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Missions for Microspacecraft

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COVER: The next wave of planetary exploration could well be conducted by small robotic spacecraft carrying two or three instruments tightly focused on a few scientific questions. The targets for these new microspacecraft will be Earth's neighbors in the solar system: the Moon, Mars, and the asteroids and comets that pass close to our planet. In the background here is the crater Copernicus, one of the more spectacular features on the mostly inert lunar surface. In the center is the north polar cap of Mars, a repository of water on the now dry and windswept martian surface. To its left is a false-color image of the asteroid Gaspra.
Images: United States Geological Survey and JPL

FROM THE EDITOR

The way we explore planets is changing. Gone are the days when we could build space-traveling, multipurpose vehicles, load them with a profusion of instruments and send them off to answer a multitude of scientific questions.

The *Cassini* mission to the saturnian system, if it survives the congressional budget process, will probably be the last "flagship" mission launched for a long time. The United States is burdened by a monstrous deficit, the new nations of the former Soviet Union are reexamining their commitments to space endeavors, the European Space Agency is scaling back its plans and Japan is starting slowly in its development as a spacefaring power.

For those of us who are curious about the planets, who want to witness humans walking on Mars, who want to see the exploration of the solar system continue, it's time to get creative. We must find new ways to send our robotic surrogates to other worlds.

The Planetary Society recognized the shifting wind a couple of years ago, so last fall we organized a workshop on microspacecraft for planetary exploration. We had expected to host perhaps a handful of scientists and engineers who, like us, wanted to find new ways to explore. But when word of the workshop spread, we had dozens of people clamoring to come.

They came from NASA centers, other space agencies, government laboratories, aerospace companies and universities. Some were students hoping that jobs would be available when they graduate; others were recent retirees who wanted to see the endeavor they began continue.

They brought eagerness and energy to the workshop, and the Society served as a catalyst for new ideas. Through such efforts and those of many others around the world, we are embarking on a new program in planetary exploration. NASA is now institutionalizing the concept of small spacecraft with phrases such as "faster, cheaper and better."

The US space agency is proposing in its 1994 budget a new Discovery class of missions to cost no more than $150 million each and to be accomplished in three years or less. Whether or not Congress will fund these missions remains to be seen.

Meanwhile, there are other concepts for small spacecraft missions, many of which grew out of papers presented at the Society's workshop. Rather than bring you summaries of each paper, we've asked a few participants to detail their ideas for new missions.

 —*Charlene M. Anderson*

Members' Dialogue

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

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

Ann Zawistowski's letter in the May/June 1992 *Planetary Report* suggested donating back issues of the magazine to area high school science departments. Please do! I have some 200 astronomy students a year taking our one-semester high school course. I cut out pictures and captions and save them by subject until there are enough to organize into a custom poster for lamination. This helps keep the course up to date and fleshes out the minimal imagery in texts. The magazine's color and resolution beat the library's microfiche.

In response to a different issue from Members' Dialogue—false coloration of images has at times misled me and has certainly confused the students. Enhanced images need to be labeled as such.

—BART WORMINGTON, *Omaha, Nebraska*

I am the first amateur to use the Hubble Space Telescope (HST). Five years ago, I started sending in proposals. One project, on post-eclipse brightening on Io, was just completed, and another is being done as part of a professional's study of Mars. Yet another is now under consideration.

Using the HST was just about the biggest thrill of my life. I actually had the feeling that I was looking through the telescope, even though it was orbiting nearly 300 miles above Australia at the time.

Thank you so much for publishing *The Planetary Report*. As a member of many years, I have eagerly studied each issue. *The Planetary Report* has kept me up to date on planetary astronomy and has helped to stimulate my thinking. Keep up the good work.

—JIM SECOSKY, *Manchester, New York*

I am dismayed by the thought of NASA spending $137 million of my tax money on such things as soda machines. [See News Briefs in the March/April 1992 issue.] Although I have been a fan of the space program since *Sputnik,* and a charter member of The Planetary Society, I am also a very disgruntled taxpayer. If NASA and the space program have become pure political pork, then we need some major changes. Getting the federal budget under control is more critical for the country than any or all of the NASA programs. It may be necessary to delay the entire space program to eliminate government waste and congressional micromanagement. This country can't afford the outrageous price we pay for big-government science.

What should The Planetary Society do? Things that need concerned people, but don't cost a lot of money. The asteroid occultation project [see the July/August 1984 *Planetary Report*] was an outstanding example of what amateurs can do that NASA and its billion-dollar budget can't. Let's see more low-budget, good science.

—FRANK J. WEIGERT, *Wilmington, Delaware*

I am greatly pleased with the apparent willingness and ability of The Planetary Society to participate directly in science and exploration, in both the United States and abroad, as represented by our Mars Balloon and Mars Rover activities. It is my sincere hope that the Society will expand these efforts to include micromissions to the Moon and near-Earth asteroids. With the dramatic trend we now see toward reduction of costs of launchers, communications equipment and computation, there is no excuse for continued whining about inadequate government funding. There should be, and I predict will be, a renaissance of small, rugged, practical experiments funded entirely by traditional, forward-thinking institutions such as the National Geographic Society and the Smithsonian Institution.

I'd like to see the Society circulate a preference poll, including total dollar costs and per-member prices, for several very minimal missions, particularly lunar mapping and near-Earth asteroid sampling. Is this idea ridiculous? Need I suggest that a minimal mission is preferable to no mission at all?

—COLIN KEIZER, *Fall City, Washington*

NEWS BRIEFS

Astronauts may someday explore Mars without leaving their base camp using "telepresence," a mix of science and engineering that NASA is now developing at Ames Research Center. "When we begin to explore Mars, it won't be easy for the astronauts to travel far from their base to gain access to the whole planet," said Geoffrey Briggs, scientific director of the new Center for Mars Exploration at Ames. "Telepresence will allow humans to project themselves, by way of a suitably equipped robot, into a remote environment without endangering themselves. It's a very powerful research technique."

While "virtual reality," another computer science innovation, allows a user to see and interact with a computerized video image, telepresence lets a researcher see what a robot sees and do actual tasks in a real environment.

—from Ames Research Center

In early June, Yuri Koptev, director general of the Russian Space Agency, urged Japanese space officials to commit to cooperative space projects but received just a promise to consider the idea.

Kanzo Tanigawa, minister of the Japanese Science and Technology Agency, promised that Japan would send a large delegation of scientists and business executives to Russia in July to study possible joint projects, said Tsuyoshi Maruyama, director of the agency's international space affairs division.

"We haven't decided on anything concrete," Maruyama said. The delegation will survey Russia's space facilities, confer with Russian scientists and seek areas where cooperation would be possible. One of the delegation's concerns will be the structure of the Russian space program, which has gone through many changes since the breakup of the Soviet Union last year, he added.

—from *Space News*

Doing More With Less: The New Way of Exploring the Solar System

by Rex Ridenoure

The solar system exploration community worldwide is facing a near-term future of constrained budgets and shifting priorities. Everyone is being forced to think hard about how to work with less than was once expected. The community is challenged to devise creative concepts for using limited resources efficiently. In the long run, responding to this challenge should reinvigorate and diversify the community.

The world has changed drastically since we first began to explore the solar system in the early 1960s. Once-powerful nations have evaporated, and government's "discretionary funds" have shrunk inexorably.

Hopes for approval—in *any* spacefaring nation—to start new major planetary missions in the next several years are generally unrealistic. Indeed, the United States' recent cancellation of the Comet Rendezvous Asteroid Flyby (CRAF) mission indicates how vulnerable the *existing* major missions have become.

If we are to continue exploring the planets, and adapt to the trend to smaller missions, we must address several factors.

Cost

If a prime mover exists for the trend toward small missions, this is probably it. Adjectives such as *affordable*, *cost-effective* and *cheap* are often used for these new mission concepts.

A planetary mission qualifies for the low-cost label if it has an estimated total cost of a few hundred million dollars or less (but few ideas for meaningful planetary missions have surfaced with estimated price tags of less than $100 million). This contrasts with major or flagship missions, which typically cost $1 billion or more.

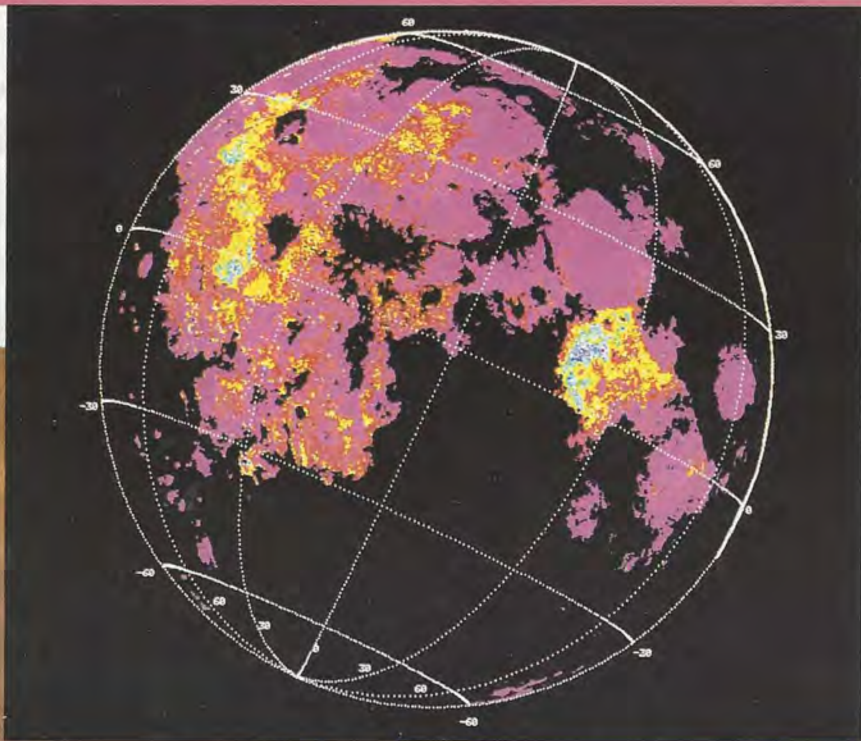
NASA now assigns the low-cost mission concepts to one of two classes—"Discovery" and "Intermediate."

A Discovery-class mission would require no more than $150 million for development through launch plus 30 days. (Discovery-class missions would further be limited to a development cycle of no more than three years.) NASA's Discovery program provides stable funding each year to enable the parallel development of several small missions.

In contrast, an Intermediate-class mission is one with development costs of approximately $400 million. Intermediate-class missions are generally moderate-size, one-of-a-kind projects. (There are various caveats that must accompany these classifications, such as which year's dollar is assumed, what's included in the costs and what reserves are assumed.)

Schedule

It is not uncommon for major planetary missions to take a decade or so to develop and another decade or more to execute. Pathfinding missions such as *Viking*, *Voyager*



Small spacecraft can serve as scouts for eventual human expeditions to the Moon and Mars. One early goal for a small lunar orbiter will be to map the abundances of useful minerals on the Moon's surface. Using Earth-based telescopes, scientists can produce useful charts of mineral locations, such as this map of the distribution of ilmenite. (Since it is made of iron, titanium and oxygen, this mineral could be particularly useful to explorers.) But to settle on a landing site, we will want more detailed information.

Researchers have been using Viking *orbiter images to search for landing sites on Mars that offer "the most bang for the buck." This site in the east Mangala region offers channels possibly cut by running water (bottom), old degraded craters (middle and upper left), a young crater surrounded by "splosh" (center right) and a scarp marking the boundary between the southern and northern hemispheres of Mars. Small spacecraft could provide more detailed information on potential landing sites.*

Mars image: United States Geological Survey
Moon map: J.R. Johnson, S.M. Larson and R.B. Singer

and *Galileo* are good examples. Such missions pay major scientific dividends and make careers, but tax the stamina and patience of those involved in the process.

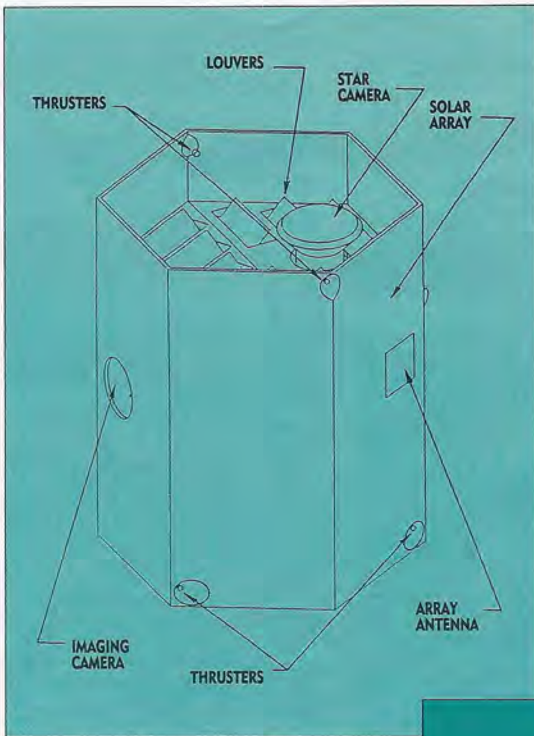
But tolerance for such long, drawn-out projects is waning; times have changed. There is growing support for missions taking much less time to complete. The recent Japanese *Hiten* mission to the Moon (see the May/June 1992 *Planetary Report*) is a good example of such a mission. Other mission concepts, particularly for NASA's proposed return to the Moon (see page 8), would take three to five years or so from initial concept development through end-of-mission.

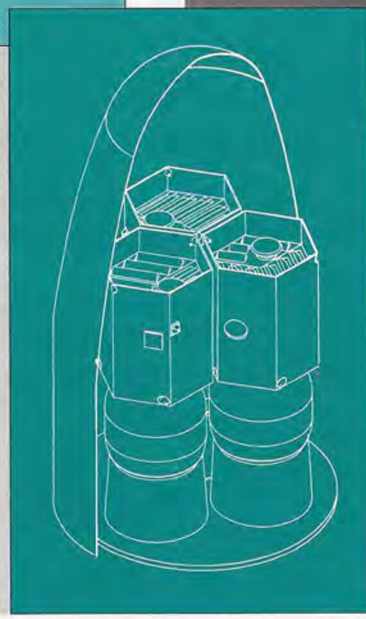
Realistically, there are limits on where such missions can go. Our launch vehicle and propulsion systems operate within a certain performance envelope and no more, which in turn limits trajectory options to the planets. The Moon can be reached from Earth in a matter of days. Venus and some near-Earth asteroids and comets require a few months of travel; Mars, about a year; Jupiter and perhaps Mercury, a few years of trip time. These—plus, of course, Mission to Planet Earth—comprise the set of missions in the three-to-five-year category.

Science

Small missions do not necessarily produce "big" science, but they certainly can if they are conceived and implemented correctly. Indeed, much of the enthusiasm for the small- and moderate-class planetary missions is coming directly from the scientific community. A compelling scientific rationale for a mission can often be articulated if the mission is tailored to a specific scientific objective or wrapped around the synergistic potential of a few, state-of-the-art instruments. Good examples of such missions include the Near-Earth Asteroid Rendezvous (NEAR) concept (see page 15) and the small Mars lander concept (see page 10).

Past experience with small scientific missions, such as the Infrared Astronomy Satellite (IRAS) and the Cosmic Background Explorer (COBE), tells us a few things about *how* the science will probably be done in this new environment. Only a few, multitalented scientists are required to support small missions with focused objectives and a limited number of instruments. Much of the effort required to articulate, direct, administer and interpret the science can be provided by one principal investigator and a small, coordinated body of supporting scientists and technical staff. The same team may even design, build, test and operate the instruments, coordinating its work with engineers from a company or government laboratory tasked with supplying and operating the spacecraft.





In the past decade we've gotten used to interplanetary spacecraft like Voyager *and* Galileo, *crowned with large, parabolic antennas and festooned with instrument-laden booms stretching out from the spacecraft's body. These complex configurations carried arrays of instruments supporting many different experiments. The new generation of microspacecraft will be less sophisticated.*

This is a concept for a microspacecraft designed to investigate near-Earth asteroids. It resembles a hexagonal cookie tin more than it resembles Voyager, *yet it would be able to obtain useful scientific data. In this design, three spacecraft can be packed into the small* Pegasus *payload shroud, tripling the cost-effectiveness of the launch.*

Illustrations: JPL/NASA

Technology

Superficially, it might appear that the trend toward smaller spacecraft and missions is a step backward—a regression to the early days of space exploration when nearly everything was small. The difference is the technology involved. Today, electronics and instruments of small physical size have capabilities that exceed comparable 1960s packages by several orders of magnitude. Propulsion and navigation performance have also improved dramatically.

Advances in the electronics industry and spin-offs from the Strategic Defense Initiative (SDI) technology research programs have provided much of the recent impetus for this change. Another important factor is that smaller, cheaper, quicker missions tend to increase the rate at which new or better technology can be introduced into the quite conservative space arena. In fact, the SDI and commercial space segments are three to five years ahead of the space exploration field in developing and applying new small-satellite technology; these groups were preceded by the academic and amateur-radio communities.

Politics

Signs and symptoms of national economic malaise appear daily in headlines around the world. Spirited public debates addressing a variety of economic ills are under way in the US, European countries, the Commonwealth of Independent States and Japan—all leading spacefaring nations. There are no clear indications that any of these large economies will significantly improve soon.

Consequently, space mission planners and scientists see the writing on the wall: Big-ticket space programs will not be easy to sell in coming years; small missions stand a better chance. Recent, well-publicized problems with major projects such as the Hubble Space Telescope, *Galileo* and space station *Freedom* have cast a cloud over any new concept perceived as "big." Even if the problems on these large projects are eventually rectified, the public, media and government officials will probably harbor lingering doubts and biases about larger missions.

Competition

With the exception of the *Pioneer* program, administered by NASA's Ames Research Center, and the *Viking* project, managed by Langley Research Center, US planetary exploration has been conducted by the Jet Propulsion Laboratory. But should the Space Exploration Initiative (SEI)—the Mission From Planet Earth—achieve its stated goals, this may change, and other organizations may join in leading the way.

NASA's Office of Exploration, tasked with planning and implementing SEI, is studying, as precursors to a human return, small missions to the Moon that will employ an organizational arrangement differing from that used by previous US lunar automated missions, which were led by JPL.

In 1990, the Japanese became the third country to deliver a probe to the vicinity of the Moon. Organizations

Planetary spacecraft all begin their journeys propelled by rockets. To cut costs, it helps to begin with the launch vehicle. One of the first new rockets designed to carry small payloads is the Pegasus, *15 meters (50 feet) long, seen here (left) during its second flight. The* Pegasus, *built by Orbital Sciences Corporation, follows the trail blazed by rocket planes like the X-15. The small rocket is carried aloft by a large jet and released; its engine then ignites to carry it into space.*

Planetary mission designers are planning to use the Pegasus *or a slightly larger cousin to launch spacecraft to the Moon, Mars and near-Earth objects. These spacecraft will have to be small enough to fit into the little rocket's payload compartment (a little over a meter in diameter) and light enough (a few hundred kilograms) for it to lift. But with cleverness and thrift, it will be possible to send a microspacecraft on a mission of scientific discovery.*

Photographs courtesy of Orbital Sciences Corporation

in the US such as Johns Hopkins University's Applied Physics Laboratory (APL), the Los Alamos National Laboratory and the SDI organization have expressed interest in sending missions—all small—to places beyond Earth orbit. Selected US aerospace companies and perhaps other organizations in Europe and Japan may follow suit in coming years. The common denominator: small, affordable, achievable missions.

Collaboration

Planetary space missions, no matter how small, are expensive. Their required infrastructure is formidable. One way for new participants to enter this field is to collaborate. Companies are doing it, universities and laboratories are doing it and countries are doing it. Several relatively small organizations can thus combine talents and resources and form a critical mass of capability to enable a new mission to proceed. For the time being, such missions will probably be relatively simple and low in cost.

Diversification

Many aerospace and technical companies worldwide, but particularly in the US, are looking to sell their products and talents in markets besides the shrinking defense markets. Many companies that have jumped on the commercial or SDI small-satellite technology bandwagon also see potential in the space exploration arena.

Training

As a practical matter, technical and scientific people acquire some of their best training by getting hands-on experience—by working with real hardware on real missions. For this reason alone, the small, rapid-turnaround missions are a good idea, particularly for younger people entering the field from school. More experienced people often express nostalgic delight at the thought of picking up a quick refresher course by serving on a small-mission team.

Redirected Efforts

It's clear that the end of the epic space mission era does not have to mean the end of planetary exploration. Everywhere in the space community people are busily regrouping and redirecting their efforts. Luckily, the technology is there to let us do what we've been forced into doing, and the political climate is ripe for cooperative efforts. Charles Elachi, Assistant Laboratory Director for the Office of Space Science and Instruments at JPL, engaged in a grass-roots search for new planetary mission concepts having low cost and short schedules, summed it up: "We can't look at the past," he said. "The past got us where we are today. We have to think of new ways of doing business."

Rex Ridenoure is a mission engineer at the Jet Propulsion Laboratory. He was a mission planner for the Voyager *Neptune encounter and has contributed to several JPL conceptual planetary mission studies.*

To the Moon: Faster, Cheaper—and Better

by Paul D. Spudis

Since the last *Apollo* astronaut left the Moon 20 years ago, the agenda for its scientific exploration has not changed. Despite its closeness, there is still much we have to learn about Earth's satellite. We have yet to complete a global reconnaissance and to map its surface composition, topography and morphology.

To accomplish these tasks, we need to map the entire Moon from orbit and deploy a global network of geophysical stations equipped with instruments such as seismometers and heat-flow probes. Then we will select particularly interesting sites for in-depth study, taking measurements on site and collecting samples for return to Earth. Finally, human scientists, assisted by robotic helpers, will conduct lunar fieldwork to understand more completely lunar processes and history.

This plan has been triggered by NASA's drive to implement President Bush's proposed Space Exploration Initiative, which would send humans back to the Moon to pick up where *Apollo* left off, and then on to Mars. As a beginning, the Office of Exploration is planning to launch a series of small robotic probes to the Moon within the next few years. [However, Congress is reluctant to fund SEI, and recently "zeroed out" two proposed lunar missions. See World Watch, page 17.]

This series of three missions will include both orbiters and landers, targeted to answer a variety of scientific questions. But of equal importance to their scientific merit will be the proof that such missions can be executed much more inexpensively and more quickly than has become the norm. This so-called new paradigm of "faster, cheaper, better" is actually a return to the operational and managerial philosophy of an earlier, more successful NASA.

So, can we do meaningful science with such a program? Most emphatically, yes!

Mapping Resources

The first mission in the current plan is a polar-orbiting satellite to map surface chemistry and mineralogy.

This spacecraft will carry a gamma-ray spectrometer, which measures natural radioactivity and secondary radiation induced when cosmic rays strike the surface. It will also be equipped with an X-ray spectrometer, which measures surface fluorescence induced by X rays from the Sun hitting the surface. The gamma-ray experiment will give us a global map of thorium, uranium and most of the major elements, while the X-ray instrument will tell us about the distribution of aluminum, magnesium and some other significant rock-forming elements.

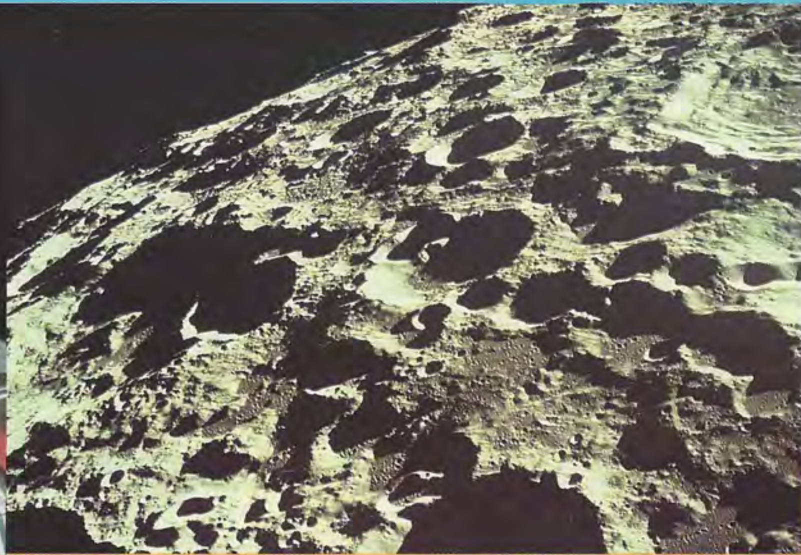
The orbiter will also carry an imaging spectrometer designed to diagnose the minerals present, especially the important rock-forming ones such as plagioclase (a calcium-aluminum silicate) and olivine and pyroxene (magnesium- and iron-rich silicates).

Using the information gathered by these instruments, we can construct a global map of surface mineralogy, and increase our understanding of the variations in crustal composition. By adding this new information to the superb data base provided by the *Apollo* lunar samples, we can more confidently address the geologic processes that shaped our Moon.

Tugging at Gravity

The second mission will deploy an orbiter to map the Moon's gravity field and terrain. We already know that the Moon has a very complex gravity field, shaped by mascons (mass concentrations) that perturb orbiting spacecraft and cause their orbits to decay. By using radio to track the orbiter carefully as the Moon tugs at it, we can map the lunar gravity.

Although the Moon was the first extraterrestrial object explored during the Space Age, we actually know its terrain very poorly. To understand its shape, topography and surface morphology, we will use two instruments, an altimeter and a camera for digital imaging.



Above: The back side of the Moon is still largely unexplored territory. Until the Space Age, no human had ever seen it. The Soviets first photographed it in 1959 with their Luna 3 *spacecraft. The US followed with the* Lunar Orbiter *in 1966. Finally, the* Apollo *astronauts orbiting the Moon took photographs like this one of its heavily cratered surface. Despite these cursory looks, this hemisphere of the Moon is still largely* terra incognita. *We must send many more spacecraft before we know it well.* Photograph: NASA

Left: A small robotic rover, about 1 meter long, is a candidate for a payload to be carried to the Moon by an Artemis *lander. The rover would survey a landing site for humans to use on their return to the Moon. NASA scientists and engineers feel they can carry out such a mission expeditiously and inexpensively by using an expendable launch vehicle and small, cleverly designed spacecraft.* Painting: Pat Rawlings, Science Applications International Corporation

With the altimeter, which can use either a radar or laser beam as a ranging source, we can measure the height of the spacecraft from the lunar surface, and use these data to derive a map of the surface topography.

The camera allows us to distinguish surface features as small as 50 meters (165 feet). Moreover, it will provide the first image set that covers the entire Moon uniformly, from the same perspective.

Together these experiments will give us global maps of the terrain of the Moon, creating a cartographic data base that will serve the needs of both science and exploration.

On the Surface

The third mission will begin the on-site investigations necessary before we can understand the details of lunar processes and history. One current concept is to deploy a robotic rover, to be delivered by a landing vehicle we are calling *Artemis*. This rover could be sent on several types of missions, but here I will consider a resource-prospecting mission.

Many people have speculated on how we might use lunar resources, and among the most plausible ideas is to extract oxygen and hydrogen from the soil to make rocket propellant and water to supply a human outpost on the Moon.

The first *Artemis* can land about 65 kilograms (140 pounds) on the Moon, enough to accommodate two mini-rovers. The rovers would carry high-definition, stereo cameras to map the site and locate small craters, blocks and major landforms.

A set of remote sensing instruments will measure the chemical and mineralogical properties of the site. For prospecting, we will need to measure the chemistry (particularly the iron and titanium content) and the maturity of the soil (a measure of the duration of its exposure to solar radiation), as well as the amounts of gases (mostly hydrogen) implanted in the lunar dust by the solar wind (a stream of charged particles blowing out from the Sun).

Using detailed maps, on scales of a few meters, we can see the variations in these properties and so determine how we can best extract resources needed to support human operations and eventually habitation on the Moon.

Timely Missions, Well Conceived

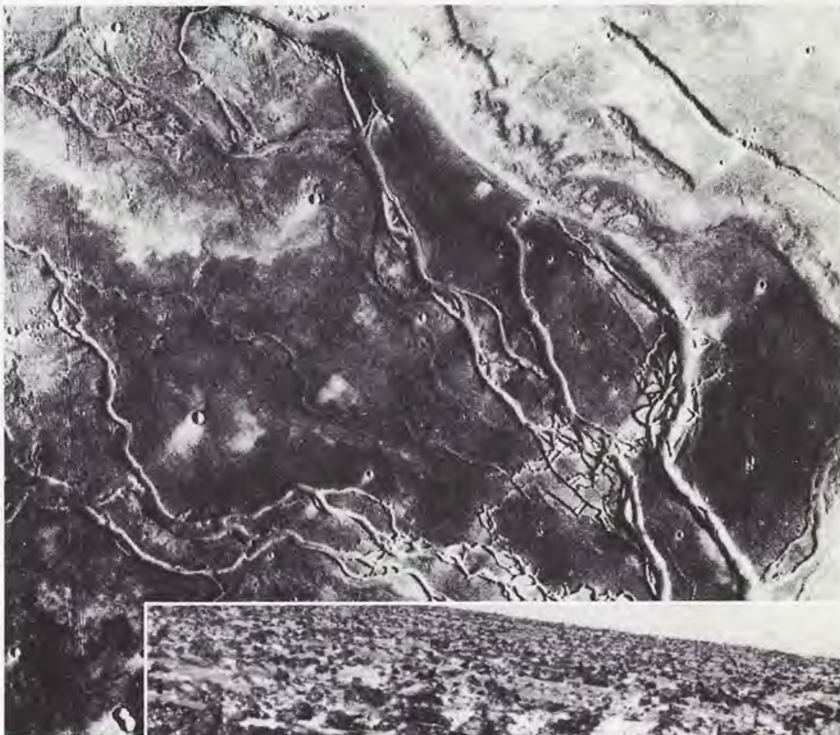
The three missions I have described here can all be accomplished within the next three years. Each will cost between \$100 million and \$150 million —including the launch vehicle. They will not only provide high-quality data, they will also give us a much-needed capability—to fly small, focused missions on a rapid but technically prudent schedule.

When we can conceive and conduct missions in a timely manner, we will be able to follow up discoveries quickly or undertake new exploration with advanced techniques. Such a program of robotic space exploration is not only faster and cheaper, it is also better.

Paul D. Spudis is a staff scientist at the Lunar and Planetary Institute in Houston. He was a member of the Synthesis Group, a White House panel that examined SEI architecture, and he currently serves on NASA's Lunar Exploration Science Working Group.

Starting Small on the Road to Mars

by Robert P. Hanel, G. Scott Hubbard, Larry G. Lemke, Ruben Ramos, George L. Sarver and Paul F. Wercinski



Innovative ideas, seasoned with tried and true methods of the past, are now fermenting in the world's space programs. With hard work, creativity, adaptability—and luck—we may see a resurgence of exploratory energy directed toward that most Earth-like of planets, Mars.

In the 1960s and 1970s, Mars was the focus of an ambitious campaign in both the United States and Soviet space programs. The US sent four *Mariners* to Mars, and with *Viking*, the most ambitious planetary mission yet launched, orbited two spacecraft and landed two stations equipped to search for life. The Soviet Union sent seven spacecraft to the Red Planet, including two *Phobos* craft in 1988, although none of those missions was completely successful.

NASA's *Mars Observer*, set for launch in September of this year, will reach its destination in 1993. In 1994, the Russians will send *Mars '94*, which will be followed two years later by *Mars '96*. These missions were planned before the end of the Cold War and the breakup of the Soviet Union, and before the US federal deficit came home to roost.

There is now no approved Mars exploration program in the US or Russia. Japan will launch *Planet-B* in 1996 (see page 12), but has no concrete plans to return to Mars thereafter. President Bush has made Mars the ultimate goal of his Space Exploration Initiative, but, despite the administration's efforts, SEI has found little support.

So, what can we do to continue the exploration of the Red Planet after *Mars Observer, Mars '94* and *'96*, and *Planet-B*?

From the ferment of exploratory ideas has come a flurry of proposals for small, inexpensive, but impressively "doable" missions. Billion-dollar missions like *Viking* are just not in the cards—for the foreseeable future—but missions costing about $100 million are still possible.

Many people and institutions have proposed small Mars missions, and we don't have room to cover them all. Here we present two ideas from NASA's Ames Research Center.

—*Charlene M. Anderson*

The *Mars Explorer* Mission

The *Mars Explorer* mission concept is directed to preparing for human exploration of the Red Planet. The strategy of this mission is analogous to that of the series of *Surveyors* that were launched to the Moon as precursors to the *Apollo* landings. The mission theme is human landing site reconnaissance, exploration and characterization.

Our goals are to return high-quality images of likely human landing sites, characterize the geology and mineralogy of the sites, and prospect for subsurface water. A key element of our design work is to develop a low-cost approach to meet these goals.

The baseline design assumes that four spacecraft will be launched on a single *Delta II* launch vehicle in late November or early December of 1996. The solar-powered landers will be targeted to the low to mid-latitudes, to regions near the equator that are potential human landing sites. Using parachutes, the landers will approach the martian surface, imaging the surface as they descend. About 100 meters (300 feet) above the surface, the parachutes will be jettisoned and propulsion stages will be activated. Thrusters will fire, and about 1 meter (3 feet) above the surface the vertical and horizontal velocities will be "nulled," allowing the spacecraft to make soft landings.

In this design, we plan to use a propulsion stage, under development by the Strategic Defense Initiative Office, that uses high-performance propellants and lightweight thrusters.

Upon command from Earth, the landers will activate their science instruments. The scientific payload might consist of a multispectral panoramic camera, a neutron/gamma ray spectrometer and a UV-

Far left: The presence of water on Mars is one reason for this planet's attraction for humans. From evidence such as the scars of extensive channels cut in its surface , we suspect that abundant liquid water once flowed across the Red Planet.

Left: Frozen water is still abundant in the polar regions; at the north pole, it has formed a layered terrain that holds clues to the past climate of Mars.
Images: JPL/NASA

Left: At the Viking 1 landing site, the spacecraft even imaged water frost sprinkled across a landscape eerily similar to that of Earth. To find water on Mars, perhaps hidden in permafrost, will be a prime objective of spacecraft scouting the planet for human explorers.
Image: JPL/NASA

fluorescence spectrometer. The landers will not need a communications relay on a Mars orbiter but will be able to transmit their data directly to Earth.

Each lander will be equipped with spring-deployable legs. During the cruise phase of the mission, these legs will be folded to fit within a 1.5-meter-diameter cylindrical envelope. When the legs are deployed, the landers will sit about 0.75 meter above the ground.

After scientists have interpreted the data from the landing sites, the landers will be commanded to perform ballistic hops of about 100 meters to nearby sites. That is, they will briefly fire their propulsion stages to move from place to place. They will gather more data at each of the new sites.

All the primary mission objectives will be completed about four months after the initial landing.

SLIM: Surface Lander Investigation of Mars

At Ames Research Center we are studying a modest mission called Surface Lander Investigation of Mars, or SLIM. This would be a single-probe mission to land a simple scientific payload on Mars. It would be launched in 1996.

SLIM will use many of the concepts developed during studies for the Mars Environmental Survey (MESUR) mission previously studied at Ames. The spacecraft will be launched piggyback with another payload on a *Delta II*, a refurbished *Titan II* or an *Ariane*.

In late June or early July of 1997, the vehicle will enter Mars' atmosphere, targeted at a mid-latitude site. At an altitude of about 8 to 10 kilometers (5 to 6 miles), the probe will deploy a parachute that will separate the lander from the heat shield and reduce the lander's descent rate to about 30 meters (100 feet) per second.

During descent, a camera will take a series of nested images of its landing site, which it will later transmit to Earth. The probe will also take measurements of the upper atmosphere. The probe's impact will be softened by an inflatable or crushable cushion.

Once on Mars, it will image the surface, take meteorology measurements and investigate the soil chemistry. It is particularly important that we understand the martian soil chemistry before attempting a human landing. The *Viking* lander experiments indicated that an oxidizing agent in the soil destroys organic compounds. Thus SLIM will address this and other scientific questions we need to answer before humans walk on Mars.

The authors are aerospace engineers at NASA's Ames Research Center in Mountain View, California.

MESUR Pathfinder: A Mission of Discovery

Recognizing the budgetary constraints now placed on its ambitions, NASA is developing a new program of robotic planetary exploration called Discovery. Missions in this program will cost no more than $150 million and are to proceed from approval to launch in three years. The first Mars mission to be proposed for the Discovery program is the MESUR Pathfinder, an offshoot of the original Mars Environmental Survey (MESUR) mission.

MESUR would land 16 spacecraft at widely spaced locations around the Red Planet. This array of stations would measure the atmosphere, analyze soils and rocks, track weather and seismic activity and conduct other experiments. The current hope is to launch the first group of MESUR spacecraft in 1999.

But MESUR will be expensive, perhaps costing hundreds of millions of dollars before it completes its task. So mission planners have proposed the MESUR Pathfinder, a single-spacecraft mission that should fit into the Discovery-class constraints.

The MESUR Pathfinder would deposit a small lander on the martian surface, perhaps carrying a microrover. The microrover could carry a small camera and one or two other scientific instruments. The lander itself might carry instruments to search for water ice beneath the martian surface and to measure the soil's toxicity.

NASA is planning to seek funding for the MESUR Pathfinder in its 1994 budget. We will then see how Congress will react to the new Discovery program for planetary exploration. —*CMA*

Japan Sets Out to the Moon and Mars

by Hitoshi Mizutani

In 1996 the Japanese plan to launch Lunar-A, *which will carry three penetrators to the Moon. Penetrators are particularly useful devices for examining a planetary body. They can take measurements beneath the surface, which is not possible with remote sensing instruments on orbiting spacecraft. The* Lunar-A *penetrators should help us better understand the nature and structure of the lunar interior.*

Paintings courtesy of the Institute of Space and Astronautical Science

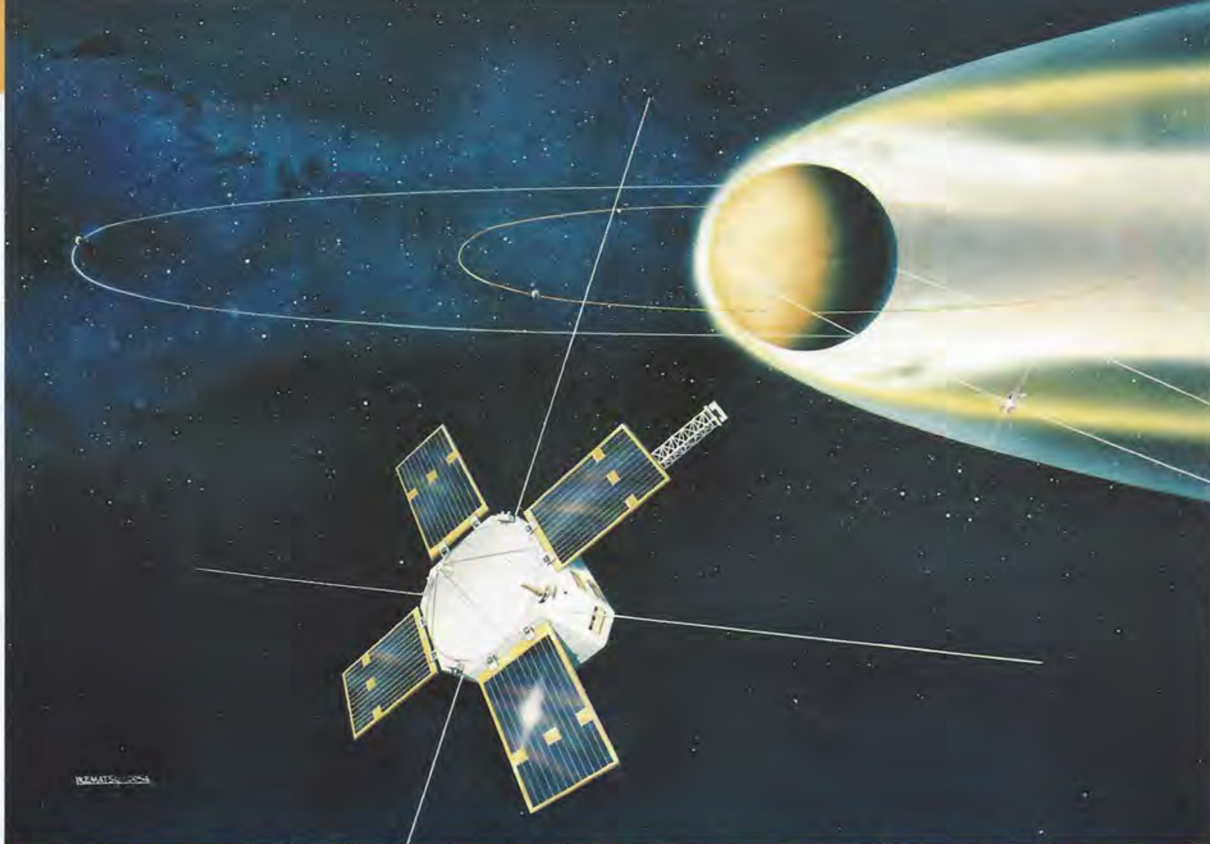
The 1990s are shaping up to be eventful years for the Japanese space program. Building on the successful *Hiten* mission launched in 1990, in which a daughter satellite became the first terrestrial visitor to the Moon in 14 years, we are preparing for two major planetary missions—*Lunar-A*, which will send penetrators to the lunar surface, and *Planet-B*, which will go to Mars.

First, a bit of background. We have two space agencies in Japan—the Institute of Space and Astronautical Science (ISAS), which is part of the Ministry of Education, Science and Culture, and the National Space Development Agency (NASDA), a division of the Science and Technology Agency. ISAS oversees the research and development of scientific satellites and their launch vehicles, and NASDA focuses on Earth-orbiting satellites, such as weather and communication satellites, and their launch vehicles. Both agencies are coordinated by the Space Activities Commission (SAC) of the Prime Minister's Office.

Since ISAS' first launch of a satellite into low Earth orbit in 1970, our space capabilities have steadily expanded. In 1985, our first two interplanetary spacecraft joined *Giotto* from the European Space Agency (ESA) and the two *Vega* spacecraft from Intercosmos on a mission to study Halley's Comet. Then, in 1990, we succeeded in first putting a daughter satellite into lunar orbit from the *Hiten* mother satellite, and then, using a new gravity-assist technique called ballistic capture, inserting the *Hiten* itself into lunar orbit on February 15, 1992. (See Edward Belbruno's "Through the Fuzzy Boundary: A New Route to the Moon," in the May/June 1992 *Planetary Report*.)

The next milestone for us is the development of a new solid-fuel rocket, the M-V. More powerful than its predecessors, but modest in cost, the M-V is capable of putting a 2-ton satellite into low Earth orbit, sending a 550-kilogram (1,200-pound) spacecraft to the Moon, or a 350-kilogram (770-pound) package to Venus or Mars. The M-V will really give Japanese scientists a leg up in planetary research.

The first M-V will launch in 1995, carrying *Muses-B* and its radio telescope into space. This radio telescope will coordinate with Earth-based radio telescopes, producing a dish with an effective diameter of 20,000 kilometers (about 12,400 miles).



Both the United States and the Soviet Union have sent several missions to Mars, but none has been targeted to explore its upper atmosphere. This will be the objective of Planet-B, to launch in 1996. Soviet craft detected what might be a very weak magnetic field on Mars, although US craft found no such evidence. Planet-B could resolve this contradiction. Even if Mars does have a weak magnetosphere, it is probably not extensive enough to protect the upper atmosphere from the effects of the solar wind, as Earth's powerful magnetosphere protects our atmosphere. Planet-B will let us know what is happening in the upper reaches of the martian atmosphere.

To the Lunar Surface in 1996

Our understanding of the origin and evolution of the Moon is incomplete; to flesh it out, we need more information. We need global geochemical and geophysical data, and we need to know more about the Moon's internal constitution.

In order to achieve this goal, we plan to launch *Lunar-A* in early 1996. Its purpose is to place three penetrators at three different sites on the lunar surface. With the *Lunar-A* spacecraft in orbit, the penetrators, each carrying a seismometer, a heat-flow probe, an accelerometer and a tiltmeter, will be deployed. Striking the Moon at 250 to 300 meters (about 800 to 1,000 feet) per second, they will penetrate to a depth of 1 to 3 meters (about 3 to 10 feet). Here, their seismometers will have good contact with the lunar soil, and the penetrator temperature will remain constant. Heat-flow measurements—which the *Apollo* astronauts made by painstakingly drilling into the surface—will also be possible at this depth.

The seismometers are extremely sensitive and will record vibrations from meteorite impacts, shallow moonquakes and repetitive deep moonquakes triggered by tidal stress. They have been designed to pick up and identify waves from moonquakes deep within the mantle, such as those picked up in *Apollo* seismic data. Observations of these deep quakes on both the near side and far side of the Moon will give us important data on the size of the lunar core and its properties.

Onward to Mars

The objective of the *Planet-B* mission to Mars, scheduled to launch in 1996 following *Lunar-A*, is to study how the solar wind interacts with the thin martian atmosphere. Because Mars has a very weak magnetic field, if any, there is no substantial magnetosphere to shield the martian atmosphere from the "wind" of charged particles streaming out from the Sun. Thus, the solar wind directly encounters Mars' atmosphere. By sending a probe to study the upper atmosphere of Mars, we will be able to learn about the mechanism of this atmosphere–solar wind interaction, which in turn will help us understand the dynamics and structure of its terrestrial counterpart.

Planet-B's orbit will bring it as close as 150 kilometers (about 90 miles) from the surface, an ideal position for its mission. Its onboard camera will provide information on global meteorological conditions near the surface. Designed to operate for at least one martian year (about two Earth years), it will relay its findings to Earth, giving us data on Mars' magnetic field, the composition and motion of the upper atmosphere, the surface temperature and the interaction with the solar wind, along with images of the martian surface and dust storms.

Anticipating Future Enterprises

The missions that will follow *Planet-B* have not yet been officially approved. We are studying several, and a Venus balloon, a comet coma sample return, an asteroid rendezvous, a Mars penetrator and a Mars minirover are all possibilities. We are also interested in participating in international projects, such as the Mars Environmental Survey Mission (MESUR) proposed by NASA. Since all these missions could significantly advance science, we hope that they will be undertaken during this decade and the next.

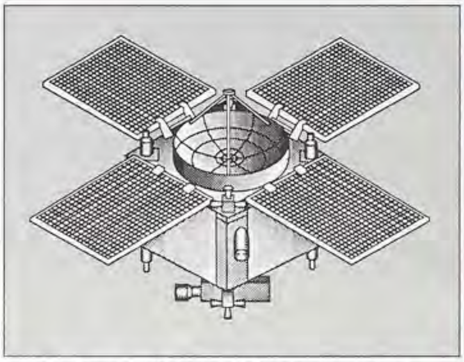
Hitoshi Mizutani is a professor of planetary science at the Institute of Space and Astronautical Science. He is the project scientist for the Lunar-A *mission.*

Small Missions to Asteroids: The

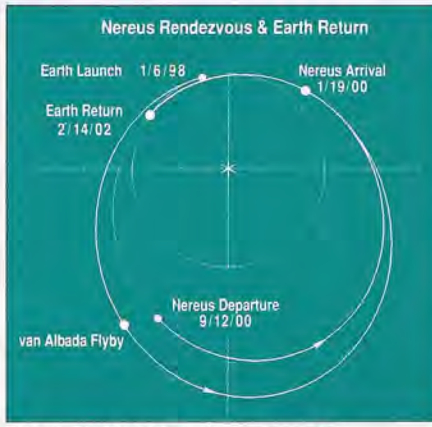
by Michael J.S. Belton

Asteroids are extremely hard to observe from Earth. In fact, we can only discover their existence when they appear as streaks against a background of pinpoint-like stars. This is the discovery photograph of asteroid 1992KD, found by Eleanor "Glo" Helin and Ken Lawrence on May 27, 1992. It is only one of the most recent in a string of discoveries in the Planet-Crossing Asteroid Survey supported by The Planetary Society.

Photograph of 1992KD courtesy of Eleanor Helin



The Near-Earth Asteroid Rendezvous spacecraft will be a small but capable vehicle. It will be powered by a solar array that can deliver 300 watts of power at twice Earth's distance from the Sun. It will carry a camera to provide detailed images of an asteroid and other instruments to determine the composition of surface materials. *Drawings: Applied Physics Laboratory of Johns Hopkins University*



Should the NEAR mission proposed by NASA be funded by Congress, it could take this path to rendezvous with the asteroid Nereus. With a little luck, after completing its primary mission the spacecraft might also be able to fly by the asteroid van Albada.

Under a banner headline that screams "Killer Asteroid Dooms Earth," the journalist reports on a deep split in the scientific community on what to do about asteroids that might one day strike Earth. The Stargazers want to step up efforts to find and study the asteroids that pass through Earth's neighborhood, whereas the Star Warriors want to intercept and prepare to divert asteroids from dangerous orbits. With scientists unable to reach consensus, what can be done?

Not to worry. The world has finally discovered that the solar system harbors objects that directly affect people's lives and security. Unpredictable objects, perhaps 100 meters (about 300 feet) in diameter, capable of disrupting a nation's fragile infrastructure, interrupting the productivity of agricultural lands, raising a tsunami or even wiping out a community—this is serious stuff. Why, it could affect me, my family, my granddaughter! The Threat has finally been defined. Now, what can be done about it? How do I buy insurance?

The answers to these questions are, like the problem, enormously complex. To characterize the potential impactors, an in-depth reconnaissance from space is essential. When a possible impactor is identified, we need to make an intelligent response. In some cases we may choose to do nothing, whereas in others we may want to fragment the impactor. In still others, our only option may be to deflect the object toward a less significant impact zone.

The objects in question, which we call near-Earth objects (NEOs), follow orbits about the Sun that periodically bring them close to our planet. Such an object might have the strength and density of a metallic asteroid at one extreme, and the friability and porosity of a dormant comet at the other. From the ground it is hard to tell, for at present there is no easy telescopic way to be sure of the bulk composition, structural integrity or mass of an object that appears only as a point of light in the most powerful telescopes. We urgently need to calibrate our Earth-based observations with measurements taken in space. A well-conceived program of small space missions can provide the basis for rational choices when The Threat materializes.

What Kind of Program Do We Need?

Small missions that are low in cost are the logical choice, since we need lots of them. Of the hundreds of NEOs, there are a dozen or so classes we need to characterize. A hundred missions would be fine, one would be ridiculous, ten to twenty could suffice. It is affordable and prudent to mount a program that consists of a launch once every one or two years and a total cost per mission between $50 million and $100 million, including the launch vehicle and flight operations. By comparison with current projects these would be exceptionally low cost missions, and their implementation would present an enormous challenge to today's NASA and the aerospace industry.

Why Small Missions Are Workable

One key to the feasibility of low-cost small missions is an inexpensive launch vehicle that has just enough performance and accuracy to deliver a 10-kilogram (22-pound) payload to the target. The *Pegasus*, recently flown by NASA and the Air Force, provides this. With an off-the-shelf solid rocket upper stage, *Pegasus* can deliver a 50-kilogram (110-pound) spacecraft to a wide selection of NEOs in less than a year of flight time for about $10 million to $20 million.

The other essential ingredient for a

Threat and Future Exploration

low-cost mission is organizational: It must have highly focused objectives and be managed, developed and flown by a small principal investigator team with the authority for the entire mission budget committed up front. (This differs from the current way of doing business, with mission management spread out among NASA centers and funding provided on a year-to-year basis.)

Alan Delamere of Ball Aerospace and I have found that there are people in the aerospace industry who already have wide experience with small spacecraft and instrument designs that make 50-kilogram systems feasible. Several spacecraft configurations are currently possible in the $30 million to $40 million range.

Two Possible Mission Formats

Let's speculate on what a mission to an NEO would look like. On January 12, 1999, a *Pegasus* with a small spacecraft is dropped from the wing of an L-1011 and launched toward the object 2201 Oljato.

Six months later, the spacecraft arrives at its target. The payload, a compact, high-resolution near-infrared and visible light camera, locks onto the target. The onboard microprocessors sequence the encounter, and the data are compressed and stored in a massive solid-state memory. A few months later, when conditions are optimal, the data are dumped through NASA's Deep Space Network, a system of sensitive receiving stations.

Oljato has become a known object. Its surface topography and chemistry are mapped and the evidence for the processes that shaped its evolution becomes available for analysis.

Perhaps the mission would take another form. On launch day, two spacecraft streak toward Oljato. One is a derivative of the SDI "Brilliant Pebble" concept of tiny but "smart" spacecraft. The other carries a miniaturized mass-spectrometer payload designed to identify the chemical components of a comet. At Oljato, the Brilliant Pebble learns how to do what it may be called on to do when Earth is threatened by an impact: It intercepts, and hits, Oljato.

A cloud of gas and dust from several hundred kilograms of material is vaporized (Oljato itself barely notices the impact) and moves out into the surrounding space. Some 30 minutes later it is sampled and analyzed by the instruments on the companion NASA spacecraft. Images of the object's surface taken by the camera on the Brilliant Pebble as it descended are transmitted back to the NASA spacecraft.

What We Stand to Gain

There are many other benefits to society that would come with such a reconnaissance program. Frequent launches will obviously provide frequent access to space, speeding up solar system exploration and promoting technical innovation and creativity. The short mission times and the principal investigator team management concept will provide a structure within which a flow of young scientists and engineers can gain experience.

Moreover, the knowledge returned will provide the basis for using NEOs as space resources in the human exploration of the solar system. If 2201 Oljato is a dead comet, as some have proposed, it becomes an accessible, and almost inexhaustible, reservoir of water and other volatile materials. Tony Zuppero and others have pointed out that such a gold mine in near-Earth space would be an inexpensive source of rocket propellant (steam rockets!) and, possibly, food and construction materials for humans to use in space.

Why haven't we flown such small missions before? Part of the answer is that the technology simply was not there before the microelectronics revolution of the last decade or the demonstration of the *Pegasus* launch concept. The other part of the answer is less flattering. Until now, small missions were simply unthinkable. It is time to change the way we've been operating for the past two decades. Small can be beautiful. And extremely worthwhile.

Michael J.S. Belton is team leader of the imaging experiment on the Galileo *project to Jupiter and an astronomer at the National Optical Astronomy Observatories.*

Visit to a Nearby Asteroid

The first asteroid mission to be considered under NASA's new Discovery program, the Near-Earth Asteroid Rendezvous (NEAR), has just been awarded to the Applied Physics Laboratory of Johns Hopkins University. If Congress approves the plans for this mission, a spacecraft could reach the asteroid Nereus by January 2000.

NEAR is one of two missions being proposed for the Discovery program, a new approach to planetary exploration that would cap mission costs at $150 million each. The other proposed mission is the MESUR Pathfinder to Mars. (See box, page 11.)

NEAR's target, Nereus, follows an orbit that closely approaches that of Earth, making it an easy target for a spacecraft. Mission planners are considering two possible scenarios for NEAR: In one, the spacecraft would spend a year flying alongside the asteroid; in the other, it would orbit it.

This asteroid is an old friend of Planetary Society members. It was discovered in February 1982 by Eleanor "Glo" Helin during the Planet-Crossing Asteroid Survey. As the first asteroid found after the Society began supporting this program, 1982DB (to use its discovery designation) held a special place in our hearts. When it was recovered in September 1990 by Malcolm Hartley of the Anglo-Australian Observatory and Rob McNaught of the University of Adelaide, the asteroid became eligible for a name. (See the January/February 1991 *Planetary Report.*)

To thank our members for their support, Glo asked them to help her name 1982DB. We received hundreds of suggestions, and from them Glo chose "Nereus," after a benevolent sea god with the power of prophecy.

NASA will propose the NEAR mission to Congress in its budget for 1994. How Congress reacts to the Discovery program of low-cost missions may determine the path of planetary exploration for the next decade and possibly beyond. —*Charlene M. Anderson*

ISAAC ASIMOV

Isaac Asimov in 1974.
Photograph by AP Wide World Photos

BY CARL SAGAN

Isaac Asimov, one of the great explainers of the age, died in New York City on April 6, 1992, at age 72.

He was a member of The Planetary Society's Board of Advisors from the beginning. He lectured to our members, participated in our functions and sent out membership solicitations on our behalf. Through his writings he helped generate an intellectual climate that permitted the exploration of the solar system and did much to communicate the wonders of the planets. He was a true friend of The Planetary Society, and we shall miss him.

He was born in Russia, just after the Revolution, of Jewish parents (although he speculated that the name might be Islamic, meaning "son of Hassim," and have Uzbek roots). Emigrating to Brooklyn, New York, at age three, his early life revolved around his father's candy store, where from the magazines on the shelves he taught himself to read and first encountered science fiction. He received a PhD in chemistry at Columbia University, became professor of biochemistry at Boston University School of Medicine, and was coauthor of the text *Biochemistry and Human Metabolism*. But he became world famous for his work in science fiction and the popularization of science.

Like T.H. Huxley, Asimov was motivated by profoundly democratic impulses to communicate science to the public. "Science is too important," he said, paraphrasing Clemenceau, "to be left to the scientists." It will never be known how many practicing scientists today, in how many countries, owe their initial inspiration to a book, article, or short story by Isaac Asimov—nor how many ordinary citizens are sympathetic to the scientific enterprise from the same cause. For example, Marvin Minsky of the Massachusetts Institute of Technology, one of the pioneers of artificial intelligence (and a Society advisor), was brought to his subject by Asimov's robot stories (initially conceived to illustrate human/robot partnerships and to counter the prevailing notion, going back to *Frankenstein*, of robots as necessarily malign). At a time when science fiction was mainly devoted to action and adventure, Asimov introduced puzzle-solving schemes that taught science and thinking along the way.

A number of his phrases and ideas have insinuated themselves into the culture of science—for example, his spare description of the solar system as "four planets plus debris," or his notion of one day carrying icebergs from the rings of Saturn to the arid wastelands of Mars. He wrote many science books for young people, and as editor of his own science fiction magazine he made efforts to encourage young writers.

His output was prodigious, approaching 500 volumes, always in his characteristic straightforward, plainspoken syntax. The Science Fiction Writers of America voted his "Nightfall" the best science fiction short story of "all time." He was a recipient of prizes from the American Chemical Society and the American Association for the Advancement of Science, and of more than a dozen honorary degrees from American colleges and universities. His interests were not restricted to science, and his books ranged broadly—including two-volume guides to Shakespeare and the Bible, and a thick commentary on Byron's *Don Juan*. Part of the reason his *Foundation* series on the decline of a galactic empire worked so well is that it was based on a close reading of Gibbon's *Decline and Fall of the Roman Empire*: A principal theme was the effort to keep science alive as the Dark Ages rolled in.

Asimov spoke out in favor of science and reason and against pseudoscience and superstition. He was a Founding Fellow of the Committee for Scientific Investigation of Claims of the Paranormal, and President of the American Humanist Association. He was not afraid to criticize the United States government and was deeply committed to stabilizing world population growth.

The microscopic probe he described in his novel *Fantastic Voyage*—which could enter the human bloodstream and repair tissue damage—was unfortunately not yet available at the time of his death. As someone born in grinding poverty, and with a lifelong passion to write and explain, Asimov by his own standards led a successful and happy life. In one of his last books he wrote that "my life has just about run its course and I don't really expect to live much longer." However, he went on, his love for his wife, psychiatrist Janet Jeppson, and hers for him, sustained him. "It's been a good life, and I am satisfied with it. So please don't worry about me."

I don't. Instead, I worry about the rest of us, with no Isaac Asimov around to inspire the young to learning and to science.

Carl Sagan is Professor of Astronomy and Space Sciences and Director of the Laboratory for Planetary Studies at Cornell University.

World Watch

by Louis D. Friedman

WASHINGTON, DC—During their June 1992 summit meeting, George Bush and Boris Yeltsin reached an agreement for their nations to cooperate in exploring space. In 1993, cosmonauts will fly on the space shuttle and astronauts will fly on *Mir*, according to the new plan. Then, in 1994 or 1995, a shuttle will dock with *Mir* and the nations will together conduct medical experiments to prepare for human spaceflight.

As exciting as these prospects are, another agreement of special interest to Planetary Society members was made: The United States is considering the purchase of one of the small stations that will land on Mars during the Russian *Mars '94* mission.

This purchase, for hard currency, will help stabilize the financial status of the *Mars '94* and *'96* missions. The Mars Balloon and Mars Rover, in which the Society is closely involved, are set for launch on *Mars '96*. The US involvement will help ensure that this mission stays on schedule.

The Society played an active role in fostering this opportunity for the two spacefaring nations to work together. Each of the Society's officers met with Daniel Goldin, the new NASA Administrator. In early May, our President, Carl Sagan, urged cooperation with the Russians in space.

In late May, at the conclusion of our Mars Rover tests, Goldin visited us in Pasadena and was impressed with the capability of the Russian team. He asked Society Vice President Bruce Murray about the possibility of working with the Russians on their Mars missions. Murray suggested that the Russians were well along in the development of the small lander stations and might be willing to include NASA experiments on one during the *Mars '94* mission.

Goldin then directed NASA engineers and planners to consider the idea. The timing fit well with the scheduled summit, and now a small NASA station on the *Mars '94* mission may be equipped to fly with US instruments.

This small lander could give NASA a jump start in its planning for the Space Exploration Initiative (SEI) and could boost its Mars exploration program—specifically, the planned Mars Environmental Survey (MESUR) mission. The ultimate goal of SEI is to land humans on the martian surface.

The director general of the newly formed Russian Space Agency, Yuri Koptev, and Goldin also signed a $1 million contract covering the study of the *Soyuz* spacecraft as a crew-return vehicle for the US space station, an automated rendezvous and docking system, and life science experiments aboard *Mir*.

This summit marks a turning point in Russian-American cooperation in space. There is now a formal framework for the joint ventures The Planetary Society has been advocating for so long. Every one of us in the Society can take pride in our efforts to move our vision of the international exploration of Mars closer to reality.

WASHINGTON, DC—NASA's budget for fiscal year 1993 is still tangled in the congressional budget process. As I write this, the authorization committees in both the House of Representatives and the Senate have acted, as has the House Appropriations Committee. The mission of greatest concern to Planetary Society members, *Cassini* to Saturn and Titan, has survived. We are hopeful that the full Congress, when it finally acts, will support the project.

In a bold move, NASA and JPL took the initiative and reduced the cost and complexity of the *Cassini* mission before Congress acted on the budget. This action saved over $200 million and was well received by the legislators. The cutbacks reduced the spacecraft's operational flexibility and affected some planned science operations, but the number and scope of the experiments were not affected.

The grass-roots support demonstrated by Planetary Society members also helped *Cassini* through Congress. One congressional staffer told us that they received more mail about *Cassini* in a week than they usually receive about all space matters in a year. Our campaign was effective, so let's keep on demonstrating that there is popular support for planetary exploration.

WASHINGTON, DC—While *Cassini* survived the congressional budget process, two small, innovative missions to the Moon proposed by NASA's Office of Exploration were "zeroed out" of the budget. The office had proposed a small lunar orbiter and a lander as precursors to a human landing.

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

NASA SETI Endangered Again

As we go to press, NASA's program in the Search for Extraterrestrial Intelligence (SETI) is once again in doubt. The project is ready to begin on October 12, but the US Congress has refused to authorize it for NASA's fiscal year 1993 budget, which begins October 1, 1992.

Congress votes twice on funds for federal projects, once to authorize the money to be spent, and once to appropriate funds for a project.

The House Appropriations Committee voted against SETI, while the Senate committee has not yet acted. The SETI program's chances now lie with the Senate Appropriations Committee.

The Society's officers have strongly supported NASA's SETI program during this latest attack. If you wish to express your support for NASA SETI, you should write to:

Sen. Barbara Mikulski, Chair
Senate Committee on
Appropriations
Subcommittee on VA, HUD and
Independent Agencies
Washington, DC 20510

News & Reviews

by Clark R. Chapman

Even as society faces global warming, gene splicing and computerized appliances, the public is increasingly illiterate when it comes to science. Blame it on the mass media or the educational crisis. It need not be that way, for science is truly a *human* activity shaped by the aspirations of real people, capitalizing on personal strengths like creativity and passion to excel, and affected by all-too-human foibles.

Comet Hunting

Comet hunter David Levy adeptly describes the human drama of science in the June issue of *Smithsonian*. He shares the joys of both amateur and professional research and reminds us of the historical context of modern astronomy. Levy is a leading comet discoverer of our time, indeed of all time. Both at home in Arizona and on Palomar Mountain with Eugene and Carolyn Shoemaker, comet discovery is Levy's passion. He is gifted at sharing his enthusiasm for astronomy with laypersons, both in "public night" lectures at the local observatory and in articles in magazines like *Smithsonian*.

According to Levy, one comet hunter valued these denizens of the outer reaches of the solar system more than he valued his wife. Others sought comets in order to pay the rent. For Levy, comet-hunting is a sporting event, a race against competitors in Massachusetts and Japan to sweep the skies as the Moon with its comet-hiding glare moves, night by night, out of the way. Levy's most poignant story about his pastime involves its role in prolonging his parental connections while his father, who had Alzheimer's disease, was dying.

David Levy's discoveries occasionally benefit science, as when he and the Shoemakers independently discovered two different—but physically related—comets, defining an event some 13,000 years ago when a parent comet split in two. More often than not, someone else would have discovered Levy's comets had he chosen to watch television instead of searching the skies for hundreds of hours between successes. Exceptional rewards emerging from the tedium of hard work mark the lives of scientists, and of us all.

Human Explorers or Robots?

What of the future? Individual scientists like Levy are becoming rare, as large scientific teams increasingly command expensive technological facilities. More and more tasks are being done by automated, computer-aided techniques. The robotic exploration of the solar system is one of the most technologically sophisticated endeavors ever. Can there be a role for human beings? Assumptions underlying NASA's planetary exploration program are now being reexamined, including the long-standing controversy about whether space exploration should be conducted by human or robotic explorers.

One might expect, in the face of declining planetary exploration budgets and recent successes in robotics and artificial intelligence, that the ever-cheaper machines would be the way to go in the 21st century. Not so, according to planetary geologist Paul Spudis, writing in the May/June issue of Sigma Xi's magazine, *American Scientist*. Although he finally calls for a rational mix of both robotic and human explorers, he maintains that human beings are necessary to conduct research on planetary surfaces, to install and repair equipment and to engage in the intelligent, interactive interpretation of landscapes that has traditionally been the forte of the field geologist. His context is President Bush's Space Exploration Initiative (SEI). Despite a ho-hum reaction from much of the public and Congress, SEI remains NASA's official goal. Spudis believes that returning astronauts to the Moon and then sending them on to Mars within three decades would not only be high adventure but would be good—indeed essential—for science as well.

Spudis' case is one well worth reading. He recounts some well-known successes of astronauts and recent disappointments in getting robots to duplicate some human capabilities. But his argument fails. It will always cost vastly more to keep human beings alive while they are on an interplanetary expedition, even more so as our society becomes ever more averse to subjecting astronauts to high risks.

Spudis mentions a difference in cost of a factor of 10 or 20. One could make up for many past instrument failures by using the savings to build them so they don't need to be adjusted or fixed, or to send a second if the first should fail. And lots of human intelligence can be employed while people sit comfortably back on Earth in Mission Control.

Apollo astronauts had few precious minutes to use their brains for the creative interactive thinking that Spudis touts. In any cost-constrained future program, time will continue to be precious. Certainly, in the early decades of the next century, robotics and artificial intelligence—assisted by human beings back on Earth—could be much more cost-effective than astronauts in the scientific exploration of the planets.

In the end, however, Spudis is right. It won't be done that way. Indeed, it shouldn't. The involvement of human beings has always been central to science and exploration, and it will continue to be that way. Perhaps it requires high adventure to get our creative juices really flowing. Space exploration has been and will remain a human drama. Robotics will increasingly aid us as we move out into space, just as personal computers invented only 15 years ago now dominate our offices and, increasingly, our homes. But Mars will be visited by human explorers, sooner or later.

Clark R. Chapman, as a member of the Galileo *imaging team, has been studying the latest pictures of the asteroid Gaspra.*

SOCIETY *Notes*

DOUBLE YOUR MONEY

You can double your donations to The Planetary Society if you work for a company that offers a matching gift program. In such a program, the company matches an employee's gift to a nonprofit organization, in effect doubling its value.

We thank the following companies and their employees for matching donations in fiscal year 1991: American Express, Arco, Avon, Black & Decker, Boatmen's Trust, Boeing, CBIC (Contractors Bonding and Insurance Company), Citicorp, Cray Research, Digital Equipment, the Equitable Foundation, Exxon, General Dynamics, Illinois Tool Works, John Hancock Financial Services, Johnson & Johnson, the John D. and Catherine T. MacArthur Foundation, Microsoft, Monsanto, Morton International, Olin, Pfizer, Pitney Bowes, PNC Financial Corp., Power Technologies, Southern California Gas Company, TRW, US West, the Washington Post and Westinghouse.

If you work for a company that offers a matching gift program, make sure your donations are included in their program. —*Lu Coffing, Financial Manager*

JOIN THE SOCIETY AND SPACE EXPLORERS IN WASHINGTON

There's still time to make plans to join The Planetary Society and the world astronaut organization, the Association of Space Explorers (ASE) at an exciting public event that will take place in Washington, DC, on August 28, during the annual ASE convention.

The event will honor the 20 winners in the Society's H. Dudley Wright International Student Contest. Society President Carl Sagan and Vice President Bruce Murray will be there to congratulate the winners personally, and Dr. Sagan will talk on "Together to Mars."

For information on tickets, write to: ASE Event, c/o The Planetary Society. —*Susan Lendroth, Manager of Events and Communications*

PLANETARY SOCIETY RECEIVES BEQUEST

Recently, The Planetary Society received the final distribution from the estate of Vernon Lynn. A lawyer from Las Vegas, Nevada, Mr. Lynn joined The Planetary Society in 1988. Before his death in 1990, Mr. Lynn expressed his support for the Society by bequeathing to us the bulk of his estate, which totaled around $120,000.

As a nonprofit organization, The Planetary Society depends on the contributions of our members; it's your generosity that enables us to continue our promotion of planetary exploration. We are grateful for Mr. Lynn's generous bequest and support of The Planetary Society and our goals. —*Mitchell Bird, Production Editor*

THE PLANETARY SOCIETY MOURNS THOMAS O. PAINE

On May 4, 1992, Planetary Society Director Thomas O. Paine died at his home in Los Angeles. With his passing, The Planetary Society lost an inspirational director. The space exploration community lost one of its most effective leaders. And our world lost a visionary who worked tirelessly for a human future among the planets.

Tom joined the Society's Board of Directors in 1986 after decades of distinguished leadership in high technology. His career was capped by service as administrator of NASA, which he headed in 1969 during the *Apollo 11* mission, when the first humans set foot on another world.

In 1985, Tom was appointed chairman of the National Commission on Space (the Paine commission), a panel created by Congress to chart the United States' future course in space. In 1990, he served on the Advisory Committee on the Future of the US Space Program (the Augustine committee), and in 1991, on the US Space Policy Advisory Board.

Tom's achievements, influence and vision are too broad to address properly in a short obituary note. We will devote the next issue of *The Planetary Report* to his life and the future he envisioned for the human species.
—*Charlene M. Anderson, Director of Publications*

MARS ROVER PROVES ITS METTLE

The Planetary Society Mars Team has just returned from Death Valley, where for five days we tested the capabilities of the Mars Rover in some of the most forbidding terrain on Earth.

The little Russian-built rover performed wonderfully, satisfying scientists and engineers from Russia, France, Hungary and the US. On the rover's return from the desert, NASA Administrator Daniel Goldin stopped by for a demonstration of its capabilities.

These field tests of a prototype spacecraft would not have been possible without the help of the Planetary Society volunteers who donated time and equipment to the project.

The Mars Team was joined in the field by 100 hardy members, who traveled to Death Valley to share the excitement of preparing for Mars.

With the fieldwork completed, the task of analyzing the collected data will now begin. We will report the test results in detail in the November/December issue of *The Planetary Report*. —*CMA*

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A Planetary Readers' Service

You have already demonstrated, as a member of The Planetary Society, your special interest in the exploration of the solar system and the search for extraterrestrial life. By reading The Planetary Report, *you've shown that you want to learn more about the science and adventure of our voyages to other worlds. So, to serve you better, we are instituting a new feature in this magazine: A Planetary Readers' Service.*

With this service, we will alert our readers to new and notable books about the planets and the people who study them, and we will make these books available at the lowest possible prices. Each title will be offered for six months, or three issues of The Planetary Report. *We will keep rotating our stock so that the titles we offer are always fresh.*

When other publications are decreasing their column inches devoted to science while their editorials decry scientific illiteracy, The Planetary Society has decided to buck the trend. We will offer our members even more to read, and give you the chance to learn more about the worlds around us.

Isaac Asimov's Guide to Earth and Space

By Isaac Asimov; Random House, New York, 1991, 285 pages.

Price for Planetary Society members: $17.95, plus $2.50 shipping and handling charge for the United States, Canada and Mexico, $5.00 for other countries.

Isaac Asimov is gone now, leaving a legacy of close to 500 books about science fact as well as science fiction. In this *Guide to Earth and Space*, Asimov demonstrates that science begins by asking the right questions.

Asimov's Guide consists of answers to 111 of these especially well focused questions, such as, What makes the wind blow? Is there life on the Moon? What is SETI? Asimov's replies reveal an encyclopedic familiarity with the history, language and logic of science. In a tone equally appropriate for a wise child or a weary scientist, he moves from everyday observations to scientific theory.

He uses Columbus' voyages, for example, to explain the wind. It seems that as Columbus set out, he picked up winds blowing steadily from the east that carried him swiftly across the Atlantic. And when he was ready to return, he sailed north where he found complementary winds blowing from the west. Asimov tells us that the winds from the east were later named the trade winds, because they helped merchants move their goods to distant markets. So far, so good. These winds seemed predictable. The deployment of weather satellites in our own time once held the promise that all weather could be foretold. But that's not what happened. At this point, Asimov transforms this simple narrative of early transatlantic travel into a short message about chaos theory. The complexity of the weather characterizes a "deficiency in science and a limitation of human knowledge," which, Asimov suggests, we may be better off simply acknowledging.

As he moves from question to answer, Asimov often traces the historical development of an idea, and sometimes he walks his reader through a practical solution. Take the question of the size and shape of Earth. We learn that in about 240 BC the Greeks, who traded by sea, watched the sails on their ships disappear beyond the horizon and suspected that Earth was a sphere. To measure its curvature then, the philosopher Eratosthenes (who was familiar with the newly invented branch of mathematics known as trigonometry) erected two rods miles apart, one in the city of Syene, and one in Alexandria on the 21st of June, the spring solstice. He then compared the slight differences in the angles of the shadows they cast, and from this he estimated that Earth at the equator is 8,000 miles in diameter.

Eratosthenes reached this correct answer without elaborate instruments or computers. Simple logic works, Asimov reminds us, but it works better when it has better tools.

As Asimov spins exotic theories using mundane facts, he drops such nuggets as the derivation of familiar words. From the Greek comes the word *magnet*, from the city of Magnesia where Thales, in 550 BC, noted the attractive powers of lodestone toward iron. And *spectrum*, Newton's reference to the way white light passing through a prism has a ghostly look, comes from the Latin for "ghost."

The spectrum leads Asimov to the spectral analysis of the elements, their "fingerprints" in light, and to the observation made early in this century that the spectral "fingerprints" of carbon dioxide were detectable on Venus and Mars. This put to rest Aristotle's contention that Earth is fundamentally different from the rest of the universe.

On the contrary, Asimov reminds us, all of Earth and space is made up of the same fundamental particles. With a nod to SETI, the Search for Extraterrestrial Intelligence (and perhaps an aside to Aristotle), Asimov dismisses the possibility of there being anything more than bacterial life on Mars and holds out little hope for finding life elsewhere in the solar system. Human intelligence may be unique. But if another intelligence should pay us a call, it could do worse than familiarize itself with Earth's history and place in space by reading the words of Isaac Asimov.

—Reviewed by Bettyann Kevles

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Questions & Answers

Why can't we use an antenna on a spaceship to receive maser or laser waves beamed from Earth or the Moon, and convert these to electric power for spacecraft propulsion?
—T.M. Morse, Mooresville, North Carolina

Beamed power using Earth-based lasers may be an innovative, cost-effective way to provide large amounts of electrical energy to reduce space transportation costs, power large satellites and develop a lunar base.

Current minimum transportation costs are at least $30,000 to lift 1 pound from Earth to geosynchronous orbit and $39,000 per pound from Earth to the Moon. Not only might beamed power for high-thrust electric propulsion greatly reduce these costs, it could lower the amount of mass (in the form of fuel) that must be transported to the Moon for a lunar base. Power beamed to the Moon could also provide a lower-cost source of electricity for initial lunar base development.

Because of these possibilities, NASA has been pursuing research on new lasers and optics with the objective of maturing efficient and reliable new technologies and lowering their costs for future NASA missions.

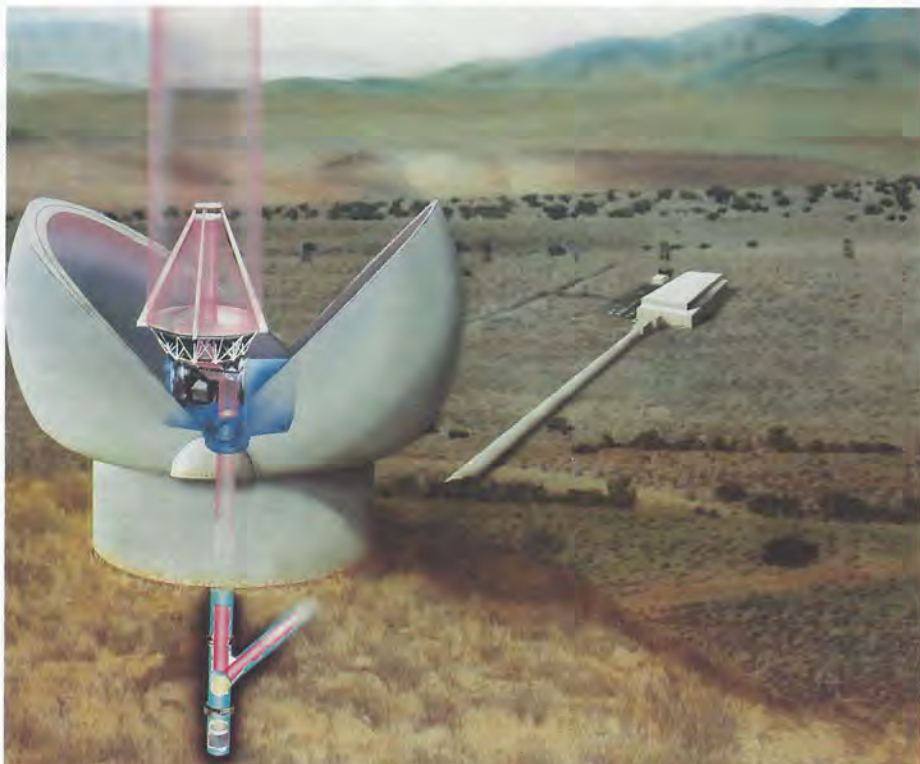
If large-scale space power beaming is ever to happen, it must beat the competing energy options. It must be so economically and environmentally attractive that the key users and aerospace technology producers will support it and lobby for it. This is not to say that the government cannot take a leading role, but for this kind of catalysis to occur, there must be a ground swell of grass-roots support to stimulate the government.

For monumental space technology projects like power beaming from space to become feasible, the entire space program must be expanded by many orders of magnitude. Space transportation costs must be greatly reduced. This would require fundamental changes in national and international attitudes toward the use of space. The potential for such changes is driven by economic, environmental, political and social factors much more than by questions of technical feasibility.
—JOHN D.G. RATHER, *NASA Headquarters*

What would our climate be like if Earth were not rotating?
—Mario Labrecque, Saint Gervais, Quebec

Our climate would be *very* different! If Earth were not rotating at all, we would have six-month days and six-month nights! If Earth rotated once per revolution (that is, once a year) as does the Moon around Earth, we would have eternal day in one hemisphere and eternal night in the other. The nightside might be one big glacier, and huge winds might circulate between the dayside and the nightside, as they do on slowly rotating Venus.

What the weather would be like under those conditions is hard to imagine, but it surely would not be pleasant.
—JAMES D. BURKE, *Technical Editor*



One space power-beaming project envisioned by NASA is called SELENE (for Space Laser Energy). In this artist's conception, a laser transmits 10 megawatts of power into space via a 10-meter telescope, which could correct for atmospheric disturbances.
Painting: NASA

Sand, Surf and Sun—

Note: All items listed in our 1991 catalogue or in previous issues of* The Planetary Report *are still available. To order, simply refer to previous listings to obtain order numbers, and include on the order form.

Mission to the Planets
By Patrick Moore. The well-known astronomer and BBC commentator relates what we've learned so far from humankind's exploration of the solar system. 128 pages (soft cover). 3 lb. **#136 $22.50**

Pathways to the Universe
By Sir Francis Graham-Smith and Sir Bernard Lovell. Learn how to find your way around the sky using binoculars, telescopes or the naked eye. Explore the frontiers of modern astronomical research and read a fascinating account of the origin of life. 238 pages.
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By *Apollo 11* astronaut and member of The Planetary Society Board of Directors Michael Collins. A concise and timely survey of the United States space program and a daring vision of our future in space. 307 pages.
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Now that you're dressed for action and ready to hit the beach, you'll need a way to carry your supplies. What better way than in a Planetary Society tote bag? Our durable canvas tote celebrates Earth with a photograph of the planet from low orbit, contrasting our atmosphere against a black sky. Once you've arrived, stretch out and catch some rays while you relax with a copy of *Beyond the Blue Horizon*, by E.C. Krupp. This is an extraordinary collection of folktales and myths relating to the cosmos, tracing humankind's fascination with the sky from ancient sacrifices up to today's spaceflights. 387 pages.

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Enjoy a Summer Among the Planets!

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Mars Team T-Shirt	1 lb.	**#630**	**$14.00**
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Dive Europa T-Shirt	1 lb.	**#568**	**$14.00**
Ski Mars T-Shirt	1 lb.	**#553**	**$14.00**

This spring, The Planetary Society's Mars Team of scientists, engineers and volunteers from Russia, France, Hungary and the United States tested the capabilities of the Russian-built Mars Rover, which will be an integral part of the *Mars '96* mission. Now you can show your support for this important project with the Society's newest T-shirt. Our 100% cotton T-shirt depicts the rover on a Mars-like terrain and lists The Planetary Society's name in English, French and Russian. Available in sizes S, M, L, XL. If T-shirts aren't quite your style, we also offer a smaller version of the design on a brightly colored button or sticker.

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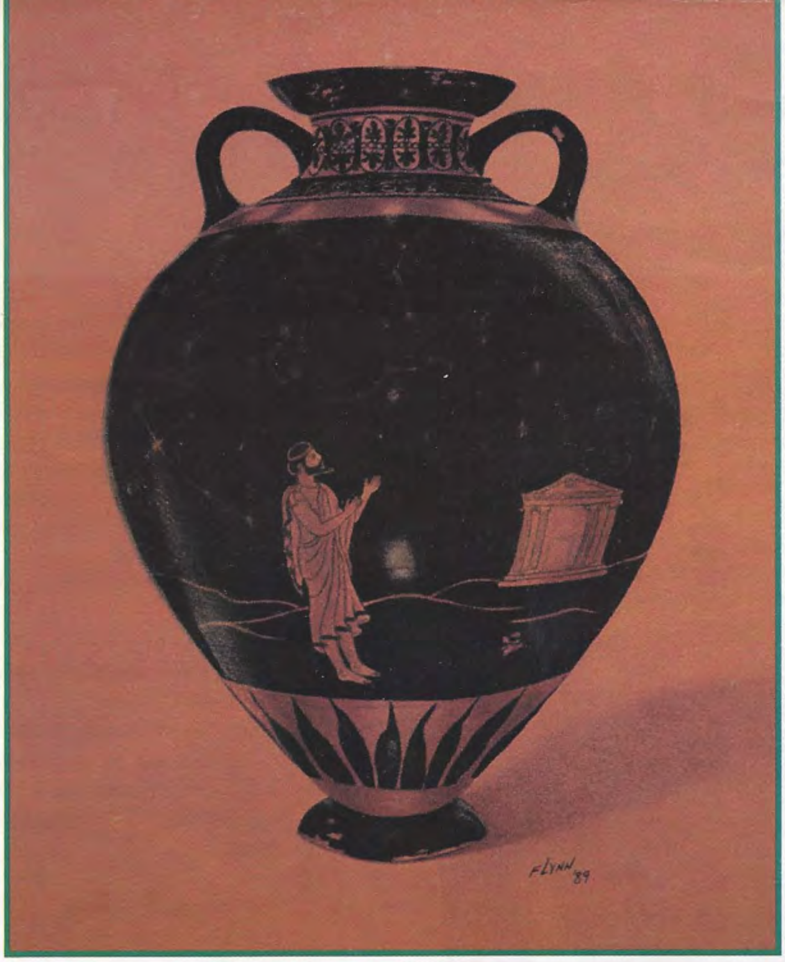

HIPPARCHUS VASE—
Perhaps the greatest astronomer of antiquity was the Greek Hipparchus, who lived during the 2nd century B.C. His contributions to astronomy were many: He discovered the precession of the equinoxes, the slight wobble of Earth as it spins on its axis. He estimated the distance from Earth to the Moon as 29 1/2 Earth diameters; the correct value is 30. His method of classifying stars by their relative brightnesses, or magnitudes, has been used throughout the centuries.

This drawing depicts a vase in the ancient Greek style, adorned with a figure of Hipparchus studying the heavens.

Marilynn Flynn lives in Abu Dhabi, United Arab Emirates, and is producing watercolors of the local desert landscapes that she'll then translate into paintings of Mars. Her work will be on display at the Cleveland Museum of Natural History this fall.

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