The PLANETARY REPORT

Volume XVI Number 2 March/April 1996

Project BETA: The Search Begins

On the Cover:

The Andromeda galaxy is the nearest spiral galaxy to our own, the Milky Way. Only 2.2 million light-years away, it graphically demonstrates the immensity of galaxies, and feeds our wondering if other planets exist on which a technical civilization exists. The various searches being conducted from Earth mostly concentrate on detecting radio signals from another civilization within the Milky Way. The Planetary Society's Project BETA, now on-line, is able to search a quarter-billion channels at once, making it the most powerful continuing SETI program on Earth.

Photo: Tony Hallas

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From The Editor

In putting together the pages of a science magazine, it's sometimes hard to convey that science is a human activity—complete with joy, fear, excitement and all the other emotions—and not a characterless march toward the physical truth of the universe. People "do" science, each individual investigating the universe in an idiosyncratic way, and each with a unique story to tell.

In *The Planetary Report*, we try to bring you scientists and engineers telling their own stories, but often, I'm afraid, they aren't able to fully convey the human side of their work. Trained by tradition to make science appear to be an activity carried out in complete objectivity (even if the appearance belies the reality), they find it hard to let the readers inside science.

In this issue, we are lucky enough to have writers able to overcome the tradition. You'll read of the celebration of switching on a powerful new piece of equipment, the frustration and hope of dealing with politicians, and the fun and fears engendered by a field trip. Plus, we have all our regular features and reports on Society activities. Let me know if you find this issue as great a read as I do.

—Charlene M. Anderson

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Members' Dialogue

Space Spending

I think that Robert Reimer (see the November/December 1995 issue of *The Planetary Report*) is right to draw attention to the social questions raised by government spending on space, but I also think he misses one of the most important social justifications for a major space program in the post-Cold War world. While he notes that "the huge reduction in military spending has ruined the careers of many aerospace workers," he fails to draw the obvious conclusion that an expanded space program would provide a socially desirable alternative for the aerospace industry.

The financing of space and military projects is similar. In both cases, the money comes from the taxpayer, and is spent by the federal government. Moreover, it is generally spent with the same companies (such as Rockwell, Lockheed Martin and McDonnell Douglas), and on the development of similar products. It is in everyone's interest for these companies to find alternatives to the manufacture of high-tech weaponry, and a greatly expanded space program seems to be an obvious candidate.

This is a powerful argument for an ambitious space program. Moreover, unlike some other arguments for space exploration and development, it stands a real chance of influencing political opinion because it is compatible with some powerful vested interests, within both the aerospace industry itself and the United States Congress.

I urge The Planetary Society to develop this argument for turning swords into spaceships, and to bring it to the attention of a wider public.
—IAN CRAWFORD,
London, England

SETI Questions

Why is it necessary to imagine bolides extinguishing life in other star systems in order to explain the Search for Extraterrestrial Intelligence's lack of success? There has been intelligent life on Earth for uncounted millennia, and for over 99 percent of that time there has also been radio silence. We produced Socrates, Bach and Newton before we hurled a single modulated wave toward the stars. Not only has radio been around for little more than a century, but it is the child of one culture out of the thousands that have existed during human tenure on this planet.

No one expects intelligent extraterrestrial creatures to look like human beings or to live like human beings. Why should we expect them to develop radio or any sort of advanced technology? Before we build computer models of bolide-impacted star systems, perhaps we should check our own assumptions and our anthropocentric arrogance.
—R.W. MULKINS,
Olmsted Township, Ohio

Health in Space

I find it rather surprising to see the November/December 1995 issue of *The Planetary Report* devoting significant space to the subject of a future human mission to Mars without any mention of the major unsolved problem with such a mission: interplanetary radiation. While there has apparently been only a limited amount of study of the radiation environment that will be encountered by a Mars mission, it is probable that very high radiation from the Sun will be difficult to shield against and intense enough to be lethal for exposure during the time span of the mission.

I would hate to think that Alexei Leonov is advocating a suicide mission for the boys and girls he thinks will be the future astronauts, or that Dan Goldin hasn't considered that the astronauts he wants to work on Mars will have their lives dramatically shortened if this problem isn't solved.
—MORTON PANISH,
Springfield, New Jersey

Earthview

In "What Is the Value of Space Exploration?" (see the November/December 1995 issue of *The Planetary Report*), Stephen Jay Gould states that "those first photographs of our entire planet, the very notion of an Earthrise over the Moon, or the concept of a crescent Earth rising over the Moon provided a thrill which is still with me."

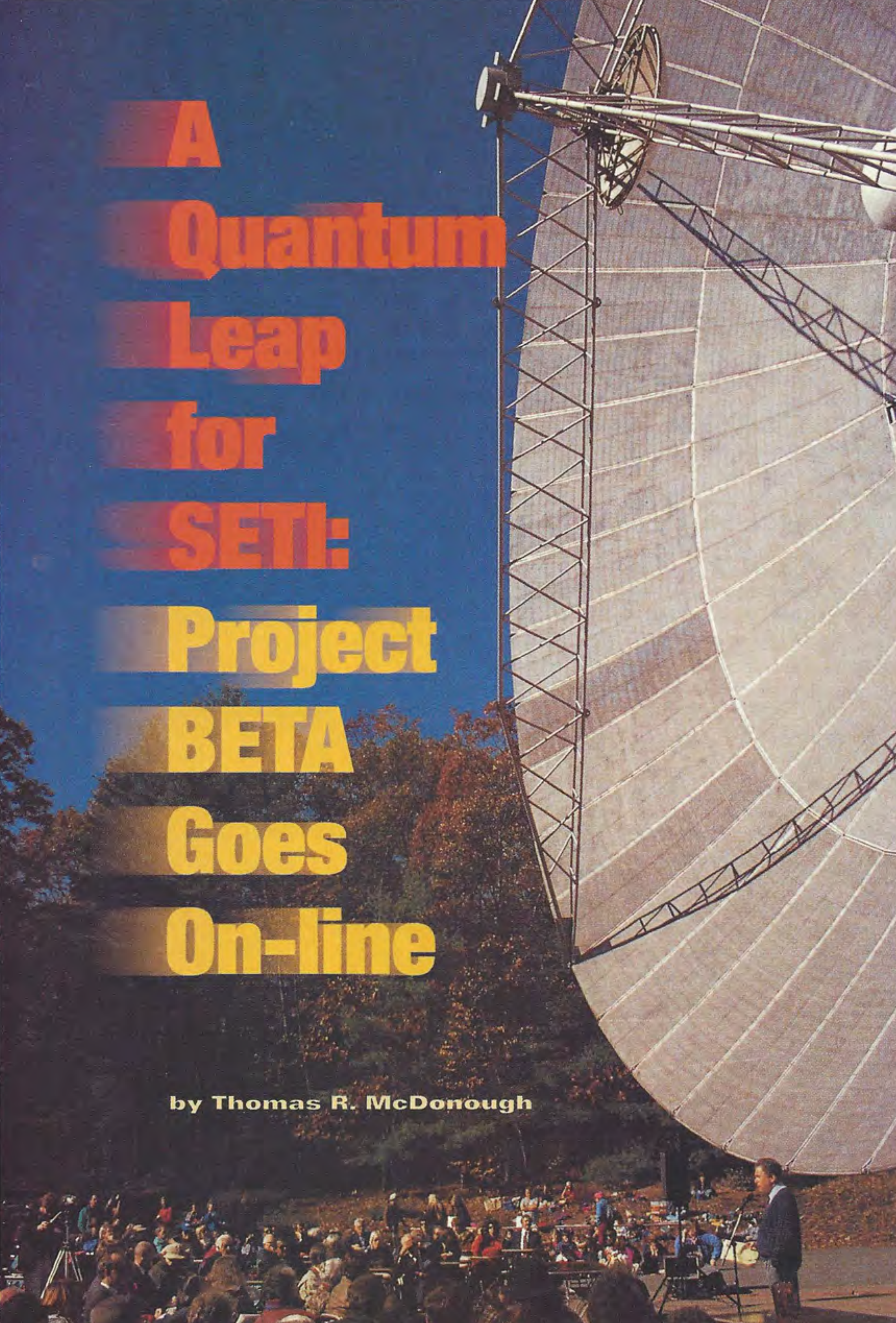
There is no Earthrise on the Moon. And no Earthset. For many millions of years our Moon has turned the same side toward Earth, and this will continue as long as Earth and the Moon exist. Thus, if you stand on the Moon, watching Earth, you will see it in a totally fixed position. And if you were to decide to live the rest of your life on the remote side of the Moon, you would never see Earth again.
—LENNART NEK,
Stockholm, Sweden

True, but if you are in an Apollo-*type orbit around the Moon, you do see Earth rising and setting. Astronauts orbiting Earth often remark on the beauty of the sunrises and sunsets that they see about every 45 minutes.*
—James D. Burke,
Technical Editor

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

A Quantum Leap for SETI: Project BETA Goes On-line

by Thomas R. McDonough



Left: Planetary Society Executive Director Louis Friedman addresses those gathered to share the historic moment when Project BETA began its search for another civilization.
Photo: Thomas R. McDonough

It was on a sunny October day in 1995 that Project BETA began searching for extraterrestrials. We were at the Harvard/Smithsonian Agassiz Station in the town of Harvard, Massachusetts, half an hour's drive from the university. Nestled in a forest of multicolored trees, the 26-meter (84-foot) radio telescope dish-antenna stared at the horizon.

Hundreds of people were there: members of the Society, scientists, journalists, TV crews and busloads of schoolchildren. They had come to see the turning on of The Planetary Society's new project in the Search for Extraterrestrial Intelligence (SETI). Representatives from two other SETI projects were also present: Frank Drake and Kent Cullers of Project Phoenix and Dan Werthimer of Project SERENDIP. It had taken 15 years of hard work to bring The Planetary Society to this point.

How We Got Here

In 1981, Harvard physicist Paul Horowitz spoke at the Ames Research Center of Mountain View, California, where NASA was building a powerful SETI system. He proposed to create a portable computerized receiver, Suitcase SETI, to search 131,000 extremely narrowband radio channels for signals from other civilizations.

NASA's SETI budget had just been killed by Congress, but The Planetary Society had formed recently. With support from the Society and NASA, Horowitz turned his paper plans into solder and silicon. He installed Suitcase SETI at the same observatory where Project BETA would begin, renaming it Project Sentinel. Then, in 1982, Congress reinstated NASA's SETI program.

The Society's next major step came in 1985. The 8-million-channel Project META (Megachannel Extraterrestrial Assay) was turned on, thanks to the $100,000 gift that Ann Druyan and Carl Sagan elicited from *E.T.* director Steven Spielberg. Later, a duplicate—META II—was built and operated by Argentine scientists with much help from Horowitz.

META has found several dozen intriguing signals. None has repeated, so interference can't be ruled out completely. But the sources—if they are really in the sky—tend to be concentrated toward the Milky Way, just as would be expected if they were galactic.

Right: Viewed from beneath, the BETA radio telescope scans the sky for signals. Radio telescopes are essentially giant metal webs designed to catch faint radio signals beamed in their direction, either from astronomical objects or, in the case of SETI programs, from artificial sources.

Above: Kevin Duesman of Micron Technology (left) and raffle winner Jim Burke (center) throw the switch initiating Project BETA, while Planetary Society Executive Director Louis Friedman (right) looks on.
Photos: Thomas R. McDonough

Inspired by the ever-increasing power of computer chips, Horowitz next conceived a radically new design that would look at a quarter of a *billion* channels. He called his dream machine BETA, for Billion-channel Extraterrestrial Assay. Instead of focusing on a small part of the radio spectrum, it would cover the entire "water hole" (1,400–1,720 megahertz), the quiet region many think is the best bet for detecting another civilization. By jumping in 40-megahertz hops, it would have the equivalent of 2 billion channels.

In 1991, the Society agreed to support BETA, which also received funds from the Bosack/Kruger Charitable Foundation and NASA. The NASA funds soon ended when Congress killed its SETI program again. Donations came in from Advanced MicroDevices, Fluke, Hewlett-Packard and Intel corporations, and from Ohio State University SETI pioneer John Kraus.

The biggest single expense for BETA was for memory chips. We needed 3 gigabytes of RAM—400 times more than a typical PC—$100,000 worth. But one day Steve Trimberger of the Silicon Valley firm Xilinx called me about the SERENDIP SETI project of the University of California at Berkeley. Xilinx wanted to donate some chips to SERENDIP, and he needed to verify that it was a legitimate project. I said it was excellent, then asked if they could give us chips, too.

Xilinx didn't make the chips we needed, but Trimberger's coworkers suggested contacting Kevin Duesman of Micron Technology in Boise, Idaho. Success! Micron was willing to donate the huge number of chips we needed.

Throwing the Switch

And so, on that beautiful fall day, Horowitz addressed the crowd: "It's hard to believe, in a universe of a hundred billion galaxies, each of which contains a hundred billion stars—that what happened here is unique. If any of you can prove that there's no advanced life in our galaxy, I'll jump off the top of the dish." They laughed.

With present radio technology, he noted, "for a dollar per word, you could send an interstellar telegram to any of the nearest million stars." BETA is "like having 250 million radios sitting on your desk—small ones—all tuned to adjacent channels, all listening at the same time."

"The consequences of detection are stupendous," Horowitz observed. "It would be entering into the galactic Internet. And it would forever change the way things happen on Earth."

He then introduced our keynote speaker, SETI pioneer Frank Drake. In 1960, Drake had conducted the first modern SETI observations, Project Ozma. Today he is president of the private SETI Institute in California, the headquarters for what had once been NASA's SETI system, now called Project Phoenix (see the May/June 1995 issue of *The Planetary Report*).

Drake revealed a secret. "Forty years ago, we held another ceremony just like this, on this very spot." They were celebrating the antenna's construction (nothing to do with SETI), and had a big knife switch wired to turn on the telescope, just like the one at Drake's side today. "But the truth was, that wire wasn't connected to *anything*."

So a graduate student hid inside the antenna's pedestal and looked through a hole. When the director of the National Science Foundation threw the switch, the student secretly pushed the real button that caused the antenna to move. And Drake confessed: "I was that graduate student."

He pointed at the wire running from the switch to the antenna and said, "I checked. That wire *is* connected." The crowd laughed and applauded.

Drake's student days at Harvard changed the course of SETI history. One night a few months later, he was at the radio telescope. "It was very cold, and the snow was about a foot deep. I was observing the Pleiades star cluster, which gives a very beautiful hydrogen spectrum. Suddenly, a new feature appeared in the spectrum.

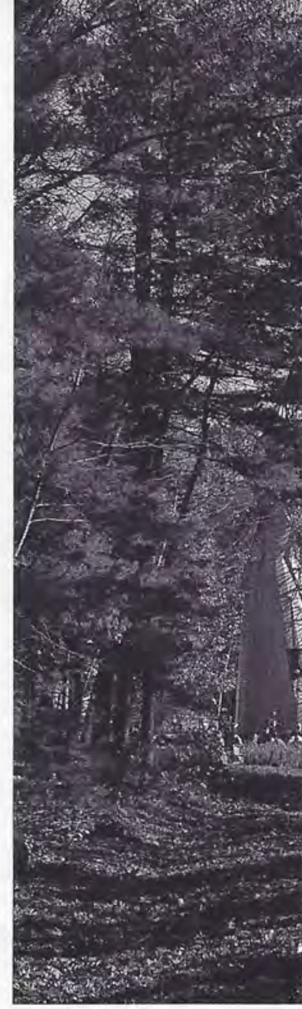
"But what really struck me, and I must say at the time gave me goose pimples, was that the frequency of that new feature was exactly the frequency you would get if the signal was being radiated from the Pleiades star cluster. And that triggered the thought which eventually led to Project Ozma:

Perhaps radio signals do come from other worlds."

Later, that inspired the famous Drake equation, which estimates the number of civilizations we might be able to detect. His signal turned out to be interference, but it made him a SETI pioneer.

The Planetary Society's Executive Director, Louis Friedman, held a drawing among members for the honor of throwing the switch that would begin BETA. The winner was Jim Burke of Newton, Massachusetts.

Kevin Duesman of Micron Technology joined Burke, and they threw the switch together. Music played and the dish rose until it was pointing to the same spot in the sky that META II in Argentina was pointing to. A quantum leap in The Planetary Society's quest for interstellar neighbors had begun.



Symposium

That night, back at Harvard University in Cambridge, Massachusetts, we held a symposium. Horowitz, Drake and Friedman were joined by Freeman Dyson of the Institute for Advanced Study in Princeton, New Jersey.

The British-born Dyson, one of the world's leading physicists, urged us to remember "that nature always has more imagination than we have." He noted the discovery of planets around a pulsar, and the recent detection of a planet around the star 51 Pegasi.

"Both of these discoveries were completely against all the conventional wisdom," he said. Pulsars were never thought to have planets, and 51 Pegasi had a Jupiter-size planet where no one expected it—much closer to its star than Mercury is to our Sun. "Any self-respecting planet should evaporate."

Dyson warned us to guard against two common assumptions: that planets are only near stars, and that intelligent creatures live on planets. "Both of those assumptions are very highly questionable." Laughter greeted this, but then he explained his reasoning.

Perhaps there are many planets in the galaxy unattached to stars. Stars, we think, condense from clouds of gas and dust, and, he said, "there's no reason why this should produce stars rather than planets." The Sun's heavy elements could have made 5,000 Earths. "So there could be 5,000 loose planets in the galaxy for every one star."

Even if that's not true, he thinks civilizations will colonize space, and not just planets. "We are messing the planet up very seriously, and before long we will undoubtedly move elsewhere, where we can live more freely and be more spendthrift without destroying the ecology of this very beautiful planet." He expects that "our friends and colleagues of the galaxy" will move away from stars, taking advantage of comets far beyond the planets.

Drake described the international SETI protocol, which is to be followed if we succeed in detecting extraterrestrials. Essentially, it says to make certain you're not being fooled by earthly interference or a nonintelligent natural phenom-

BETA designer Paul Horowitz monitors the progress of the supercomputer from the console at the Harvard/Smithsonian observatory. In the bottom right corner is a portrait of Jean Baptiste Joseph Fourier, whose mathematical "transform" makes possible the BETA search.

Photo: Thomas R. McDonough

For Techies

The heart of BETA is a 250-million-channel Fourier spectrometer covering a total bandwidth of 40 megahertz for each feed, with a resolution of 0.5 hertz per channel. Every two seconds, it moves over to another 40-megahertz band, covering the 1,400–1,720-megahertz water hole in eight hops.

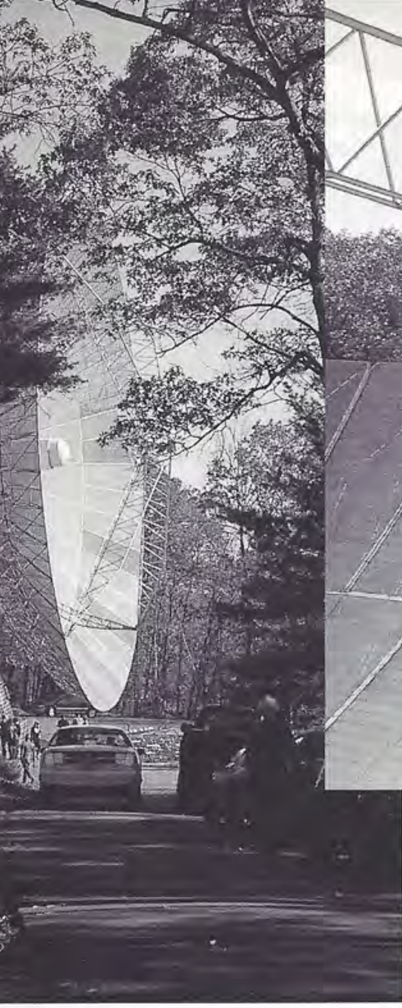
META did 75 million instructions per second and had 16 megabytes of RAM. BETA does 40 billion instructions per second and has 3 gigabytes of RAM. BETA has over 200 processors, handling 250 megabytes per second of data—about half of a CD-ROM every second.

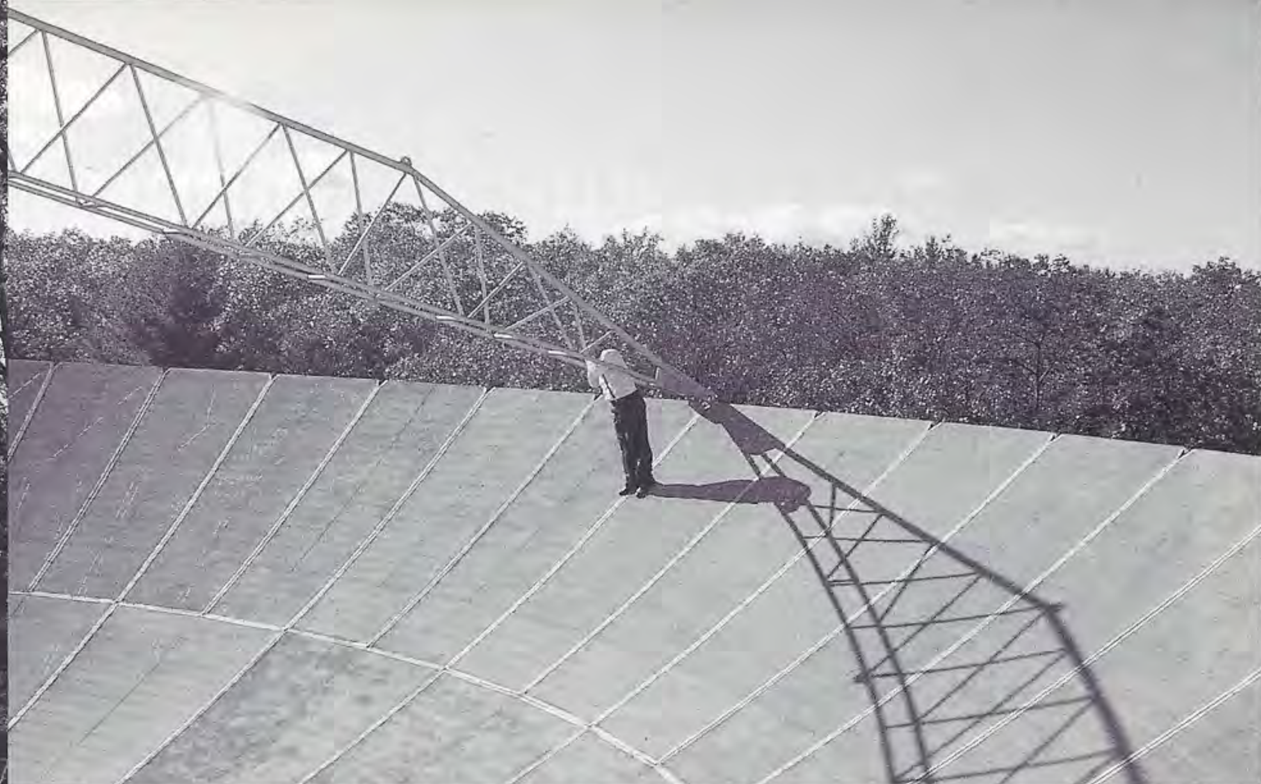
Because BETA covers far more of the radio spectrum than did META, BETA encounters much more radio noise. To reduce interference, it uses an innovative three-beam system.

Usually, the antenna does not move; Earth's rotation scans a strip of sky about half a degree wide. There are two feedhorns at the focus of the dish, oriented in the east-west direction. There is also a broad-beam antenna looking at Earth.

Valid signals display a "first east, then west, never terrestrial" signature, providing a "spatial filter" against interference. Good signals are then automatically reobserved.

Overall, BETA is a 300-fold improvement on META. —*TMcD*





Above: Despite their delicate appearance, radio telescopes are sturdy objects—they have to be to support their own weight. Here, an adventurous visitor takes in the view of autumn foliage from the edge of the dish, which is 26 meters (84 feet) across.

Left: The site proved a bucolic setting for a scientific experiment that, if it succeeds, could change the course of human civilization. Photos: Thomas R. McDonough

enon, and then announce your discovery immediately to the public.

There's a new kind of protocol being developed to answer the question of how we should reply: "What do you say to an extraterrestrial?" asked Drake. "Not knowing the language, unless somebody here speaks fluent Galactic, in which case we'd like to speak to you. But I think it's fairly obvious that you don't answer until you know what the signal is telling you. And how far away is it? Does it make any sense to send them a signal? If it's a million light-years away, would you send them an answer?"

SERENDIP

The Planetary Society has begun to support another outstanding SETI program, Project SERENDIP of the University of California at Berkeley.

Led by C. Stuart Bowyer, SERENDIP—the Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations—taps into the giant Arecibo radio telescope, testing signals from wherever the astronomers happen to be looking. SERENDIP's Dan Werthimer, who provided essential technical contributions to BETA, has just finished building a new machine, SERENDIP IV. With no more money from NASA, Werthimer says, "The Planetary Society saved us in the nick of time."—*TMcD*

The Future

All of the speakers were optimistic about the future, even though there is only one government-sponsored SETI project left in the world—META II, built with Society funds but run by Argentina. Otherwise, SETI survives through private institutions. For example, in addition to supporting BETA, the Society is now looking for scientists and facilities to use META I to continue the search elsewhere, and it publishes *The Bioastronomy News* newsletter.

Incredibly, Drake observed, the power of SETI equipment has doubled every year since 1960. BETA is about a trillion times more powerful than Project Ozma. "And there's no end in sight," he said, "because even as this equipment goes into operation, already our friends in the computer industry are producing new, affordable chips and equipment which will allow us to make even more powerful systems."

"Nevertheless," cautions Drake, "it will not be easy. It may take years, it may take decades. But in the end, we will prevail, because as Paul has said, he's guaranteeing you there's a civilization out there. And I would second that recommendation. How hard it will be to find it, we do not know. But it's there to be found. I think we can guarantee you that."

Tom McDonough is the Society's SETI coordinator and author of Space Adventure II *educational software.*

INTERNATIONAL REPORT:

The European Space Agency

The past two or three years have not been kind to the world's space agencies. Most space budgets have been under attack from both finance ministries and parliaments, and the general public seems to have lost a lot of its interest in space programs. The European Space Agency (ESA), created in 1975 by the fusion of two earlier space organizations, ESRO (European Space Research Organization) and ELDO (European Launcher Development Organization), suffered along with NASA, the Russian Space Agency and many others.

Wanted: A Long-Term Plan

At meetings of ESA's ministerial council (its senior policy-making body), European ministers tried on several occasions to produce a medium- and long-term plan for the agency, but the necessary consensus eluded them. Each time, the ministers were able to do little more than agree on some short-term measures to keep ESA afloat. One major exception was the decision to go ahead with the development of the *Ariane 5* launch vehicle. Maintaining an independent launch capability continues to be a European priority.

It was against this rather gloomy background that in September 1995 ESA held a symposium in Munich to mark the 20th anniversary of the ESA Convention, which had been signed in May 1975. The symposium brought together ministers, civil servants, industrialists, academics and ESA staff members who had been associated with the agency's creation and its first set of programs, as well as a number of somewhat younger ministers and civil servants currently struggling to find a new way forward for the agency. Representatives of other countries, notably the United States and Russia, were also present.

Below: Europe has carved out an important niche in the world's launcher market with the* Ariane *family of rockets. This is the* Ariane 44L*, the most powerful version now ready to launch payloads into space from the European spaceport in Kourou, French Guiana.
Photo: ESA

A decisive ministerial council meeting was due to be held just over a month after the symposium, and it was widely known that the preparatory discussions and negotiations had not thus far shown promise of an agreement. There were all the ingredients for a wake rather than for a celebration.

An Unexpected Turn

In fact, however, speakers—and indeed the whole audience—were surprisingly ebullient. Informal discussions of this apparent paradox revolved around two possible explanations: Either the participants did not appreciate the seriousness of the situation, or there was in fact a stronger underlying solidarity than the recent vacillations had indicated. Fortunately, the second explanation proved to be correct when the ESA ministers met a month later in Toulouse.

The anniversary symposium concluded that, whatever the present budgetary and other difficulties, ESA must not neglect its preparations for the longer term. There was complete agreement that ESA—and the European aerospace industry—needed both short-term and long-term plans approved by member states. It was, however, recognized that ESA was no longer the only player on the European space stage, and that there was still much work to be done to clarify relations between the agency and other organizations—the European Commission, Eumetsat (European Meteorological Satellite Organization), Eutelsat (European Telecommunications Satellite Organization) and, of course, the national space agencies. But the tone was unmistakably upbeat. Although much was said in favor of programs that are of direct relevance to European and national problems (such as protection of the environment and improvement of communications), the importance of space science and planetary exploration was also stressed.

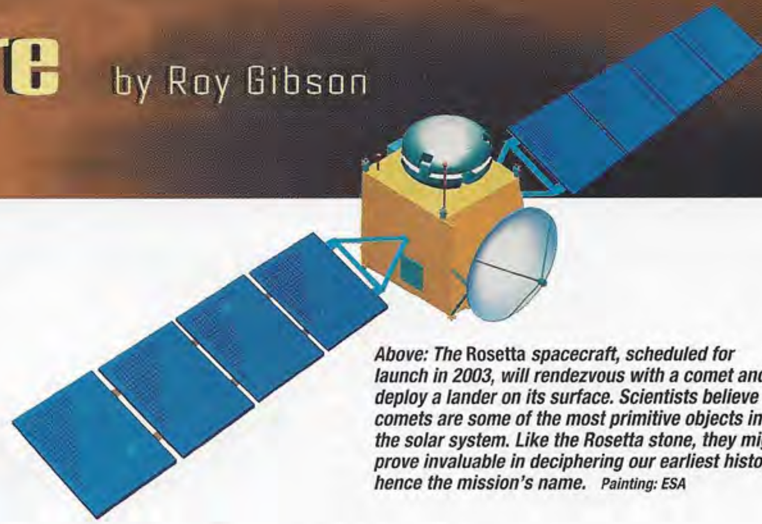
All in all, the symposium sent an important message to the ministers, who were—at least, so one hoped—busy studying their papers in preparation for the upcoming ministerial council meeting. Summarized somewhat disrespectfully, the message for ministers might be decoded as follows: "In ESA you have an instrument that has shown itself capable of successfully completing a whole series of important, world-class programs. The agency may have accumulated a certain excess weight here and there over the years, but an effective diet can easily be arranged if only you can make up your minds over what you want to do in space in the next 10 or so years. If you don't decide now, you can effectively say good-bye to the ESA you have paid to create."

The Council Meets

The ESA ministerial council duly met in Toulouse on October 18–20, 1995, under the chairmanship of Belgian Minister for Space Policy Yvan Ylieff, who, incidentally, had participated actively in the anniversary symposium in Munich a month earlier. After three days of animated discussions, both in the plenary sessions and in parallel

Faces the Future by Roy Gibson

negotiations, the ministers were able proudly to announce some results. Even if these are not so spectacular as some optimists had hoped, they are undeniably more substantial than the outcome of the previous three such council meetings. Observers had the impression that ministers had taken control of the meeting and, in an attempt to reach the elusive agreement without which the event would have been a political disaster, had gone beyond the briefs provided by their civil servants. If this is indeed the case, it is an encouraging signal that politicians still regard the European space program—and the associated infrastructure—as too valuable an asset to destroy by further procrastination.



Above: The Rosetta *spacecraft, scheduled for launch in 2003, will rendezvous with a comet and deploy a lander on its surface. Scientists believe comets are some of the most primitive objects in the solar system. Like the Rosetta stone, they might prove invaluable in deciphering our earliest history, hence the mission's name.* *Painting: ESA*

This is not the place to describe in detail the decisions made at Toulouse, but an understanding of the following main points is essential for anyone trying to assess where European space will be going in these next 10 or so years:

♦ A constant funding level for ESA from 1996 to 2000.

♦ A funding formula that will enable ESA to make a meaningful contribution to the international space station.

♦ Continuation of the ESA scientific program Horizon 2000 and its evolution into the Horizon 2000 Plus program, although with a slight paring of the annual budgets.

♦ A program designed to improve the performance of the *Ariane 5* launcher, scheduled for its first launch in 1996.

♦ Encouraging, if rather vague, measures for the Earth observation and telecommunications programs.

A Renewed Stability

This may not make very exciting reading, but it means that ESA's period of stagnation and uncertainty is over. Funding will continue to be short, management and financial experts will be continually searching for economies in staff and money, but these decisions give a renewed stability to ESA, something that has been lacking for several years. This stability is a prerequisite not only for the effective completion of the agency's programs, but also for any future international cooperation.

For those who are studying the tea leaves in an attempt to see whether or not Europe is likely to join major international space science and exploration programs, it is interesting to note that the Final Resolution from the ministers' council in Toulouse contained a section on exploration. This inclusion owes much to the report, published some weeks previously, of ESA's Long-Term Space Policy Committee, chaired by Peter Creola of Switzerland. Item number three in the committee's list of recommendations reads: "Europe remains at the forefront of space science, and actively pursues its initiatives of an international lunar program."

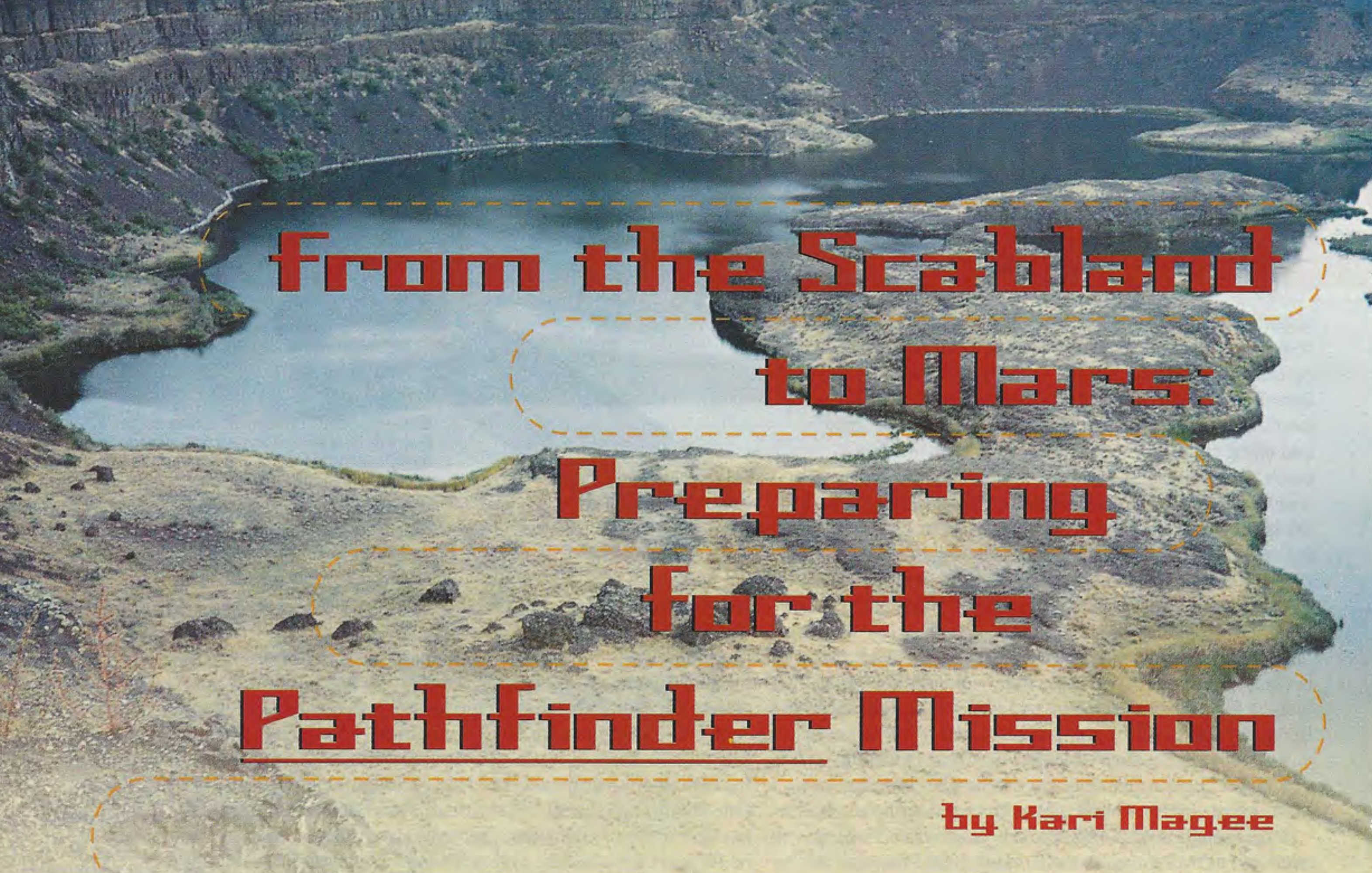
Ministers took note of this recommendation and specifically acknowledged ESA's concept of a four-step international lunar program (see the January/February 1995 *Planetary Report*), and the director general's intention to develop proposals for a European contribution to precursor missions for the first step of such a program. This is the usual coded language to tell the director general to go ahead as he plans but not to count on any additional funding for the next few years.

It would be premature to hoist celebratory flags and bunting, but there is real cause for optimism, or at least for ending our pessimism. Europe is back in the game. One should not expect too much too quickly, but there is every reason to hope that gradually over the next five or 10 years ESA will be able to take part in the next generation of space adventures.

Meanwhile, the name of the game for ESA is to try to keep the talent and enthusiasm ready for when the financial climate improves, and to proceed quietly to make whatever preparations the current funding level allows. The ministers decided to meet again in 1996, and this will provide an opportunity to confirm or modify our impressions from the Toulouse meeting. Much depends on how ESA now responds to the challenges set by ministers, but experience shows that once politicians have declared their intentions, ESA has never let them down.

Roy Gibson is a former director general of ESA and of the British National Space Center. He is currently an independent aerospace consultant.

Below: The European Space Agency hopes to fly the Ariane 5*, a powerful rocket capable of launching large payloads into space, in the near future. With this rocket, Europe will be able to consider a Moon program that would begin where the Americans left off over 20 years ago.* *Photo: ESA*



From the Scabland to Mars: Preparing for the Pathfinder Mission

by Kari Magee

It was a cold day in what is now eastern Washington state. Not far from present-day Spokane, near the Idaho border, the Clark Fork River was dammed behind a lobe of ice extending south from the massive ice fields of British Columbia.

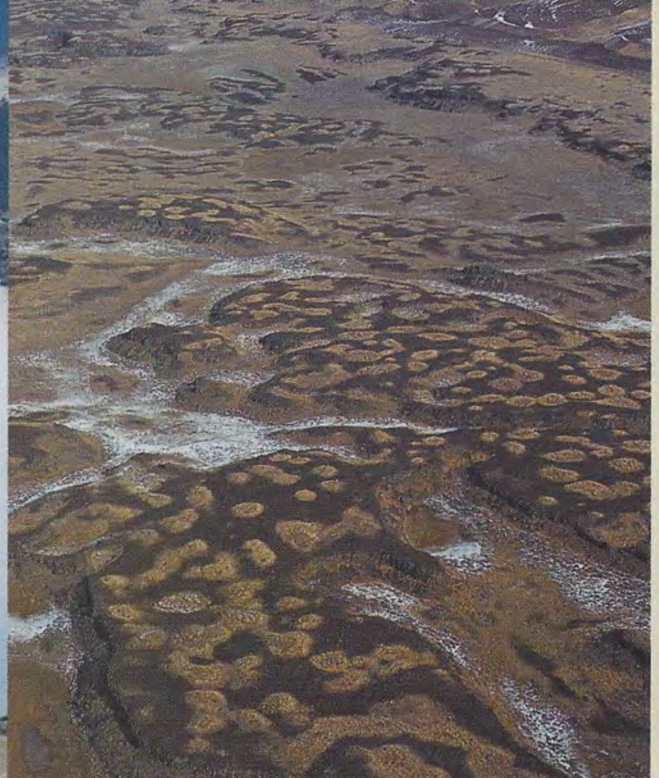
The trapped river swelled to tremendous proportions, flooding tributary valleys for miles to the east and forming one of the deepest lakes ever known. Glacial Lake Missoula covered about 8,000 square kilometers (3,000 square miles) and held 2,100 cubic kilometers (500 cubic miles) of water, nearly half the volume of Lake Michigan. Icy waters lapped the shoreline at 1,260 meters (4,150 feet) above sea level and reached depths of 600 meters (2,000 feet).

When the icy cork suddenly popped, the dammed waters burst forth at speeds of 80 to 100 kilometers (50 to 60 miles) per hour, draining Lake Missoula in a scant 48 hours. Downstream, an ominous thundering would have been heard 30 minutes before the rampaging waters hit, scouring the landscape and plucking massive columns of basalt from the bedrock like so much loose foliage. Channels and cataracts cut into the surface, ravaging more than 34,000 square kilometers (13,000 square miles) of eastern Washington and producing the terrain now known as the Channeled Scabland. Giant ripple marks 11 meters (35 feet) high and 3 kilometers (2 miles) long, spaced 110 meters (350 feet) apart, testify to the awesome power of the flood.

From Moses Lake

Some 15,000 years later, in the last week of September of 1995, I'm sitting in a restaurant in the city of Moses Lake in central Washington, marveling at the scale of these enormous features and the magnitude of the flood that produced them. I'm here to represent The Planetary Society at the Mars *Pathfinder* Landing Site Workshop II. About 60 planetary scientists, engineers and educators have gathered to learn more about the Scabland and what the area can teach us about the Ares Vallis region of Mars, the chosen landing site for the Mars *Pathfinder* mission.

The workshop, sponsored by Arizona State University, the Jet Propulsion Laboratory, the Lunar and Planetary Institute and NASA, includes a series of field trips into the Scabland and a two-day conference



Above: Seen from above, it's easy to see how the Scabland got its name. With the topsoil removed by the floodwaters, much of the land is unfarmable and truly resembles the legendary Waste Land. Photo: Ted Wood

Left: The Scabland of Washington was not carved over millennia by gently flowing water; it was gouged out of volcanic rock by catastrophic floods thousands of times larger than anything we see today. These are the sorts of forces scientists think shaped the floodplains of Mars. **Pathfinder** ***is slated to land on a martian floodplain where rocks of various origin may have been deposited.***
Photo: Kari Magee

Above: The great floods scraped away layers of soil and scoured Earth's surface down to bare basalt. Even today, thousands of years later, much of the Scabland remains barren.
Photo: Ted Wood

in Spokane. The waitress serving me breakfast strikes up a conversation and, noticing my conference agenda and field trip guide spread across the table, asks, "What brings you all here? What in Moses Lake could possibly look like Mars?" The Channeled Scabland, of course!

In the *Viking* orbiter images, large channels and tear-shaped, streamlined hills can be seen just to the south of the planned Mars *Pathfinder* landing site. Current theory holds that massive floods similar to the Great Spokane Flood cut these broad channels, including Ares Vallis, into the martian landscape billions of years ago, during a much warmer, wetter period in Mars' history. Catastrophic flooding through Ares Vallis carried boulders, cobbles and finer sediments from distant reaches, including the ancient highland terrain of the southern hemisphere. All of this material was dumped in a chaotic jumble as the floodwaters debouched onto the Chryse plain.

Such a grab-bag assortment of rocks, especially rocks from the southern highlands, is what makes this an attractive region to explore with the Mars *Pathfinder* rover, named *Sojourner* by Planetary Society member Valerie Ambroise (see the November/December 1995 *Planetary Report*). Without having to travel great distances, the rover can sample a wide variety of rock types. Although we won't know the exact provenance of each rock, we will gain a better understanding of the range of rock types found on Mars. In fact, we have the potential to sample a wider variety of highland rocks at the Ares Vallis site than would be accessible if we actually dared to land in the highlands.

What is the composition of rocks in the highlands, and elsewhere in the martian crust? Are all rocks on Mars basalt? Are there fossil-bearing rocks on Mars? These are the kinds of questions that we hope to address using the rover, the camera and instruments such as the alpha proton X-ray spectrometer on Mars *Pathfinder* (see the January/February 1996 *Planetary Report* for more details on the mission).

The views from the Mars *Pathfinder* microrover and lander, however fascinating, will be somewhat constrained: Imagine trying to interpret a regional landscape by crawling around on your belly and occasionally sitting upright to get the big picture! Without descent imaging or satellite imaging from orbit, scientists may find it very difficult to understand what the rover sees. By coming to the Scabland, we can see firsthand the kind of surface features the rover is likely to encounter at Ares Vallis. Our hope is that this experience will enable us to better interpret what we see there, and help us put the rover's observations in the proper geologic context.

Right: Ripple marks are common sights in streambeds, but imagine ripple marks so large you can't recognize what they are while standing on the ground. The ripple marks created by the Lake Missoula floods range from 1 to 15 meters high and are from 20 to 200 meters apart. The Columbia River flows to the left in this photograph. Photo: John Shelton

Right: Great potholes like these, hundreds of feet deep, were among the first hints that catastrophic floods carved out the landscape of the Scabland. How large were the floods? The water ran up to 450 meters (1,500 feet) deep, flowing more than 18 cubic meters (600 cubic feet) per second, and carrying 10 times the flow of all modern rivers combined. As monstrous as this sounds, the floods that created Ares Vallis on Mars were even larger. Photo: Ted Wood

Into the Scabland

Ken Edgett, director of the Arizona Mars K-12 Education Program at Arizona State University and the new editor of The Planetary Society's *Mars Underground News* newsletter, and Jim Rice, also of ASU, lead our excursions into the Scabland. Vic Baker, professor of planetary science at the University of Arizona and an expert on Scabland geology, provides scientific commentary at each site we visit.

On the first day, our bus follows along the Lower Grand Coulee, one of the major channel systems in the Scabland. We travel in a downstream direction from the Dry Falls cataract, across the gravel beds of the Ephrata fan, and out onto the sand dunes of the Quincy Basin. A huge volume of gravel and other sediments was deposited in the fan, and planetary geologists think it may be a miniature analogue of the Ares Vallis landing site.

A site on the Ephrata fan nicknamed the Monsters of Rock is littered with rocks, the most prominent one 18 meters (60 feet) tall and 12 meters (40 feet) wide. The rover engineers immediately bring out the *Sojourner* stunt double, an eight-wheeled microrover that was a prototype abandoned in favor of the six-wheeled design now being developed. The rover maneuvers across the rough, rocky terrain with little difficulty, and the rover engineers are very pleased.

The balloon engineers, however, are terrified! Responsible for the air bag system that is key to the safe landing of the spacecraft, they find the Monsters of Rock site a nightmare of large boulders and jagged edges. Sharp edges like these could puncture the air bags during one of the 10 or so bounces expected during landing, eliminating or reducing the protection provided for impact. Tall boulders and, more important, sharp cliffs or mesas could interfere with altimetry readings during descent, altering the time when rockets are fired to slow the descent of the lander just before the air bags are deployed. If the rockets are fired too soon, the descent won't be slowed enough and the lander will hit the surface too hard.

Fortunately for the engineers, the consensus among the scientists in our group, including project scientist Matt Golombek of JPL, is that the Monsters of Rock locale is much rockier than anything anticipated at the Ares Vallis landing site. Analyses of *Viking* images and recent Earth-based radar studies indicate that the *Pathfinder* landing site should be no rockier than the *Viking 2* lander site and may contain even fewer rocks, making it more like the *Viking 1* site. Mars *Pathfinder* is expected to land far enough downstream from the channel mouth for the rocks to be relatively small and, with luck, harmless. The next day, we visit a site thought to be more similar to Ares Vallis in rock size and abundance, and the *Pathfinder* engineering team is much relieved. Of course, a smooth plain with few boulders doesn't make for dramatic scenery, and some in our group begin to wonder how interesting it will be to visit such a site.

The Debate

After the field trip, we meet in Spokane to discuss what we know about Ares Vallis and what we've learned by looking

Above: The Scabland proved a challenging test site for an eight-wheeled prototype of the Sojourner *rover that* Pathfinder *will carry to Mars. Any Mars rover's primary goal will be to explore without getting stuck; the rovers are off-road vehicles par excellence. The strange, multiwheeled designs are engineers' solutions to navigating almost any terrain the rovers might encounter.*

Left: The eight-wheeled Sojourner *prototype overcame some very unusual obstacles during the Scabland expedition. Obstructing bodies of this type are not expected to be found on Mars. However, they were plentiful during the educational programs the* Pathfinder *team put on for local residents and educators in the Scabland area.*

Background: Mars Pathfinder *team members personally explore some of the large boulders that litter the Ephrata fan, one of the suggested analogues for the* Pathfinder *landing site on Mars. They hope the boulders their tiny spacecraft encounters on Mars are nowhere as large as this one, for an attempt to land on something this imposing could lead to disaster. Fortunately, it seems that the region selected for the landing is not this rugged.* Photos: Kari Magee

at the Channeled Scabland. The discussion becomes a debate about whether the landing site should be one that is safe or one that is scientifically (and aesthetically) more interesting.

Without a safe and successful landing, no scientific exploration is possible. But how safe is safe? Interestingly, the Mars *Pathfinder* landing site was rejected, for safety issues, as one of the *Viking* lander sites, although today we have no reason to think that this site is any more hazardous than either of the *Viking* sites. The main objective of the *Viking* lander experiments was to detect life. Mission planners assumed that if life existed on Mars it would be ubiquitous, as on Earth. Almost anywhere the landers set down would have been conducive to their analyses. Thus, landing sites were chosen with safety as the primary concern.

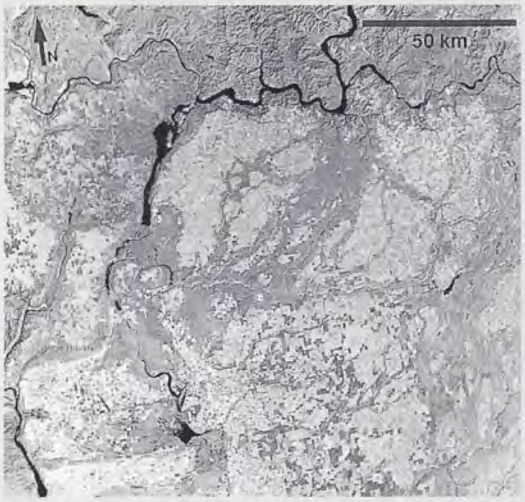
The situation for Mars *Pathfinder* is very different. There is a distinct trade-off between absolute safety and valuable science. Matt Golombek states that even if the landing is perfect, satisfying 70 percent of the criteria that define *Pathfinder*'s success, he will consider the mission a scientific failure if the site yields no interesting features to examine. He believes this is very unlikely, however, and expects to find a large number of different kinds of rock to investigate.

Peter Smith, who is responsible for designing the mast-mounted camera on the *Pathfinder* lander, believes in the importance of a good view. He suggests touching down off-center in the landing ellipse to be closer to one of the streamlined islands north of Ares Vallis. Even a distant view of one of these hills would be more interesting than a flat expanse cluttered with rocks. And if we could resolve stratigraphic layers in the stream-cut hillside, we could get much more information about the regional geology than from composition alone.

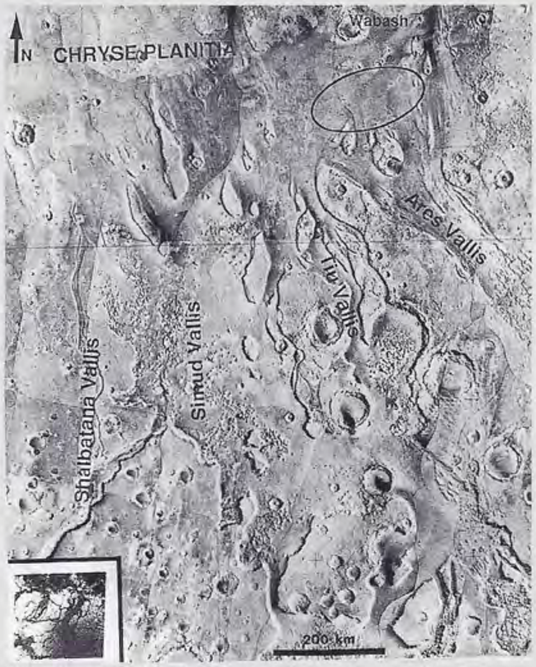
While Peter's suggestion is tantalizing, it's clear that specifically targeting one of these hills is too risky. The Ares Vallis site was chosen very carefully to fit within all of *Pathfinder*'s landing and engineering constraints and will provide an opportunity to address some very interesting and important scientific questions.

I can't help but wonder what our options for exploration would be with a rover capable of traversing great distances. *Sojourner* will be able to explore only within view of the camera mounted on the lander. More capable rovers will someday be able to roam far afield. We won't have to worry so much about balancing a landing site's hazards with its scientific interest: We can land in a safe place and then drive over to what we really want to look at.

The Russian Mars rover would permit this. Unfortunately, it is big and heavy and, therefore, expensive to launch. Donna Shirley, director of the Mars Exploration Program at JPL, states that the next lander in the United States' Mars program will have half the mass of *Pathfinder*. So it's unlikely that we'll be able to send something like the Russian rover to Mars for many years to come, unless we're able to cut costs dramatically by working with the Russians and other spacefaring nations.



Above: Viewed from Landsat in Earth orbit, the Scabland is an obvious scar on the planet. That the scar has remained for 15,000 years is testimony to the great power of the catastrophic floods that scoured the land.
Image: EROS Data Center, modified by Ken Edgett



Right: As mighty as the floods were that carved the Scabland, they would be dwarfed by the floods that shaped the face of Mars. The Landsat image appears in the lower left corner at the same scale as this photomosaic of the* Pathfinder *landing site. The landing ellipse is at upper right. Scientists hope that these great floods deposited a variety of samples from many regions, providing rich pickings for an exploring spacecraft. *Image: JPL/NASA, modified by Ken Edgett*

A Good View

On my flight home, I can see much of the Scabland terrain we explored during the past week. From the air, it's easy to link the channels, streamlined hills and ripple marks to the work of a great flood. From the ground, the picture isn't so clear. Geologist J. Harlen Bretz deserves our admiration for fitting together all the pieces of the puzzle back in the early twenties and thirties, and for having the courage to propose such a radical explanation in the days when catastrophic floods were considered bad geology. It impresses upon me the importance of perspective, and the need for "a good view."

This year will be an exciting one, with the launch of Mars *Pathfinder* in December. It's a long-awaited return to the Red Planet and one in a series of bold new Mars missions. As it has in the past, The Planetary Society must continue to support new initiatives for Mars exploration. All of us must work hard to promote cooperation with international partners, including the Russians, to ensure that worthwhile mission concepts, such as the big Mars rover, are vigorously pursued and that the future of Mars exploration will be as exciting as the present.

Kari Magee is Resource Center Manager for The Planetary Society. She is also an assistant science coordinator for the SSI (solid-state imaging) team on the Galileo *project at the Jet Propulsion Laboratory in Pasadena.*

Teachers Show the Way to Mars

One of the goals of the Channeled Scabland workshop was to bring together members of the Mars scientific community and K-12 educators from Washington and Idaho. Thirteen teachers, chosen on the basis of their plans to share what they learned with their students, their fellow teachers and the parents in their home communities, participated. The workshop sponsors hope that this kind of interaction will increase during the course of the Mars *Pathfinder* mission.

The teachers' enthusiasm and curiosity were infectious and contributed to a real camaraderie within the group. Mars *Pathfinder* project scientist Matt Golombek commented at the end of the week that he would have been privileged to have been taught by the teachers in the group during his school years; any one of them would have been the best teacher he ever had.

The scientists, engineers and educators combined forces one evening during the workshop to host an open house (Mars Night) at Chase Middle School in Spokane. Between 600 and 700 students, parents and local residents attended the event, which featured rover demonstrations, models of the *Pathfinder* spacecraft and lander, question-and-answer periods and lots of hands-on activities specially developed by the teachers in our group. When asked if any astronauts who would be going to Mars would be at the open house, Ken Edgett said yes—the students in our midst!

At a separate workshop conducted at the Salk Middle School, also in Spokane, I put on George Powell's hat and presented an overview of The Planetary Society's Red Rover, Red Rover project. (George is the project head.) The teachers were excited by the project. Many commented that to convey the positive aspects of space exploration to our children and the general public, dynamic projects like Red Rover, Red Rover are needed. We certainly hope that the Red Rover, Red Rover project and our new Planetary Society Resource Center help spread the joy and fascination of space exploration to students of all ages! —*KM*

Research Update: Near-Earth Asteroid Studies Continue

by Richard P. Binzel

At The Planetary Society, we seek out research and discovery programs where a small amount of money can be leveraged into a substantial return. We found such a program in Rick Binzel's research to characterize near-Earth asteroids.

These objects are the easiest targets for spacecraft exploration, and, as humanity moves out into the solar system, they could prove to be reservoirs of much-needed resources. While these asteroids could be stepping-stones to a future among the planets, they might also spell the end of civilization as we know it—through a collision with Earth. To understand this threat, and how we might be able to counter it, we must know more about these nearby bodies.

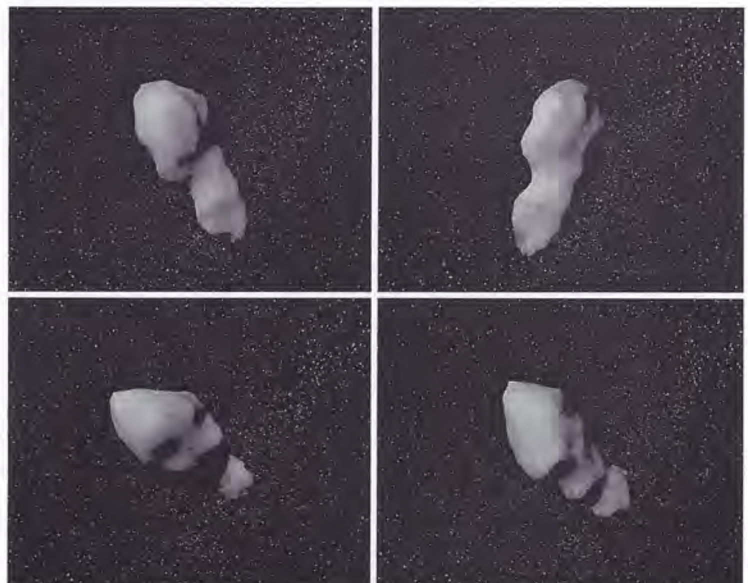
Rick's work is crucial to answering questions about all aspects of these asteroids. Society members can be proud that we have been able to make a difference in his work. Here he reports on recent progress.
—Charlene M. Anderson

Because of their small size, most near-Earth asteroids are observable for only a short interval when they make close approaches to Earth. The key to studying them is to have frequent access to a large telescope. With the aid of funds provided by The Planetary Society, a research team at the Massachusetts Institute of Technology—myself and graduate students Schelte J. Bus and Thomas H. Burbine—has been able to do just that in a continuing astronomical observing program aimed at using spectroscopic measurements to determine the composition of these small bodies.

To capture data on these fleeting objects during their favorable passages, we most often use the 2.4-meter (94-inch) Hiltner telescope of the Michigan–Dartmouth–MIT Observatory located on the southwest ridge of Kitt Peak, near Tucson, Arizona. Light collected by the telescope is passed into a spectrograph, which disperses the light into all of its visible components. The resulting spectrum falls onto an electronic charge-coupled device (CCD) detector, which produces a digital record of the properties of the spectrum. Because the near-Earth asteroids are faint, many long exposures of the spectrum on the CCD detector are needed to record usable results. These exposures can total several hours for the faintest near-Earth asteroids.

Over the last two years, we have measured the spectral properties of about 40 near-Earth asteroids, effectively doubling the number of these objects for which spectral measurements are available. Although a full analysis of the results is in progress, the preliminary analysis shows that the objects in near-Earth space are diverse in composition. Most fall into the category of asteroids known as S types, which have either a stony or stony-iron composition. Asteroid 433 Eros, the target for the Near-Earth Asteroid Rendezvous (NEAR) mission scheduled for launch in February of this year, is such an asteroid and is included in our data set. The NEAR mission may help to resolve the question of the composition of this class of asteroids.

Several of the other near-Earth asteroids we have measured display spectral properties similar to those of ordinary chondrite meteorites, remnants from the early solar system that have undergone only slight heating over their lifetimes. Others display the properties of C-type asteroids, fairly pristine samples from the early solar system that may contain some water. A few of the sampled objects may be metal-rich M-type asteroids. By supporting our work in making these preliminary assessments, The Planetary Society is helping to provide the first reconnaissance of our nearest neighbors in space.



The near-Earth asteroid 4179 Toutatis is one of the strangest objects yet seen in our solar system. Using the Arecibo radio telescope, scientists Steven Ostro and Scott Hudson bounced radar signals off the asteroid. With the resulting data, they created a computer model that shows Toutatis to be an elongated body with a distinct "neck." The shape suggests that the asteroid may actually be two objects that gently collided and stuck together. Toutatis also exhibits one of the strangest rotations yet observed. Hudson describes it as tumbling through space "like a flubbed pass." Images: JPL/NASA

Richard P. Binzel is an associate professor of planetary science at the Massachusetts Institute of Technology. He is also the editor of our specialty newsletter, The Neo News, *available by contacting Society headquarters.*

Basics of Spaceflight:

Propulsion Systems

by Dave Doody

Interplanetary spacecraft such as *Voyager,* Mars *Global Surveyor, Galileo* and *Cassini* aren't usually called "rocket ships." But let's use that colorful term just for the sake of novelty. Even though they spend most of their lives coasting in free fall, they are nonetheless equipped with rockets. *Voyager,* for example, fires tiny bursts from its rocket thrusters at least once every few hours (see the September/October 1995 issue of *The Planetary Report*)—something it has been doing for over 18 years now.

At the time of its launch from Earth's surface, a powerful launch vehicle, such as the *Titan,* the *Delta* or the space shuttle (which is usually equipped with additional powerful rockets in an upper stage), lifts the spacecraft up and away from Earth and gives it all the push it will need to get to its first planet. The launch vehicle and any upper stages finish their job within a handful of minutes, but the spacecraft will continue to travel for months or years.

The Right Place at the Right Time

Many spacecraft pass close to other planets, as *Galileo* did, to trade orbital momentum and gain speed via gravity assist (see the May/June 1995 issue of *The Planetary Report*). Gravity assist can provide as much speed as does a launch vehicle, requiring nothing of the spacecraft except that it be in exactly the right place at the right time. And that's one of the main reasons an interplanetary rocket ship has a propulsion system: to provide trajectory correction capability. It takes only a tiny fraction of the initial launch energy to fine-tune a spacecraft's trajectory and achieve a perfect planetary flyby or arrival. Small, computer-controlled onboard rockets can do the trick.

A propulsion system can also stabilize a spacecraft's attitude (covered in the September/October 1995 *Planetary Report*), as is happening with *Voyager 1* and *Voyager 2* right now. But there's a third function, and this was nicely demonstrated on December 7, 1995. At The Planetary Society's invitation, people packed Beckman Auditorium at the California Institute of Technology and watched hopefully as a bright pink line on a computer screen, projected for all to see, reported the progress of *Galileo*'s German-built propulsion system while it fired its main rocket engine.

The same plot was broadcast live on the NASA TV network, and on the Internet, for many to see worldwide. Half a billion miles away, the *Galileo* orbiter had arrived at Jupiter. Its atmospheric probe had completed its mission and sent its data up to the orbiter, where they were stored for later playback. *Galileo* was positioned with its antenna facing back to Earth and its main rocket engine pointing forward. As the engine burned, it decelerated *Galileo.* After 49 minutes, which is a long time to sit on the edge of your seat, *Galileo* had slowed enough to be captured into a perfect jovian orbit, and the rocket ship's computer shut down the engine. Without a functioning propulsion system, *Galileo* would have flown by Jupiter and remained in an elliptical solar orbit much like a comet's.

Action and Reaction

Propulsion systems work by accelerating mass in one direction, resulting in a reaction, or a push, in the opposite direction. The mass (hot gas) doesn't have to push against anything; it just has to be accelerated away for the reaction to occur. Prove this to yourself by sitting in a swing and holding a bowling ball. If you throw the bowling ball forward, you're going to be thrust back. That's the reaction you get from accelerating mass away from you.

The propulsion system you'll find on your typical interplanetary rocket ship uses liquid propellant because you can start and stop the flow of a liquid using valves, thereby starting and stopping your engine when you need to. *Magellan* did carry a solid rocket motor to Venus, igniting it to decelerate the spacecraft into orbit. Once ignited, it couldn't be shut off but had to burn out. But the orbit insertion burn was its only function in life, and *Magellan* was also equipped with a liquid propulsion system for ongoing attitude control, trajectory and orbit correction.

Start with a spherical tank made of titanium for high strength and low mass, large enough to hold a hundred kilograms or more of hydrazine. From the tank, a system of plumbing carries the propellant (which in this example is called monopropellant, since there's only one liquid) through filters and valves and eventually to the rocket engine. There, inside the rocket engine, is a bed of catalyst, heated using electricity from the spacecraft.

When the valve is opened (electrically, on command from the spacecraft's computer), hydrazine squirts onto the hot catalyst, which provokes the hydrazine to decompose rapidly, releasing heat and expanding in the process. The hot, expanding gases force themselves out through the exhaust nozzle. This act of expelling mass provides the desired mechanical reaction, or thrust, pushing the rocket and its attached spacecraft in the opposite direction.

In a spacecraft's propulsion system, clusters of several rocket engines of different sizes are typically mounted at

Cassini's Propulsion System

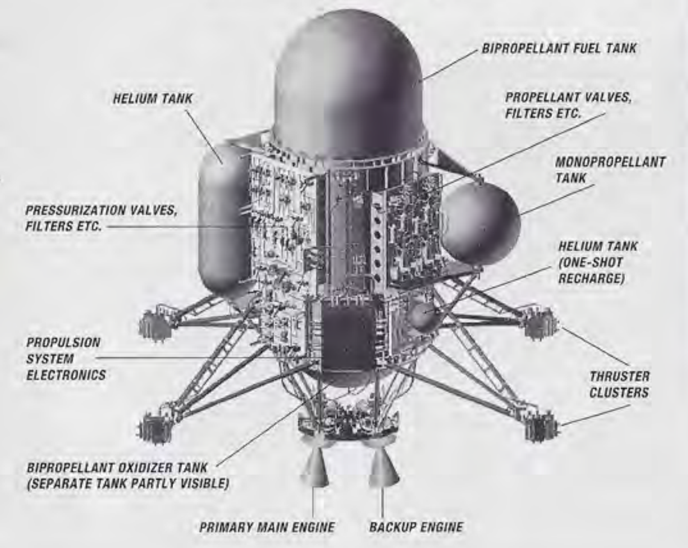
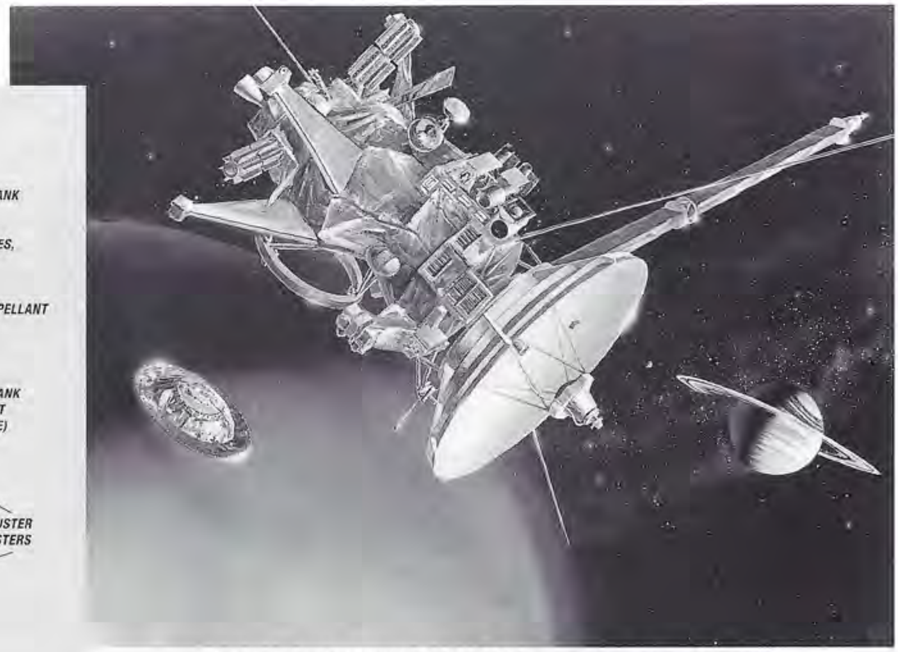


Image: Lockheed Martin; redrawn by B.S. Smith



Cassini drops the *Huygens* probe at Titan. Illustration: Michael Carroll/NASA

the ends of struts, pointing in selected directions, in an arrangement that provides leverage to rotate the spacecraft while keeping the hot exhaust gases away from sensitive equipment. Generally, the more powerful rocket devices are called engines. They may be the size of a large champagne bottle, providing a force of hundreds of newtons. (One newton is about a quarter-pound of thrust.)

Engines can be used to provide large torques to maintain stability during a solid rocket burn, as with *Magellan,* or they may be the only devices used for orbit insertion, as in *Galileo*'s case. The smaller rockets generate anywhere from fractions of a newton up to about 10 newtons, and are called thrusters. They're used to rotate the spacecraft for routine three-axis stabilization by firing one at a time or in pairs, and to provide thrust to accelerate the whole spacecraft for trajectory correction or orbit correction by firing together.

Galileo's propulsion system includes the main engine, rated at 445 newtons, whose December performance was watched worldwide, and several smaller thrusters. The system is supplied with two special liquid propellants that ignite and burn spontaneously when mixed. Such reagents are called hypergolic. From one tank comes the fuel, and from a separate tank comes the oxidizer. When the valves open to admit these hypergolic propellants into the rocket engine, the propellants ignite automatically and accelerate hot gases through the exhaust nozzle.

Cassini, which launches in October of 1997, is equipped with both kinds of systems. (See the illustration.) A monopropellant hydrazine system will feed thrusters for small trajectory correction maneuvers and for attitude control, and a hypergolic (bipropellant) system with two 445-newton main engines (a primary and a backup) is to be used for larger trajectory corrections and for orbit insertion at Saturn.

Liquid in Zero Gravity

You may be wondering about the behavior of liquid in tanks under "zero-g" conditions. It doesn't just automatically go to the bottom of the tank where the tubing connects, like gasoline does in an automobile. Aboard *Cassini,* there are two ways of dealing with it. Within the monopropellant tank, there's a flexible, rubbery diaphragm that separates the hydrazine from an area (called ullage) that is pressurized with helium. This keeps the propellant pressed up against the tank's outlet, and it provides force to drive the liquid through the plumbing when the valves are opened. *Cassini* also carries a small tank with extra helium to allow a single repressurization of the ullage after years of propellant use. *Magellan* had the same kind of system.

Cassini's two large bipropellant tanks manage their load differently. Both are pressurized with helium, supplied at a regulated pressure from a dedicated high-pressure helium tank, but there's no diaphragm to separate the liquid propellant from the gaseous helium. Instead, there's a "surface tension management device" in each tank. This consists of a sump at the bottom, with petal-shaped vanes attached to a center post. The sump is made up of perforated plates to ensure that once the sump is filled it will remain filled as long as there is propellant in the tank. When the propellant touches the vanes, surface tension wicks it to the tank bottom. When the engine fires, it accelerates the spacecraft, forcing gas-free propellant to flow steadily "down" toward the engine.

In the next issue, we'll look at the electrical systems found on interplanetary "rocket ships."

If you have access to the World Wide Web (via a Web browser like Netscape or Mosaic), be sure to look in on JPL's *Basics of Space Flight* manual, on-line at its brand new Uniform Resource Locator (URL): http://www.jpl.nasa.gov/basics/. (If you use the previously published URL, you'll receive a message directing you to its new permanent location.)

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

News and Reviews

by Clark R. Chapman

I'll soon drive up to Mount Graham, three hours away, to test a new spectrograph on the Vatican Observatory's Advanced Technology Telescope (VATT). I've been on this 10,700-foot mountain often during the last 20 years—camping, harvesting wild raspberries or just sitting by Riggs Lake. It is the tallest and most massive of Arizona's "sky islands."

Mount Graham is an outpost of Montana and Canada—with spruce/fir forests, meadows and bears—rising above the desert scrub. As the climate warmed following the last Ice Age, forests retreated to the cooler, wetter mountaintops, isolating the ecosystems. An archipelago of sky-island refuges stretches from the Rockies south to the Mexican Sierra Madres. Species from both ranges intermingle, forming what Paul S. Martin calls "a biogeographic melting pot, richer in species of small mammals, reptiles, ants, butterflies, and many other kinds of organisms" than anywhere else in North America.

Martin's is the last chapter of a new book, *Storm Over a Mountain Island* (University of Arizona Press; edited by C.A. Istock and R.S. Hoffman, 1995). The "storm" refers to the battle that has raged for a decade between astronomers and environmentalists over developing the Mount Graham Observatory. This book chronicles how an initially modest proposal to build a few telescopes in the extensive multiple-use National Forest lands on Mount Graham ran up against the red squirrel and ever angrier environmentalists.

A fight resulted in the halls of Congress when the Arizona delegation (even including veteran environmentalist Morris Udall) pushed through the first-ever de facto exemption to the Endangered Species Act. Angry eco-raiders threatened sabotage and physical harm to university scientists and officials. With two now built (including the VATT), the remaining telescopes have been delayed by court orders and pullouts by national and international collaborators.

Biologists, who have written many of this book's chapters, should be natural allies with astronomers to preserve our planet's wild mountains. But astronomers often neglect high-mountain values other than their own. Some congratulate themselves about their sensitive development of Kitt Peak National Observatory; others shudder, thinking of the road-cut eyesore facing the major Tohono O'odham town and of attempts to transfer Papago gods to the neighboring mountain. Analogous battles were fought on the Big Island of Hawaii two decades ago, but economic development again won the day. Domes continue to sprawl across Kitt Peak and Mauna Kea with scant regard for earlier promises of limited development. No wonder activists feared that Mount Graham's initial three domes really *would* become 18! The road to the top, now closed in winter, might open the wilderness to crowds year-round.

Peter Strittmatter is Arizona's aggressive promoter of astronomy. His chapter's facts and figures make an overwhelming case that Mount Graham is an astronomical treasure. But he omits other sides of this story. Hiking one exceptionally clear day, I could look out over all of southern Arizona. Just one cloud was visible: perched over Mount Graham! Though sometimes cloudy, Graham is a good Arizona site—but is it world-class? A high-tech competition in the early 1980s cast doubt: Mount Graham fell far behind Hawaii's Mauna Kea by crucial astronomical criteria.

This book's authors have diverse views. Given Mount Graham's 32 square miles above 8,000 feet, it is hard to believe that an observatory on a few tens of acres (with only a few acres actually cleared for buildings and roads) would pose a major threat. The red squirrel evidently has survived vastly greater habitat destruction in the past—from wildfires and loggers. The wilderness lovers fear, however, that the thin edge of the wedge (or the camel's nose under the tent) heralds worse to come. Insensitive development of precious ecosystems like Mount Graham's is often a one-way road toward degradation and loss of diversity.

The red squirrel gets more than its fair share of treatment in this book. It is an accident that it was listed as an endangered species just as the telescopes were being proposed in the mid-1980s. Although environmentalists originally had many of the broad concerns reflected in this book, the tough language of the Endangered Species Act gave them a single strong legal hook. So it has become easy to forget that there is much more at stake than a single subspecies of squirrel—which, by the way, seems not to have noticed the observatory construction at all.

As Martin Harwit writes in his chapter, the new generation of large, lightweight mirrors and advanced techniques for controlling "seeing" (image quality) are incredible resources for unlocking the secrets of the universe (we can't afford many Hubble Space Telescopes!)—but they must be put somewhere. In the future, let's hope that dispassionate dialogue and data, like what's given in this book, can take place *before* there has been a political train wreck of the sort recounted here. We, and all Earth's species, have one planet to share—and a universe to explore.

Clark R. Chapman, at the height of the storm, appeared on Tucson's PBS channel as a "moderate" voice—an astronomer, a Sierra Club member and a county planning commissioner familiar with land-use issues.

Society News

Milk Caps

On November 17, 1995, The Planetary Society joined forces with the Canadian Space Agency, Spar Aerospace and Liberty Yogurt at the Montreal Cosmodome to launch the new Planetary Milk Caps.

Designed to interest young people in planetary exploration, these milk caps are illustrated with pictures relating to planetary missions and offer intriguing bits of information about the missions. They are produced and distributed by Liberty Yogurt, whose president is longtime Society supporter and New Millennium Committee member Abe Gomel.

The event was a planetary electronic feast, offering children who attended the chance to teleoperate a rover in Utah as part of the Red Rover, Red Rover project; they could also view the *Visions of Mars* CD-ROM on one screen and a Red Rover, Red Rover video on another.
—Louis D. Friedman, Executive Director

1996 Society Tours

We're planning several exciting tours for 1996, including a working expedition in Italy (we'll search for geophysical evidence of the asteroid impact believed to have killed the dinosaurs), launches in the United States (Mars *Global Surveyor*) and Kazakhstan (*Mars '96*), stargazing in the beautiful Arizona desert and a trip to Puerto Rico where we'll visit the largest radio telescope in the world. Join us for a trip you will remember for a lifetime.

- Tucson, Arizona, June 19–23, 1996
- Arecibo, Puerto Rico, summer 1996
- Gubbio, Italy, August 6–19, 1996 (tentative)
- Orlando, Florida, November 4–10, 1996 (tentative)
- Baikonur, Kazakhstan, November 1996

The deadline for applications for the Gubbio expedition is April 1. For tour information, fax (818-793-5528), e-mail (tps.cj@genie.geis.com) or call me at Society headquarters (818-793-5100).
—Cindy Jalife, Manager of Program Development

Visions in Space

We are pleased to report that our *Visions of Mars* CD-ROM, developed for the first human explorers of Mars (see the November/December 1995 *Planetary Report*) may actually be "discovered" much earlier than we had anticipated. US astronaut Shannon Lucid is planning to carry it into space on March 21, 1996, aboard the space shuttle *Atlantis,* which is to rendezvous and dock with *Mir,* the Russian space station. Lucid wants to take our science fiction collection with her as part of a selection of reading material for her stay in space. She will be able to share it with fellow crew members, and since the stories are published in their native language, perhaps the Russian cosmonauts will enjoy reading some of the Russian science fiction that has motivated the exploration of Mars. *—LDF*

Meet Us in St. Louis

Saturday, March 30, is Planetary Society day at the National Science Teachers Association convention in St. Louis, Missouri (March 28–31, 1996). Speakers include Paul Horowitz on SETI, Christopher Chyba on the Tunguska explosion, Ray Arvidson on Mars and William Hartmann on craters and impacts. For registration information, contact me at Society headquarters.
—Susan Lendroth, Manager of Events and Communications

Galileo Events Lead to Planetfest '97

A Society event in Mountain View, California, on January 22, 1996, was the setting for the very first public presentation of the data sent back by the *Galileo* probe as it plunged into Jupiter's atmosphere on December 7, 1995. Six hundred people attended the event, which was cosponsored by the managers of the probe mission at NASA's Ames Research Center. Another 500 watched via satellite TV at the Exploratorium in San Francisco.

This was the second of two events heralding a series of public programs connected with *Galileo* mission results. The first took place on December 7 at the California Institute of Technology in Pasadena, where 1,100 people awaited the news of *Galileo*'s arrival at Jupiter and the probe's descent.

All through 1996 and into 1997, we will host public events each time the spacecraft encounters one of the Galilean satellites in its orbital tour around the planet. The next such event will be in July 1996, during the Ganymede encounter.

The *Galileo* series will culminate on July 4, 1997, with Planetfest '97, a celebration not only of *Galileo*'s extraordinary discoveries but of the Mars *Pathfinder* landing scheduled for that day. For information on Planetfest, which will take place in southern California, and on the *Galileo* events, contact Society headquarters or check our Web site. *—SL*

Keep in Touch

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Questions and Answers

I've read that it would actually be better for an extraterrestrial civilization to send its messages by laser light instead of radio waves. For example, infrared lasers travel more easily through dust clouds and can carry larger amounts of information. Why not an additional search for laser messages?
—Hans Starlife, Stockholm, Sweden

While advanced civilizations might be tempted to use optical means such as lasers to send information between the stars, there are some good reasons that nearly all of the major Search for Extraterrestrial Intelligence experiments are looking for radio signals instead. To begin with, microwave transmissions are completely oblivious to the dust clouds that clog the spaces between the stars. They pass through these gauzy barriers far better than light, even infrared light. So if the extraterrestrials are far away, or are interested in truly long-distance communication, then we should take advantage of the fact that radio will get through when a laser beam won't.

There's also the matter of cost. Optical photons are considerably more energetic than their radio counterparts; they are "heavier bullets." For example, an infrared photon at 20 microns wavelength has 10,000 times as much energy as a radio photon at the 21-centimeter wavelength. To make an infrared signal as simple to find as a radio signal (given the noise present in any receiving system), the extraterrestrials will have to expend a lot more energy generating it. Consequently, SETI researchers are inclined to look for the cheaper, longer-wavelength communications. They are easier to pick out of the noise and might be more prevalent.

Finally, optical broadcasts are really most suitable when you know exactly where your listeners are. If you mount a powerful microwave transmitter on a 10-meter telescope and beam a greeting into space, that beam will cover an amount of sky that's about the same as a dozen full moons. But if you use an infrared transmitter mounted on a 10-meter optical telescope, the beam will be a hundred million times smaller. You would have to be very careful with your aim, even to the point of knowing the orbit of the planet you're trying to signal. Obviously, unless the extraterrestrials know a lot about our solar system and are deliberately targeting us with a broadcast, there's a much greater chance that we'll be in someone's radio beam than in an optical one.

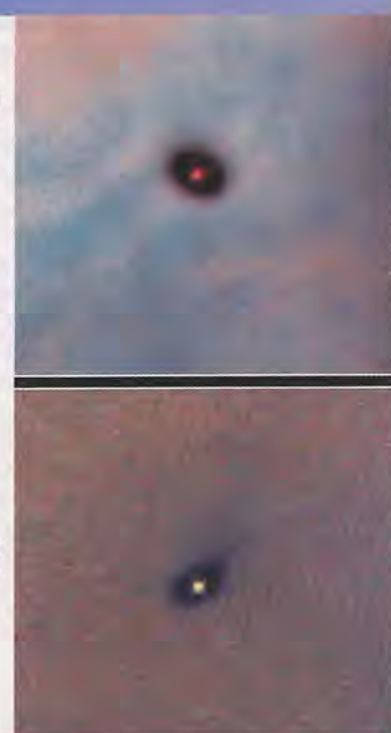
For these and other practical reasons, radio is still the wavelength of choice for SETI. Some optical observations have been made, and Stuart Kingsley in Ohio is running an optical SETI experiment now. But for the moment at least, most scientists are betting on radio.
—SETH SHOSTAK, *SETI Institute*

Why do Saturn's rings look blue-green (A ring) and white (B ring) when viewed relatively face-on (as in early Hubble Space Telescope images) but uniformly brownish when viewed nearly edge-on (as in* Voyager *and recent Hubble images)?
—Dave Hardenbrook, Huntington Beach, California

Factinos

Four protoplanetary disks around young stars (see images at right) have been discovered in the Orion nebula, 1,500 light-years from Earth. Mark McCaughrean of the Max Planck Institute for Astronomy in Heidelberg, Germany, and his collaborator, C. Robert O'Dell from Rice University in Houston, Texas, spotted the new disks in large-scale survey images of Orion that O'Dell had taken with the Hubble Space Telescope between January 1994 and March 1995. As they evolve, these disks may go on to form planetary systems like our own.

The red glow in the center of each disk is a newly formed star, roughly one million years old (compared to the Sun's age of 4.5 billion years). The stars' masses range from 30 to 150 percent of the mass of our Sun. Even the small amount of dust in these disks (about 1 percent) is enough to make them dark and opaque at visible wavelengths. Although only a handful of these dark silhouette disks have been discovered so far, they appear to belong to a much larger family of similar objects. Current indications are that protoplanetary disks are common in the Orion nebula.
—from the Space Telescope Science Institute



These protoplanetary disks surrounding young stars were recently discovered in pictures taken with the Hubble Space Telescope. Each image is of an area 257 billion kilometers (167 billion miles) across, which is about 30 times the diameter of our solar system. The disks themselves range in size from two to eight times the diameter of our solar system.

Each picture is a composite of three images taken by Hubble's Wide Field and Planetary Camera 2. The hot gas of Orion in the background emits strongly at each of these wavelengths, providing a strong backdrop for the disks to be silhouetted against. In each image, the central star is clearly visible.

Images: Mark McCaughrean, Max Planck Institute for Astronomy, and C. Robert O'Dell, Rice University and NASA

If you walk into your local electronics store, you will be greeted by a wall full of television screens showing the same vividly colored images. When you begin to inspect the images more closely, you will notice subtle differences in shadings and skin tones from one set to another. Start adjusting the relative brightness of green and red on a set and you can achieve a fairly wide range of colors, from very unnatural to "realistic." Of course, "realistic" is a subjective judgment.

Astronomers putting together color images face the same problem. Individual images taken through different filters, frequently at wavelengths the human eye cannot detect, are combined in a standard blue, green and red format. Levels are adjusted until the image "looks right." Sometimes an attempt is made to approach the natural colors of objects. Often, contrast is deliberately enhanced to bring out details. This way of looking at data can be a powerful way of seeing, at a glance, phenomena that would be difficult to describe in other ways.

Scientists are also very interested in how an astronomical object's light intensity varies as a function of wavelength—that is, its color spectrum. But for this kind of work, the most powerful tool is a spectrograph that accurately measures the variations in brightness with wavelength on a scale far more detailed than can be perceived by the eye. For example, spectra of Saturn's rings at infrared wavelengths show characteristic dark bands caused by water ice. The explanation for the differences in the images you have described, however, lies with the way the images were produced and printed rather than with Saturn.
—KEITH NOLL, *Space Telescope Science Institute*

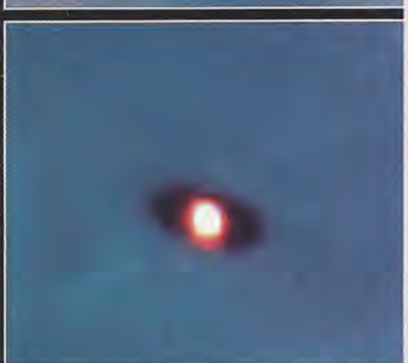
Are distances between planets, or planets and their moons, measured from their centers or their surfaces?
—Jon Siegfus, Norwalk, California

The answer to your question depends in part on the nature of the interaction being discussed. The most common practice, at least within scientific circles, is to designate the distances between body centers, not their surfaces. The gravitational force between two objects is inversely proportional to the square of the distance between their centers. The path traced by the center of an orbiting object is an ellipse with the larger orbited object at one focus of the ellipse. Sometimes, when we are planning a planetary flyby, we don't know the precise size of the target, and so it is impractical to talk about a distance to its surface. This was the situation with almost all the outer planet satellites prior to the *Voyager* flybys of those planets.

On the other hand, it is often more instructive to talk about the altitude (distance to the surface) of an object. For example, we would never consider saying that intercontinental airline flights fly at an average distance of about 6,388 kilometers from Earth's center. Similarly, shuttle flight orbits are usually described by their high and low altitudes above Earth's surface, even though their orbits, like that of the Moon, are primarily controlled by their distance from Earth's center.

A few examples from the upcoming *Cassini/Huygens* mission to Saturn and its largest satellite, Titan, might be instructive. The majority of our Titan, icy satellite, ring and atmosphere studies are of the actual or apparent surfaces of these objects. Since the size of the smallest features that can be seen in images of these objects is dependent on the distance to their surfaces, it has become our practice to talk about Titan or icy satellite flyby altitudes when specifying the characteristics of the spacecraft flybys. The *Huygens* probe, provided by the European Space Agency, will begin its measurements of Titan's atmosphere at an altitude of 170 kilometers above Titan's surface. Since the inner ring of Saturn extends almost to the planet's cloud tops, we sometimes refer to this ring's distance from the cloud tops rather than from Saturn's center.

A possible rule of thumb might be to use "range" to refer to distances between centers and "altitude" to refer to the distance above a planet's or a moon's surface. If the distance is smaller than or comparable to the size of the object, "altitude" is preferable. If the distance is large compared to the size of the object, then "range" is a better term.
—ELLIS D. MINER, *Jet Propulsion Laboratory*



Clues about the potential for life on Mars may exist in microbes that are found deep below Earth's surface, say scientists from the Pacific Northwest Laboratory in Washington State. The researchers found the microbes in groundwater deep under the surface at the Department of Energy's Hanford, Washington, site. Unlike most living things, the microbes do not depend on photosynthesis to produce essential complex organic materials.

"Subsurface lithoautotropic microbial ecosystem"—"SLiME" for short—is what the scientists named their discovery. They found that the microbes might be able to live off rocks alone, as long as those rocks are rich in basalt and iron. These microbes appear to be hydrogen-eating bacteria that get their energy from an interaction between groundwater and the iron in basalt, a rock found on both Earth and Mars.

In theory, this finding could indicate that microbes might exist under Mars' surface if, as some scientists now believe, not all of the planet's groundwater is frozen.
—from Reuters in the *Los Angeles Times*

EXTRATERRESTRIALS

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Are they intelligent?

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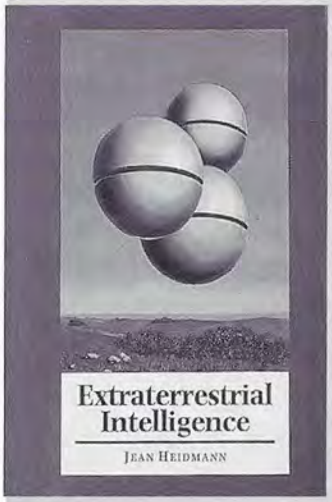

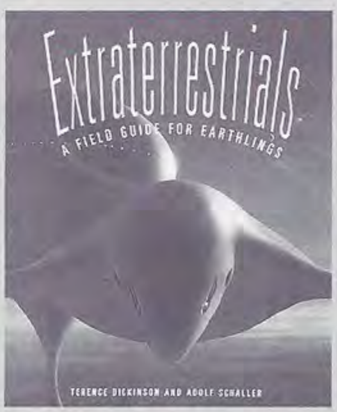


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Before the science, there was the dream: Mars. As a gift to future Mars explorers, a CD-ROM illustrating the dream will be placed on the *Mars '96* spacecraft, now scheduled to launch in November 1996. Created by The Planetary Society, the CD-ROM contains a collection of Earth's best science fiction and art relating to the Red Planet. This is a replica of that CD-ROM. (Windows- and Macintosh-compatible.)
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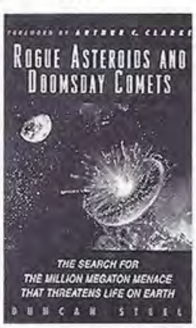

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Space artist Michael Carroll is also a science journalist. His children's book, *Spinning Worlds,* will be published by Victor Books in July.

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