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Monitoring the Milky Way

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COVER: Clouds of stars fill the night sky near the center of the Milky Way. Among the hundreds of billions of stars that make up our galaxy, there may be some that have nurtured life-forms similar in technological development to ourselves—that may be aiming radio beacons in our direction. This is the hypothesis behind Project META, The Planetary Society's search for the radio signals that could tell us that extraterrestrial beings exist.
Image: © ROE/Anglo-Australian Observatory, photo by David Malin

FROM THE EDITOR

The peaceful, early days of summer here at Planetary Society headquarters have not been easy ones for our mail carrier. He's been lugging unusually heavy mail trays into our offices every day.

In our May/June issue, we published a letter by Clay Kallam criticizing the Society for what he saw as an overemphasis on the exploration of Mars. He clearly struck a nerve among other members, for we have been deluged with letters both attacking and supporting his position. We print two more in this issue's Members' Dialogue. (In case you're curious, the letters have been running about 60 percent against Kallam's position.)

An exchange like this is very important to The Planetary Society. To maintain the organization's vitality and to keep members in touch with one another, we have to share our differing views of the Society. So let's keep that mailbag loaded.

—Charlene M. Anderson

Don't Miss Our Annual Sales Catalog!

Admittedly, it will be pretty hard to miss the catalog, since it's bound into the center of this magazine. But please take the time to leaf through it and take a look at the many new offerings.

This is an extremely easy way to begin your holiday shopping, and any profits from the sales department go to support the Society's programs.

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 North Catalina Avenue, Pasadena, CA 91106.

I read Clay Kallam's letter in the May/June 1993 issue of *The Planetary Report* and was pleased to see that it got a real dialogue going. The issue he raises is not just whether we should send people to Mars and other planets, but, more important, the raison d'être for the human exploration of space. Like Kallam, I am afraid that after 30 years of hearing the old science fiction mantra "It is our *destiny* to fly to other worlds—Space is our *final frontier*," popularized by John F. Kennedy and repeated ad infinitum at the start of every *Star Trek* episode, we have come to believe (and enjoy believing) our own propaganda.

Our space race, culminating in *Apollo 11*, was a product of economic and political pressure. President Kennedy didn't talk about new frontiers because it is our destiny to be in space. Rather, he was getting us psyched up for that decade-long "peaceful competition" with the Soviets to get to the Moon first. The Moon race was a product of historical, political, economic and technological pressures and attitudes that will never happen again. So, let's stop comparing it to everything we do in space.

The Planetary Society has tried to bring back the old enthusiasm for space travel by focusing on a human trip to Mars. But the enthusiasm of those days was unique and can't be repeated. That's why there is no equivalent ground swell of public or political support now for a human trip to Mars. At a time when money is just plain tight, there has to be more of a reason for sending humans into space than the call of destiny.

Also, what's the rush? Because we got to the Moon in 10 years, we feel disappointed when we don't get to Mars in 15. Whose timetable are we using? Kennedy's? Captain Kirk's? Critics carp that those who don't advocate a trip to Mars, or wherever in space, lack vision. There are plenty of people with a different kind of vision—one that works right now—that isn't tailored to the 1960s or the 22nd century. It's a vision of sending robotic, cost-efficient probes throughout the solar system. It's a vision of how to truly justify and solve the incredible dangers and costs of putting people into space.

This sounds like the kind of platform The Planetary Society is already working with. There's a long way to go and a lot of work to be done. Maybe, after a while, we *will* find a reason to send humans to Mars.
—JOHN ROUNDS, *Hoboken, New Jersey*

Clay Kallam wrote in the May/June 1993 issue that the urge to colonize Mars should be questioned in favor of a more balanced view of the glories and dangers of space exploration. The issue here is diversity, not just plain curiosity, which automatic probes could satisfy for us. Humankind has reached a point in its evolution where it can choose between a single path on a limited planet, where scarcity of resources will dictate what social evolution will be and an unknown future, but where our full potential as a species should be able to unfold. In space, and on other planets, humans will surely become more diverse—exploring avenues of knowledge and thinking unknown today.

I am not saying that isn't happening right now. But who can imagine what other ways there are? Are we ready to be too cautious and ignore the immediate possibilities? I don't think we should be left thinking about what we might have been. Let's be it.
—RUI SOUSA, *Gaia, Portugal*

I am a retired scientist and have been a strong supporter of space exploration all my life. After reading "A Hopeful Gathering of Planetary Scientists" in the May/June 1993 issue of *The Planetary Report*, I was disappointed to learn that additional probes to the planet Mercury are being considered. It is my opinion that the time, effort and money would be better spent on other projects. Mercury is a burned-out piece of rock, too close to the Sun. On the interesting list of planets, moons, asteroids and comets that can be explored, I place Mercury at the very bottom.
—WALKER RIDEOUT, *Corpus Christi, Texas*

NEWS BRIEFS

Like fans at a cosmic stock car race, astronomers are lining up to watch a historic pileup next summer. In late July they plan to aim virtually every telescope in the world toward Jupiter to see what happens when big chunks of a shattered comet (Shoemaker-Levy) punch into the far side of the planet at almost 40 miles a second, exploding with energy equivalent to almost a billion megatons of TNT. (See the July/August 1993 *Planetary Report.*)

Scientists calculate that the comet train will hit the far side of Jupiter from July 21 to 23, causing repeated flashes over two or three days. Jupiter rotates once every 10 hours, so the impact zone will soon spin into view and they can inspect the results.
—from Kathy Sawyer in the *Washington Post*

Last spring's announcement that NASA would seek Russian help to redesign and build the space agency's beleaguered white elephant of a space station seemed like such a good idea it was almost shocking. . . . The inclusion of Russia could breathe new life into the tired space station project and into the entire once great, once imagination-grabbing American space program. As it turns out, that idea *was* too good to be true. The new space station approved by Clinton and the Congress bears little evidence of that utopian dream. . . .

The space station lurches on, like a fighter out on his feet but held up because he's entangled in the ropes—that is to say, politics. The universe is too big for one nation to rule, even with the dedicated bureaucrats of NASA. The lesson is that we are all humans, earthlings. In space, what matters is not what language you speak but what kind of air you breathe. A truly international space station would be worth the price. . . .

But this is not the best of worlds. This shrunken little station is not the glorious conquest of space once rhapsodized about in these and other pages. If it goes up we will have to listen to years of astronaut hyperbole about the joys of drawing blood from each other in orbit. The space station has stunk up the joint long enough. Let the Russians in or stand aside and let the bum fall.
—from Dennis Overbye in *Time*

Project META

What Have We Found?

by Paul Horowitz

The center of our Milky Way galaxy, in the constellation of Sagittarius, is a spectacular sight in the southern skies.
Photograph by Akira Fujii, taken with a fish-eye lens; reproduced courtesy of Dennis Milon

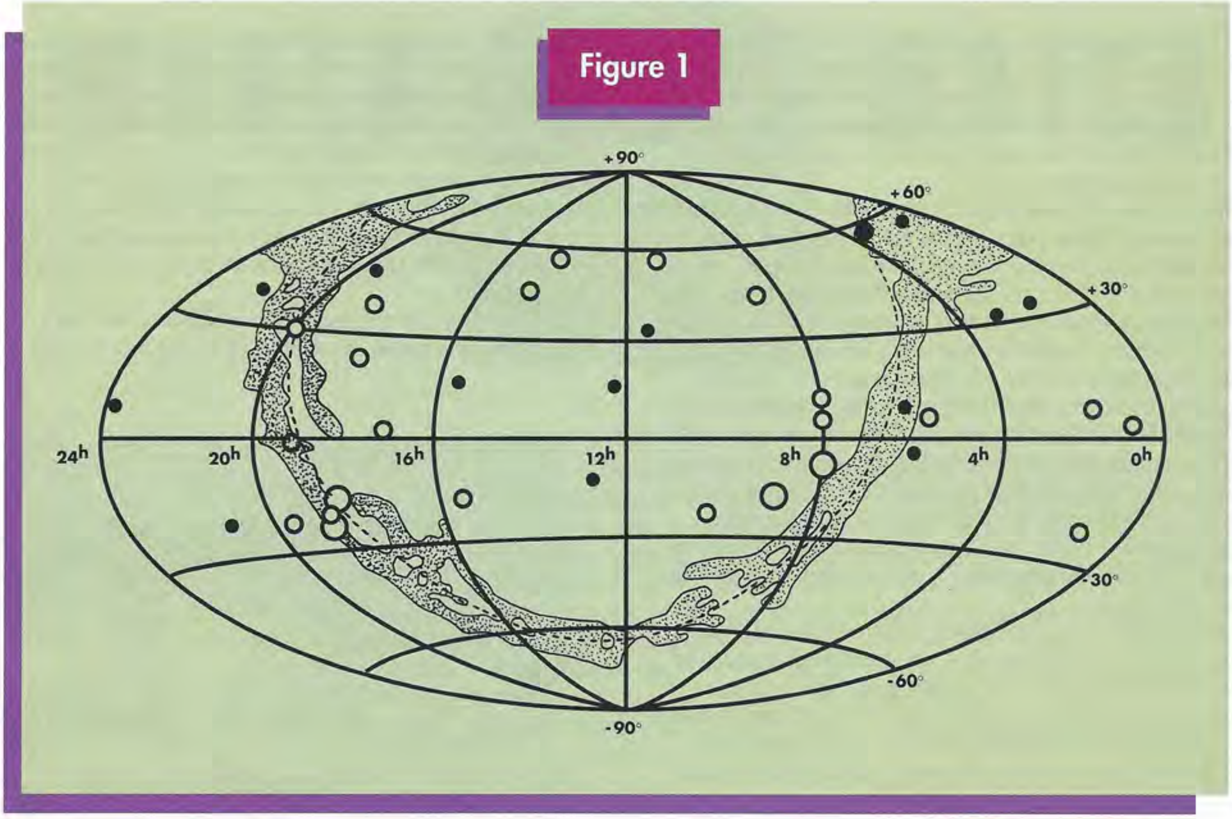


Figure 1. This map of the sky (complete with visible Milky Way and galactic plane) shows where META's antenna was pointed when the 37 candidate signals were received. The filled circles are from observations at 21 centimeters, and the open circles are from observations at 10.5 centimeters. The five strongest signals are drawn larger.
Chart: B.S. Smith

On a brilliantly clear day in the autumn of 1985, Steven Spielberg (following instructions from Carl Sagan, standing nearby) threw an enormous copper knife-switch that formally initiated Project META, the world's first million-channel search for signals from distant intelligent civilizations. META stands for Megachannel ExtraTerrestrial Assay, which is a bit of an understatement since it actually has 8,388,608 channels (plus another 1,048,576 redundant channels to check up on the main bunch).

The name is a good one, though, for a couple of additional reasons. According to my battered *Webster's New Collegiate Dictionary* ("thin paper" edition, with duct-tape-fortified crinkled black cover and gold-edged pages), the Greek prefix *meta* means (among other things) "beyond" or "transcending." Better yet, the acronym's middle initials form the title of a certain movie, whose success has surely contributed to public interest in this unusual search activity; indeed its success may have encouraged its director to show an interest (*financial*, that is), as well—Spielberg's $100,000 contribution to The Planetary Society fully funded the construction and launching of META. Individual contributions by Society members have supported it ever since.

It has now been eight years. What have (or haven't) we found? Before answering that question, it's worth noting that, although a search could hit the jackpot (by finding an alien signal), *no search can ever establish that extraterrestrial intelligence does not exist.* The best we can do, given negative results, is to set some limits on the prevalence of civilizations. And whatever limits we set are riddled with footnotes—"we include only civilizations that choose to broadcast, at the wavelengths we have searched, and with sufficient transmitter power to be detected by our modest technology," and so on.

How META Works

To understand the footnotes, you have to understand the experiment. META's strategy (see the July/August 1987 *Planetary Report*), simply put, is to search the northern sky for an intentional radio beacon, transmitted at a guessable wavelength and corrected for the effects of the sender's motion relative to a handful of guessable frames of reference. On Earth, we usually don't worry about relative motions when we try to communicate: I can shout an understandable greeting to a passing jogger. With care I may notice the Doppler effect, for example in the changing pitch of a passing ambulance's siren.

On astronomical scales, however, the velocities are enormous—hundreds of kilometers per second within our galaxy alone, and much larger between galaxies—causing analogous Doppler shifts that would cause us to miss the carefully chosen beacon wavelength. Miss it, that is, unless we (and the sender) correct for our motions relative to a common frame of reference. We are freight trains in the night, but we each know our own speed over the ground, our common frame of reference on Earth.

We *know* that META's strategy could work—it is a straightforward radio engineering calculation to demonstrate that Earth could thus signal to a similarly equipped sister planet anywhere in our galaxy of 400 billion stars, or that telegrams to any of the nearest million stars cost less than a dollar per word. But then the *footnotes*, again—they have to point their antennas directly at ours, and vice versa; we have to choose the same wavelengths; and we have to listen at the right time.

META does the best it can. Some of the best brains on Earth (those of Giuseppe Cocconi and Philip Morrison, to be precise) have guessed a compelling wavelength, namely 21 centimeters: That's where neutral hydrogen, the stuff of the universe, emits radio signals naturally. It also happens to be a wavelength almost completely devoid of cosmic static. It has been our favorite (though not only) choice. Similarly, we found three frames of reference irresistible: the center of gravity of the galaxy, the average motion of nearby stars, and the uniform bath of "cosmic microwave background" left over from the Big Bang. The rest is engineering, and patience. We designed and built the megachannel receiver, with lots of student labor (a half-million solder joints, all done by hand!), and we started collecting data.

One of META's early findings is that there *is* life on Earth, and that it is sufficiently advanced, technologically, to launch radio signals into our antenna. Although one can argue about whether such activity reveals real intelligence, one still has to do something about it. The mitigation of RFI (radio frequency interference) is probably the central problem of SETI; every search has struggled with it, generally with mixed success. META's strategy is unusual, and pretty good.

Here's how it works: By good fortune it turns out that the galaxy is especially kind to radio signals at these wavelengths, allowing them to travel thousands of light-years with only the slightest degradation of their purity; it also adds almost no noise of its own. META is matched to the properties of the signal that would finally arrive on Earth—a "narrowband carrier" in technical jargon, the purest radio note that can be generated, broadened by only fractions of a hertz in its journey of several millennia. That makes META very sensitive. It also makes it discriminating, because Earth's rotation, in cooperation with the Doppler effect, endows an extraterrestrial carrier wave with a characteristic signature, in the form of a changing, and precisely predictable, variation of wavelength.

Results

META has now covered the sky five times, variously looking at the celebrated 21-centimeter wavelength, and also at its closest relative, its "second harmonic" at 10.5 centimeters. (Alien beacon builders might choose to forbid transmissions at the precious 21-centimeter wavelength, to keep it clear for radio astronomy. That's what we do, by international agreement, on Earth.) And META's garbage can is bulging, with a hundred thousand billion channels—8 million every 20 seconds, for six years—having been sifted through. Of those, META only keeps what it judges to be the most interesting; it's especially impressed by strong signals, and always puts them into the archives, along with whatever immediately follows. That works out to about a million candidates over the duration of META's life on Earth.

With the dedicated assistance of Nancy Hecker, a graduate student at Harvard, we first boiled down this residue to a few thousand "events," mostly by being less gullible than META's computer: Primarily we insisted that signals show none of the telltales of interference. For example, a signal that persists for 20 minutes cannot come from space, because any point in the sky spends only 2 minutes passing through our antenna's beam on its diurnal journey. Then, by applying further stringent criteria, we reduced our list to 74 candidate events that displayed the most important characteristic—a strong narrowband carrier, captured by a receiver that is deliberately insensitive to signals that do not display the correct Doppler signature of an extraterrestrial transmission.

Seventy-four out of a hundred thousand billion isn't much! But, given that the detection of just one beacon

SETI From the Southern Hemisphere

On Columbus Day 1990, just five years after META I began, The Planetary Society extended its Search for Extraterrestrial Intelligence to the southern hemisphere with a project known as META II. On that day, the Argentine Institute of Radio Astronomy began its Society-sponsored SETI program: scanning the southern skies with an 8.4-million-channel spectrum analyzer located near Buenos Aires.

As with META I, Society members provided the new project's funding. Under Paul Horowitz's supervision and following an agreement with Argentina's National Research Council, Argentine engineers Eduardo Hurrell and Juan Carlos Olalde built the system at Harvard University. Institute of Radio Astronomy Director Raul Colomb and Planetary Society Executive Director Louis Friedman turned on the system's power in 1990, and since then META II has observed the skies for about 9,000 hours and has sifted through some 12,000 gigabytes of signal data.

Complementing META I's search from the northern hemisphere, META II "listens" for signals in the southern hemisphere. The antenna scans up and down from a declination (celestial latitude) of minus 10 degrees to minus 80 degrees. Then, with the antenna fixed at the meridian, the system records signals at intervals from 0 to 360 degrees in right ascension (celestial longitude) as the Earth rotates. This represents nearly 1.6 million independent spectra, each consisting of 8.4 million channels (about 12,000 gigabytes all together). After determining that most of the signals are unimportant, the system throws these out, saving only about 0.5 megabyte per month.

Looking carefully at the META II data that re-signal from an intelligent extraterrestrial civilization would be the greatest discovery in the history of the human race, we can't afford to be cavalier. Each event has to be thoroughly investigated. We did two things. First, we hunted through catalogues of stars and other known astronomical curiosities, looking for clues. Nothing interesting there, though a plot in sky coordinates suggested a concentration in the galactic plane. Second, we looked more deeply into the family tree of each remaining event—what had happened just before, and after? Were any signals seen simultaneously at related wavelengths? Had META's redundant electronics reported any processor errors recently? Had the neighbors noticed anything unusual? And so on.

In the report of the Special Prosecutor for Suspicious Events, a number of reasons were cited (often in combination) for the elimination of 37 of the 74 candidate events. By digging deeply into the archives, we found clear evidence that some of these putative signals had persisted far longer than the 2-minute drift time, but hadn't been filtered out because the continuing signals fell below the normal threshold. In other cases, a series of signal events displayed a progression of received frequencies corresponding precisely to a terrestrial transmitter of fixed frequency; in a few cases, the pattern seen could only be produced by signals entering the receiver after the "second local oscillator," a portion of the electronics far from the antenna. Additionally, four of the original 74 candidates were unmasked as counterfeit by the redundant processors used for checking. This kind of sleuthing found smoking guns in exactly half the cases, leaving 37 events without conventional explanation. They are shown in Figure 1 (page 5).

Shrewd readers are surely wondering why we don't do the obvious—look *again* at places where the antenna was pointed when we've gotten interesting signals. Well, we do! If a large signal is detected, META returns to the frequency band and reference frame in which it was first seen, approximately 40 seconds after initial detection, and continues for 3 minutes (after which the source will have drifted out of the antenna's beam). Also, we often leave the antenna's declination (the north-south position of its search beam) unchanged for a second day, if we notice a suspicious event. Moreover, with astronomer Joe Caruso's help, we carry out manual reobservations—with the antenna tracking the source location for several hours—for the best candidates collected during the previous year. None of our 37 surviving candidates has ever repeated.

Are We Alone?

What does it all mean? Well, as much as we might have hoped otherwise, the sky apparently is not teeming with civilizations beaming messages at us. That may not surprise too many readers. But there's a stronger limit set by META's results, because the presence of a *single* powerful (and continuously running) transmitter, of the sort we seek, is all that's really required. Can it be that, among the 400 billion stars that comprise the Milky Way, not a single one harbors a highly advanced civilization?

Carl Sagan and I have pondered this question, and we find META's results surprising. (Our article on the subject will appear in September's *Astrophysical Journal.*) First some history, to set the stage.

Back in 1964, the Russian astrophysicist Nikolai Kardashev classified highly advanced civilizations according to how much energy they consume. Let us adopt similar Kardashev-like definitions of energetically extravagant civilizations, calling a Type I civilization one that uses power comparable to the solar power falling on Earth (in round numbers, 10^{17} watts, for which astronomer Tom Bania has coined the acronym "twit": total watts incident, terrestrial). A Type II civilization would be one that has harnessed the total output power of its sun (10^{26} watts). (Kardashev actually went one better, talking of Type III civilizations, which harness the entire power of their *galaxy*!) To these let us add ourselves, a humble civilization of Type 0, with planetary power resources of a mere 10^{13} watts.

META's nondetection says the following about civiliza-

mained, we found that 80 percent of the signals that might have been of extraterrestrial origin were radio interference, equipment malfunction or just plain noise that was louder than the usual space static. However, about 60 peaks were inexplicably louder than the average noise. We are examining these signals to figure out where they came from, and we plan to reobserve the skies in their direction.

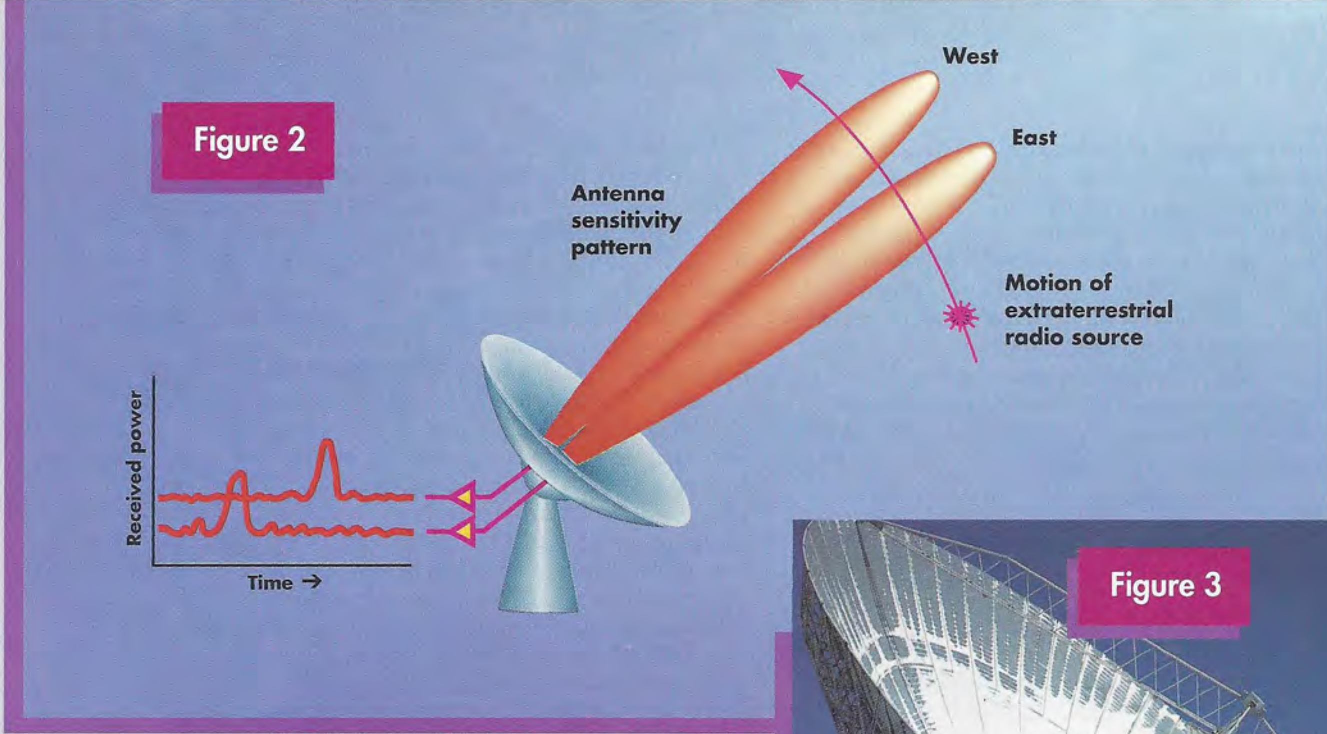
This reexamination and reobservation won't be easy. META II takes twice as long as META I to complete a full survey of a celestial hemisphere, since META II operates only 12 hours a day. Researchers working on other projects use the telescope during the remaining time.

But both META systems can survey the entire sky at 1420 megahertz with consistent spectral resolution and sensitivity. This frequency is one of the proposed "magic frequencies"—wavelengths that correspond to the frequency of the hydrogen atom, which other civilizations might use as an interplanetary communication channel.

In fact, META II might be able to coordinate its efforts with META I. As Paul Horowitz and Carl Sagan have noted, the most promising candidate signals are very brief, typically lasting only 20 to 100 seconds, which is certainly not enough time to call other observatories to confirm the event. However, META I and II scientists can observe certain portions of the sky—the fringe between declinations minus 10 degrees and minus 30 degrees—simultaneously and with the same spectral resolution and sensitivity. If both systems record a candidate signal at the same time, we are more certain that it does not have a terrestrial origin, because it's unlikely that interference would occur at both places simultaneously.

In addition to reobserving the events we have already detected, we intend to make a second run of the southern hemisphere survey, observe the nearby stars and possibly cover other frequencies. In the future, we expect to build a new front end (a receiver that will observe signals in other frequencies) and improve our antenna surface so we can observe signals at higher frequencies. We're working toward making these improvements as we gradually expand and refine our continuing search.

Fernando Raul Colomb, Eduardo Hurrell, Guillermo Andres Lemarchand and Juan Carlos Olalde, Argentine Institute of Radio Astronomy



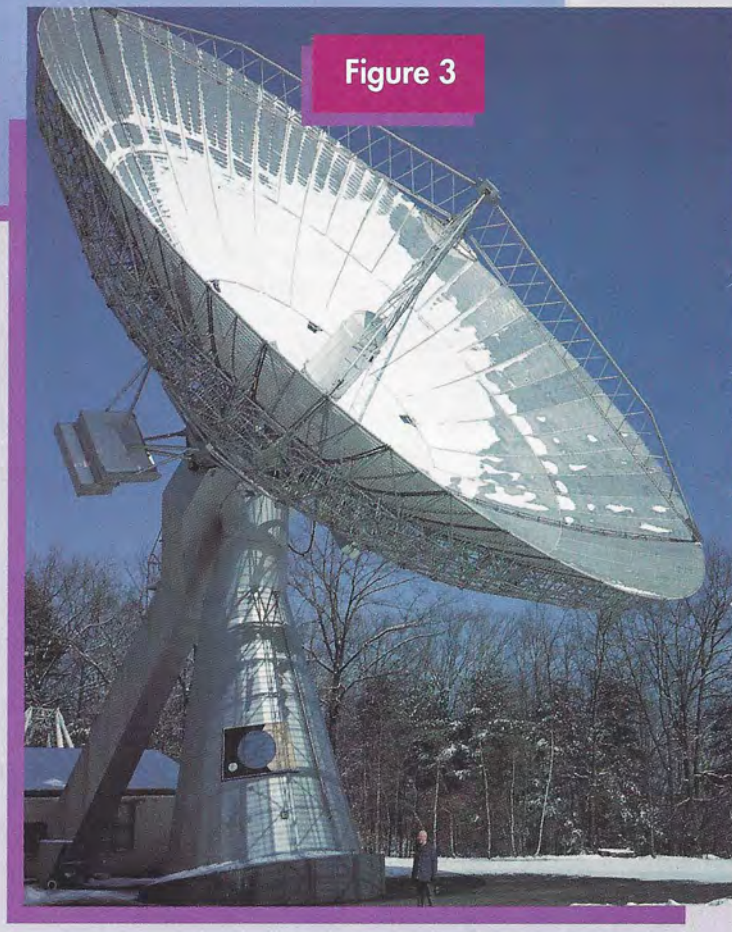


Figure 2. With BETA's dual-beam strategy, a real signal coming from the sky must pass through the two antenna "lobes" in the correct sequence, with correct timing. It must also not be seen by a third terrestrial antenna. Illustration: B.S. Smith

Figure 3. A visitor lends scale to the Harvard/Smithsonian 84-foot radio telescope at Oak Ridge Observatory, here shown after a light snow. The flag of Earth was planted by Mal Jones and Mike Williams, who are responsible for the antenna's gleaming appearance. Photograph: Paul Horowitz

tions transmitting continuously at our wavelength (and using everything they've got to run their transmitter!): There are *no* Type 0 civilizations within 25 light-years (that includes about a dozen Sun-like stars) broadcasting uniformly in all directions (omnidirectionally), and there are none anywhere in the galaxy beaming our way with an antenna as large as the great Arecibo radio telescope, which is 300 meters (1,000 feet) in diameter. For Type I, there are none out to 2,500 light-years transmitting omnidirectionally (that volume includes about 10 million Sun-like stars), and none anywhere in the galaxy beaming our way with even a modest (6 foot or larger) backyard antenna. Type II civilizations don't need to bother with beaming at all—we'd hear from them, transmitting omnidirectionally, out to 70 million light-years (which includes the 400 billion stars in our galaxy, plus another 100 trillion stars in neighboring galaxies). Based on META's results, it's safe to say that there are no Type II civilizations in our galaxy that are transmitting omnidirectionally and continuously at the 21-centimeter wavelength, and using a significant portion of their available power for the task.

When thinking about our planetary loneliness implied by these grand statements, please remember those *footnotes*, again: META only looks at a tiny portion of the radio spectrum, for a certain kind of signal, transmitted to reach our antenna when we happen to be pointed in their direction. Of course, you can handle the timing business by saying something like "the number of Type I's in the galaxy, multiplied by the fraction of time they transmit toward us, is less than 1." But there's no way to quantify the effect of a bad guess: If they happen to be fond of infrared lasers, and we're looking for microwaves, then all bets are off!

META has shown that it is possible to run a powerful million-channel search program at modest cost, and with good resistance to terrestrial interference, if we are willing to confine our attention to a particular choice of wavelength and signal type. But it is a weakness of the META system that it is unable to track the position of a candidate signal immediately (hence the residue of the 37 unrepeatable candidates). And, in retrospect (meaning we haven't found anything!), META has been rather myopic in its insistence on narrowband carriers at the magic wavelength of 21 centimeters.

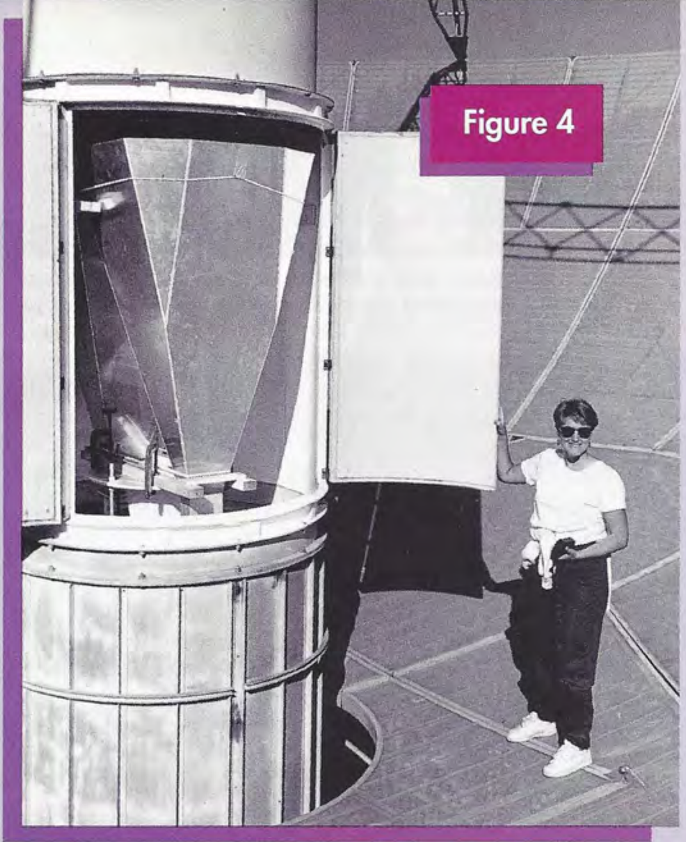


Figure 4. This is what the dual feedhorns look like, in their fiberglass radome. That's Alicia Falsetto, from the Bosack/Kruger Foundation (which is helping to support our students), providing a scale of size. Photograph: Paul Horowitz

Figure 5. BETA is growing! The electronic equipment shown here converts the analog radio signals received by the antennas to a stream of 240 million numbers (bytes) per second, in preparation for the digital spectrum analyzer and signal recognizer, which together perform about 25 billion operations per second (25,000 MIPS). Photograph: Paul Horowitz

Next Steps

Enter BETA (Billion-channel ExtraTerrestrial Assay), our newest scheme to find those elusive signals that we believe must be lurking. BETA fixes META's myopia by covering 1,000 times the wavelength range, and it fixes META's inflexibility by having two antenna beams pointed up in the sky. Specifically, BETA's 240 million channels (OK, it's not really a billion. But, heck, it's closer to a billion than a million!) cover the whole "water hole," the range of wavelengths between H and OH (HOH is water), and its two beams, oriented east and west of each other, force a real source to run the gauntlet, at a rate determined precisely by Earth's rotation (see Figures 2 and 4; Figure 3 shows our dish at Oak Ridge Observatory). In fact, a third terrestrial antenna acts as an additional veto, to reject the sea of human signals in which we are immersed.

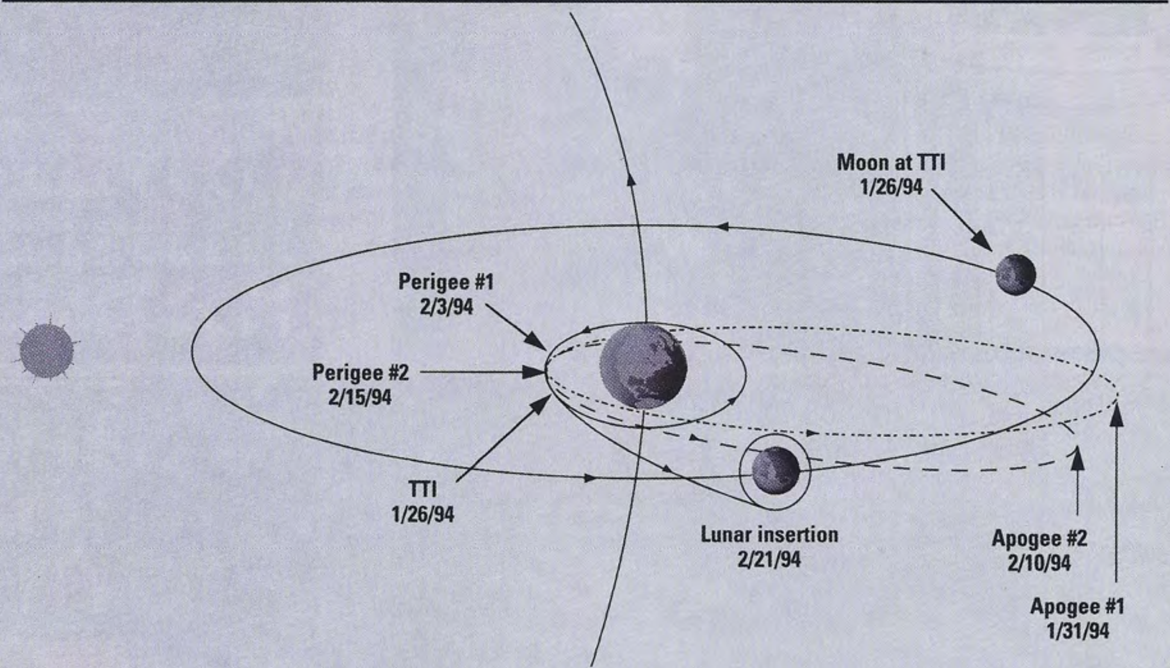
We are assembling BETA right now, as a joint venture of The Planetary Society, NASA and the Bosack/Kruger Foundation, and we hope to have it running within a year. It's going together nicely, and, to us at least, it is a beautiful sight. (Look at Figure 5 and see if you agree!) BETA will break new ground in many ways. It combines the high resolution of NASA's targeted search with the coverage of the sky survey (the two parts of NASA's High-Resolution Microwave Survey, or HRMS, SETI project). By employing a novel three-antenna arrangement, it provides a complementary search strategy. And, especially important to us at Harvard, it is an ideal topic for university research: It combines aspects of several sciences with radio astronomy, communication, and computer technology, in pursuit of what we believe is the boldest venture in the history of the human race.

We are indebted to the many members of The Planetary Society for more than a decade of your continuing and faithful support.

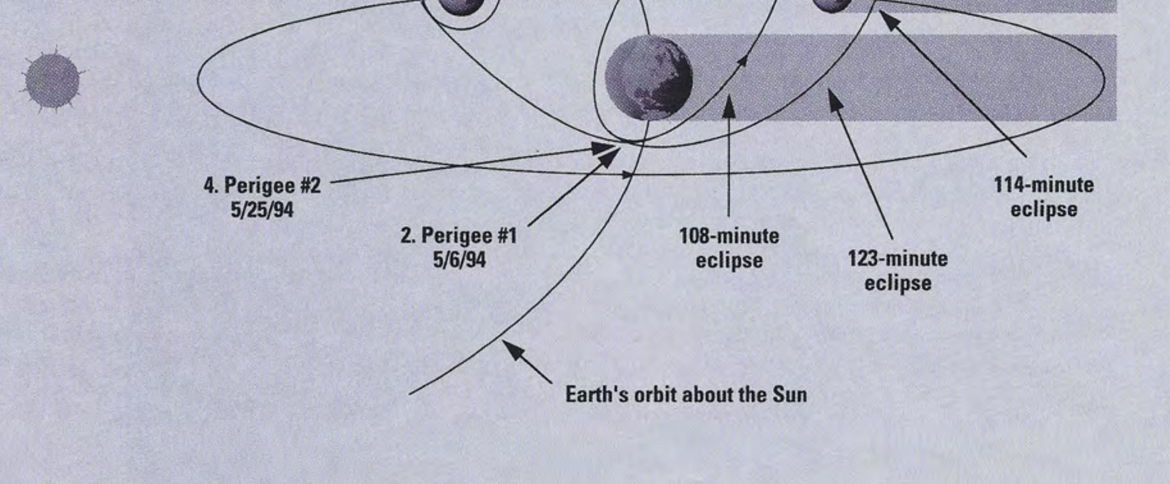
Paul Horowitz is a professor of physics at Harvard University, where he teaches courses in physics and electronics. He is coauthor (with Winfield Hill) of The Art of Electronics, *and lives outside Boston with his wife, Carol; sons, Jacob and Misha; and golden retriever, Cayenne.*

BACK TO THE MOON,

Lunar Orbit Insertion Overview



Trans Geographos Trajectory Insertion



ON TO AN ASTEROID:

THE CLEMENTINE MISSION

CHARTS ON PAGE 10: Clementine *will follow a very complicated path on its way to the Moon and the asteroid Geographos. The spacecraft will leave low Earth orbit on January 26, 1994 (TTI for Translunar Trajectory Insertion). It will then make two looping orbits around Earth (the perigees, the closest points to Earth, and the apogees, the most distant points, are indicated) before its insertion into lunar orbit on February 21. During this perambulation, the spacecraft will swing under Earth's shadow.*

On its way to Geographos, Clementine *will have to pass through the shadows of both Earth and the Moon. These passages will stress the spacecraft support systems, so project engineers had to design supporting subsystems to help ensure* Clementine*'s continued health. On May 3, the spacecraft will leave lunar orbit, then loop around Earth, swing back by the Moon and finally head out to encounter the asteroid.*

Charts: Naval Research Laboratory

BY STEWART NOZETTE AND EUGENE M. SHOEMAKER

In early 1994, after a lapse of more than 20 years in lunar exploration, the United States will once again place a spacecraft in orbit about our nearest neighbor. Popularly called *Clementine*, this spacecraft will spend about two months mapping the Moon and will then travel on to encounter the near-Earth asteroid (1620) Geographos.

Although the spacecraft will return valuable scientific data, planetary exploration is not *Clementine*'s raison d'être. The mission's primary purpose is to space-qualify a set of lightweight electronic cameras for the Department of Defense to use in detecting and tracking ballistic missiles. For over three decades the department has used satellites to monitor missile movements and launches. *Clementine* will test some of the technologies that could be incorporated into the next spacecraft generation, which will be lighter and cheaper than previous systems.

In 1990, NASA recognized that a mission to test the new lightweight technology might also make scientific observations of the Moon or near-Earth asteroids. The Strategic Defense Initiative Organization (SDIO; now renamed the Ballistic Missile Defense Organization), which was looking into the project, began to explore that possibility with NASA in 1991, envisioning not only the direct return of scientific information but also the development of lightweight spacecraft components for use in NASA's Discovery class of inexpensive spacecraft or in missions such as the proposed fast flyby of Pluto.

The satellites that the Department of Defense has been using to monitor Earth from space have been relatively massive and expensive, require large launch vehicles of the *Delta*, *Atlas* or *Titan IV* class and send all their data to the ground for analysis. SDIO began to investigate smaller, lighter, cheaper sensor platforms compatible with smaller launch vehicles. Such satellites could be built and deployed quickly to distant locations to monitor local situations. (In November 1992, one experimental satellite, MSTI 1—for Miniature Seeker Technology Integration—was launched into Earth orbit by a small NASA *Scout* vehicle.)

For small sensors to do the job of monitoring, the laws of optics require the spacecraft carrying them to be in low-altitude orbits to obtain the necessary image sharpness (resolution). Such spacecraft must also be numerous to maintain continuous surveillance of sites from low orbit. This approach requires mass production, as opposed to the custom building of one or a few spacecraft, which has been the rule to date.

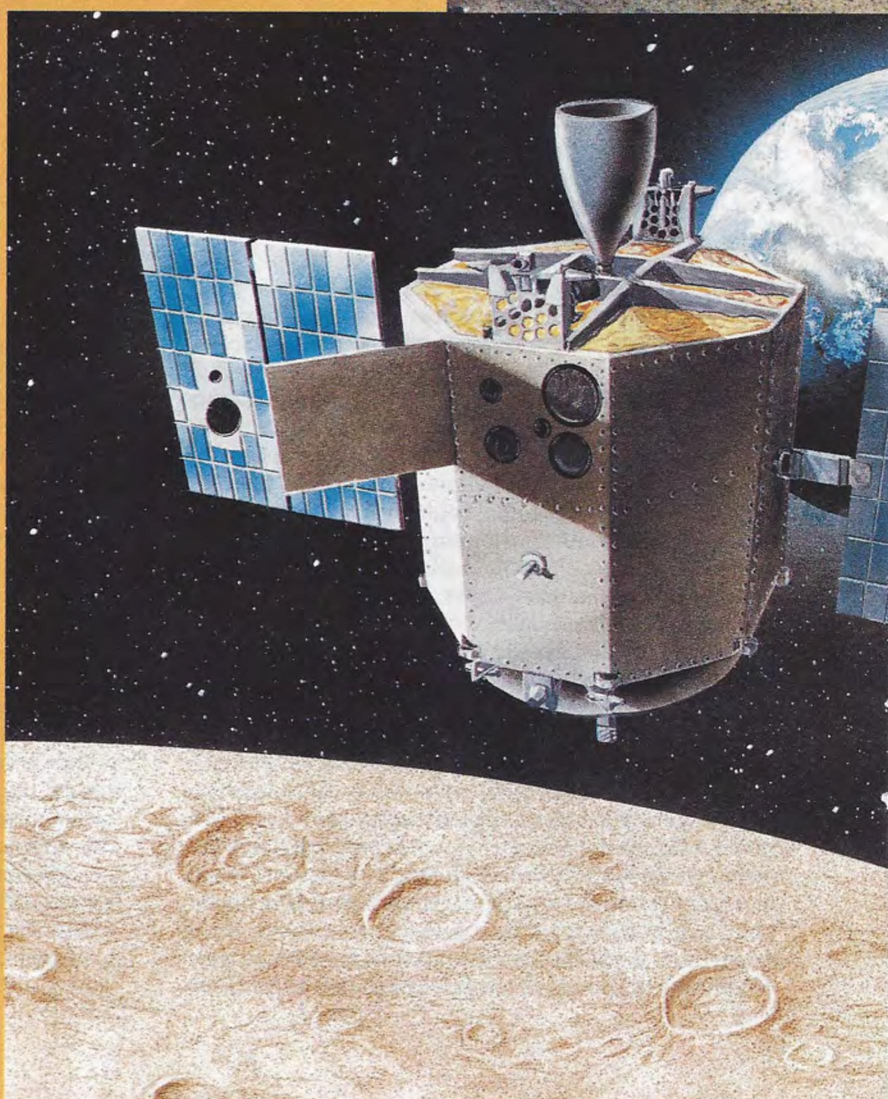
With the technology available today, small spacecraft can process, on board, vast amounts of data, and they can

(continued on page 14)

Approaching Geographos

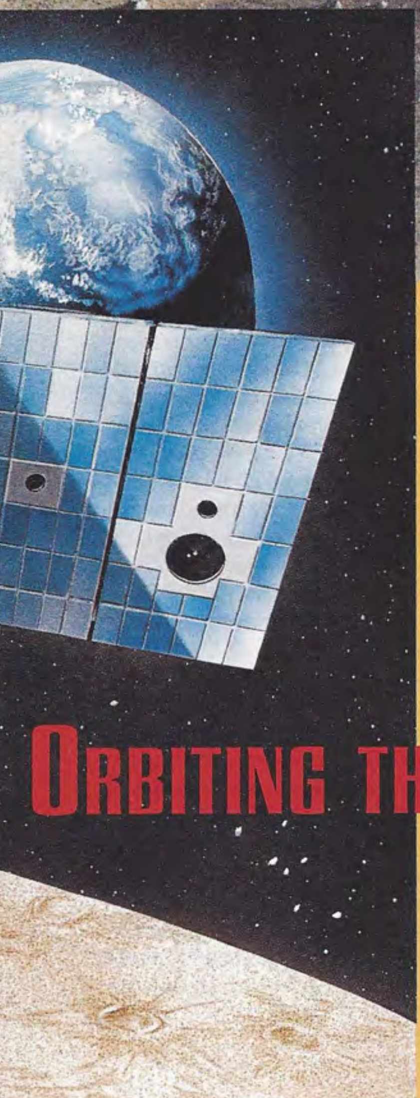
The asteroid Geographos is an elongated hunk of rock some 3 to 4 kilometers long and 1.5 kilometers wide. Its orbit carries it across the orbit of Earth, placing it in the class of Apollo asteroids. Clementine's cameras will gather over 2,000 images of this asteroid and should tell us much about its nature and history.

Painting: Don Davis



TARGET: THE LUNAR SURFACE

Humans have crashed spacecraft into it, sent instrumented platforms to orbit it, landed robots upon it, and even walked upon it. But our knowledge of our closest neighbor is still incomplete. We have direct evidence about its composition from only a few sites where Surveyor, Luna *and* Apollo *landed, or over which* Apollo *flew.* Clementine *will give us detailed data on the entire lunar surface.* Painting: Kazuaki Iwasaki



ORBITING THE MOON

During its time in lunar orbit, Clementine *will map the various rock types and geologic features that make up the Moon's surface. The spacecraft will add to the store of knowledge gathered by its predecessors,* Ranger, Luna, Surveyor, Lunar Orbiter *and* Apollo, *and pave the way for the* Lunar Scout *that NASA hopes to dispatch to survey the lunar surface in great detail.* Painting: James Gray

(continued from page 11)
identify and track objects. It is now possible to construct a lightweight spacecraft that carries computers equivalent to one-third of a CRAY 1 supercomputer, with memory equivalent to 200 megabytes of hard disk, and an array of imaging sensors operating in the ultraviolet, visible and infrared portions of the spectrum. Such a spacecraft can be likened to a rocket-powered camcorder combined with a super laptop computer and tied into a cellular telephone.

Testing the Components

To prove that the sensors, computers and other subsystems can actually perform their missions, they will have to be tested in space for long periods. Suborbital flights lasting only a few minutes won't do the job. Furthermore, the spacecraft components must prove their ability to use data collected on board to operate without help from Earth. Power storage also needs to be checked out. The hazards to be overcome include cosmic and solar radiation (which can degrade all solid-state electronics), repeated heating and cooling, and wear on moving parts such as filter wheels, which are small wheels with openings for various color filters that can be rotated into the optical path of a camera.

To test a spacecraft's vulnerability to cosmic radiation, in a reasonably short time, it needs to be exposed to relatively intense radiation. To accomplish this, it could be placed in geosynchronous orbit or sent on a looping, elliptical orbit, such as a geostationary transfer orbit, which would take it repeatedly through Earth's Van Allen radiation belts (belts of high-energy electrons and protons that are trapped in Earth's magnetic field). However, to test the sensors under these conditions, artificial targets would have to be launched.

As these test options were being considered, another possibility emerged: Why not send the spacecraft out into deep space for a long-duration flight to locate and track natural objects? Reasons for doing so were compelling. The radiation environment would be realistic and stressing. Testing the sensors on natural objects would eliminate the need for artificial targets, with their extra launch and tracking costs. The sensors' performance could be measured by using targets having known spectral characteristics. Moreover, the launch requirements would not be much more than what a geosynchronous orbit or highly eccentric Earth orbit would call for. Long-term autonomous navigation and operation in deep space would stress the onboard computers to their limit.

Such a test would be designed to comply with the antiballistic missile (ABM) treaty, and nothing would be done in deep space that was not treaty-compliant near Earth. The spacecraft would have no capability to act as an ABM radar or to intercept a missile.

An excellent target would be a near-Earth asteroid. Moreover, it would be possible to go to lunar orbit either before or after the asteroid flyby. The late August 1994 opportunity provided by the Apollo asteroid (1620) Geographos seemed just the ticket. Apollo asteroids cross Earth's orbit on their travels around the Sun, and Geographos' close approach would make communication with Earth easy during and after encounter.

Clementine Takes Shape

In January 1992, SDIO informed NASA of its intent to fly a Deep Space Program Science Experiment—*Clementine*. NASA then formed a science working group to help develop the mission. The Naval Research Laboratory is in charge of the overall mission design and operations, with support for the design being provided by NASA's Goddard Space Flight Center and Jet Propulsion Laboratory. NASA's Deep Space Network will track and communicate with the spacecraft. Following a recommendation of the National Research Council's Space Studies Board, NASA competitively selected a formal science team in early 1993.

Without its load of propellant, *Clementine* weighs about 220 kilograms (500 pounds). The lightweight craft will be launched on a refurbished *Titan IIG* missile. SDIO's goal is to build *two* spacecraft, including the sensors, for less than $100 million. The total time between the decision to proceed and the launch will be two years. For comparison, missions in NASA's proposed Discovery program are planned to cost no more than $150 million (exclusive of the launch vehicle) and take no more than three years for development.

The mission time line calls for launch on January 24, 1994, with the spacecraft entering lunar polar orbit on February 21. On May 3, *Clementine* will escape from lunar orbit, and it will transfer onto a trajectory to Geographos on May 27. It will encounter Geographos on August 31 in a fast flyby (10.7 kilometers per second, or 24,000 miles per hour) at a planned miss distance of 100 kilometers (60 miles).

Clementine's Capabilities

Clementine will carry instruments that are sensitive in several portions of the electromagnetic spectrum. This ability to "see" in different kinds of light is what makes the spacecraft interesting to the scientific community. *Clementine*'s instrument complement, developed and calibrated by the Lawrence Livermore National Laboratory, includes an ultraviolet/visible charge-coupled-device (CCD) camera, near-infrared and long-wavelength infrared cameras, and a combined high-resolution CCD camera and laser ranging system (LIDAR).

The mission is designed to obtain complete coverage of the Moon with the ultraviolet/visible and near-infrared cameras in 11 narrow-wavelength bands distributed through the visible and near-infrared parts of the spectrum. Ten of these bands were selected by the science working group to obtain optimum discrimination of different types of rock on the Moon and on Geographos, using the available number of filter-wheel positions on the cameras. Common rock-forming minerals found on the Moon and in meteorites can be identified by their "color" in the visible and infrared parts of the spectrum. In particular, the major silicate minerals are recognized from their absorption of particular colors in the near infrared from sunlight reflected from the Moon and from asteroids. Thus rocks, which are composed of various proportions of these minerals, can be distinguished and mapped by means of the multispectral images to be taken with the *Clementine* cameras.

As the spacecraft orbits the Moon, its cameras will be pointed directly down toward the lunar surface most of the time when it is passing over the sunlit side. At high latitudes, however, images will also be taken at oblique angles. The spacecraft's altitude at closest approach to the Moon will be 425 kilometers (260 miles). Resolution at this distance will be about 100 meters (300 feet) per pixel (picture element) in the visible wavelength images and 150 meters (500 feet) in the near-infrared images. The LIDAR camera will take long strings of images with a pixel resolution of about 10 meters (30 feet). It will also take range measurements (measurements of the distance from the spacecraft to the lunar surface) with a precision of plus or minus 40 meters (130 feet) at intervals of about 1 kilometer (0.6 mile) along the subspacecraft track.

The LIDAR may also be operated in the "burst" mode to take up to eight range measurements per second. Near the poles, the high-resolution LIDAR camera will provide a very detailed picture of the topography and geologic structure of the lunar surface. Early and late in the lunar part of the mission, the camera will be used to take mosaics of high-resolution frames covering various *Apollo* and *Surveyor* landing sites.

In Lunar Orbit

A rich store of scientific information will be returned by the *Clementine* spacecraft during the two months it spends in lunar orbit. The total amount of data will be comparable with that transmitted from the *Magellan* spacecraft during its first radar mapping cycle of Venus. The *Clementine* data will fill a small library of compact discs that will be distributed to NASA's Planetary Data System, which is a nationwide system of repositories for data returned from the lunar and planetary flight projects, and will be widely available to lunar and planetary scientists.

A successful *Clementine* mission will lead to the next step in our understanding of the Moon. The *Ranger, Luna, Surveyor, Lunar Orbiter* and *Apollo* missions of the 1960s and early 1970s provided the foundation for our present knowledge of lunar geology. But our information on the composition of the lunar surface is limited mainly to the *Surveyor, Luna* and *Apollo* landing sites and along the ground tracks beneath the *Apollo* capsules as they orbited the Moon's equatorial regions.

We know that the structure of the lunar crust is very complicated and that the early history of the Moon was complex. *Clementine* will provide high-resolution data on the rock types and geology of the entire lunar surface. Years of research will be needed to fully decipher these data. It is to be hoped that the *Clementine* mission will be followed by NASA's *Lunar Scout*—a pair of polar orbiting spacecraft that will provide, among other things, a survey of the elements that make up the lunar crust and very high resolution images of the Moon's surface features.

At Geographos

Clementine's encounter with Geographos will permit the first close view of an Apollo asteroid. Geographos has an unusually elongate body, about 3 to 4 kilometers (2 to 2.5 miles) long and 1.5 kilometers (1 mile) wide, as estimated from ground-based observations. Most Earth-crossing asteroids are thought to be fragments produced by collisions between bodies in the main asteroid belt between Mars and Jupiter and later perturbed into Earth-crossing orbits. Very possibly, Geographos consists of a few large fragments and perhaps fine collisional debris, all weakly bound by gravity. Steve Ostro of JPL has taken radar images of another Earth-crossing asteroid, (4179) Toutatis, that show it also to be elongate and made up of two or more pieces. (See the March/April 1993 issue of *The Planetary Report*.) These images suggest that the shape of Geographos and other Earth-crossers might be much more complex than previously suspected.

Clementine will approach Geographos from the dark side, at an angle about 40 degrees away from the direction to the Sun. When the spacecraft gets close enough to pick out details with its cameras, the sunlit side of the asteroid will appear as an irregular crescent. *Clementine*'s cameras will be programmed to automatically lock on the asteroid while passing from the dark to the sunlit side at close range.

As the spacecraft whips by, most of the illuminated side of the asteroid will come into view. At closest approach, about 100 kilometers (60 miles), the pixel resolution will be about 30 meters (100 feet) with the ultraviolet/visible camera, 40 meters (130 feet) with the near-infrared camera, and roughly 1 meter (3 feet) with the LIDAR camera. The long-wavelength infrared camera will obtain images of both the dark and sunlit sides with a best pixel resolution of about 8 meters (26 feet).

Altogether, *Clementine* will take more than 2,000 images at Geographos and store them on board in the solid-state memory for later playback to Earth. Those acquired at close range, when combined with LIDAR measurements, will enable an accurate determination of the asteroid's size and shape. The high-resolution images will also provide the basis for study of the composition, surface properties, structural features, cratering history and age of Geographos as an independent body in the solar system.

The Promise of the Prospector's Daughter

The *Clementine* mission can help point the way to new approaches in solar system exploration. It is vital that we learn to do things "faster, cheaper and better." Relatively inexpensive, lightweight spacecraft present a means of sustaining a healthy exploration program into the future.

Stewart Nozette is deputy for sensor integration for the Integrated Sensor Experiment at the Ballistic Missile Defense Organization's Innovative Science and Technology Office, and Eugene Shoemaker is a research geologist with the US Geological Survey and leader of the Clementine *science team.*

Our familiar Moon's face has been scrutinized by generations of observers, beginning back before recorded history. People have tried to discern its nature, first with the eye alone, then with telescopes, recently with robotic spacecraft, and eventually with human explorers. Despite this onslaught, in many ways our planet's natural satellite remains terra incognita, but the* Clementine *mission should help further our understanding of this world.

FROM CYCLE TO CYCLE: *Magellan*'s Mission Continues

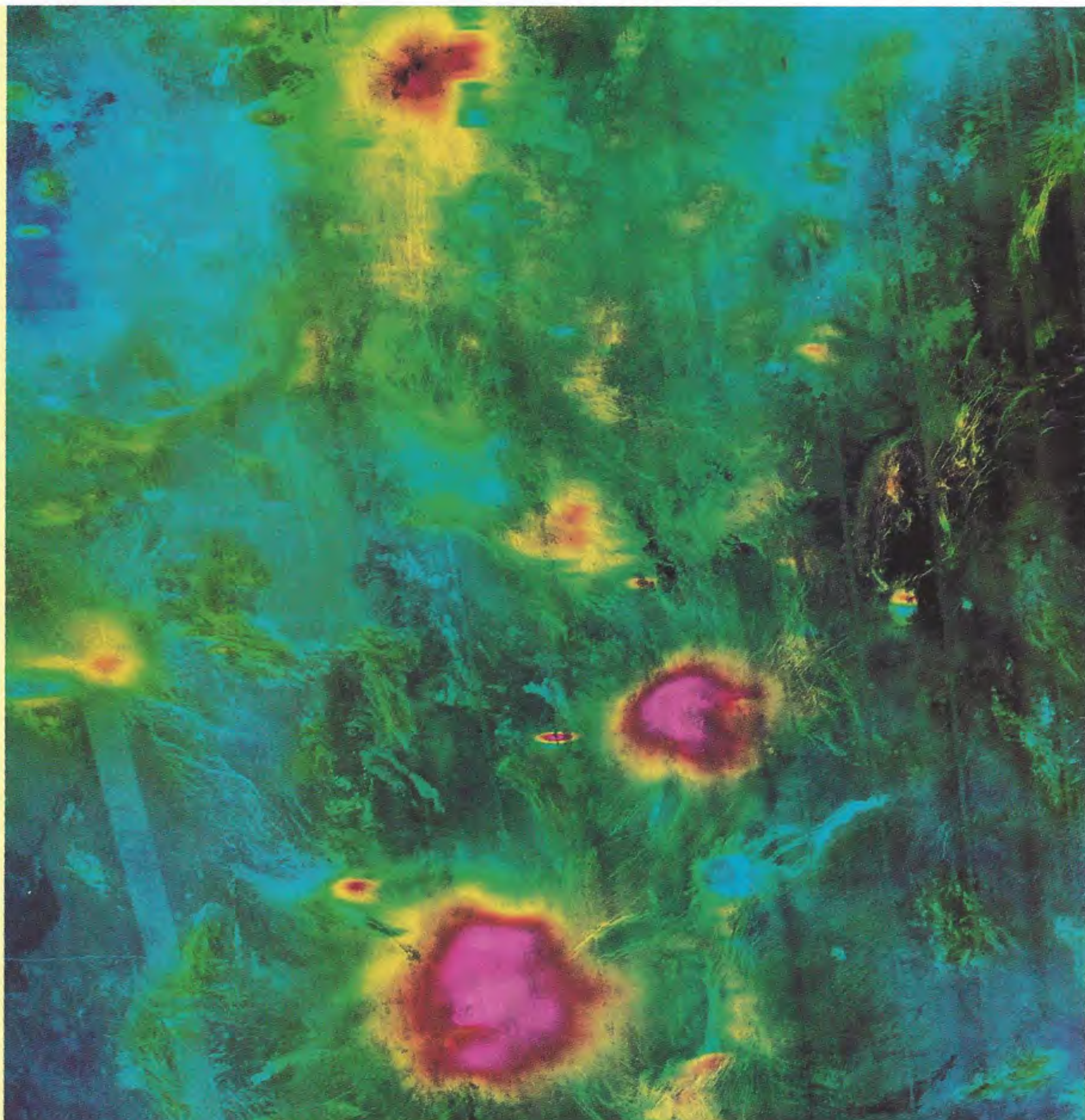
Although *Magellan* has accomplished its radar mapping mission, completing three mapping cycles, it continues to explore Venus. The spacecraft has finished one cycle of measuring variations in the planet's gravity caused by differing densities in the rock structures from the surface to deep within the interior. Mission controllers have now altered its orbit so that it passes repeatedly through the planet's upper atmosphere in a test of a technique called aerobraking.

In aerobraking, atmospheric drag from gases slows the spacecraft down, lowering its orbit without the use of thrusters and the expense of propellant. *Magellan* is tolerating the increased stress and high temperatures caused by the drag, and mission managers are hopeful that they will be able to circularize its orbit and add to their store of gravity data.

The aerobraking experiment has already returned scientific results. In analyzing the effects of atmospheric drag on the spacecraft, scientists have discovered that Venus' atmosphere fluctuates in density about every four Earth days. This cycle may be related to the circulation of clouds some 100 kilometers (60 miles) below the craft; these circle the planet every 4.2 days. Since *Magellan* is not equipped to observe the clouds directly, the effect on the upper atmosphere is speculative.

The *Magellan* team is hoping to keep the spacecraft going until October 1994. They need only $6 million to complete the gravity mission and are awaiting a decision from Washington on whether the spacecraft will continue its mission of exploration.

For a review of *Magellan*'s discoveries, see the May/June 1993 *Planetary Report*. —*Charlene M. Anderson*



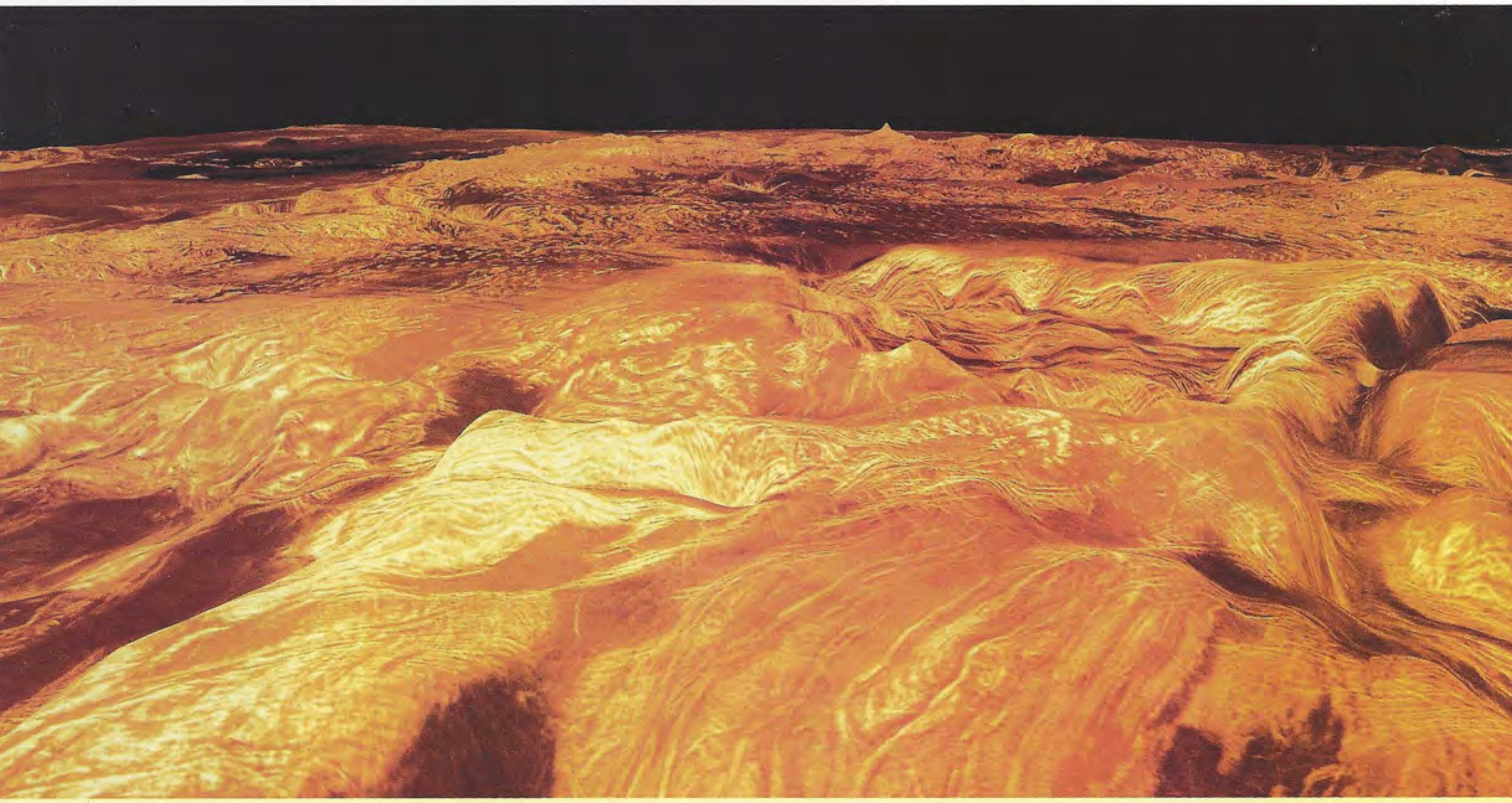
Here the cooler colors of topographic maps replace the fiery yellows and oranges of the other* Magellan *images on these pages. We see three volcanoes in* Venus' *southern hemisphere, with red and magenta indicating the highest elevations and blue the lowest. The area shown is 2,100 by 1,650 kilometers (1,300 by 1,000 miles).

This volcano chain is probably the surface manifestation of a hot spot in the planet's mantle, where molten material is welling up through the crust. Looking from north to south, the volcanoes are* Ushas Mons, *slightly less than 2 kilometers (1.2 miles) above the surrounding plains;* Innini Mons, *at 2.8 kilometers (1.7 miles); and* Hathor Mons, *at 2.6 kilometers (1.6 miles).

Image: JPL/NASA

Were you to hover over Venus' north pole and look straight down with radar eyes, this is how the planet might appear to you. This computer-simulated globe was created with data compiled by Magellan, *with a few gaps filled in by* Venera 15 *and* 16, Pioneer Venus *and* Arecibo Observatory *data. The computer-added color is based on images taken by the* Venera 13 *and* 14 *landers. Zero degrees longitude is at the bottom of the globe.*

In this image you can sample Venus' varied terrains. From your polar vantage point, you see ridge belts, lava flows, impact craters and two types of strange and intriguing features: the round, cracked features called coronae and the tesserae, named for their tile-like appearance. The largest mountain range on Venus, Maxwell Montes, *rises* 11 *kilometers (6.6 miles) above the average elevation, and it appears here as the bright feature in the lower center.* Image: JPL/NASA



With powerful computers to help them, scientists can take spacecraft data, generate an image, color it, tilt it, exaggerate it, and even create a motion picture to simulate flying over an alien world. This simulated perspective of the highland region Ovda Regio *was created by combining radar and altimetry data. The vertical measurements are exaggerated 22.5 times to bring out relationships among geologic structures.*

You are looking from the northeast portion of Ovda Regio *toward the southwest. The complex ridged terrain, also known as tesserae, was probably formed by compressional forces. The dark areas are relatively smooth and so don't reflect radar as do the brighter rough areas. Scientists interpret radar-dark features as lava flows. In this image, several flows overlie the tessera, indicating that they erupted after the ridges were formed.* Image: JPL/NASA

News & Reviews

by Clark R. Chapman

Earlier this year, I wrote some uncomplimentary words in this column about *Sky & Telescope*'s glossy new look. (See the January/February *Planetary Report.*) The August issue of the venerable popular astronomy magazine, which sports a colorized, golden image of Venus on the cover, commands another look. I like it better.

Still glossy, *Sky & Telescope* has now gone 3-D. Six pages of blurry, purple pictures crystallize into three-dimensional aerial perspectives of venusian craters, canyons, pancake domes and other exaggerated topography once the reader assembles and wears one of the two red/blue eyeglasses stapled into the magazine. I could find no instructions on how to detach the eyeglasses and assemble them, but after a few mistakes (including seeing craters as mesas) I was gratified by impressive 3-D views of eight of the 10 *Magellan* pictures printed.

The 3-D feature is part of a set of articles summing up NASA's spectacular *Magellan* radar mission to Venus, which is now winding down. *Sky & Telescope* Senior Editor J. Kelly Beatty offers a fine story about the *Magellan* project's history. And *Magellan* Deputy Project Scientist Ellen Stofan has contributed a good summary of the scientific results of the mission—and the remaining controversies.

Meteor Storms

A resurgence in the long-neglected science of meteors has been accelerated by predictions of meteor "storms." Last year's recovery of comet Swift-Tuttle, parent object for the annual Perseid meteor shower, spawned predictions of a celestial spectacle this year. Normally, the Perseids are a predictable two-week spell of faintish shooting stars emanating from the constellation Perseus. But for several years in the early 1990s, Earth will intercept a part of the meteor stream near the source of the grain-sized particles—comet Swift-Tuttle, which hasn't been so close for the last 130 years. Some meteor scientists have forecast that an hour-long blizzard of meteors might be visible to lucky observers in Europe or Asia on the night of August 11–12, 1993.

Sky & Telescope has long been a favorite of backyard astronomers, so three articles in its August issue emphasize observing this year's enhanced Perseids: a general article on the "storm watch," a how-to-watch-them article for backyard astronomers and a column on how to photograph the meteors. (The last two articles are almost equally relevant to any meteor shower.) Two other pieces in the same issue delve into historical observations of the Perseids and the physics of meteor streams for readers who are historically or technically inclined. In short summary, I rather like the package of informative articles on meteors, keyed to a timely event.

The Big Bang

The August issue also features a contest, which would never have been found in the staid *Sky & Telescope* of old. Never mind that there is no prize, nor even any guarantee that the winning entry will be used. There is a panel of esteemed judges, including The Planetary Society's own Carl Sagan. The idea is to rename the Big Bang. I am not overwhelmed by Timothy Ferris' Focal Point essay about the need for such a change, but maybe a fantastic winning entry will convince me. ("Focal Point" is *Sky & Telescope*'s name for its op-ed page.) Ferris is another contest judge; the third is the National Space Society's Hugh Downs.

Despite the sheen and color, the remodeled *Sky & Telescope* still runs its traditional back-of-the-magazine array of features, columns and ads oriented toward its bread-and-butter readers: amateur astronomers. Included are the August star and planet charts; plots of the positions of the moons of Jupiter, Uranus and Neptune; David Levy's always readable essay; and columns for makers and users of backyard telescopes.

Clark R. Chapman started reading Sky & Telescope *40 years ago, and he still loves it.*

WORLD  WATCH

BY LOUIS D. FRIEDMAN

WASHINGTON, DC—In June, the Clinton administration decided on a design for a smaller and cheaper space station, one that is estimated to cost $15 billion less than space station *Freedom.*

The White House had instructed NASA to provide three lower-cost options, and the agency complied, although none of the options met the cost or schedule targets given by the White House. Option A was a significantly scaled-back version of the *Freedom* design; Option B, the most expensive of the three, was most like *Freedom;* and Option C, called "the can," was a stripped-down cylindrical design capable of being launched on a single shuttle flight.

After an advisory committee headed by Charles Vest, president of the Massachusetts Institute of Technology, recommended either Option A or Option C, President Clinton selected the former.

Representative George Brown of California, head of the House Committee on Science, Space and Technology, and others in Congress seeking to protect the existing plan and aerospace jobs had supported Option B. The European, Japanese and Canadian space agencies, which are building equipment for the space station based on the *Freedom* design, also preferred Option B in order to keep close to the status quo. Option C probably would not have supported their modules. The selection of Option A, however, appears compatible with their existing work.

NASA was given 90 days to firm up the new plan for the Option A space station. Other changes to satisfy political, technical and cost requirements can be expected. Pressures in Congress continue for Option B, and greater involvement with the Russians in the design is still being investigated.

WASHINGTON, DC—The United States' space station program has survived two more attempts to kill it in the House of Representatives. During debate on the authorization of the NASA budget, two amendments were introduced that would have canceled all funding for the space station program. Both amendments were defeated, but by narrow margins. It is possible that letters from Planetary Society members, which we asked that you send in June, made a difference here. The many calls from congressional offices that we received at our headquarters indicated that our efforts were noted.

In June, the Society's officers released a statement laying out our position on the station redesign. In it we asked that the station be made smaller and cheaper, that funding for science and technology development be assured and that the station effort include the Russians.

Later that month, we were asked to testify before the Senate Subcommittee on Science, Technology and Space. Since the administration's redesign process addressed the points we had made in our statement, we were able to support the process, but we urged that a few more steps be taken.

Our major suggestion was to place the station in the same orbit occupied by *Mir*, the Russian space station—an orbit inclined 51.6 degrees to Earth's equator—instead of the planned 28-degree orbit. This change was also recommended by the Vest committee, which advised the president on the redesign process. The 28-degree orbit would position the space station to make observations near Earth's equatorial regions, while the 51.6-degree orbit would enable it to observe almost all of the major land masses on the planet. The choice of this orbit would enable the US and its European, Japanese and Canadian partners to take advantage of existing Russian capabilities, leading to the construction of a truly international space station having important safety and reliability advantages.

The inclusion of the Russians was encouraged during the redesign process, but discussions with them were put on hold when the US learned that Russia was going ahead with plans to sell rocket technology to India. The US believes that this technology could be used for nuclear weapons delivery systems, and asked that the sale be halted. The dispute has now been settled, and a new Russian–American space agreement has been signed.

As we go to press, Congress has not completed its work on the NASA budget. The administration's budget includes a new start for the Discovery program of small planetary missions (see the July/August 1992 *Planetary Report*). The Mars Environmental Survey (MESUR) Pathfinder is one of these, making a 1996 launch possible. NASA intends to propose a new start for the Near-Earth Asteroid Rendezvous (NEAR) next year.

WIESBADEN, GERMANY—In a historic agreement, representatives of the US, Russia, France, Germany, Italy, Canada and the European Space Agency established an International Mars Steering Group. The agreement, the outcome of a meeting held here in May, could lead to international cooperation in the exploration of Mars.

The meeting was, in part, the result of The Planetary Society's strong advocacy of international Mars exploration. For several years, we had lobbied the space agencies to coordinate the planning of their various Mars missions.

Those attending the meeting expressed their strong support for existing mission plans, including *Mars '96*, MESUR Pathfinder and the *Mars Observer* extended mission. Extending the *Mars Observer* mission is important so that the Mars Balloon Relay will be available to provide a communications link to Earth for the Mars Balloon and Rover, set for launch in 1996.

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

Questions & Answers

If the Moon formed out of material ejected from Earth's mantle during a gigantic impact, how did this material attain a stable orbit? Wouldn't anything ejected at less than escape velocity follow an elliptical orbit that would bring it back around to the point of ejection, where the material would reimpact before completing one orbit?
—Joe Roberts, St. Louis, Missouri

This is a good question. It's true that a body propelled instantaneously and ballistically off a planetary surface at less than escape velocity could not go into permanent orbit, because it would come back toward its starting point and hit the ground, just as you describe.

For years this argument was used to challenge the idea that the Moon could have resulted from a giant impact. A related idea—that stones could be crushed by the acceleration needed to launch them off the surface—was also used to debunk the idea that meteorites could be blasted into space from the Moon or Mars. I call these ideas the golf ball model of cratering explosions. They assume that material has to be launched by a single impulse operating exactly at the surface level of the planet, after which the material follows a ballistic orbit, just as a golf ball is launched by a nearly instantaneous impulse from the golf club.

Clearly the golf ball model is wrong, since meteorites do come from the Moon and (almost certainly) Mars. There are probably several reasons why this theory is wrong. Some of these reasons are better understood than others, and we depend on still-incomplete theoretical computer models to understand what happens during impact explosions.

For one thing, a large impact explosion (especially from an icy comet nucleus) releases a tremendous expanding cloud of vapor—more or less like a fireball—which cushions, lofts and helps propel the debris outward. The dispersal of the debris isn't purely ballistic. In the case of a 200-kilometer crater (about 120 miles), this fireball may rise higher than 200 kilometers—and well beyond Earth's atmosphere.

Second, the motions of debris caught in the fireball may be chaotic; the fragments may collide and jostle each other so that as a given mass of debris is "launched" onto its final trajectory, it might find itself entrained in the expanding fireball 200 kilometers above Earth and moving parallel to the surface—a condition for remaining in space and not coming back to the surface. Bodies initially on elliptical orbits heading toward reimpact, as you describe, may have been hit in the confusion and redirected onto stable orbits.

Third, in the case of the giant impact that may have formed the Moon, the impacting planetesimal is believed to have been nearly as big as the planet Mars! It was perhaps the second- or third-largest planetesimal to grow in Earth's vicinity. That planetesimal and the whole upper mantle of Earth near the impact deformed and exploded. Much of the atmosphere itself was blown away. Clearly, fragments were not being launched like a golf ball from the surface.

The best computer simulations of the giant impact, by researchers such as A.G.W. Cameron, Jay Melosh and Willie Benz, suggest something a far cry from the golf ball scenario. Much of the mantle material of both bodies was deformed—essentially "splashed" outward—during the impact. A vast cloud of incandescent vapor expanded from the site. Some computer simulations show blobs of material actually going into orbit from this cloud as it expands above Earth's surface. We think that such blobs were probably too small and ill-defined to form the Moon. Instead, the post-impact Earth was probably surrounded by a cloud of debris, which, due to dynamic forces, would have formed a ring or flat nebula

Based on a computer simulation provided by Jay Melosh at the University of Arizona, this painting shows the form of the impact debris about half an hour after the collision that formed the Moon. The plumes of debris are "splashing" and expanding outward into a debris cloud around Earth.
Painting: William K. Hartmann

of dust over the equator. Debris in the outer rings aggregated into moonlets that collided and aggregated into the Moon itself, probably at several Earth radii, just beyond Roche's limit (a critical distance that exists between two bodies within which the tide-raising force on the smaller body is strong enough to pull it apart—provided it is held together only by gravity). Then tidal forces took over and quickly forced the Moon outward toward its present position.
—WILLIAM K. HARTMANN, *Planetary Science Institute*

Who discovered what the distance between Earth and the Sun (or the astronomical unit) is? What method did they use?
—Arthur S. Arroyo, San Diego, California

The first known determination of the distance between Earth and the Sun was carried out by the ancient Greek astronomer Aristarchus around 275 BC. He estimated the angle between the Moon and the Sun at the moment the Moon was exactly half illuminated. His measurement of 87 degrees was not very accurate, so he deduced that the Sun was only 18 to 20 times farther away than the Moon. Although his estimate was a factor of 20 too small, we must admire the audacity of the attempt.

Aristarchus' estimate was adopted by Ptolemy and, 14 centuries later, by Copernicus. They expressed the solar distance as 1,200 terrestrial radii (1,200 times the distance from Earth's center to its surface), since by then the Moon's distance was fairly accurately known in terms of the size of Earth. Finally, around 1620, Johannes Kepler argued that the distance must be at least three times larger.

The introduction of the telescope in the 17th century changed astronomical practice profoundly. In 1672 John Flamsteed and Jean Dominique Cassini independently found a solar distance of about 21,000 terrestrial radii. Flamsteed derived his result from observations of Mars made in the course of a single night, during which the rotation of Earth carried his telescope around, giving him a baseline of about one terrestrial radius for his triangulation. (Triangulation is a method of determining the distance of an object from two observation points—forming a triangle consisting of those points and the object being measured.) Cassini made observations of Mars from Paris at the same time that his colleague Jean Richer observed from Cayenne in French Guiana, again producing a baseline of about one terrestrial radius.

The fascinating story of these determinations is nicely described in Albert Van Helden's *Measuring the Universe: Cosmic Dimensions From Aristarchus to Halley* (Chicago, 1985).
—OWEN GINGERICH, *Harvard Smithsonian Center for Astrophysics*

FACTINOS

The late *Pioneer* Venus orbiter returned new evidence that ancient Venus may have had three and a half times more water than even advocates of a once-wet Venus thought—enough to cover the planet's entire surface between about 8 and 23 meters (25 and 75 feet) deep.

"Many of us have long thought that early in its history Venus had temperate conditions and oceans like Earth's," said Thomas Donahue of the University of Michigan, head of the *Pioneer* Venus steering group. "Findings that Venus was once fairly wet do not prove that major oceans existed, but do make their existence far more likely. The new *Pioneer* data provide evidence that large amounts of water were definitely there," said Donahue.
—from the Lunar and Planetary Institute

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Almost 15 years after they left home, *Voyagers 1* and *2* have found the first direct evidence of the heliopause—the boundary that separates our solar system from interstellar space. Since August 1992, the spacecraft's plasma wave antennas have been recording intense, low-frequency radio emissions from beyond the solar system. For months the source of these radio emissions was a mystery.

"Our interpretation now is that these radio signals are created as a cloud of electrically charged gas, called plasma, expands from the Sun and interacts with the cold interstellar gas beyond the heliopause," said Don Gurnett of the University of Iowa, principal investigator of the *Voyager* plasma wave subsystem. In May and June of 1992 the Sun experienced a period of intense activity and then emitted a cloud of rapidly moving charged particles. It was these particles which interacted violently with the interstellar plasma to produce the radio emissions, explains Gurnett.
—from the Jet Propulsion Laboratory

❖

NASA scientists have discovered water molecules frozen in the surface ices of Jupiter's moon Io. "This is the first strong evidence of solid water on the surface of this satellite," said Farid Salama of the University of California, Berkeley, who led the project at NASA's Ames Research Center.

The absorption lines for water were found in the infrared spectrum of Io by researchers on board NASA's Kuiper Airborne Observatory (KAO). The KAO is unique in its ability to conduct infrared astronomy while flying above 99 percent of Earth's atmospheric water vapor. "We've finally seen the spectral signature of something for which we've been searching for years—water on Io," said Jesse Bregman of Ames, who developed the spectrograph used with the KAO telescope.

The water ice is combined with the more abundant sulfur dioxide ice on Io's surface. "Studying the variation of water ice on Io with time and longitude would tell us if the water correlates with volcanic activity. We also need to look at the finer structural details of the new band in Io's spectrum to understand its thermal history and water concentrations," Salama said.
—from NASA

A Planetary Readers' Service

Our Planetary Readers' Service is an easy way for Society members to obtain newly published books about the science and adventure of voyages to other worlds.

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The Evening Star: Venus Observed

By Henry S.F. Cooper, Jr.;
Farrar Straus Giroux, New York, 1993, 274 pages.
Retail price: $22.00
Member price: $19.00

A *New Yorker* staff writer for over 25 years, Henry S.F. Cooper, Jr., has chronicled the American role in what he calls the classic era of planetary exploration. Representing Everyman—a technically naive but enthusiastic space buff—Cooper writes in the first person innocent.

The Evening Star is the story of *Magellan*'s mission to Venus. Our closest neighbor, Venus has been visited by more space vehicles than any other planet. Earlier explorations were hampered by conditions that destroyed landing vehicles within minutes—intense heat (surface temperatures around 900 degrees Fahrenheit) and a surface pressure 90 times that of Earth—as well as by a thick atmosphere impenetrable to ordinary cameras on orbiting spacecraft.

The imaging problem was solved by bouncing radar signals off Venus' surface, catching their reflections and interpreting the signals by computer. *Magellan* carried an advanced radar that promised to solve a myriad of questions about the planet. A dramatic series of computer glitches threatened the mission, but they were overcome, and the resulting pictures have been spectacular.

Cooper begins this story at the Jet Propulsion Laboratory in 1990 just as data from Venus started to arrive. Like noodles wrapped around a globe, strips of images slowly built up to form a planetary map. Cooper readily explains "pixels" and digital enhancement, and tells us how radar-created images are different from ordinary photography.

The author notes that the scientists responded to *Magellan*'s data just as other scientists had responded to *Voyager* information. At first they were struck by the similarities of other planets to Earth, and only later by the great differences. This awareness leads, eventually, to a deeper understanding of Earth.

Deadpan, Cooper relates the decision to use only female names for the sites on the planet, noting that the decision to do so was made by an all-male committee.

There may not have been much gender diversity on the *Magellan* project, but, Cooper notes, as the first post–Cold War venture, *Magellan* included several ex-Soviets. Some are immigrants to the US, but others are still part of the Russian space program, an interesting sidelight to his tale.

The ideal *Magellan* mission would have included data from six *Magellan* orbital cycles, but things have changed since the glory days of fat Cold War budgets, and the radar mapping was concluded after only three cycles; gravity data were collected for an additional cycle. A greatly reduced team now awaits word on whether or not the mission will continue until 1994.

In a wistful tone, Cooper describes a budget-squeezed NASA trying to maintain programs. *Magellan*, he concludes, may be the first space mission to be halted while the spacecraft is still functioning, an act somehow analogous to killing a living creature.

Cooper's sympathies are with the members of the *Magellan* team, who want to play it to the end. NASA has been good to him, allowing him an intimacy with the space program that has clearly enriched his life. He has returned the favor by bringing the drama and personalities of the adventure, as well as the science, to a broad audience.
—Reviewed by Bettyann Kevles

Still Available:

Conversing With the Planets: How Science and Myth Invented the Cosmos, *by Anthony Aveni.*
This provocative look at human planetary observations shows how lights in the sky were seen by astronomers before the rise of science.
(Reviewed May/June 1993.)
Retail price: $21.00
Member price: $18.50

To a Rocky Moon: A Geologist's History of Lunar Exploration, *by Don E. Wilhelms.*
A highly personal story of the Moon race, mission by mission, by a geologist who was involved from the start.
(Reviewed July/August 1993.)
Retail price: $29.95
Member price: $24.00

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SOCIETY *Notes*

NORRIS FOUNDATION FUNDS SPACE EDUCATION

The Kenneth T. and Eileen L. Norris Foundation has given the Society a generous three-year grant to help the Society's Education Office distribute MarsLink Preview Packets. Part of the Society's ambitious educational efforts, MarsLink will distribute *Mars Observer*, *Viking* and other planetary exploration data to middle- and high-school students through 1996.

In its letter, the Foundation stated, "We look forward to hearing more about the *Mars Observer* spacecraft as it approaches Mars and we wish you success with this program." Thanks to the Norris Foundation's support, the Society has an excellent chance of achieving that success.
—Carol J. Stadum, MarsLink Project Director

AUTHOR SUPPORTS PLANETARY SOCIETY AND MARS EXPLORATION

Science fiction writer and Planetary Society member Raymond Z. Gallun recently demonstrated his support for both the Society and human exploration of Mars.

Gallun made a generous donation to the Society, and we express our sincere thanks here. But the farsighted author has also done something even more remarkable.

In his will, Gallun has set aside $50,000 as a reward for the first human crew to land on Mars. In the tradition of the scientific and exploration prizes of the past, this reward is Gallun's expression of how committed he is to nurturing human exploration of the Red Planet.

Gallun was one of the first writers to present sympathetic portraits of extraterrestrial beings. In the stories "Old Faithful," written in 1934, and "Son of Old Faithful" (1935), he described an intelligent martian astronomer trying to communicate with an astronomer on Earth. This story predicted many of the actual communication challenges SETI scientists face today. Gallun is also the author of *Skyclimber* (published in 1981) and *Starclimber: The Literary Adventures and Autobiography of Raymond Z. Gallun* (written with Jeffrey M. Elliott, 1991).
—Louis D. Friedman, Executive Director

NO ACCELEROMETER FOR THE MARS SNAKE

After much consideration, French officials in charge of the Mars Balloon's Snake project have rejected a Planetary Society proposal to equip the instrumented guide-rope with a miniaturized speed-measuring device.

Working for the Society on our Mars Balloon team, George Powell of Utah State University invented the novel neural-network system for measuring speed. Neural networks are new to planetary missions. Powell's system uses computer software to build learning algorithms inside a small microcomputer that uses accelerometer data to estimate the balloon's speed. This entire system can fit within the Snake.

The proposal was rejected largely because of budget constraints. The Society had proposed co-funding the miniature instrument with the Centre Nationale d'Études Spatiales and USU. However, CNES officials still could not come up with funds because of the project's other demands.

Increasingly, as they attempt to keep *Mars '96* on schedule, the French have had to pick up more engineering and funding responsibilities from the Russians. Russian support for *Mars '96* has dropped as they focus on *Mars '94* and deal with the other problems in their economy.

Despite the failure to get the neural-net accelerometer on board, work on the Snake continues. *—LDF*

SPACE EVENTS

Here's one of the highlights of The Planetary Society's latest space events calendar. You can get a complete and updated listing of these events simply by writing to Carlos J. Populus at Society headquarters.

• In Washington, DC, at the Smithsonian Institution's National Air and Space Museum, "A 'Blueprint for Space' From *Collier's* Magazine" continues through April 24, 1994. This exhibition traces the development of rocketry and space travel in the 20th century. Admission is free. For more information, contact the National Air and Space Museum at (202) 357-2700.
—Susan Lendroth, Manager of Events and Communications

FOR STUDENTS ONLY: LAST CHANCE TO NAME THE MARS ROVER

Students, if you were born between January 1, 1980, and December 31, 1984, you have a mission to accomplish:

Mission: Name the Mars Rover

Mission Deadline: October 1, 1993

Mission Description: Write your name, address, telephone number, native language and two paragraphs (no typewritten entries, please, and no drawings or other materials). In the first paragraph, state the name you have chosen for the Mars Rover and why (100 words or less). In the second paragraph, describe why the rover's mission is important (150 words or less).

First Prize: $500

Second Prize: Globe of Mars

Ten finalists will each receive a copy of *An Explorer's Guide to Mars*, and everyone who enters the contest will receive a color print of Mars. Send your entry (with proof of your date of birth) to Name the Rover Contest, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106. For more information, see page 15 of the January/February 1993 issue of *The Planetary Report*.
—India Wadkins, Administrative Assistant

WORLDS ABOVE THE GALAXY — An Earth-like planet and its large moon float serenely above the luminous star clouds of the Milky Way. If Earth were in such a location, our night sky would be spectacular—an island universe glowing in the dark.

John R. Foster's space art has been exhibited in Russia, in Washington, DC, at the National Air and Space Museum and in several other shows around the United States.

John lives with his wife, Karen, in Portland, Oregon. He is currently producing a series of archaeoastronomy-related paintings. These works depict outstanding astronomical events of the past.

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