is behind the times in appreciating the latest work on the chemistry and the environmental consequences of the enormous impact. But Dr. Schneier is correct in saying that the controversy has stimulated an enormous amount of excellent scientific research in many fields.—Clark R. Chapman

Charlene M. Anderson's enjoyable and informative article on planetary mapping in the November/December 1990 issue of *The Planetary Report* contains a confusing reference (page 19) to a lunar radius of "almost exactly 1,738 kilometers (1,850 miles)." The latter figure is obviously in error because the two don't equate. It appears that someone has transposed numerals for the value of the Moon's radius in miles—it would be close to 1,080 miles.

Anyway, I look forward to each issue of the *Report* and wish you even greater success in the coming year.

—FRED J. ADAMS, *Brooklyn Park, Minnesota*

Thanks for catching our mistake.—Editor

NEWS BRIEFS

NASA and United States Defense Department officials recently announced that a joint $490 million investment over the last five years has given the US the technology needed to develop a new large launch vehicle. This booster would be the first new expendable heavy-lift rocket to be built by the US in more than 20 years.

"We have laid the foundation for the next generation of launch vehicles for this nation," said Air Force Colonel Roger Colgrove, program manager for the Advanced Launch Development Program (ALDP). The launcher will combine elements of the new ALDP technology with space shuttle components.

In January NASA and Defense Department officials agreed to move the joint program beyond technology research into actual design and construction of medium- and heavy-lift launch vehicles. The January agreement was forged following the December 1990 report of the Advisory Committee on the Future of the US Space Program (see pages 4-6).

—from Douglas Isbell in *Space News*

Chemicals that are eating a hole in Earth's protective ozone layer are still being released into the air at record levels despite international agreements to phase out their use. F. Sherwood Rowland, the University of California at Irvine chemist who discovered the link between chlorofluorocarbons (CFCs) and the ozone layer, has released the results of tests that show CFC emission reached a record high this year and is still growing. "The striking thing is that we haven't seen the fall-off yet," Rowland said. "We thought by now we'd see a little downturn, but we haven't. The announced cutbacks so far haven't shown up in the atmosphere."

In 1987, the world's major industrialized nations agreed to cut use of CFCs in half by the end of the century. Later they decided to cut use by 20 percent in 1993, and 50 percent in 1995, eliminating them by 2000. But according to Rowland, the last five years have been the worst in history for CFCs entering the atmosphere.

—from Marla Cone in the *Los Angeles Times*

The Future of the US Space

***by* Norman R. Augustine**

"The purpose of the Advisory Committee on the Future of the US Space Program is to advise the NASA Administrator on overall approaches NASA management can use to implement the US space program for the coming decades." This was the charge given the committee by the National Space Council, headed by Vice President Dan Quayle. In the past few years, NASA has appeared as an agency beset by problems both within and beyond its control. The establishment of the committee was an attempt to find a new, inspired and immediate direction for the US space program.

The committee was chaired by Norman R. Augustine, Chairman and Chief Executive Officer of the Martin Marietta Corporation. Mr. Augustine is widely respected both within the space community and outside it for his management skills. Here he reports on the committee's findings for Planetary Society members.

The *Report of the Advisory Committee on the Future of the US Space Program* has now received wide distribution, and substantially greater support than most of the committee members would ever have thought possible. The committee was established late in the summer of 1990 and asked to report within 120 days to NASA Administrator Richard Truly. Together, they were to deliver the committee's findings to Vice President Quayle. This schedule has been met and the report is a matter of record. Congressional hearings have begun, and the committee is encouraged by the positive, constructive approach evidenced throughout NASA in assessing the specific recommendations offered.

At the time the study began, there was of course considerable criticism of the space program, both in the media and in parts of the technical community. It was observed that almost every American seemed to favor a strong space program, but no two Americans seemed to favor the *same* space program. The committee believed that one of its most important contributions could be to help build a consensus throughout the space community. It is simply not possible to pursue projects that take 10 to 30 or more years and span perhaps 10 administrations and dozens of budget cycles without a clear consensus at the outset.

Our instructions from the Vice President were that "everything is on the table," and issues soon emerged at a prodigious rate:

With the space race with the Soviet Union now over, what is an appropriate rationale for a space program for the US? What is the role of humans in space? Why do we need a space station? What should be done with regard to the shuttle? How much can the nation afford to spend? What in space should we explore? Why? How?

Behind these questions were others relating more specifically to NASA. Has NASA lost its spark? Does it think only in terms of multiyear and politically high-profile mega-missions, at the cost of less expensive scientific endeavors with quick turnaround, which sometimes provide unexpected and valuable discoveries?

To address such important issues in a relatively short time, it was clear that a team of individuals experienced in the various facets of the space program would be needed. Particular effort was therefore devoted to including people with diverse backgrounds. As actually constituted, the committee consisted of members with experience in science, in the manned space program, the unmanned space program, industry, academia, the military, Congress and general management. As is so often the case, given a common factual basis, diverse people can agree with one another. Each of the committee's findings ultimately received the unanimous support of the entire group.

From the start, the committee received outstanding cooperation from NASA Administrator Dick Truly and his staff. NASA was an open book. But we also wanted to hear from as many other knowledgeable individuals as possible, and from a diversity of viewpoints. Over the first three months, we formally met and received advice from more than 300 persons. They ranged from senators to young engineers; from such people as Carl Sagan, Bruce Murray and John Logsdon to former Librarian of Congress Daniel Boorstin and former US Ambassador to the United Nations Harlan Cleveland. We heard from environmentalists and inventors. We received hundreds of carefully thought-through letters from interested citizens. We visited every NASA center. We asked

Space science provides the vision, imagination and direction for the space program.

Program

lots of questions. We received lots of good advice.

We soon recognized that we were expected to come up with a program that everyone from President Bush to the person on Main Street would recognize as being sufficiently challenging to capture the national imagination, to produce worthwhile results—and to be affordable, given today's tight fiscal environment.

We also recognized that the manned space program represented the most controversial element of our task, both because of its cost and because of concern for risk to human life. The committee asked itself whether the US should be satisfied with a space program involving *no* human flight. The answer was . . . clearly not. Although it may be hard to explain in words, in truth there *is* a difference between Sir Edmund Hillary reaching the summit of Mount Everest, and merely using a rocket to loft an instrument package and flag to the summit. There *is* a difference between the now largely forgotten Soviet robotic Moon explorer that returned lunar samples, and having people all around the world watch on television as Neil Armstrong and Buzz Aldrin explored the Moon's surface collecting rocks while Mike Collins circled above. So, we concluded that there *is* a role for humans in space, one that relates to helping all of humanity share the wonder and exhilaration of exploring the unknown.

On the other hand, this difference between human and robotic exploration can also be measured in terms of dollars—large numbers of dollars. Thus we concluded that there are some things that can be accomplished better without direct human presence, and these missions should not be burdened by some broad commitment to human involvement. Thus, a balanced program seemed to be in order.

Another early concern was to answer the question of who should be responsible for the conduct of the US space program. Given recent events, some said the time had come to establish a form of management structure other than NASA. Should some new agency be instituted to pursue such major initiatives as the exploration of Mars? Should an industrial corporation be selected to handle space shuttle operations, so NASA could focus its efforts on the development of the advanced technology needed for future missions?

> **When we are prepared, we shall set off for Mars with humans to find what is to be found.**

We decided that neither these nor various other alternatives that were considered were preferred options. In spite of its imperfections, NASA still represents the greatest body of space expertise and knowledge in any single organization in the world. Thus, we concluded that it was best to leave NASA in charge of program management, but to recommend that it make a number of organizational improvements to prepare itself for the new challenges ahead, all while being provided clear and enduring policy guidance from above. For example, the committee suggested that NASA refocus its centers to minimize technological overlap, separate the responsibilities for spaceflight operations and spaceflight development, pay the salaries needed to be competitive in attracting and retaining highly talented and motivated people, and add an independent cost analysis group to make certain that its cost and schedule estimates are as credible and achievable as possible.

What sort of a space program is the US able to afford? By way of perspective, it will be recalled that during the Apollo years the US spent 0.8 percent of its gross national product (GNP) on the civil space program. Today, we are spending about 0.25 percent of the GNP. This past year Congress approved an 8.5 percent real increase in NASA's budget for 1991, coming on top of fairly steady growth over a number of years. Thus, the committee presumed that the nation may be willing and able to increase NASA's annual budget by about 10 percent per year in real dollars through the rest of this decade, leveling out at about 0.4 percent of the GNP—that is, half of that for the Apollo period. This budget could support a strong and multifaceted space program—as long as funding is stable and predictable and NASA manages these assets in a highly efficient manner. In the event such funding could not be forthcoming, priorities were suggested to address budgetary demands.

So, what should be our civil space program? The diagram (page 5) captures the essence of what is proposed, namely a balanced portfolio based on good science, with a reliable transportation system and technology program supporting two major missions, one called Mission *to* Planet Earth, and the other, Mission *from* Planet Earth.

In this portfolio, space science is given highest priority, because it is science that uncovers fundamental knowledge, that supports education, that permits us to improve the quality of life here on Earth. It provides the vision, imagination and direction for the space program.

Mission to Planet Earth will be composed of a series of Earth-observing satellites, probes, and related instruments, and a high-speed data-handling system capable of handling 10 trillion bits of information—about one Library of Congress—per day. Its objective will be to produce a much clearer understanding of the impact that human activity is having on Earth's biosphere. We shall then have a more logical basis for deciding how to restore and sustain the environment. This is of course, in most respects, the mission previously defined in *Leadership and America's Future in Space,* the report produced in August 1987 under the direction of Dr. Sally Ride.

Mission from Planet Earth, on the other hand, is focused primarily on space exploration, and it is within this undertaking that most of our human space ventures will reside. The committee shares the view of President Bush that the long-term goal for this aspect of our nation's space program is the human exploration of the planet Mars. But the committee also believes that the demands of getting there and back safely, doing something useful while there and conducting an affordable program are not at this time compatible with establishing some particular arrival date.

Real uncertainties remain with respect to the feasibility of long-duration human spaceflight, uncertainties related to the effects on astronauts of solar flares, muscle deterioration due to weightlessness, the loss of calcium in human bone structure and the impact of galactic cosmic radiation. These basic issues must be resolved before undertaking any human planetary missions.

This conclusion led us to the fundamental reason for building a space station, which we believe is to gain the necessary pre-mission life sciences knowledge. There is simply no way this can be obtained on Earth.

The legacy our generation would like to leave to the future is that we pioneered the exploration of space.

And, while in space, our astronauts can also develop the technologies they will need to survive and thrive on an alien planet.

Given this critical but thus more limited function, the committee concluded that the space station can be simplified and reduced in cost from its present configuration. Moreover, it should be possible to construct it in a modular fashion, so that it can conduct useful secondary missions and its components can be fully tested on Earth prior to being placed in orbit.

Beyond the space station, our next step is to return to the Moon to stay. Here, over a period of a few years, we shall refine the skills, technologies and protective measures required for long-term planetary living, all while gathering useful scientific data. At the same time, we shall be sending robots to Mars to, among other things, identify the most interesting sites for human exploration.

Then, when we are prepared, we shall set off for Mars with humans to find what is to be found. As noted, the committee did not set a date for this big event. Instead it proposed that the schedule be tailored to match the availability of funds and the development of appropriate technology and expertise. This approach is considered to be prudent in terms of both economics and political realities. Even so, we expect that the first Martians are already in elementary school, we hope in the US.

There remain two other elements of our space portfolio that need to be mentioned. First is our technology base, which has been sadly neglected over the past 20 years and has to be rebuilt. Second is the need to develop a launch vehicle complementary to the shuttle to ensure the resilience of our space transportation system. In this regard, the committee recommended that the nation begin right away to develop a new unmanned, but potentially manrateable, heavy-lift launch vehicle using, wherever practical, components from existing or emerging systems to save time and cost. This should be backed by a vigorous launch vehicle technology program to lay the foundation for more distant missions.

This then, briefly, is the space program our committee has recommended. It is based on the belief that the legacy our generation would like to leave to the future is that we pioneered the exploration of space, and thereby made possible many important but unpredictable discoveries that will prove of benefit to our descendants. It will depend heavily upon the use of unmanned probes—but will involve men and women in its ultimate triumph. It represents an undertaking of such great importance and challenge that it can involve, in a cooperative effort, many of the nations of the world.

The committee cautioned, however, that space activity is inherently difficult, and that we will not always be successful. If we, as a nation, are more concerned with ensuring that nothing can possibly go wrong, and with ridiculing those who strive but occasionally fail, than we are with the pursuit of great accomplishments, then not only do we have no business in space, but we shall also fail to live up to our national heritage of reasoned risk-taking, handed down from the early explorers, immigrants, settlers and adventurers. It is *this* element of our national character that is the wellspring of the US space program. □

World Watch

by Louis D. Friedman

The positive reception of the Augustine committee's report bodes extremely well for the future of planetary exploration—if NASA embraces the recommendations. We at The Planetary Society were delighted with the committee's recommendations (see the January/February 1991 *Planetary Report*) and have testified before Congress in support of the report.

It is too early to know if NASA's program will indeed be changed significantly. President Bush's proposed budget for fiscal year 1992 does reflect some of the committee's language, but we've yet to see any concrete influence. There is no commitment to a new launch vehicle; space shuttle expenditures amount to $700 million per flight in fiscal year 1991, before amortization; the space station redesign is vaguely defined; and support for scientific and robotic missions is not specified in the allocations for the Space Exploration Initiative (SEI).

We will be watching congressional actions very closely.

With the budget battles about to begin, let's review the various planetary exploration missions now planned or under development. Since The Planetary Society is an international organization, in our list we include missions by all spacefaring nations, not just those planned by the United States.

• The US *Mars Observer* is scheduled for launch in September 1992. Some instruments and other spacecraft elements are costing more than expected, and development and construction are somewhat behind schedule. However, project officials expect to meet critical deadlines for delivery of all flight hardware and software in time for launch, and no "descoping" of the mission is now planned. The *Mars Observer* is scheduled to carry a communications relay for the Mars Balloon on the *Mars '94* mission.

• The Soviet *Mars '94* mission is set for launch in October 1994. Despite concerns that it may slip to 1996 because of budgetary, organizational or hardware difficulties, in late February Soviet space officials apparently recommitted to a 1994 launch. The spacecraft design and payload are now fixed, and all elements are under construction, including the orbiter, the balloon, penetrators, small meteorological stations and a newly added rover.

• The Comet Rendezvous Asteroid Flyby (CRAF) mission is scheduled for launch in February 1996; the other half of this dual mission, *Cassini*, will launch in December 1995. Escalating costs forced the cancellation of the CRAF penetrator that would have been the first instrument to directly sample a comet's surface. CRAF is now targeted to fly in tandem with the comet Tempel 2, then to fly by the asteroid Mandeville.

Cassini will send an orbiter to Saturn and an entry probe, called *Huygens*, onto its large moon Titan. The orbiter is being built by NASA; the European Space Agency (ESA) is building the probe. Because the mass of the spacecraft has continued to increase, *Cassini* will have to take a long path through the inner solar system, getting "gravity assists" from Venus and Earth to build up the velocity it needs to reach Saturn. On its way to the outer solar system, *Cassini* will fly by the asteroid Clarissa.

• The *Lunar Observer* had been proposed by NASA to orbit the Moon with the primary task of looking for water. This mission is a victim of low funding for SEI: It received no money in the 1992 budget. Japan is continuing to prepare its lunar orbiter for a 1993 launch. In the Soviet Union, talk of a lunar orbiting mission remains vague.

• ESA continues to study a Comet Nucleus Sample Return as one of its cornerstone missions for the late 1990s.

• *Mars '96* or *'98* is still an undefined mission that will take advantage of one of the biennial Mars launch windows. Rover missions, sample returns from either Mars or Phobos and repeats of the lost *Phobos* mission are all being discussed. The Soviet space program seems committed to taking advantage of at least one of these launch windows.

• A Mars Network is being considered by NASA for the 1998 to 2003 launch windows, with up to five launches of four landers each. The network would be made up of penetrators and small meteorological stations that could study Mars while serving as radio beacons for later missions. The mission design and science requirements are still being worked out.

• A Mars Rover Sample Return mission has long been on the wish list of planetary scientists, but it has been deferred in the plans of both the US and Soviet space programs. In the US, the lack of congressional support for SEI has hurt its prospects. The Soviets, however, still see it as a candidate for a 1998 or 2001 launch. The ambitious scope and large costs of this mission make it a prime candidate for international cooperation.

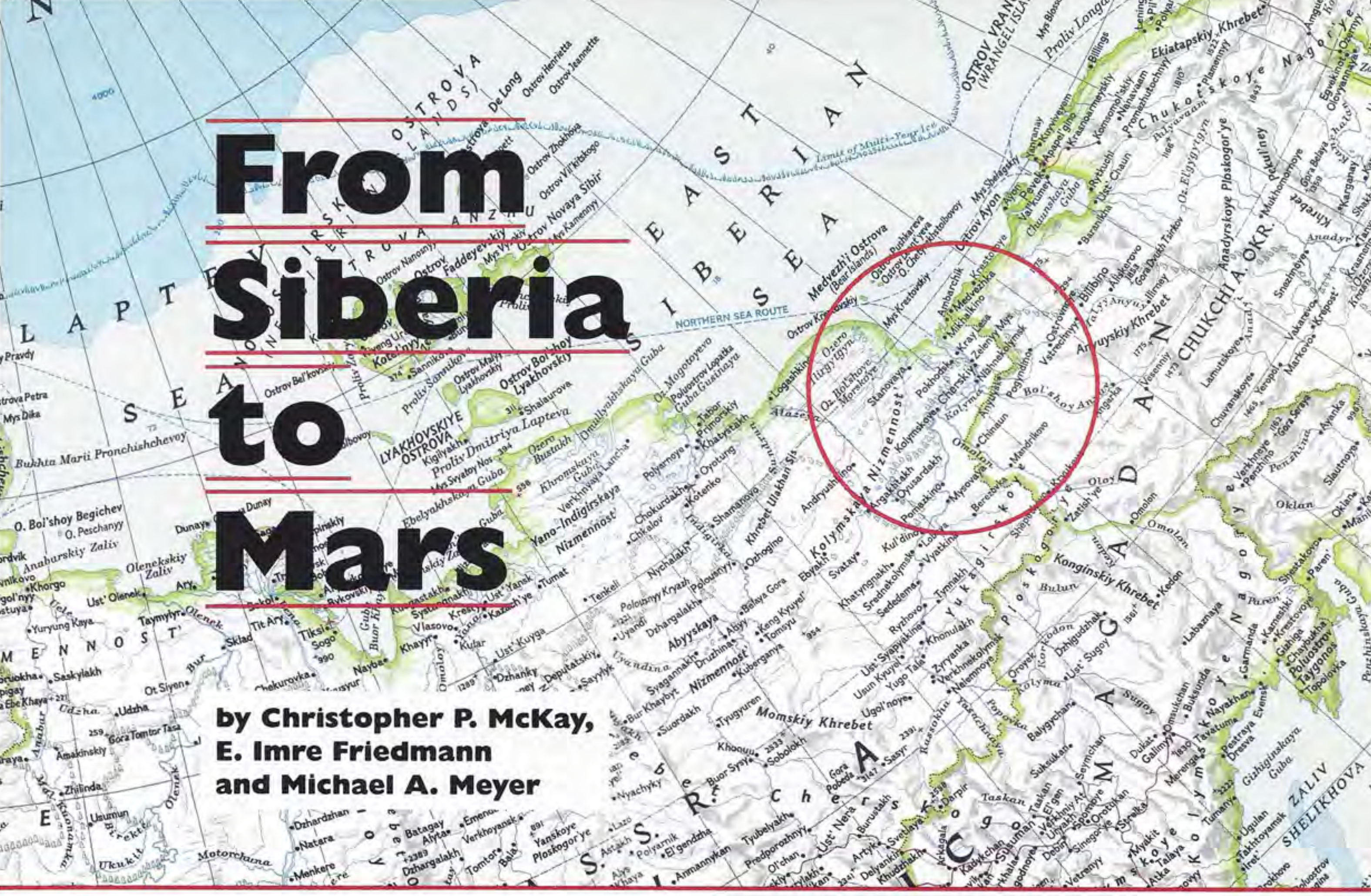
• Several other missions are being considered for the future, such as a flyby of Pluto, a mission to a near-Earth asteroid (in a new NASA program, Discovery, that would use small spacecraft) and a probe into the Sun. These ideas are only being studied, so serious development is at least a few years off.

• The human exploration of Mars is the ultimate goal of SEI, and the 1992 budget allocates $15 million for preparatory mission studies. The Mars missions listed above can be seen as precursor missions. Limited work is also under way in the Soviet Union. The accomplishment of this goal will be costly and challenging, and the Society has maintained for years that the only way we will reach it will be through an international endeavor. But development of such a cooperative initiative has been maddeningly slow.

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

From Siberia to Mars

by Christopher P. McKay, E. Imre Friedmann and Michael A. Meyer



ABOVE: **In search of Mars-like terrain, the authors traveled to the edges of Siberia, to the region circled in the map.**

Early in its history, some 3.5 billion years ago, Mars seems to have enjoyed a more clement climate. *Mariner 9* and *Viking* revealed long, sinuous surface features that are probably scars cut by flowing water—water that has long since been locked away in ice. If water did flow on Mars, then it must once have had a warmer temperature and a thicker atmosphere—conditions that would have supported the origin and early evolution of life. From our investigations of terrestrial fossils, we know that at that time life was flourishing on Earth. Could the same thing be true of Mars?

As first suggested in 1962 by Joshua Lederberg and Carl Sagan, fossil evidence that may hold the answer to this question may lie frozen in the permafrost regions that we think cover both the northern and southern hemispheres of Mars above 40 degrees latitude. More questions: Could the permafrost hold evidence of life from 3.5 billion years ago? If it does, what form would such evidence take, and what would be the best ways to detect it? Would humans be needed to do the job, or could robots do it for less cost and danger?

Mars-Like Environments on Earth

Because Mars is so similar to Earth, planetary scientists looking for answers to questions like these often use analogous environments on Earth to help them design future Mars missions. Such terrestrial sites, however remote, are still much more accessible than Mars. Field studies in such places give us a chance to test and refine instruments and procedures, develop overall concepts and collect baseline data to compare with actual results from Mars.

Perhaps the best terrestrial analogue to the martian permafrost lies in northeastern Siberia. Freezing conditions have persisted here for over 3 million years. Although young by martian standards, these are among the oldest continuously frozen localities on Earth. They also hold something remarkable: not only organic residues, but also large numbers of viable bacteria (up to 100 million per gram of frozen soil), preserved for 3 million years in ice. When thawed out, these bacteria can and do resume their life functions.

Until now, both the site of this exciting discovery and the frozen material were inaccessible to Western scientists. The recent thaw in relations between the United States and the Soviet Union, and the concomitant emphasis on joint space projects—particularly future Mars missions—have opened the door for US exobiologists to join their Soviet colleagues in the study of Siberian permafrost. The first USSR-US exobiology expedition to northeastern Siberia took place in 1990, from July 15 to September 5.

The US group—composed of the authors—was led by E. Imre Friedmann of Florida State University. We had already worked together in the Ross Desert of Antarctica (the McMurdo Dry Valleys), another environment analogous to martian locales (see box on page 11, "Life in the Rocks"). Our Soviet counterparts were from the Institute of Soil Science and Photosynthesis of the USSR Academy of Science in Puschino, near Moscow. Soviet team leader David A. Gilichinsky, head of the Laboratory of Soil Cryology, has been working with the Siberian permafrost for 20 years.

Off to the Permafrost

We left Domodedevo Airport in Moscow for Cherskiy, a small town on the Kolyma River in the Yakut Autonomous Soviet Socialist Republic in northeastern Siberia. It was unusual for foreign scientists to be allowed into this region. Cherskiy, situated in a sensitive border area, was a main receiving center for prisoners under the gulag system, and the entire region is normally closed to visitors, Soviet and foreign alike. Over 5,000 kilometers (3,000 miles) and eight time zones away from Moscow, the Kolyma region is a vast, and in many ways untamed, frontier zone. It is far from the bureaucracy of the European Soviet Union, referred to as "the mainland" by the Kolyma inhabitants.

On a small riverboat, we headed 300 kilometers (185 miles) up the Kolyma River from Cherskiy into the permafrost country. Later, we moved our camp by helicopter to the Bolshoya Chukochya River, close to the Arctic Ocean. In this region the mean annual air temperature is minus 12 degrees Celsius (10 degrees Fahrenheit) and the annual range is from minus 40 to 20 degrees Celsius (minus 40 to 68 degrees Fahrenheit). Each year the upper layer of soil, from 0.5 to 1 meter thick, alternately freezes and thaws. However, below this layer, the ground, a soil-and-ice mixture, is permanently frozen. Evidence suggests that the permafrost could be as deep as 1 kilometer.

When permafrost thaws, the original sections of relatively pure ice melt and drain away, and the resulting spaces fill with dirt and gravel, providing lasting evidence of the event. In addition, the thawing alters layers of microorganisms in characteristic ways. The distribution of sediments and ice wedges in the northeastern Siberian permafrost indicates that these sediments have not thawed since they were deposited at their current sites.

The age of this permafrost material has been determined from extensive paleontological studies of fossils and pollen grains in the sediments and from the signature of a reversal of Earth's magnetic field about 2.4 million years ago. According to Soviet scientists, the oldest sediments date back over 3 million years, and they have been continuously frozen since they were deposited. Determining the biological state of these ancient sediments

American and Soviet scientists collect samples on an exposed slope of permafrost along the Kolyma River, about 100 kilometers upriver from the town of Cherskiy in northeastern Siberia. The river is melting and eroding the permafrost, continually exposing fresh material.

All photographs: E. Imre Friedmann

To obtain uncontaminated samples of permafrost, we used a special drill. Here David Gilichinsky is drilling into the permafrost near the Kolyma River exposure seen in the photo above. Dr. Gilichinsky is a leading authority on permafrost and drilling operations.

We set up camp at a location where a tributary of the Kolyma River is exposing more of the permafrost. Ice formations indicate that the permafrost has never thawed here. Paleomagnetic dating has established that the sediments at the bottom of this exposure are over 2.4 million years old.

Each summer the top 0.5 to 1 meter of soil thaws out in places and forms shallow lakes on top of the permafrost. Below this active zone the ground is frozen solid to a depth of hundreds of meters. The mean annual air temperature is about minus 12 degrees Celsius.

Above the Arctic Circle the Bolshoya Chukochya River carves spectacular formations in the permafrost.

The Origin of Life in Our Solar System: If Earth, Then Mars?

Life, as we know it, is a chemical phenomenon powered by reactions among the so-called biogenic elements: carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. These elements formed within the furnaces of massive, ancient stars that have long since died. Their death throes spread these elements throughout the universe, and some of them were caught in clouds of dust and gas, which then condensed to form new stars and, in at least one case, a planetary system.

The same processes that formed the life-bearing Earth were at work on all the planets. The differences among them were determined by distance from the Sun and random chance—such as the collision with Earth of a planet-sized object (this hypothesis is now the leading contender for the origin of the Moon). Without discounting the role of chance, it seems reasonable to assume that the chemical processes that produced life here might have been at work on other nearby Earth-like planets—such as Mars.

Mars has roughly the same chemical composition as Earth, and hence a goodly supply of the biogenic elements. We know that liquid water once flowed on Mars, and we believe that the presence of liquid water was the crucial factor in the origin of life here. Ultraviolet radiation from the Sun, a possible energy source for the first chemical reactions leading to life, falls on the martian surface in nearly the same intensity as it did on the early Earth (before the life-driven formation of the ozone layer).

From the evidence uncovered by our spacecraft, we know that about 3.8 to 3.5 billion years ago was the time water carved out the martian channels. This is also the time life seems to have arisen on Earth. The earliest fossils yet found are 3.5 billion years old, and these cyanobacteria (blue-green algae) life-forms were already using photosynthesis to power their activities. The first living things on Earth were undoubtedly more primitive and probably arose millions of years earlier, perhaps during the same time in which water flowed on Mars.

We will never know for certain if life arose on Mars until we send robots—or humans—to search for the traces that life-forms might have left behind.
—*Charlene M. Anderson*

was our expedition's primary objective.

Using a 4-inch drill capable of boring down 50 meters (160 feet), we took cores from the Kolyma and Chukochya permafrost. We stored the frozen, aseptic samples in natural freezers—in the drill holes or in caves hewn into the permafrost—for future laboratory testing. They were then flown in insulated containers to Moscow and to the United States.

Kluge Communications

During our drilling work, we learned the importance of communication to a team working on permafrost. The Russians spoke English at varying levels of proficiency, and we learned a little Russian. As long as the entire operation went as expected, this worked fine. However, if anything differed from the ordinary, getting a message across could be difficult.

There were not enough people to have separate Russian and American teams, so we had to work together. It was important to work closely coordinated to keep the drill from freezing into the ground, and to keep the drill string and bit from falling irretrievably into the hole. We used the Russian word *kluge* to mean "Take the big pair of vise grips and hold the drill string so that it doesn't fall into the hole."

Once, late at night, two of us (McKay and Meyer) were part of a three-person team operating the drill. The two of us were pulling the string up out of the drill hole while a Russian student (from Moscow State University and quite good in English) was operating the vise grips. Suddenly the drill string started slipping through the vise grips. We could see this, but the Russian student could not.

After failed attempts in both English ("The string is slipping! The string is slipping!") and Russian ("KLUGE! KLUGE!"), which were both met with blank stares, communication was only achieved by wild pointing. Clearly, international crews on Mars need to be much better at communicating under stress than we were. (It is interesting to note that in the calm of the kitchen tent we could communicate quite well in both English and Russian. But under unexpected and stressful conditions, our language skills were not good enough.)

Focusing on Mars

The Soviets have extensive experience with permafrost, since these permanently frozen areas cover half of the Soviet Union. They have developed considerable technology for permafrost construction and engineering, which is likely to be useful for planning Mars surface activities. The drill that we used could be transported over rough forest terrain by a crew of four to six, and then it could be assembled in a few hours. A similar device may be useful on Mars.

The preliminary results from our studies indicate that organic material is preserved—and organisms are still viable—after being frozen for 3 million years at minus 10 to minus 12 degrees Celsius (14 to 10 degrees Fahrenheit). At the even lower temperatures on Mars, we would expect survival over even longer periods to be possible.

We believe that clement conditions on Mars deteriorated about 3.5 billion years ago, although there may have been occasional periods of warming since then. As Mars cooled and its water was immobilized into permafrost, any organic material and microbial life would have been incorporated and frozen into the sediments. The *Viking* life science experiments suggest that any organic material remaining on the surface has long since been destroyed by photochemically produced oxidants (see the November/December 1987 *Planetary Report*). With the surface of Mars barren of organic material, subsurface permafrost deposits of organics would be an important clue to the biological history of early Mars.

The now-dry river channels on Mars tell us that Mars once had a lot of water on its surface. All estimates of the amount of this water are greater than the amount found in its atmosphere. The current rate at which water is escaping from the martian atmosphere is too low to have depleted the initial water, so most of it should still be somewhere on the planet—most likely in permafrost at the polar latitudes.

There are other arguments for permafrost on Mars; we have some geomorphological evidence. The equatorial regions appear to be low in ground ice, but at high latitudes we see widespread evidence for ice held in surface sediments. The ground has moved like a viscous fluid, creeping slowly along and deforming surface features.

We are uncertain of the age of martian permafrost, but we can estimate it by using crater densities. In the northern hemisphere we find plains with few impact craters, which indicates that they are younger than 2 billion years. In the southern hemisphere, the terrain is heavily cratered, which dates it back to the period of heavy bombardment that scarred bodies throughout the solar system 3.8 billion years ago.

As on Earth, polar permafrost could form and persist over geological time, even when mean global temperatures were above freezing. Thus material deposited and preserved in ancient permafrost of the southern hemisphere should record events—and life-forms, if any—on Mars during the time when global conditions may have been suitable for life.

Material trapped within martian permafrost should be exceptionally well preserved. The mean annual temperature of the permafrost regions is less than minus 70 degrees Celsius (minus 94 degrees Fahrenheit), and organic material is better preserved at lower temperatures. Material several meters below the surface would be shielded from cosmic radiation and solar ultraviolet light. The martian climate of the past 3 billion years, while unsuited for life, is ideal for preserving frozen samples.

Furthermore, Mars does not seem to have plate tectonics, which on Earth continually moves continents, recycles the crust and resurfaces the planet. The low martian erosion and burial rates, estimated at about 1 meter per billion years, would not hide possible fossil-bearing deposits beyond our reach. Ancient materials should still be accessible from the surface, and we would expect them to be relatively unaltered by geological processes.

Thus we suggest that martian permafrost may be an ideal target for future exobiological investigations of Mars. Our studies have raised even more questions: Could organic material survive 3.5 billion years if it were buried and frozen at martian temperatures (minus 70 degrees Celsius)? Even more intriguing, could organisms survive? And if they did not survive, would their cell structures remain intact, allowing direct examination? These will be key questions in the study of Mars.

Any future human exploration of Mars will certainly make the possible origin of life there a key objective. Indeed, the search for the evidence of life is one area that may require human explorers. In biology the complexity of methods and approaches and the need for on-site decision-making call for the presence of highly trained and experienced field scientists.

To explain events and theories, science requires detailed and objective documentation, which can be supplied by robotic explorers. But this phase often follows a "discovery mode" that relies on human intuition. We have not yet even well defined what life is and what constitutes fossil evidence of life. To find evidence of life on Mars may require subjective decision-making and intuitive approaches that are not well adapted to current robots. In the future, advances in robotics and artificial intelligence may provide a way of doing this without actually sending humans.

As planets go, Earth and Mars are still very similar bodies, although their evolutionary histories diverged several billion years ago. Terrestrial geological processes seem to have obliterated evidence of life here before 3.5 billion years ago; at least we haven't found any yet. But two-thirds of the martian surface dates back further than that, so Mars may actually hold the best record of the events leading to the origin of life, even if there is no life there today. Soviet and US researchers working together on the Siberian permafrost are building a scientific—and possibly social—basis for future joint missions to the martian permafrost in search of life.

Christopher P. McKay is a planetary scientist at NASA Ames Research Center in California. E. Imre Friedmann is Professor of Biology and Director of the Polar Desert Research Center at Florida State University, Tallahassee. Michael A. Meyer is Assistant Research Professor at the Desert Research Institute in Reno, Nevada.

Life in the Rocks: Antarctic Habitats May Be Analogues for Martian Ecosystems

The Siberian permafrost may be giving us important clues to how martian fossils—and maybe even actual organisms—may have been preserved for billions of years. But above the permafrost, Siberia is not at all like Mars. In fact, it is wet and, in the hot summers, loaded with mosquitoes. The best place to go today to get Mars-like conditions on Earth is Antarctica.

There are areas on the frozen continent where there is no ice or snow. The largest ice-free expanses are the McMurdo Dry Valleys. This region is one of the coldest, driest and most Mars-like places on Earth. The annual average temperature is minus 20 degrees Celsius (minus 4 degrees Fahrenheit); in the summer, temperatures barely climb above freezing. The region receives less precipitation than the Gobi Desert. The flow of ice from the Polar Plateau is blocked by the Transantarctic Mountains, resulting in extremely arid conditions.

At first look, life appears to be absent from these valleys. However, a closer look reveals two thriving microbial ecosystems, hidden within protective habitats.

One ecosystem is found just below the surface of north-facing (on the Sunward side) sandstone rocks. Here layers of lichen and bacteria survive because the dark surface of the rock is warmed to above air temperature. Pores in the rock act as traps for liquid water generated by occasional snows. The organisms live just deep enough in the translucent rock to receive enough sunlight for photosynthesis.

The other major habitat for life is below the perennial ice cover of the lakes found on the valley floors. Here, beneath 4 to 5 meters of ice (13 to 16 feet), algae, diatoms and other microbial life-forms thrive in a liquid water environment buffered from the cold, dry conditions above.

These ecosystems are examples of life surviving in extreme cold and dryness. They could be telling us about how life adapted on Mars as the climate deteriorated from an early wet and warm period to the cold, dry, forbidding climate of today. —*CPM*

Galileo Encounters

by Charlene M. Anderson

"Make a virtue of necessity." Robert Burton's exhortation should perhaps be the motto of the *Galileo* project. Conceived in the mid-1970s, the spacecraft was originally scheduled for a launch from a space shuttle in January 1982, during a "window" when the relative positions of Earth and Jupiter enabled a quick, direct trajectory between the planets. But in 1979, even before the shuttle's first launch, troubles and delays in that program knocked *Galileo* from its critical launch window. This was only the first of many shuttle-related delays, some requiring that the spacecraft change the upper stage needed to boost it from Earth orbit, others necessitating redesign of the spacecraft. (See the September/October 1986 *Planetary Report*.) Each delay meant that mission designers had to find a new trajectory from Earth to Jupiter.

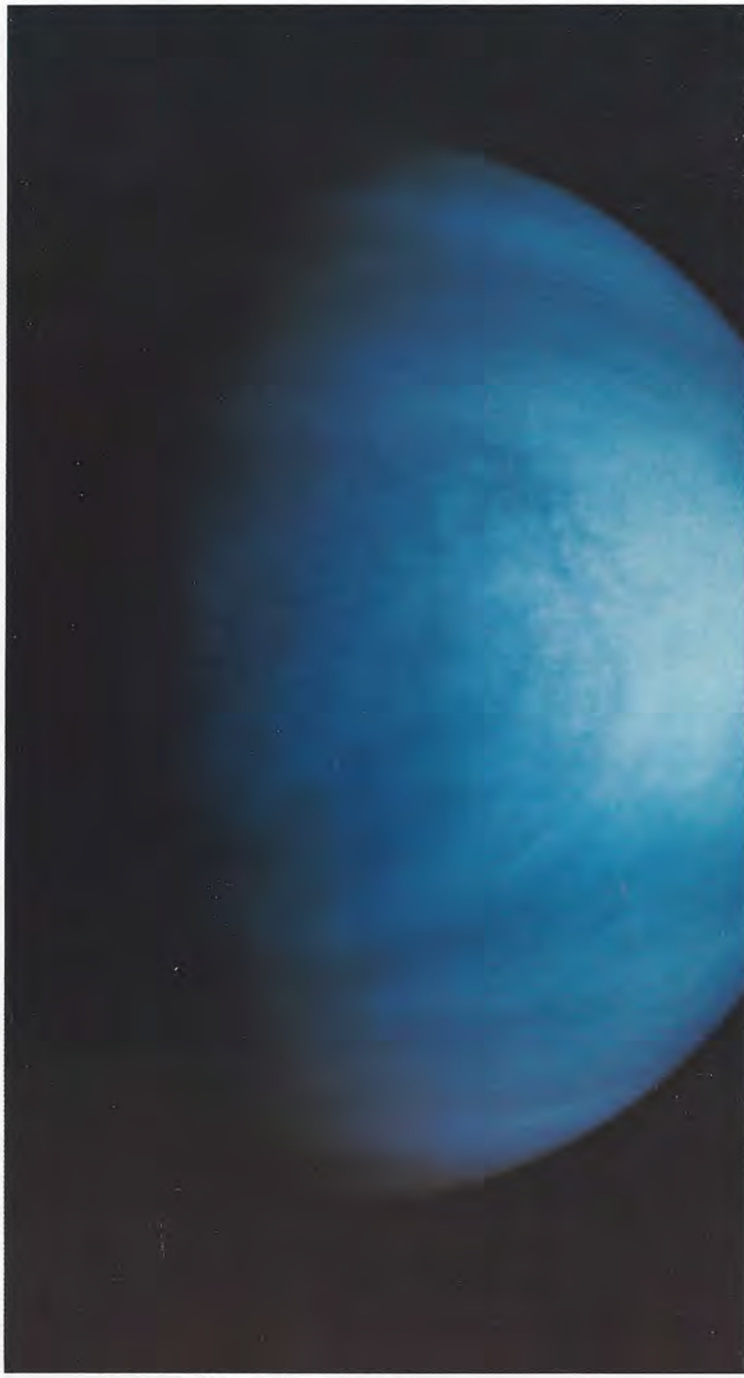
Finally, on October 18, 1989, *Galileo* left Earth, but heading for Venus, not Jupiter. The cancellation of the powerful *Centaur* upper stage (for safety reasons following the *Challenger* disaster) forced the mission to use an Inertial Upper Stage, which didn't have enough power to send the spacecraft directly to Jupiter. Instead, using a technique called gravity assist, *Galileo* would have to swing by Venus once and Earth twice to build up enough velocity to slingshot out to Jupiter. A flight that should have taken two years would take over six.

But as *Galileo* team members have proved time and again, they are nothing if not resourceful. They have turned the gravity-assist maneuvers into planetary encounters.

On February 10, 1990, *Galileo* passed by Venus. On December 8, it encountered Earth. The next encounter will be with the asteroid Gaspra on October 29, 1991. The spacecraft will swing back to Earth on December 8 of 1992, then fly by the asteroid Ida in August 1993 on the final leg of its journey to the jovian system.

On these pages we present some of *Galileo*'s first findings. It was not designed to investigate Venus, Earth or the Moon, and these bodies have been well studied by other spacecraft, so no startling discoveries were expected. But these encounters gave the spacecraft team a chance to test their instruments and make some measurements that may help us understand these familiar worlds a bit better.

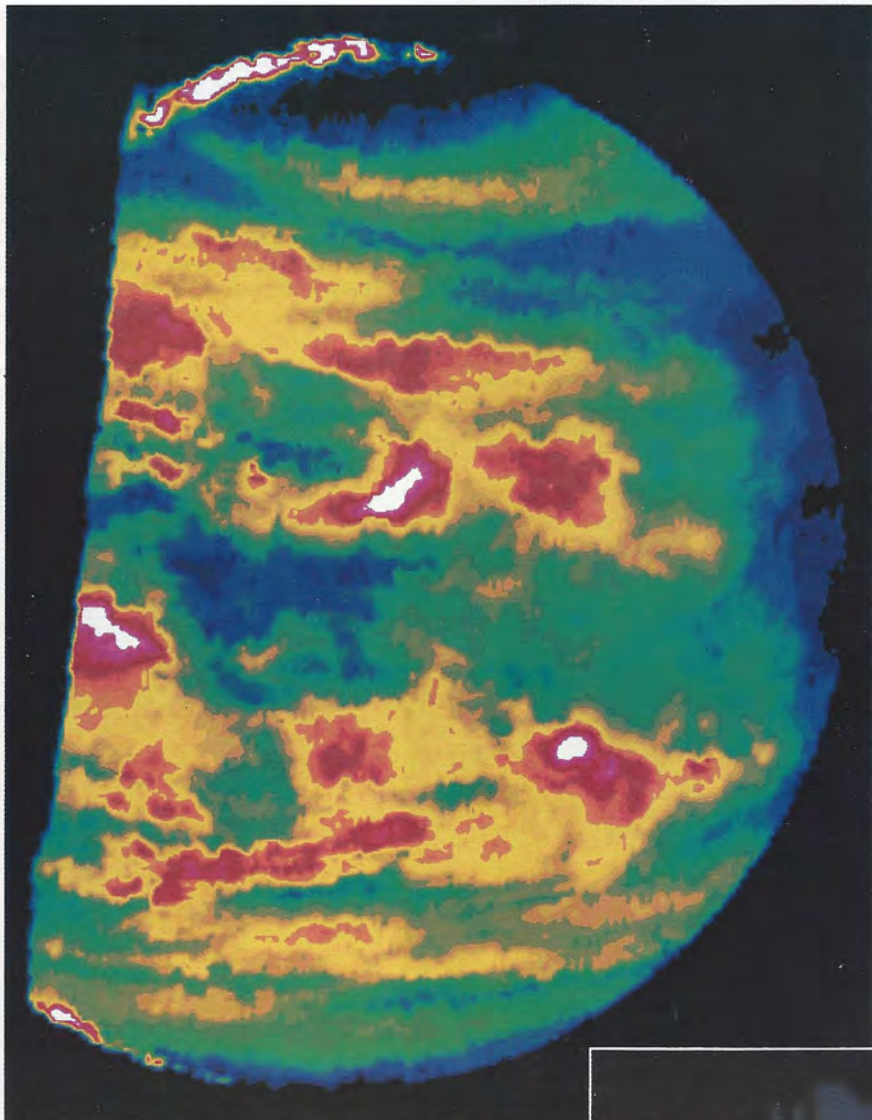
Charlene M. Anderson is Director of Publications for The Planetary Society.



Venus in Ultraviolet

Venus is a pale yellow world that most of us know as the brightly shining Morning or Evening Star. But it is the nature of its enshrouding clouds of sulfuric acid that they display their features most prominently in violet and ultraviolet light. Thus many spacecraft images of Venus, like this *Galileo* one, are taken through a violet filter that enhances contrasts among cloud features. Past studies of Venus have revealed cloud bands that tend east to west and bright polar hoods; these features are also visible here. The winds at the cloud tops blow from east to west at about 370 kilometers per hour (230 miles per hour). The smallest details visible are about 70 kilometers (45 miles) across. All Images: JPL/NASA

Earth and Venus

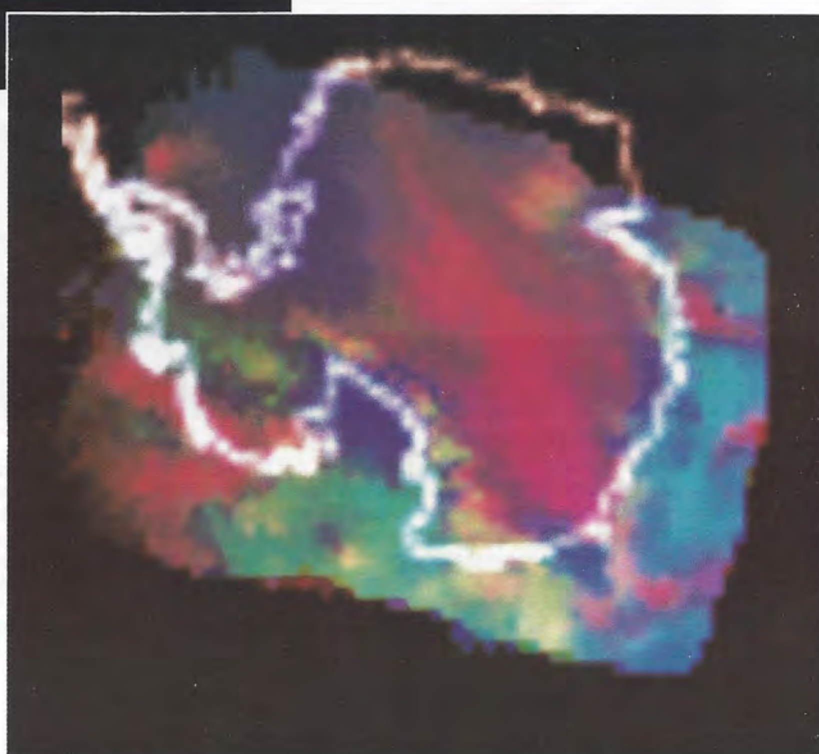


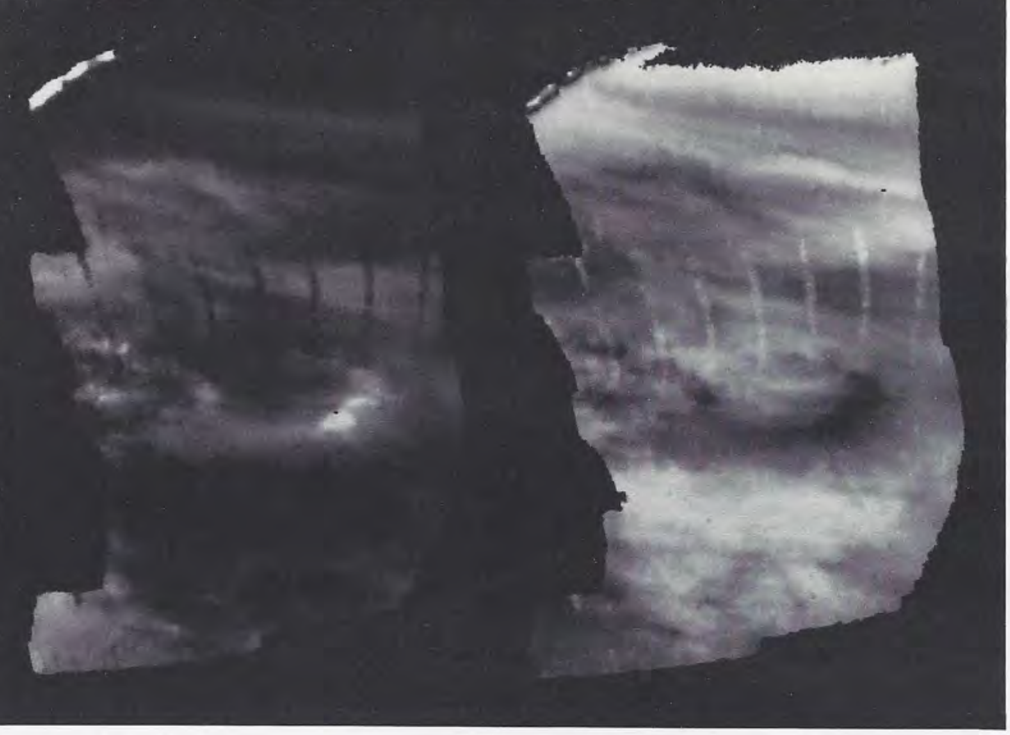
Venus in Infrared

***Galileo* carries an instrument called the Near-Infrared Mapping Spectrometer (NIMS), which can determine and map the chemical composition and temperature of planetary atmospheres and surfaces. This powerful technique was particularly useful at Venus, where NIMS' sensitivity allowed it to penetrate 9.5 to 16 kilometers (6 to 10 miles) beneath the uppermost visible cloud layers and 48 to 53 kilometers (30 to 33 miles) above the solid surface. This near-infrared map shows low-level clouds on Venus' night side. Radiant heat from the lower atmosphere (about 200 degrees Celsius or 400 degrees Fahrenheit) shines through the sulfuric acid clouds. The colors indicate varying degrees of cloud transparency.**

A False-Color Antarctica

***Galileo*'s NIMS is an extremely powerful instrument that can sense 408 contiguous wavelengths from 0.7 micron (deep red) to 5.2 microns (out of the range of the human eye). The ways in which surfaces reflect light of different wavelengths can tell scientists much about them. In this false-color image of Antarctica, NIMS revealed a polar stratospheric cloud, one that formed later in the Antarctic summer than usual (seen in upper left as a small, diffuse, circular feature east of the Palmer Peninsula). These clouds are important, for they act as catalysts in the chemical reactions that destroy ozone and create the "ozone hole." In this image, blue denotes low altitude, and thus warmer surfaces: pack ice and the sea surface. Green indicates low clouds. Red shows areas with less atmospheric water, which serves as a crude altimetry map. The high polar plateau of eastern Antarctica is the reddish band along the center.**





Venus in the Eye of the Beholder

"We saw many lovely things," said Robert Carlson, head of the NIMS team, after the Venus and Earth encounters. He was talking about images like these, which to the untutored eye can look like indecipherable blotches. These are actually the sharpest images ever obtained of low-level cloud structure on Venus. With them, scientists can infer convective processes and cloud motions and, in turn, learn much about the forces driving Venus' atmosphere. In the image on the left, we see infrared radiation from the lower atmosphere shining through sulfuric acid clouds, which here appear about 10 times darker than the bright gaps between them. The right-hand image represents what scientists believe this cloud deck would look like in visible light, with the clouds reflecting sunlight rather than blocking radiated infrared heat from below. Near the equator (bottom to center), the clouds appear fluffy, while farther north they stretch into bands, blown along by winds of over 240 kilometers (150 miles) per hour. (The vertical bands are data dropouts.) All Images: JPL/NASA

A New Perspective on Earth

"We saw Earth from perspectives we're not used to, and the experience of looking at our own planet in that way is valuable and interesting," commented Clark Chapman, leader of the *Galileo* Earth-imaging team (and *Planetary Report* columnist). The spacecraft's trajectory by the planet took it on a path unused by orbiting spacecraft, so this view of Antarctica, South America and—at the very top—North America is one we've not seen before. *Galileo*'s imaging system used near-infrared light to compile this picture. At that wavelength (about 1 micron), light easily penetrates atmospheric hazes that might block the view in visible light. It also enhances the brightness of land surfaces, making them easier to discern.

Bull's-eye on the Moon

After *Galileo*'s swing past Earth, it looked back at the Earth-Moon system, seeing the Moon from a viewpoint impossible from Earth. In this computer-processed image, the huge impact basin called Mare Orientale, whose mountain ramparts are barely visible from Earth, is at the center of the Moon's disk, while the side that always faces Earth, with the vast, dark lava plains of Oceanus Procellarum, is to the right. (The fuzz at the left on the image is a processing artifact.) Mare lavas also fill the low parts of the Orientale basin, but are nearly absent from the Moon's far side. At the lower left is the almost-invisible remnant of the biggest impact basin yet found on the Moon, stretching nearly 2,000 kilometers (1,250 miles) from the South Pole to the crater Aitken. The existence of this basin was suspected before the *Galileo* encounter, but was only confirmed by the spacecraft data.

Did Galileo Discover Life on Earth?

Two years before encounter, Carl Sagan proposed that this question be a focus for the *Galileo* Earth investigations. Its answer is important to those interested in searching for life on other worlds. After all, we *know* there is life on Earth; the problem is, can our spacecraft detect it? If they can't, how sure can we be that our robot explorers haven't simply missed signs of life on other worlds?

The answer, according to Charles Hord, leader of the ultraviolet spectroscopy (UV) team, is this: "We have unequivocally discovered life on Earth. But we're not sure yet that it's intelligent life."

His comment does not cast aspersions on the intelligence level of humans; rather, it reflects the geometry of the encounter and the sensitivity of *Galileo*'s instruments. The spacecraft's imaging system, unlike a spy satellite's, could not pick out structures that were artificially constructed. Yet if *Galileo* had flown over a densely populated area like the US's East Coast, its cameras might have detected the unmistakably artificial lights of cities.

But the spacecraft carries more instruments than just its cameras. It also carries, for example, a UV spectrometer, which measures atoms and molecules in a planet's upper atmosphere and so can identify evidence of life on a planet at a much greater distance than is possible by imaging.

Another instrument, the Near-Infrared Mapping Spectrometer, detected large quantities of oxygen (O_2), which indicates photosynthesis is likely to be releasing this molecule on the planet below. Methane (CH_4) is common in gas giant planets, but would be unexpected in a huge excess of oxygen. Yet *Galileo* measured large quantities of this gas, probably released by bacteria breaking down hydrocarbon molecules. Nitrous oxide (N_2O), a gas produced mainly by the biological activities of algae, soil bacteria and plant parasites, was also abundant.

There was one finding that might indicate some sort of technological life: an insistent transmission picked up by the radio science team. This transmission does not seem to correlate with any known natural phenomenon. Nor was it immediately identifiable by those familiar with normal terrestrial broadcasts. It may be that *Galileo* has discovered evidence of intelligent life-forms who have only inadvertently betrayed their activities to the spacecraft. —*CMA*

Tracking Spacecraft:

by Bettyann Kevles

The Canberra Complex at Tidbinbilla, Australia
NASA's Deep Space Network consists of three radio tracking stations, each spaced roughly one third of the way around the globe from one another. That way, as Earth rotates on its axis, one station can always be pointed in the proper direction to maintain contact with a wandering spacecraft. This station, located near Australia's eastern coast, has also been used in the Search for Extraterrestrial Intelligence; in 1983, The Planetary Society helped sponsor a radio search by NASA scientists from this facility. Photos: JPL/NASA

The Goldstone Complex in the Mojave Desert
The main radio telescope (seen on the left in above photo) at each DSN complex is 70 meters (230 feet) across, but in the barrenness of this California desert, it's difficult to judge the scale. The size

Thirty-seven miles west of Madrid, the road skirts concrete bunkers deep in weeds, scars of Franco's siege of the capital in 1936. The road forks near the town of Brunete, past a paddock jammed with year-old full-horned black bulls. To the north, about 10 miles away, is El Escorial, Philip II's 16th-century palace-retreat. To the west is Robledo de Chavela, NASA's Tracking and Data Acquisition Station, managed by the Jet Propulsion Laboratory in Pasadena. The hilly landscape mirrors El Greco's canvases—until the profiles of four giant silver antennas pierce the horizon.

The station at Robledo de Chavela, like its counterparts in the Deep Space Network, is set in an arid, bowl-shaped valley. Robledo and its partners Tidbinbilla, near Canberra, Australia, and Goldstone, in California's Mojave Desert, comprise the world's largest radio navigation system. Robledo is also an important milestone in Spain's tradition of astronomical research.

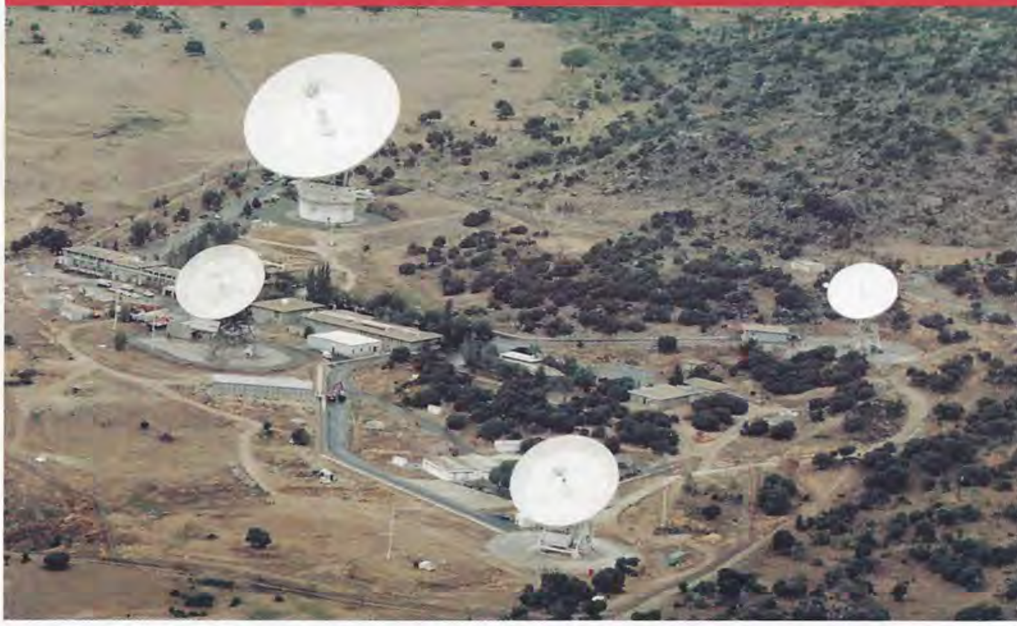
Between the 8th and 11th centuries, while Christian Europe focused inward, Muslim astronomers in Toledo and Córdoba mapped the heavens and developed the astrolabe as a navigational device. Almost a millennium later, Christian astronomers at the royal palace at El Escorial inlaid a meridian line between the floor tiles of the throne room. This carefully leveled line, oriented due north-south, provided information about the length of the solar year as well as certain astronomical constants, such as the inclination of Earth's axis to the plane of its motion. It also pinpointed the precise moment of local noon, for setting clocks.

In the early 1960s, Eberhardt Rechtin, Assistant Laboratory Director at JPL, conceived of the Deep Space Network and sent Phil Tardani to Spain in search of a southern European site. Tardani discovered that INTA, Spain's National Institute of Aeronautic (since changed to Aerospace) Technology, founded in 1942, was already operating a laboratory near Madrid. INTA was very interested in collaborating in space exploration. The United States signed an agreement with INTA in 1964, and, starting the next year, the station at Robledo joined the stations in Australia and North America in tracking NASA spacecraft. The three stations are about 120 degrees apart in longitude, and the overlap between them ensures that, as Earth rotates, one can always communicate with spacecraft in deep space.

The setup at Robledo, like the one near Canberra, includes four parabolic dish antennas—two 34-meter-diameter (110-foot) antennas, one 70-meter (230-foot) antenna and one 26-meter (85-foot) antenna. The signals from the first three can be combined to convert the array into a single radio link with an aperture equivalent to an 85-meter (280-foot) antenna. Whether used alone or together, these three dishes are operated

The Deep Space Network in Spain

and sensitivity of these antennas are crucial to the conduct of planetary missions, for they must be able to pick up extremely faint signals. For example, signals from the *Voyagers* register 10^{-16} watts (1 part in 10 quadrillion), or 10 billion times less than the power level of a digital watch.



The Madrid Complex at Robledo, Spain
Although the DSN is managed by JPL for the American space agency, this facility is operated entirely by Spanish nationals. As the host of a DSN station, Spain has played a role in American planetary missions, as well as the Soviet *Vega* mission to Venus and Halley's Comet, and *Phobos* and the upcoming *Mars '94* mission. Spain is also a member of the European Space Agency and is involved in missions such as *Giotto* to Halley's Comet and *Cassini* to the Saturn system.

by remote control to track space vehicles in deep space. The smallest antenna is still operated manually and can be moved at 3 degrees per second to track vehicles in low Earth orbit.

Robledo's major function in the NASA program is tracking American spacecraft such as *Voyagers 1* and *2*, *Galileo* and *Magellan* traveling in the solar system. Occasionally, however, the Robledo antennas join the VLBI (Very Long Baseline Interferometer) net, which connects widely spaced radio telescopes from New England, California and other parts of Europe, forming an Earth-sized radio telescope array capable of looking at distant objects such as quasars.

Isolated from the rest of Europe during Franco's reign, Spain has so far retained its national character and escaped the homogenization that has blurred national borders elsewhere in Europe. Perhaps one result of this isolation is that, compared to the rest of the continent, few people speak English.

Except at Robledo. The tracking station is like a miniature JPL. Photographs of Venus, fresh from *Magellan*, decorate the walls, and banks of computers fill the complex. In the control room, the staff—all Spanish nationals—communicate among themselves in English. And a clock on the wall gives the local time—in Pasadena.

There are 200 people on the Robledo staff, including 40 engineers and 120 technicians. NASA's agreement with INTA stipulated that, as soon as possible, all personnel would be Spanish. This goal was achieved in 1965, in part by recruiting Spanish scientists and engineers who were working in North Africa and Latin America. Astronomers at Robledo now collaborate with the French, Soviet and Japanese in space exploration projects, as well as with NASA.

Besides the array at Robledo, there is a 30-meter (100-foot) radio telescope at Pico de Veleta near Granada, built and owned by France and Germany, but for which those countries pay Spain in generous viewing hours. Spanish astronomers also have privileges at the 3.5-meter (11-foot) telescope at Calar Alto Mountain, run by the Max Planck Institute in Heidelberg.

The staff at Robledo welcomes almost daily visits from school and university groups. Young Spaniards are as excited about deep space exploration as any youngsters in the world. What next? they ask. With US congressional support, Robledo will participate in NASA's Search for Extraterrestrial Intelligence (SETI) beginning in 1992, and it will join in the exploration of asteroids and comets, Mars, Jupiter and its moons, Saturn and Titan, and worlds beyond.

Bettyann Kevles writes frequently about science and medicine. She is completing a murder mystery that takes place during a planetary flyby at JPL.

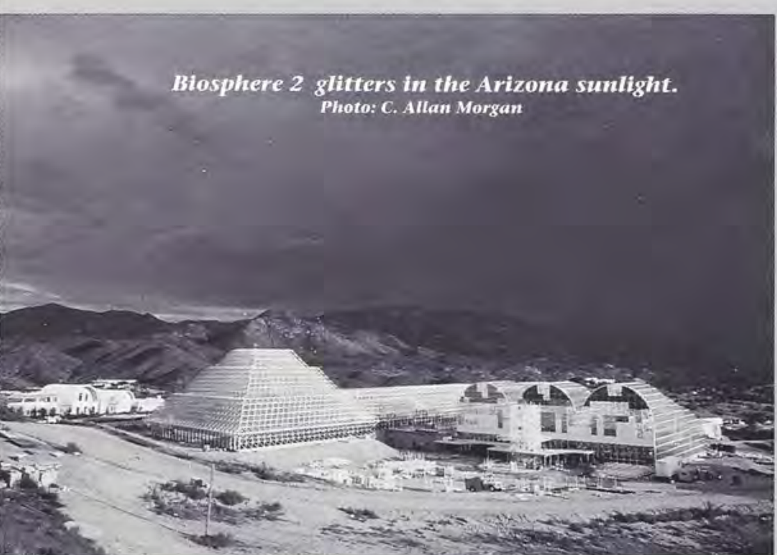
News & Reviews

by Clark R. Chapman

Biosphere 2 is a gleaming, multi-tiered space frame near Oracle, Arizona, that encloses a 3-acre mini world. It is the architectural centerpiece of a futuristic village nestled among the ocotillo. Since 1984, a community of scientists, engineers, adventurers and dreamers have been preparing for Closure Day, later this year, when eight "biospherians" (bionauts) will enter the tropical interior and close the air lock. For two years, they plan to live in 100 percent recycled environs.

Recently, I had the rare privilege of strolling inside Biosphere 2. I talked with the project's leaders and some of the human guinea pigs. Most visitors to the construction site must be content to view it from the outside, though viewing galleries and a people mover will soon provide closer access. Some adjacent greenhouses are being redesigned to simulate Biosphere 2's "biomes" (climatic ecosystems) so that tourists can experience its lush, humid environment.

Following closure, if all goes well, nobody (except for later bionauts) will ever again set foot within the delicate rain forest, savanna, marsh and desert biomes of Biosphere 2. (Apart from stowaways: one uninvited octopus has eluded capture in the Olympic-sized "ocean.") My visit gave me renewed optimism that coordinated technology and ecology might yet save Earth from relentless habitat destruction and could even propel us along pathways to new worlds beyond.



Biosphere 2 glitters in the Arizona sunlight.
Photo: C. Allan Morgan

Laboratory on Mars?

Standing in his analytical lab, bionaut Taber MacCallum told me of his hopes to have a similar lab on Mars one day. He reflects the chief motivation behind Biosphere 2: to develop a biologically (as distinct from physical-chemically) based technology for creating self-sufficient space colonies. There is much to be done before that goal is realized. Even if it weren't for NASA's paltry ability to get spaceborne, it would still be ludicrous to imagine Biosphere 2 on Mars.

The cathedral-like canopy of struts and glass triangles, enclosing 3,000 species of plants, dwarfs even the orbiting national forests in the movie *Silent Running*. And it is only the tip of the iceberg. The battleship-like steel-and-concrete bowels of Biosphere 2 house the infrastructure to regulate temperatures, pump liquids and run all the computers and machines (though algal screen scrubbing must be done by hand). The requisite 5 megawatts of power is generated in an adjacent building. Two hemispheric domes serve as giant "lungs" to maintain air pressure within Biosphere 2.

There is no way this could, or would, be assembled on Mars. Miniaturization is not part of the experiment. Biosphere 2 is a test of concept, a bold leap into the unknown. No endeavor of this scale could fail to influence our eventual approach to colonizing space. Subsequent biospheres can minimize mass and energy consumption; solar energy technology could substitute for Biosphere 2's power plant (today the acres of solar panels would have cost an extra $20 million). For now, Biosphere 2 will concentrate on demonstrating how human beings can live within a complex, theoretically self-regulating ecosystem—recycling their food, water, air and wastes, and exchanging only heat and information with the outside.

Biospheric Science

Some skeptical scientists are jealous of the immense resources—$100 million or so—invested in Biosphere 2 by Texas millionaire Ed Bass and others. They would spend the money differently. But I stand with the approach of Biosphere 2. Researchers elsewhere can run well-controlled experiments in test tubes, petri dishes and terrariums. Others can try modeling the global climate and ecology of our extraordinarily complex planet. Biosphere 2's role is appropriately between narrow, precise experiments on a facet of chemistry or biology and grand theorizing about the vast complexity of the real world in which we must live.

Biosphere 2's designers are smart and creative. Their glassy world may get covered with green slime. Unexpected things will surely happen and could cut short the hoped-for two-year closure. After all, in the real world, a tropical bush baby can hardly scamper over to munch on a desert boojum tree. But with its intermediate scale between test tube and whole planet, Biosphere 2 will surely teach us much. Scientific debates about the project are already fostering new ideas about how to synthesize the green movement with technology to address some of the most serious problems of our age.

I recommend the well-written and nicely illustrated book by the project's research director, John Allen: *Biosphere 2: The Human Experiment*, Penguin Books, 1991 ($16.95). Even though you can't enter the main structure, a visit to the site, an hour's drive north from Tucson, Arizona, will be amply rewarding.

Clark Chapman is planning for the Galileo *spacecraft's October encounter with the asteroid Gaspra.*

SOCIETY Notes

GET A NEAR-EARTH ASTEROID UPDATE

Members who have been following Eleanor Helin's search for near-Earth asteroids may want to attend a special Planetary Society symposium. This event will take place in San Juan Capistrano, California, on Monday, July 1, during the International Conference on Near-Earth Asteroids (June 30 through July 3 at the San Juan Capistrano Research Institute).

The conference is expected to attract members of the technical and scientific community from around the world to discuss near-Earth asteroids, their physical makeup, origins, impacts on Earth, search programs and projected missions. During our special event, members of this community will share their findings and provide an update on what is going on in the field.

If you're interested, please join us. For information, write to me c/o The Planetary Society. *—Susan Lendroth, Manager of Events and Communications*

TRACKING UPCOMING EVENTS

Some of the most interesting and informative space-related activities are not always well publicized by local media. To help keep our members informed, The Planetary Society has compiled a regional calendar of space-oriented events, including but not limited to activities we sponsor. If you'd like to receive a copy, or if you have an event you'd like to add to the calendar, please write to me c/o The Planetary Society.
—Carlos Populus,Volunteer Network Coordinator

GOOD-BYE TO A FRIEND

In 1979, Carl Sagan and Bruce Murray had an idea: The public's support for planetary exploration could be consolidated and focused through a non-profit membership organization. But it's one thing to have an idea, another to turn it into reality. They needed help. John Gardner (now a Society Advisor) introduced them to a remarkable man, Peter Tagger, who practically invented the techniques of funding and building membership organizations with direct mail. He knew just what to do.

Peter administered the early direct-mail campaigns that made our Society one of the greatest success stories of the non-profit sector. Through our first decade, he advised the staff and Board of Directors, sometimes tempering their often rampant enthusiasm with his knowledge and experience. He did the same for many other organizations, among them the Simon Wiesenthal Center, the Sierra Club, the Museum of Modern Art and Operation PUSH.

In early February, Peter died after a short illness. We will miss him. But Peter was a great teacher. He left behind as much of his knowledge and experience as was humanly possible. He will continue to be our mentor. His legacy touches many organizations and many causes, but he loved The Planetary Society, its cause and its people. We have accomplished much since the Society's birth; with luck, we will achieve even more. And everything will be thanks to Peter.
—Charlene M. Anderson

ANNUAL TPS AUDIT

The yearly audit conducted by the firm of Arthur Andersen has determined The Planetary Society's 1990 financial statement to be in conformity with generally accepted accounting principles. Copies of our financial statement, which includes a report on member donations restricted to special use, are available on request. *—Lu Coffing, Financial Manager*

TO MARS BY CAR

A Jet Propulsion Laboratory staff member's very generous donation of a car to The Planetary Society has enriched our Mars Balloon project. We sold the car and directed the proceeds to our work on the balloon and its SNAKE. If you have any other innovative ideas like this, call me. *—LC*

TO NEW AND RENEWING MEMBERS

To help us process your membership, please note that we can accept payment in four ways:

- By credit card (Visa, MasterCard or American Express only).
- By check (in US funds drawn on a US bank).
- By international postal money order.
- By UNESCO coupons. In countries where foreign currency is scarce, these coupons are available for the purchase of educational publications, and generally at the best rate of exchange. *—Sue Pratt, Membership Coordinator*

A SHRINKING REPORT?

You may have noticed that the last two issues of *The Planetary Report* have been a bit thinner than usual. Two factors—the 25 percent increase in third-class postage and the recession—have forced us to trim the number of pages temporarily. At the same time, we have slightly reduced the paper's weight, making the change more apparent.

These changes are saving the Society money in several ways. Our production and printing costs are down. The postage factor is saving us even more. In international postage alone, we have saved thousands of dollars. Non-profit organizations live and die by the mails, and the unexpectedly large increase is hurting all membership groups, not just our Society.

We are realizing additional savings in shipping and storage costs, and each bit will help us weather the storm. We will soon return to full size, and in the meantime, we will bring you as much exciting information about the planets as we possibly can.*—CMA*

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Questions & Answers

What percentage of meteorites found on Earth contain organic compounds or amino acids? What does this say about the population of asteroids in the solar system as a whole?
—Corey Roseberry, Stanton, California

Traces of organic compounds have been found in the carbon-rich meteorites known as carbonaceous chondrites. These meteorites constitute about 5 percent of all meteorites found. The word *organic* does not imply that the compounds were made by living organisms, only that they contain complicated carbon-based molecules.

The organic molecules appear to have been produced at a late stage in the cooling of the solar nebula, the cloud of gas and dust from which the Sun and planets condensed. Complex molecules can be produced by reactions between carbon monoxide and hydrogen helped along (catalyzed) by dust particles. With ammonia added, these reactions produce amino acids and other compounds of biological importance. The solar nebula would have contained all these gases and dust in abundance.

Applying information from meteorite studies to the asteroid population as a whole requires caution. While asteroids of certain colors have been suggested as the sources of certain types of meteorites, the linkages are often controversial. Worse, the most common type of meteorite, the ordinary chondrite, has not been identified with any asteroid. This said, there is general agreement that carbonaceous chondrites are probably fragments of the dark, C-class asteroids. Ceres, by far the most massive asteroid, falls into this category.

The C-type asteroids predominate in the outer part of the asteroid belt. They appear to have extended farther out originally. After Jupiter formed, most of the outlying objects were drawn into elongated orbits, causing them to collide with the planets. Thus the newly formed Earth is likely to have been enriched by organic material from the asteroid belt, perhaps assisting the beginning of life.
—ALAN GILMORE, *Mt. John University Observatory, New Zealand*

How can storms on the gas giants last for hundreds of years when terrestrial storms are so brief?
—Penny Duende, Peoria, Illinois

Earth has a solid surface with mountains and valleys. There is friction between the surface and the atmosphere, as well as temperature differences—both of which assist in storm-decaying motions.

In comparison, the large outer planets, Jupiter, Saturn, Uranus and Neptune, are completely fluid objects and therefore do not have solid surfaces (except at their very cores). As a result, there is no friction between the atmosphere and a surface, and there are no horizontal temperature gradients under the clouds to affect atmospheric motions. The giant planets' atmospheres behave more like huge oceans of gas than atmospheres as we know them on Earth. On the outer planets, once a storm system (like Jupiter's Great Red Spot) generates it will only decay through the viscous interactions that take place within the swirling gases. In some cases these features last for years, decades and possibly centuries.

Thus the greater efficiency of the decaying mechanisms on Earth means that storm systems are relatively short-lived compared with those found in the outer solar system.
—GARRY F. HUNT, *Planetary Society Advisor, London, England*

Do Martians have two feet? Are there any Martian babies?
—Kale Gans [age eight], Glendale, Arizona

Unfortunately, we don't know any. We don't even know if there are any. Fifteen years ago two robot spacecraft landed on Mars and looked around to discover whether or not there could be any life on the planet. They found none and, in fact, found the surface to be so hostile to life that there probably isn't any there. Therefore it is unlikely that there are Martians—with one foot, two feet or a hundred feet.

However, these *Viking* spacecraft found out something very interesting about Mars. Even though it is very hostile now, many billions of years ago it may have been a warmer and more comfortable place. Perhaps then life could have gotten started—but it didn't evolve into big people like us. It probably died out when conditions became bad—if it ever started at all.

We hope that in the next few years more spacecraft will go to Mars and look to see whether there was any life in the past or not. But that's hard to figure out. So the answer to your question will have to wait until we can conduct more specific investigations of Mars. We may even have to wait until we can send people, like yourself, sometime in the next century.
—LOUIS FRIEDMAN, *Executive Director*

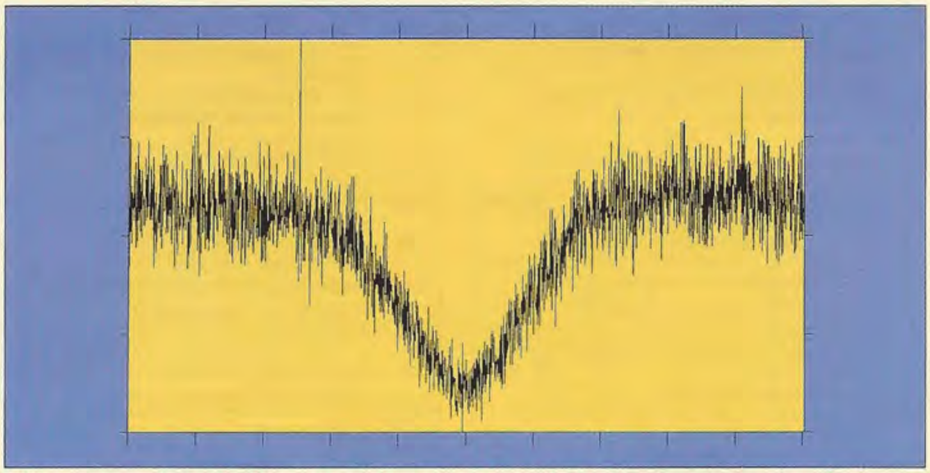
FACTINOS

On January 28 Earth had a fairly close call with a newly discovered asteroid, called 1991AQ (see photo on right). The asteroid zipped past within 8 million kilometers (5 million miles) of Earth (see chart on right).

Eleanor Helin of the Jet Propulsion Laboratory first spotted 1991AQ on January 14 from Palomar Mountain Observatory. Helin leads the Planet-Crossing Asteroid Survey (PCAS), the discovery program supported by The Planetary Society.

—from a Planetary Society press release

Here is the discovery photo of 1991AQ (see arrow). This six-minute exposure was captured on the 0.46-meter (18-inch) Schmidt telescope at Palomar Mountain Observatory. Eleanor Helin, along with team members Ken Lawrence and Perry Rose, discovered the asteroid.



This graph from the Arecibo Observatory in Puerto Rico shows the first detection of radar echoes from 1991AQ—the hair-thin spike one fourth of the way in from the left. These "radar astrometric" observations ensure that 1991AQ's whereabouts will be known precisely for at least the next few decades. JPL's Steve Ostro and his colleagues at Arecibo and the Harvard-Smithsonian Center for Astrophysics collected these data.

For over a decade scientists have debated over whether some type of the plate tectonics that shaped Earth also molded Venus' surface. Now two researchers suggest that some of the most dramatic features on Venus result not from plate tectonics, but from a process they call "blob" tectonics.

Robert R. Herrick and Roger J. Phillips of Southern Methodist University in Dallas propose that blob tectonics would involve gigantic single "blobs" of hot materials rising like bubbles from the planet's interior and punching through the stationary Venus surface. Four examples of such blobs may underlie Aphrodite Terra, a hilly region along Venus' equator, Herrick and Phillips say. Beta Regio may offer another candidate site for the process.

If the theory is correct, *Magellan*'s sharp radar images will reveal specific surface features resulting from rising individual blobs, Phillips says. He and other *Magellan* scientists are looking for elevated regions cracked by faults in more than one direction, and for areas that lack meteorite and impact craters, as if existing craters have been covered by massive volcanic flows.

—from *Science News*

The Hubble Space Telescope may have problems, but it's still returning better photos than ground-based instruments. Pluto is the bright object at the center of this HST image; its large moon Charon is the fainter body at the lower left. Charon is fainter not only because it is smaller than Pluto, but probably also because its surface is covered by water ice, whereas Pluto is believed to be covered mainly by more reflective methane frost or snow. Photo: Goddard Space Flight Center/NASA

Pluto was the first solar system object to be imaged by the Hubble Space Telescope. Thanks to the European Space Agency's Faint Object Camera (FOC) aboard the telescope, we now have the first picture ever of Pluto and Charon seen distinctly (see photos, below left).

This is also the first long-duration HST exposure ever taken of a moving target. In order to avoid smearing the images, ground controllers had to program the telescope to track Pluto extremely accurately and to compensate exactly for the "parallax" introduced by the combined motions of Pluto, Earth and the HST in their respective orbits. Pluto is currently near its closest approach to Earth in its 249-year journey around the Sun and is about 4.5 billion kilometers (about 3 billion miles) away. Further HST observations of Pluto and Charon will be very important in helping scientists to understand the nature and origin of this fascinating and frigid world where the average temperature is minus 215 degrees Celsius (minus 419 degrees Fahrenheit).

—from the Goddard Space Flight Center

The Solar System in Pictures and Books

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661	white	
557	silver 50/50 cotton/poly	
558	navy blue S M L XL **1 lb.**	$ 21.00

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505	**An Explorer's Guide to Mars** (26" x 40" poster) **2 lb.**	$ 5.00
507	**The Planetary Society Tote Bag 1 lb.**	$ 14.00
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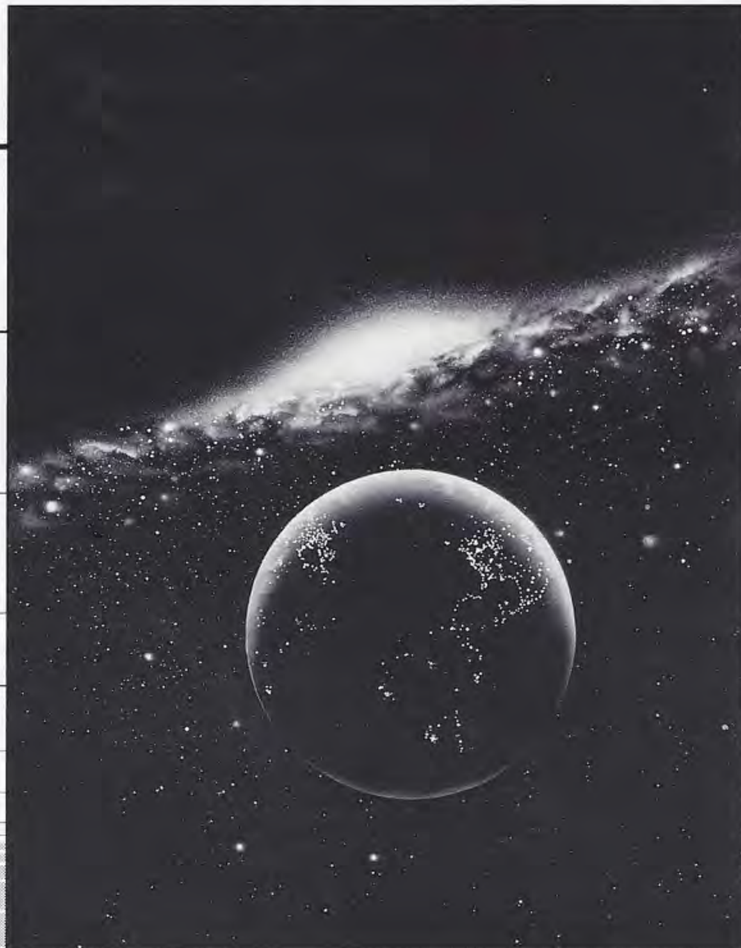

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by Jon Lomberg

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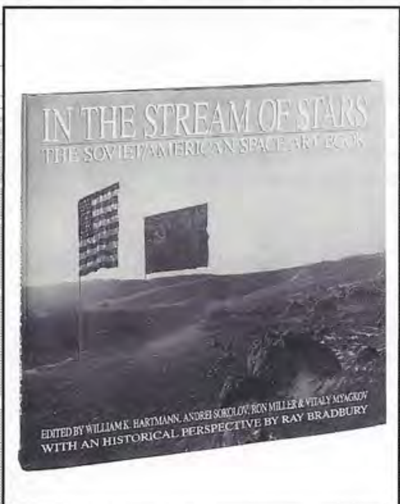
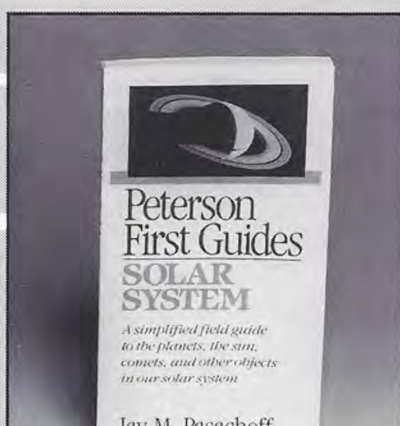


▲ #124

In the Stream of Stars

edited by William K. Hartmann, Andrei Sokolov, Ron Miller and Vitaly Myagkov

This book is a joint venture of the Soviet Artists Union and the International Association of Astronomical Artists to paint, study, exchange ideas, and dream the future of space exploration together. A portion of the royalties will be donated to The Planetary Society, which helped sponsor the artists' exchanges. (hard cover) **$27.00**

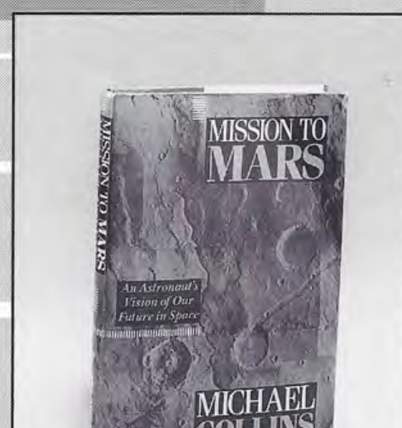


▲ #101

Peterson First Guide to the Solar System

by Jay M. Pasachoff

Take an in-depth look at everything in our solar system — planets, moons, comets, meteors, and the Sun. This book includes over 100 spectacular color photographs, including the latest *Voyager* photographs of Neptune. **$4.50**



▲ #135

Mission to Mars

by Michael Collins

Society Director and *Apollo 11* astronaut Michael Collins presents his design for human missions to Mars. Collins describes how he imagines the mission will be carried out, in addition to providing his view, often bluntly, of the technical requirements for its accomplishment. For anyone wanting to go to Mars, at least figuratively, this book is a must! **$20.00**

URANUS FLYBY—In January 1986, Voyager *flew past Uranus on the way to its final planetary encounter, with Neptune. Backlit by the distant Sun, Uranus' normally invisible rings appear as faint, dusty bands.* Voyager *scientists got more than their share of surprises from this visually bland, blue-green world. They found an extremely unusual magnetic field and magnetosphere, as well as an impressive collection of previously undiscovered satellites. But the biggest shock of all was Miranda—this rocky little moon revealed a surface more bizarre than anything else in our solar system.*

Pamela Lee is a space artist who lives and works in Modesto, California. Her paintings have been widely used in such publications as Time/Life books and Omni *and* Smithsonian *magazines. She is currently working on an international interactive space education and art computer network for children, as well as a series of paintings in collaboration with Soviet artist Andrei Sokolov. The theme of the series is space exploration and the changing self-image of humankind.*

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