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Seeking the Beacon

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COVER: Clouds of interstellar dust obscure the view of our galaxy's central region which, viewed from Earth, lies in the direction of the constellation of Sagittarius. With our solar system situated on the outskirts of the Milky Way, most of its stars appear within or beyond the galactic center. If any galactic beacon engineers are beaming a message our way, chances are it will come from that direction. Part of the fun of the Search for Extraterrestrial Intelligence is trying to guess how another technological civilization might try to contact ours.
Photograph: David Malin, Anglo-Australian Observatory

FROM THE EDITOR

As I write this, four members of The Planetary Society's Mars Rover team are on the Kamchatka Peninsula testing the prototype mobile robot. Their timing was impeccable: They left for Siberia on the day of the attempted coup in the Soviet Union.

While the Society's staff never really feared for their safety, we were relieved to receive a fax from the Institute for Space Research in Moscow which read: "TPS team is OK and comfortable. They enjoy good weather and food."

We will bring you more details of this expedition in upcoming *Planetary Reports.* With the Soviet situation changing daily, we will be keeping a close watch on our cooperative projects with the Soviet space agencies.

—Charlene M. Anderson

The Planetary Society's Annual Catalog

Bound into the center of this issue you will find our annual sales catalog. We publish this catalog once a year as a service to our members who might be looking for distinctive holiday gifts. If you prefer your *Planetary Report* without this sales insert, it can be easily removed. But we hope you first take a look at the many entertaining and educational items that we offer.

Members' Dialogue

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

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

While browsing over the United States Geological Survey's chart of Venus' northern quadrant, I noticed a feature named "Schumann-Heink Patera," and thought, "That's digging rather deep in a favorite category. There must also be features named Callas, Flagstad, Ponselle, Melba—all much more famous and influential as opera singers than Schumann-Heink." But none of them were there, and in the process of looking I found other oddities: obscure novelists like Prichard and Voynich and Lagerlöf, but not Austen or Brontë or Woolf; rulers who were defeated, like Boedicia and Cleopatra, but not those who were successful, like Elizabeth Tudor, Eleanor d'Aquitaine and Catherine the Great; and the only Indians were bedmates of European explorers—Malintzin, Pocahontas and Sacajawea. Most odd were Corday, the little assassin unknown till she killed Marat, and Tituba, the black stimulator of the hysterias that led to the Salem trials. Are terrorism and witchery back in vogue?

Names on Venus, like those on other planets, are chosen by a committee of the International Astronomical Union (IAU), under a set of 13 rules, such as: "unambiguous," "prominent in any of the six main living religions are not acceptable," "dead at least three years," and no "special individual or national significance." However, the interpretation is sometimes strange. Thus the "unambiguous" seems strained when there is someone else more famous of the same name. On the provisional list are a "Graham," who is not the pioneer of modern dance, but a 19th-century geologist; a "Lehmann," not either Lilli or Lotte, famous opera singers, but Inge, a seismologist (still alive at 103); and a "Danilova," not the 20th-century star of the Ballet Russe, but another ballerina who died at 17 in 1810.

A teenager deservedly on the list is Anne Frank, but Jeanne d'Arc is not—presumably because she is "prominent" in Catholicism. Jeanne's main association with that institution was to be burned at the stake at age 19. The Church apparently decided it made a mistake (489 years later) and made her a saint. A lot smarter was Queen Isabella of Spain ("Isabel la Católica" in nearly all Spanish histories), who is proposed to be honored by a large crater (thus breaking the implicit rule of only defeated rulers). In 1478 pious Isabella petitioned the pope to institute the Spanish Inquisition, which led to about 14,000 people being burned at the stake by the time she died in 1504. And in 1492, less than three weeks before commissioning Columbus, she signed the edict compelling all Jews to leave Spain within three months, resulting in well over 10,000 more deaths of the unfaithful from starvation and disease on the way to exile. One wonders about the IAU's definition of "prominent."

Your piece "What to Call the Crater?" in the November/December 1990 *Planetary Report* says, "The system ensures that an international panel of experts names features in a fair and evenhanded way." Whatever the panel is expert in, I bet it's not history, literature or the arts.
—WILLIAM M. KAULA, *Los Angeles, California*

Thanks for addressing the space station issue in World Watch [see the May/June issue of *The Planetary Report*]. I support The Planetary Society's stance. NASA, in an attempt to appease special-interest groups and gain public support, has again put all its eggs in one basket. It is in jeopardy of committing the same mistakes that eventually led to the *Challenger* accident.

Let us (the United States and humans in general) build a space program on a steady step-by-step basis: robotic missions, space sciences, then a new launch vehicle, a *Skylab*-type space station and so on . . . to the Moon and Mars. Keep the issues coming.
—MARK PIEKNY, *Metairie, Louisiana*

If a long-duration space mission is not to be an ordeal for the crew, it is likely that artificial gravity will be a requirement. Isn't it more reasonable to develop a space station that has artificial gravity before spending huge sums on more manned mega-projects? It might even be possible to construct a rotating space station in modular fashion without the use of a heavy-lift launch vehicle, but the concepts involved should first be tried on a small scale.

The United States space program hasn't lost its spark, but where nothing is ventured, nothing is gained.
—VICTOR COHEN, *New York, New York*

NEWS BRIEFS

As of late July, *Magellan* had collected radar images of nearly 90 percent of Venus' surface. The data set is double the amount of all other image data collected in the United States planetary program to date, said Steve Saunders, *Magellan* Project Scientist.
—from a NASA press release

A group of frustrated space station engineers calling itself the Center for Strategic Space Studies in Reston, Virginia, has begun circulating a detailed concept paper recommending that NASA slow work on the estimated $30 billion outpost in favor of refurbishing and launching the backup *Skylab* orbiting workshop now sitting in the National Air and Space Museum in Washington, DC.

The engineers behind the updated *Skylab Plus* proposal believe the museum piece has substantial capabilities as a human-tended materials-processing laboratory that have not been eroded by the millions of tourists who have viewed the workshop through holes cut in its tank superstructure. They say it could be refurbished and launched for about $4 billion aboard the still conceptual NASA/Air Force National Launch System or the Soviet Union's *Energia* heavy-lift booster.
—from *Space News*

A new flaw has been discovered in a mirror on the Hubble Space Telescope, crimping a key instrument's ability to analyze light from faint celestial objects. The problem is a buildup of aluminum oxide in the mirror of the faint-object spectrograph, an instrument designed to answer some fundamental questions about the universe through the study of light.

The buildup apparently occurred while the instrument sat in storage during much of the 1980s awaiting the telescope's launch. It went undetected until recently, said George F. Hartig, the spectrograph's chief scientist.
—from Edwin Chen in the *Los Angeles Times*

A Morning With
Exploring the

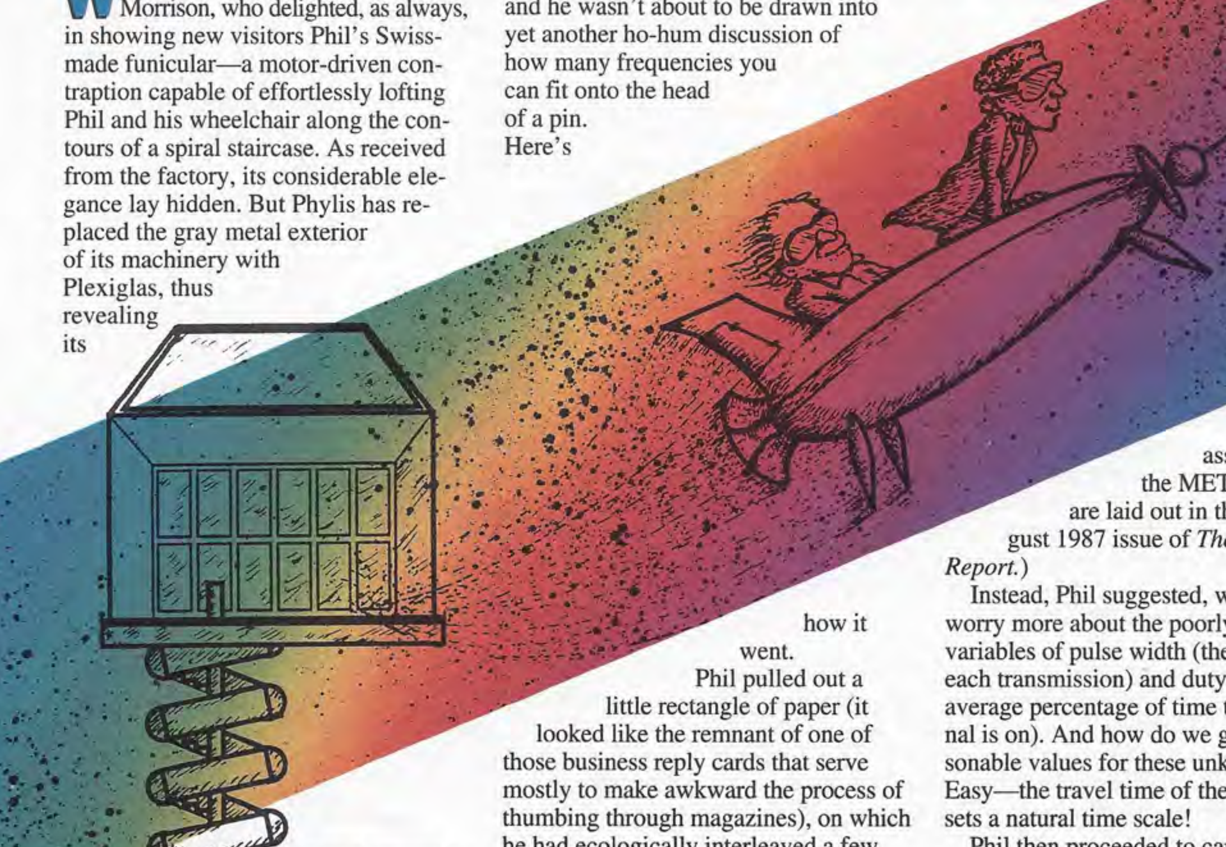
by Paul Horowitz

On a gorgeous day last spring (Thursday the 13th of June, to be exact), the author spent a stimulating morning with Professor Philip Morrison and Dr. Michael Davis, discussing the Search for Extraterrestrial Intelligence (SETI). Phil is a pioneer in SETI, having co-authored with Giuseppe Cocconi the oft-quoted 1959 paper in which the idea of interstellar communication at the wavelength of neutral hydrogen emission (21 centimeters) was first proposed. He has continued to be a prime mover in SETI, delighting even the most experienced hands with his sharp insights and surprising perspectives. Mike is the director of the Arecibo Observatory in Puerto Rico; its 1,000-foot (300-meter) diameter makes it the largest radio telescope on Earth.

We were warmly greeted by Phylis Morrison, who delighted, as always, in showing new visitors Phil's Swiss-made funicular—a motor-driven contraption capable of effortlessly lofting Phil and his wheelchair along the contours of a spiral staircase. As received from the factory, its considerable elegance lay hidden. But Phylis has replaced the gray metal exterior of its machinery with Plexiglas, thus revealing its beautifully crafted inner workings.

We spread out in the second-story greenhouse, where I expected the discussion to focus on narrow technical issues, such as the optimum receiver bandwidth and resolution to design into our next-generation search apparatus. This seemed natural, especially since two weeks earlier Phil had chaired a meeting, held by The Planetary Society, at which I had presented the rationale for a new pair of search systems: a 100-million-channel, dual-beam, all-sky search of moderate resolution (BETA I), to be followed several years later by a 6-billion-channel, high-resolution search (BETA II).

But that was not to be. Instead we took off in Phil's rocket ship for a quick tour of the galaxy and a look into the minds of those other galactic beacon engineers (if any!). Phil wanted to explore something *new* in SETI this morning, and he wasn't about to be drawn into yet another ho-hum discussion of how many frequencies you can fit onto the head of a pin. Here's how it went.



Phil pulled out a little rectangle of paper (it looked like the remnant of one of those business reply cards that serve mostly to make awkward the process of thumbing through magazines), on which he had ecologically interleaved a few notes to himself. He began by saying that we might do well to stop worrying so much about the search variable of *wavelength*, and assume instead that an interstellar beacon would most likely be transmitted at a guessable wavelength (for example, the famous 21-centimeter line at which neutral hydrogen emits naturally). Furthermore, the transmitting civilization would finesse the problem of Doppler shifts of the received wavelength (caused by the relative motions —on the order of some hundreds of kilometers per second—of stars in our galaxy). They would do this by pre-adjusting their transmitting frequency to compensate for their own motion relative to the remarkable "rest frame of the universe"—the frame of reference of the 3-degree-Kelvin radiation left over from the Big Bang. (These fundamental assumptions of the META search are laid out in the July/August 1987 issue of *The Planetary Report.*)

Instead, Phil suggested, we should worry more about the poorly explored variables of pulse width (the duration of each transmission) and duty cycle (the average percentage of time that the signal is on). And how do we guess reasonable values for these unknowns? Easy—the travel time of the message sets a natural time scale!

Phil then proceeded to carry out a minor subdivision of galactic real estate.

Philip Morrison
Extraterrestrial Mind

Consider only "good" stars, he suggested—say, spectral type G5, solitary, late generation, similar to our Sun. That takes us from an initial stellar population of something like 400 billion down to a mere billion, give or take a factor of 5. Now, let's stay away from the central area of the galaxy, say 10,000 light-years from the center—it's too violent there. That leaves a flattened disk going out from 10,000 light-years to perhaps 40,000 light-years—not many stars are out beyond that (think of a 45-rpm record, with its large hole in the center). That's the galactic real estate we're interested in, SETI-wise.

Let's divide this peculiar shape into neighborhoods, so we can have local town meetings. The galactic thickness sets the scale, something like 2,000 light-years. We imagine the disk sliced radially into roughly 50 sectors (think of slices of a pie), each further sliced at right angles every 2,000 light-years (think of eating a slice). Altogether you've now got about 1,000 neighborhoods, each with about a million good suns. Within each neighborhood, a message takes a millennium or less to reach its destination.

Looking at our handiwork, we see a progressive scale of distances, perhaps better appreciated as a progression of time scales required for a round-trip message: about a millennium for a communication within our local neighborhood, 10 millennia for a message within our slice of the galaxy, 100 millennia for a message anywhere within the galaxy, and 10 million years for communications with the local group of galaxies.

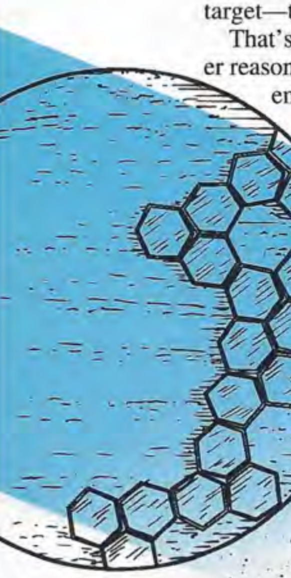
Now for the deductions about probable pulse widths and repetition times. Whatever creatures may inhabit the galaxy, we all live by the same laws of physics, and we all share the same galactic geography. It was the universal quantum mechanics of the hydrogen atom that led Cocconi and Morrison in 1959 to their brilliant insight that galactic species might well meet at hydrogen's natural frequency of 1,420,405,751.768 vibrations per second, or 1420 megahertz (still one of META's favorite stomping grounds). Phil wanted to coax another prediction from nature—this time about the complementary variable of time.

First, the minimum duration of a pulse. The argument is a bit involved, but fascinating: It's a curious property that the shorter a pulse, the wider its inherent spread of frequency. Numerically, the bandwidth (in hertz) is about the reciprocal of the pulse width (in seconds). As my colleague Ed Purcell likes to say, "If you play a 1/32nd note on a tuba, it doesn't much matter which note you play." A related fact about the galaxy: Disembodied hydrogen atoms (free electrons and free protons) also cause radio signals to spread out in frequency, although for a completely different reason. SETI pioneer (and Planetary Society advisor) Frank Drake and his student George Helou first looked into this in connection with SETI, and they concluded that the galaxy permits very narrow frequencies to be sent—as narrow as a few thousandths of a hertz, but no narrower. In SETI, narrow is good because (1) it is distinctive, (2) the received signal overcomes cosmic noise better for the same transmitted power and (3) narrow signals from space look different from narrow signals generated on Earth, because of the effect of Earth's rotation (the Doppler effect).

So, the argument goes like this: An extraterrestrial civilization would not want to squander the benefits of the narrowband properties of the galaxy by transmitting too short a pulse. How short should the pulse be? The reciprocal of the Drake-Helou bandwidth, which works out to a few hundred seconds, if the transmission is at the hydrogen frequency.

We can get some insight into *upper* limits for the pulse width by figuring that our engineers on the transmitting planet would like to send signals toward each of the million stars in their neighborhood, repeating the performance some reasonable number of times (say, 10) in the thousand years it takes for the signal to get there. In doing that, the transmitter can dwell only 1,000/(10x1,000,000) years on each target—that's about an hour.

That's an interesting result for another reason: It turns out that the same disembodied atoms that cause the Drake-Helou effect also give rise to radio scintillation, analogous to the atmospheric scintillation that causes the twinkling of starlight, and that radio twinkling has a time scale not of fractions of a second (as with starlight), but of a good part of an hour. So an hour-long transmission (a very long pulse) is likely to outlast the fading effect of galactic scintillation, and therefore will appear quite intense for a portion of the time, whereas a significantly shorter pulse might fall victim to a deep fade-out.



Were we falling prey to faulty reasoning here? Our argument so far assumed that the extraterrestrials would send a signal to only one target at a time. But if they were really advanced, it would not be difficult for them to build many transmitting antennas, so they could target many stars at once.

At this point I put forth a favorite idea: Our use of large radio-astronomical dishes, each with a single receiver able to detect signals from only a single point in the sky at one time, is really a transient phase in our technological maturation. These antennas are like cameras in which we put only a tiny speck of black-and-white film in the focal plane. Our technology is getting better: Newer spectrometers cover a wider range of wavelengths (color film). And we are beginning to use a few simultaneous receiving systems (a few specks of film).

As our technology improves—and we are becoming adept with little things made from silicon—we'll be able to omit the large reflecting dish entirely, instead using the surface of a vast array of silicon wafers as the antenna itself, connected directly to the underlying silicon receivers. This is a phased array, able to form multiple simultaneous radio beams. Not only are the interconnections part of the silicon, even the power is generated by the silicon itself! There it is, a dry lake bed tiled with glistening purple checkerboards of silicon, quietly receiving radio signals from a multiplicity of directions. It could also be a transmitter, of course: Sunlight delivers a billion watts per square kilometer.

We liked our futuristic new silicon toy, and quickly began using it. Stepping into the role of advanced alien beacon engineers, we decided to transmit multiple beams continuously to known planetary civilizations—these are messages, for which we use perhaps half our transmitter power. The other half we use for contacting new civilizations, by successively sending an intermittent beam in their directions. These are the pulsed transmissions we invented earlier, visible to the radio antennas of primitive civilizations as a flashing beacon, beckoning for an eventual reply.

These elegant, metallic purple planes patiently do their electromagnetic chores, carrying on multiple dialogues with established partners, perhaps finding a new one once in a hundred millennia. Long periods of sameness, punctuated by occasional newness. Here I mentioned the model of pulsars: many similar ones, then a new class—an optical pulsar, a fast binary pulsar, a millisecond pulsar, or urban pulsar-crowding in a star cluster. Phil's model was from a different culture: The popular music of Glasgow, for a long time relatively unchanging, now has exploded with Japanese folk tunes.

How could an object such as our silicon toy survive for millennia? On Earth it takes careful engineering to make something that runs for just a century. Active maintenance would be required. There must be redundant arrays of antennas, free-floating and self-phasing, replaced as they fail. They would illuminate the planetary neighborhoods of good stars, perhaps out to 10 astronomical units (1 AU is the average distance from Earth to the Sun), reaching all good suns in the neighborhood in a human lifetime. If, indeed, this strategy is being pursued by those other galactic beacon engineers, our job is to look at the whole sky continuously, for that literally once-in-a-lifetime signal of unusual strength.

We started scratching down numbers: Could such a signal be detectable with the sort of small—and insensitive—antenna that sees the whole sky? (In an ironic twist of nature not unrelated to the fact that pulses short in time are wide in frequency, big antennas see a small piece of the sky, and vice versa.) "Let's see, roughly 10^{-20} watts per square meter for 10 dB relative to isotropic . . . mumble, mumble . . . need to illuminate a 10 AU disk at range . . . about 10^{28} square centimeters . . . wow, only 10 kilowatts!"

We fiddled with the numbers a bit to allow for proper motions, and still concluded it was easy enough, given those handsome purple alien transmitting planes. (The idea of beacons strong enough to be detectable with small antennas has been elaborated recently by Bob Gray, a Planetary Society member and amateur radio astronomer from Chicago. See his article, "Isotropically Detectable Interstellar Beacons," *Jour.*

META and BETA

Project META (Megachannel ExtraTerrestrial Assay) is The Planetary Society's full-time, whole-sky Search for Extraterrestrial Intelligence (SETI), carried out at twin sites: the Harvard-Smithsonian 84-foot-diameter steerable radio telescope, in Harvard, Massachusetts, and the 100-foot-diameter radio telescope of the Institute of Radioastronomy in La Plata, near Buenos Aires. It is the most advanced and powerful SETI project now operating.

META's sensitive receivers and sophisticated 8.4-million-channel spectrum analyzer could detect radio signals broadcast intentionally by a civilization like ours orbiting any of the nearest thousand Sun-like stars. More advanced civilizations—with correspondingly more powerful transmitters—could make themselves detectable from the farthest corners of the galaxy, which contains roughly 400 billion stars in a flattened disk 100,000 light-years in diameter.

META has now scanned the northern sky several times in the neighborhood of the 1420-megahertz emission frequency of neutral hydrogen, and once near its second harmonic (2840 megahertz). Its companion in Argentina is now completing the combined full-sky survey, including coordinated observations in the equatorial belt seen by both telescopes.

Since its inauguration six years ago by Steven Spielberg (whose gift to The Planetary Society made its construction possible), META has patiently scanned the sky for the signature of another intelligent civilization. Its detection algorithms include compensation for the effects of rapid astronomical motions; in addition, it uses the unique signature of a changing radio frequency caused by Earth's rotation to discriminate a genuine cosmic signal from terrestrial interference. The good news is that these algorithms work—the search system has rejected almost entirely the radio mumblings (and bellows) of intelligent life on Earth. The bad news is obvious—we have made no detections!

BETA (Billion-channel ExtraTerrestrial Assay) is our planned next step. Close searching in the neighborhood of "magic" frequencies like 1420 megahertz hasn't done the trick. But in those six years technology has advanced nicely, permitting us to cast a much wider electronic net, still within the resources of university research and Planetary Society support. We plan two steps: BETA I will be a 100-million-channel analyzer, hooked to a dual-beam upgrade of the Harvard antenna, that will search the full "water hole" (the 300-megahertz band of microwave frequencies from H to OH^-; see the July/August 1987 *Planetary Report*); BETA II, following five years later, will be a 6-billion-channel analyzer that instantaneously covers the water hole at millihertz ultrahigh resolution.

The BETA searches will constitute the first full water-hole search of the sky, the first dual-beam megachannel receivers and the largest spectrum analyzers on Earth. We expect the continuation of an independent center of excellence, supported by The Planetary Society, to advance the SETI enterprise worldwide, and, through its unique approach, to complement the NASA SETI program now getting under way. And—dare we hope?—given that each successive project provides us with a receiving system far more capable than the last, *one* of these explorations will someday succeed in making the most monumental discovery in human history; might it be BETA? *—PH*

Brit. Interplanetary Soc., **43**, 532 [1990].)

We did a last bit of backseat engineering for our alien culture by noting that they could save a few bucks by going to a shorter wavelength, where a smaller antenna would produce the same accurate beam. But as the wavelength gets shorter, the Drake-Helou spreading goes down, and Doppler shifts go up: The number of receiver channels increases in proportion to frequency squared or more! Great, I said—another good reason to embark on the BETA project I've been dreaming about for the last year!

Our musings had spun themselves out, it seemed. And we had come full circle, once again embracing the merits of billion-channel receivers. Phil and Phylis couldn't say good-bye without showing us their latest electromagnetic toy, Sony's pocket-size Pro-80 all-band synthesized radio. We switched it on, and found the electromagnetic spectrum entirely barren! Earth, it seemed, had recently been showered with the byproducts of a particularly violent solar outburst. All shortwave communications over the one-tenth of a light-second that bound our communicative horizon on Earth were blanked out. A fitting counterpoint, I couldn't help thinking, to the soaring communications systems of our morning's imaginings.

Exhilarated and exhausted, we drove off from the Morrisons' house. Mike said, "What a morning! I could never reconstruct *that* argument!"

"But *I* can," I replied, "because I took notes!"

Paul Horowitz is the inventor and instigator of Project META, the SETI program supported by The Planetary Society.

Illustrations: S. A. Smith

A Clean, Well-Lighted Place: MERCURY

by **Clark R. Chapman**

Mercury is not an easy planet to see, but around the time of the great solar eclipse of 1991, it was visible in the twilight sky. From top to bottom, Venus, the bright star Regulus, Mars, the Moon, Jupiter and Mercury seem to be lined up for a portrait. Members of the Agrupació Astronòmica de Castelldefels in Spain, who are also Planetary Society members, had traveled to Colombia to experience the eclipse, and there Javier De La Vega photographed this rare planetary alignment to share with other Society members. Photograph: Javier De La Vega

Just before high noon last July 11, the Moon crept in front of the Sun. On a beach near San José del Cabo, Baja California, I joined thousands of eclipse chasers who were treated to a rare view of the inner sanctum of the solar system.

The Sun's glaring brilliance usually hides not only its own looping prominences and flaring corona, but a volume of space extending tens of millions of kilometers outward in all directions. As darkness swept across the landscape, a string of planets could be seen dangling on an invisible celestial thread beneath the gaping black disk that had replaced the midday Sun.

Three of the planets were old friends, familiar to everyone. Venus, Jupiter and Mars had been playing tag in the evening sky for a couple of months, an unusual planetary alignment that had sparked much public interest. Eclipse totality revealed a fourth object glowing near Jupiter. It was Mercury, the fleeting planet known to the ancients but rarely seen nowadays above the smoggy, skyscrapered skyline of our modern world.

Astronomers have long used the brief minutes of totality to study the outer atmosphere of the Sun, to observe Sun-grazing comets and to hunt for planetoids inside Mercury's orbit. But daytime darkness is not really needed to see Mercury. After six minutes of blackout, the Sun was returned to us by the relentless orbital motion of the Moon, and it sank toward the western horizon. As twilight dimmed, satisfied eclipse watchers gazed westward as the train of planets followed the Sun into the Pacific.

Many were surprised by how easy it was to see little Mercury, which—through the accident of geometry—was located right next to giant Jupiter in the sky. A couple of times each year, Mercury is just as readily visible against a nearly dark sky for observers favored with transparent skies and a distant horizon.

For a world so comparatively close to Earth (about the same distance as Mars), Mercury is poorly studied. Not only have telescopic measurements been hindered by the solar glare, but spacecraft investigations are rendered difficult by the Sun's unrelenting heat. There has been only a single mission to Mercury so far: *Mariner 10*, which flew past the planet three times after reconnoitering Venus in the early 1970s.

Since then, ground-based astronomers have used several increasingly sensitive observing techniques to study Mercury. For example, analysis of radar echoes from Mercury has yielded maps of the topography on the planet's unseen side. (Through quirks of orbital geometry, *Mariner 10* had observed the same face of Mercury on all three passes.) As our knowledge of Mercury has grown, appreciation for its significance has broadened, so Mercury is once again a target of interest for planetary mission planners.

A World of Extremes

Little Mercury is a world of extremes. Only Pluto is smaller, yet Mercury is the densest of the planets (5.43 grams per cubic centimeter), reflecting its enormous percentage of iron. (Actually, Earth is somewhat denser than Mercury, but only due to its greater gravitational compression; Mercury's iron-rich material is denser than the material of which Earth is made.) With essentially no atmosphere, Mercury has no way to transport the Sun's broiling daytime heat to its night side, so it is simultaneously among the hottest and coldest planets in the solar system. Although Mercury appears geologically "dead," like the Moon, *Mariner 10* found that it has a magnetic field, which suggests that its deep interior may still be very much alive.

Superficially, Mercury resembles our own Moon. Its surface is pockmarked with impact craters, ranging upward in size to the immense Caloris basin, which is reminiscent of the giant basins on the Moon. Those basins mark the end of the Moon's late heavy bombardment, some 4 billion years ago. They were subsequently flooded with extensive flows of molten rock during a period of active volcanism.

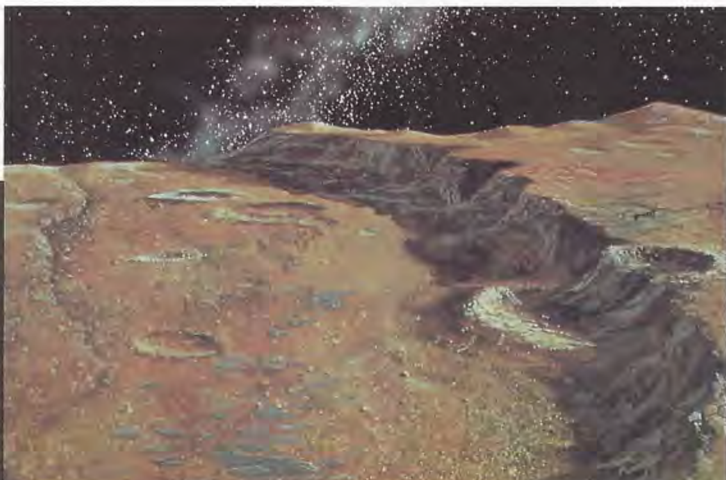
Mercury exhibits wide, flat terrains as well, but they do not share their lunar counterparts' dark color and hence may not have originated from the same processes. Mercurian craters and intervening plains are subtly different from those on the Moon. Some differences are ascribed to Mercury's greater surface gravity. Possibly some of the craters are from impacts by stray "vulcanoids," a hypothetical population of asteroid-like bodies residing even closer to the Sun than Mercury.

Mercury has some unique topographic features of its own, notably a planetwide system of huge cliffs, or scarps, some hundreds of kilometers long. Evidently during the planet's early history, the little world cooled and shrank, causing a crinkling or buckling of its rigid crust. The scarps record the degree of shortening from which geophysicists calculated the planet's cooling history. Scientists have been puzzled that Mercury could have cooled and shrunk so much and yet maintained—even to the present time—the molten core required to generate the dynamo that gives rise to the planet's magnetic field.

Indeed, Mercury's magnetic field was a surprise from the start. Experts in planetary magnetism had believed that rapid spin was necessary for dynamo action. But Mercury takes 59 days to spin on its axis just once—two-thirds of a mercurian year, as discovered by ground-based radar in the early 1960s. So nobody was really expecting *Mariner 10*'s revelation that the planet had an Earth-like, albeit miniature, magnetosphere.

Theorists also expected that a large, molten interior was necessary for dynamo action. So they had to go back to their modeling. They came up with a new mode for the creation of a planetary magnetic field involving a thin, not-so-hot spherical shell of fluid material deep within Mercury. This is an example of the creative interplay between observations and theory that drives science forward.

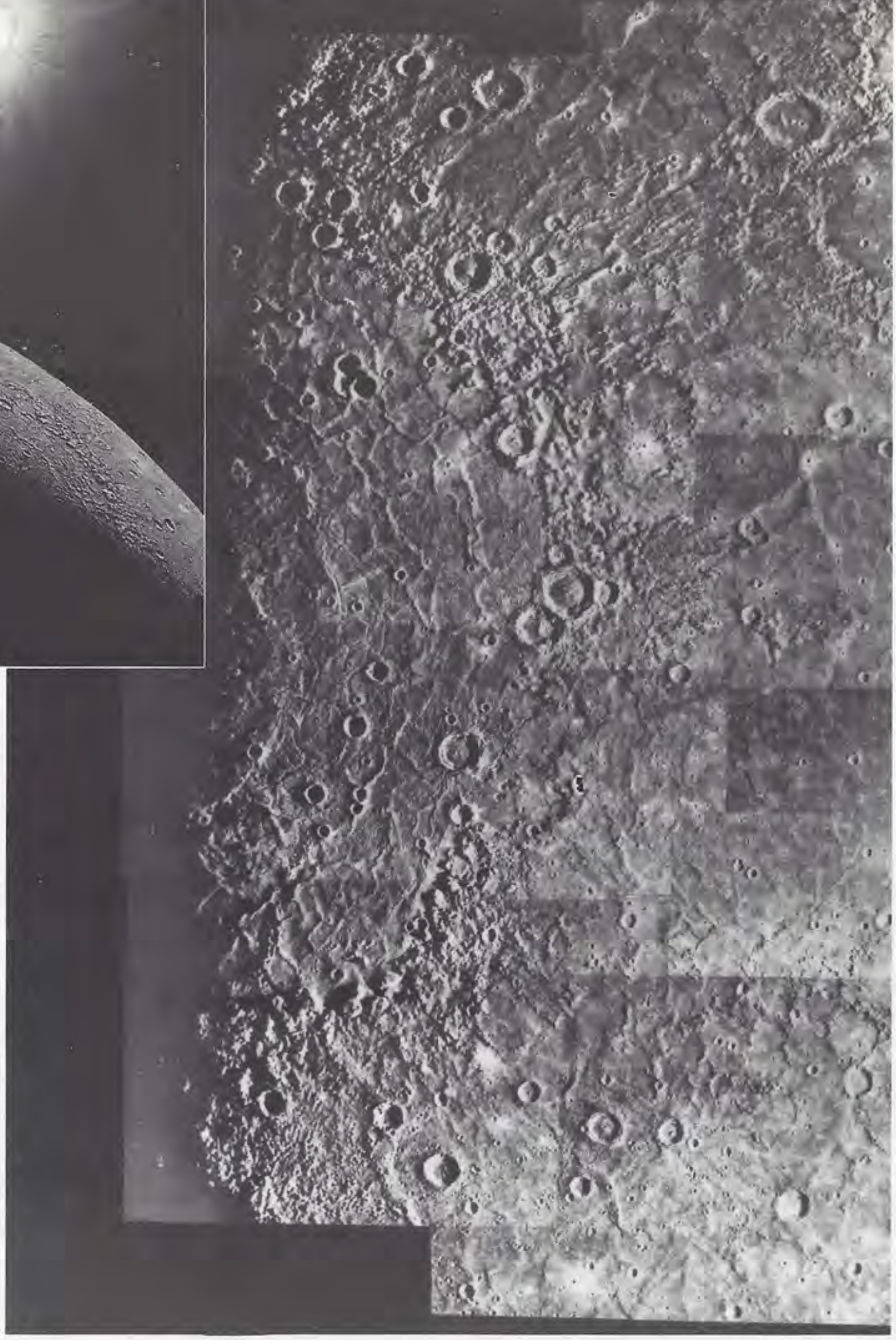
In the last few years, astronomers have been able



Left:* Mariner 10*, the only spacecraft to visit Mercury thus far, took this oblique view of the heavily cratered terrain and smoother plains that characterize this planet's face. Near the limb, or apparent edge of the planet, is a scarp, another feature that is distinctive to Mercury. These features may have formed when the crust buckled as the planet solidified and contracted around its massive iron core.
Image: JPL/NASA

Inset: Views from a perspective this close to the planet's surface can only be seen through an artist's imagination. Painter Michael Carroll here portrays Discovery Rupes on Mercury. ("Rupes" is the term used in naming scarps on the planet.)
Painting: Michael Carroll

Above: Again, an artist can give us a view impossible from a spacecraft. Here the Sun illuminates the region of Mercury seen in the image at right. If the camera on Mariner 10 *had looked into the Sun—as the artist can with impunity—it would have been burned out.* Painting: Don Davis



Right: The giant Caloris basin is partly visible in this image along the terminator (the boundary between night and day). Like rings formed in still water when you drop in a rock, circular features radiating from its center testify to the force of the impact that created this scar 1,300 kilometers (800 miles) wide. Image: JPL/NASA

to study Mercury's extremely tenuous atmosphere by using special spectral lines. Even small quantities of certain elements, including sodium and potassium, emit radiation that we can detect spectroscopically as bright, sharp spectral lines. When these lines were discovered in the mid-1980s in spectra of Mercury, a whole new vista on that world was opened up. Once we thought it had no atmosphere at all. Now we have found that the immensely thin mercurian atmosphere contains traces of sodium, potassium, oxygen, helium and hydrogen.

Using spectroscopic techniques, astronomers can also monitor the interactions between Mercury's magnetosphere and its surface. For planets with strong magnetic fields, like Earth and Jupiter, the stream of ionized solar wind particles from the Sun is held far away by a bow shock at the boundary of the magnetic field. Mercury's much less powerful field is only marginally capable of holding off the solar wind, and the planet lacks an ionosphere. It is of great potential interest to study emission lines, not only to learn about the behavior of Mercury's small magnetosphere, but also to look for possible clues about the composition of Mercury's surface.

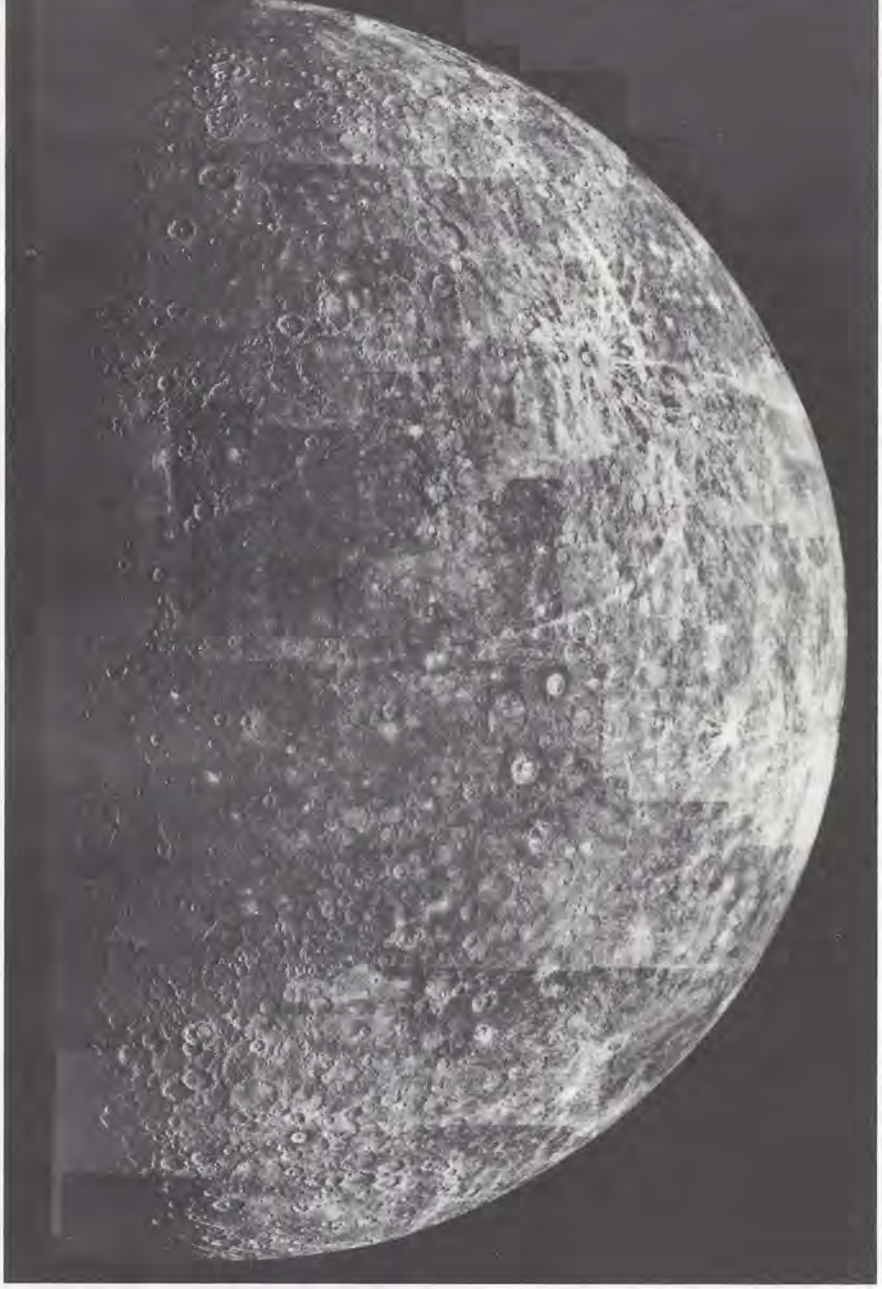
The usual techniques for learning about the chemical and mineral composition of Mercury are fraught with uncertainty. The measurements are difficult to make, given Mercury's proximity to the Sun's glare, and it is easy to imagine that Mercury's uppermost surface layer—exposed as it is to high-velocity micrometeorite bombardment and the near-solar environment—might not be pristine or representative of the planet's deeper composition.

Scientists are interested in Mercury's composition because the planet presents us with a potent way of testing theories for the origin of the solar system as a whole. Mercury is, after all, an "end-member planet"—the innermost object in an array of solid bodies that emerged out of the swirling nebula of interstellar gas and stardust from which our Sun was born. The enormous quantity of iron within little Mercury, reflected by its high bulk density, has long intrigued cosmochemists. (Mercury's iron core is thought to extend from the planet's center 75 percent of the distance out to its surface!)

At one time it was thought that planetary compositions were the result of smooth gradations in the chemistry of solid material that condensed from the solar nebula at various distances from the newly forming Sun, ranging from high-temperature condensates (rocks and metals) near Mercury to abundant low-temperature condensates (ices) in the outer solar system. In the past decade, however, planetary theorists have calculated a picture of the early solar system that is much more chaotic.

One scenario for the creation of the planets inside Jupiter's orbit involves a violent period of collisions of hundreds of worlds roughly the size of the Moon. Iron-rich Mercury could thus be a metal-rich core of a once larger body that suffered an enormous impact with another small world and was stripped of most of its crustal and mantle rocks.

We really won't know about Mercury's origin, however, until we can study it in depth and measure its rocks. It may ultimately prove to be the final piece in the puzzle about the processes that originally shaped our own planet Earth.



Mercury may not be as mysterious as Venus, as inviting as Mars or as majestic as Jupiter, but each planet has something unique to tell about how our solar system formed and evolved. This mosaic of images taken by* Mariner 10 *is the best portrait so far of Mercury. Will there be a better one someday? Scientists and engineers have studied more ambitious missions to this innermost planet, but as yet there are no official plans to return.
Image: JPL/NASA

A *World to* Explore

Earlier this year, NASA issued a 127-page report on the scientific goals of a Mercury orbiter mission. For many years, it had been thought that major technological breakthroughs would be necessary before it would be practical to take the next step beyond *Mariner 10*'s rather basic studies of Mercury. Then Jet Propulsion Laboratory (JPL) engineer Chen-Wan Yen discovered a simple but elegant way to lower a spacecraft into a near-circular orbit around Mercury using conventional propulsion systems.

The trajectory involves multiple encounters with Venus and with Mercury itself, taking advantage of those planetary gravity fields. Because velocities are so fast in the inner solar system (as a result of the nearby Sun's gravity), the total mission time is only 3.5 to 5 years. For example, an August 1997 launch would fly by Venus twice and Mercury twice before entering Mercury orbit in July 2002.

While JPL engineers were figuring out how to explore Mercury, a diverse group of scientists was expressing interest in the planet. Solar physicists desire a close planetary platform for observing our star's behavior. Astrophysicists want a Mercury mission to perform additional tests of relativity. (Long ago the advance of Mercury's perihelion, or closest orbital point to the Sun, provided an early proof of Einstein's theory of relativity.)

The planetary community has a continuing interest in Mercury for obvious reasons. But it was the space physics community that took the lead in the latest efforts to plan a new mission to Mercury.

In early 1988, NASA's newly formed Space Physics Division mandated a JPL engineering study of a Mercury orbiter mission. Detailed designs were published about a year ago, followed early this year by the scientific working group's proposals for a complement of instruments that would address the most important scientific goals.

Although the Mercury orbiter mission is both feasible and exciting, it is increasingly difficult for NASA to undertake new endeavors—even one so widely endorsed and comparatively cheap as this one.

At a February 1991 strategic planning meeting, NASA's Planetary Exploration Division tentatively decided to join the Space Physics Division in promoting a new start for the Mercury mission, but only in the speculative time frame after the turn of the century. Since then, budgetary disasters, including NASA's single-minded compulsion to build a space station at all costs, have dimmed hopes for sensible space science activities even that far in the future.

Nevertheless, you can go out some early morning or just after sunset and spot a gleaming object near the horizon. Over the months you can watch its speedy course through the zodiac, much like Disneyland's Mad Tea Party ride. While many are looking to the outer solar system and beyond as the next frontier, Mercury traces out the boundaries of our solar system's inner frontier and beckons us to learn more.

Spacecraft trip times are short, mission designs are complete, and there is much to learn. Now it is just a matter of deciding to do it.

Clark R. Chapman was responsible for one of the first maps of Mercury's surface to be made following the discovery of the 59-day rotation period. He is our regular News & Reviews columnist.

TRACKING ASTEROIDS:

When I last reported to The Planetary Society (May/June 1988 *Planetary Report*), I had the pleasure of describing how my colleague David Balam and I keep track of countless minor planets—asteroids —in their endless journeys around the Sun. I hope I managed to convey some of the excitement we experience from the hunt.

Yet, fun though it is, the question "Why bother?" might be asked. What is the point of measuring in minute detail the exact positions of all these tiny lumps of rock?

Indeed, our federal government agency here in Canada put it even more bluntly: "The committee was not convinced that the importance of the accurate measurement of yet more comets and asteroids . . . was sufficient to warrant funding."

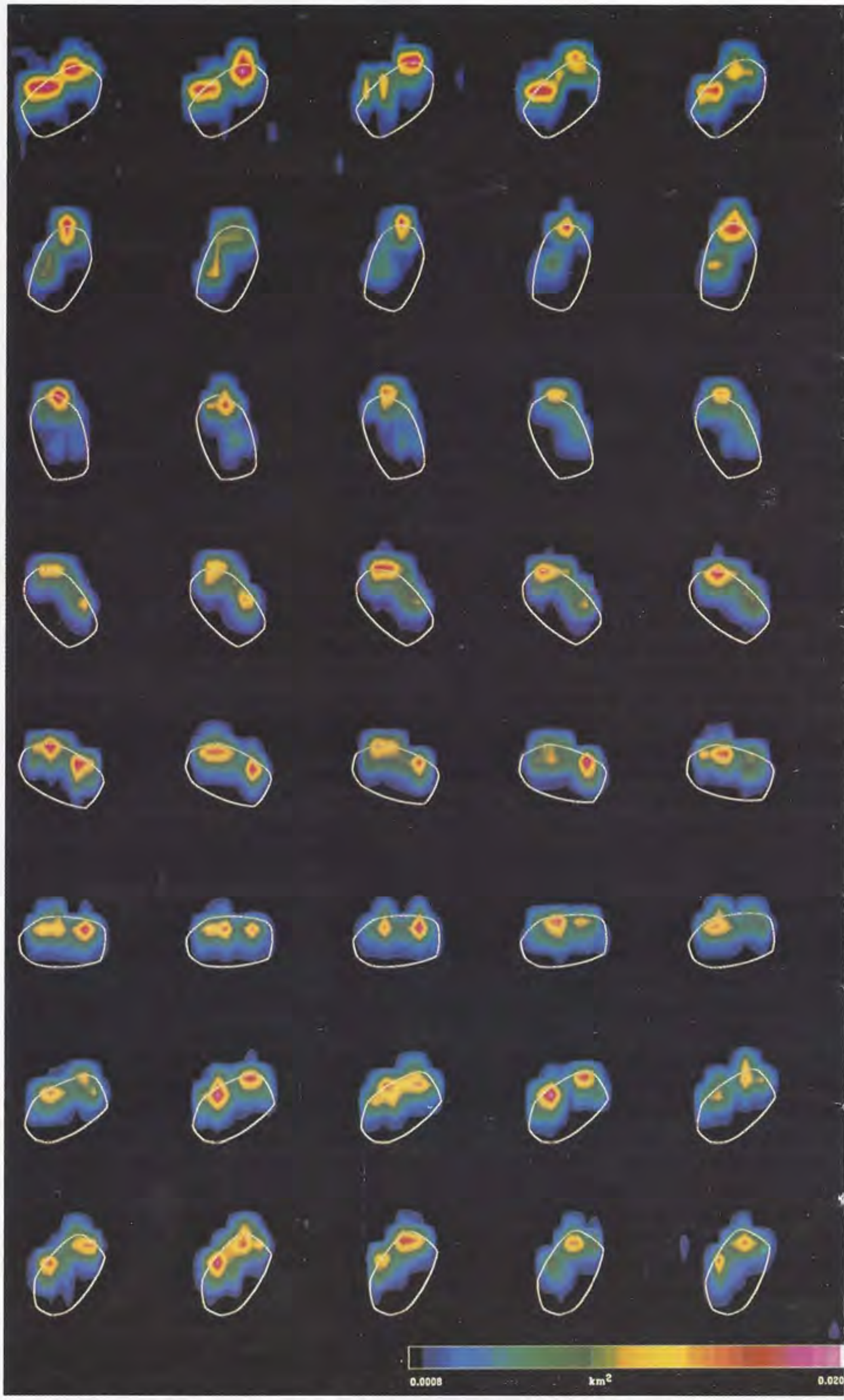
Just as the rug was thus pulled out from under our feet, The Planetary Society and the National Geographic Society stepped in and saved the day with handsome financial assistance to keep the project going. Thanks!

Designating the Known and the Unknown

Asteroid observers talk about *numbered* and *unnumbered* asteroids, and the question "Why bother?" can be asked—and answered—separately for each. The numbered asteroids are the 4,800 or so bodies whose orbits are known with fair precision. The numbers are permanent designations, usually written in parentheses, starting with (1) for Ceres, the first asteroid discovered (in 1801), and proceeding to (4789) Sprattia (discovered by Dave Balam as part of this program). By the time this article is printed, there may be more.

For the numbered asteroids, the question "Why bother?" takes the form, "If the orbits of these bodies are known precisely, and their positions can be predicted in advance, what is the point in measuring these easily predicted positions?"

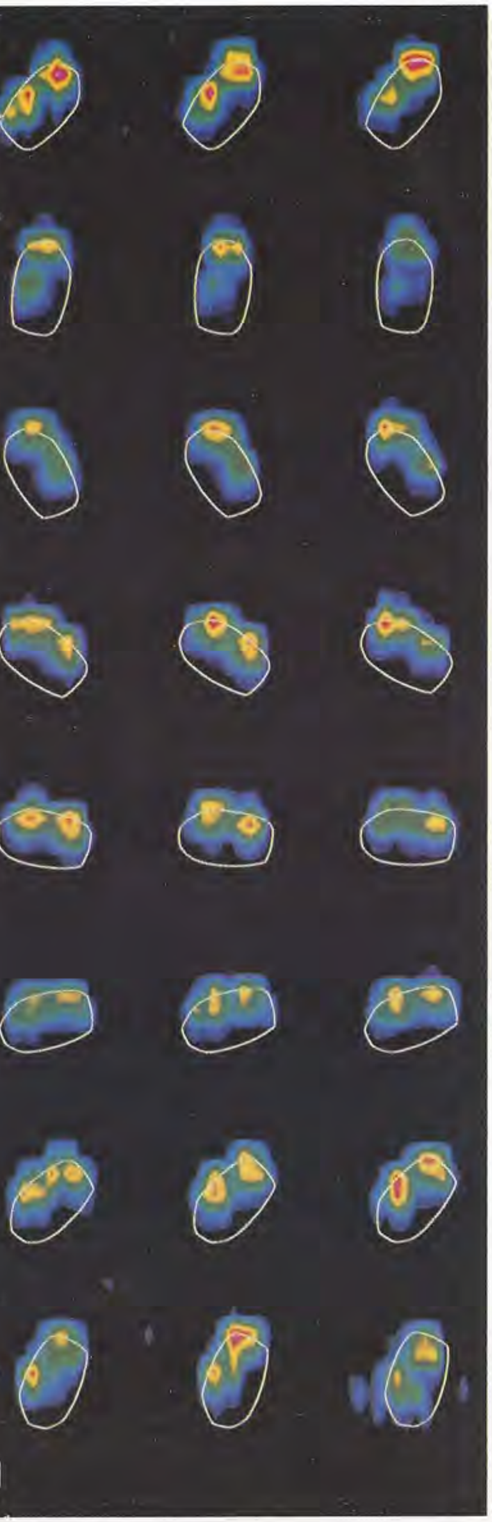
Every month, observers who photograph regions of the sky near the ecliptic (the plane of our solar system) find images of asteroids on their plates. Any that cannot be identified as one of the numbered asteroids is, not unnaturally,



This radar "movie" covering 23.5 hours gives us a pole-on view of asteroid 1989PB as it turns. The white outline indicates the object's silhouette. Astronomer Steve Ostro and colleagues used the 300-meter (1,000-foot) Arecibo radio telescope to bounce radar beams off 1989PB, enabling them to construct the first images of an asteroid. The images revealed that 1989PB consists of two distinct lobes that appear to be in contact with each other. Eleanor Helin, leader of the Planet-Crossing Asteroid Survey supported by The Planetary Society, discovered this object in August 1989. **Image: Steven J. Ostro/JPL**

WHY WE DO IT

by Jeremy B. Tatum



referred to as an unnumbered asteroid and is given a temporary designation, the year plus two letters, such as 1991JX. Many are never seen again, but often astrometrists (those engaged in positional measurements) will follow them up until they are identified again and again during subsequent passes by Earth.

If the orbit can then be well enough established so that the object's future path can be predicted, the object will join the family of numbered asteroids. For these objects, the question "Why bother?" takes the form, "Is there any point in adding more and more bodies to the roster of permanently numbered asteroids? Is this not just a purposeless make-work project?"

Intense and Indescribable Satisfaction

Honesty compels us to admit that we observe asteroids because of an intense and indescribable satisfaction obtained from striving to measure as accurately as possible and seeing our measurements match our careful calculations. We compare the usefulness of such activities to that of a Mozart piano concerto—something that is of no practical use but is part of the very essence of human striving and yearning. Yet, when pressed by those who have to foot the bill, there is no hesitation in describing the purposes, applications and uses of what to us is a highly enjoyable and satisfying study.

There is, of course, far more to studying the asteroids than merely recording their positions. We want to know their ages, shapes, masses, rotations and chemical compositions. All these things in turn will help us to answer more fundamental questions, such as how did the asteroids form, and what can they tell us about the history and evolution of the solar system? Are they derived from a major planet that somehow broke up? Or did the thousands of tiny bodies never agglomerate into a larger body in the first place?

The asteroids can probably tell us more about the conditions in the early solar system than can the major planets, since they have been unaltered, for example, by the geological and meteorological weathering processes that constantly alter Earth's face to obliterate the story of its origin.

Scientists are tackling these questions in ingenious ways, using many different types of telescopes and all the modern technology they can muster. As I write, I have in front of me a 1,200-page book (*Asteroids II*, edited by R.P. Binzel, T. Gehrels and M.S. Matthews) made up of 52 papers on different asteroid studies. The Planetary Society and NASA collaborated with several other organizations this year to organize a seminal conference on near-Earth asteroids. It is a lively subject, involving many different disciplines.

Seeing Shapes and Patterns

But there is one common requirement of all these studies, and that is for continuous, up-to-date, comprehensive and accurate astrometric and orbital computations.

Let's consider the photometry of asteroids, which is the measurement of their brightnesses and colors. By measuring how the brightness varies over time—usually hours—scientists can tell how fast these bodies are rotating. Not only that, but they can determine their shapes and whether some parts of an asteroid's surface are darker than others. How bright an asteroid appears gives us information about its size and how well it reflects sunlight. The brightness can be measured through filters of different colors, and astronomers and geologists can compare the observed reflectivities with similar properties of terrestrial rocks, and hence infer the likely mineralogical compositions of the asteroids.

Studies such as these have led to the discovery of several different mineralogical types, distributed differently in the asteroid belt between Mars and Jupiter. Darker bodies orbit, on average, farther from the Sun than brighter ones. This gives us clues to how different chemical elements separated out as they condensed from the contracting primeval solar nebula.

To measure the brightness of an asteroid accurately, the light reflected from it is measured by a sensitive photomultiplier through a tiny circular

Radar images can give us some idea of the shape of an asteroid, but our Earth-based technology has a long way to go before we can see a near-Earth asteroid with the clarity possible with a spacecraft. No missions have yet been sent to any of these bodies that pass so close to our own world, but here artist and scientist Bill Hartmann gives us a view such as a spacecraft might one day see. Earth and its Moon are visible in the background. *Painting: William K. Hartmann*

aperture, perhaps just 10 to 20 arcseconds in diameter. To do this, one must know exactly where the asteroid is going to be and how fast it is moving. This sounds obvious, and indeed it is so obvious that it is easy to forget just how closely the photometrist depends on the astrometrist for the success of his or her work.

The Real and the Unreal

A look at the main-belt asteroids reveals some obvious gaps in the distribution of their orbits. These are known as Kirkwood gaps and are thought to be caused by the gravitational influence of Jupiter. Why are some of these gaps more pronounced than others? How many are real and not due to random fluctuations?

Armed with a list of the orbital elements (the sizes, shapes and orientations of the orbits), scientists have grouped them into several families, each referred to using an eponymous member of each group: For example, we speak of the Cybele or Phocaea families. Each family may result from objects breaking up in the early history of the asteroid belt. But how many are real families, and how many are chance groupings?

Yet again, if the asteroids' colors, which reflect their compositions, are measured, we find that they can be classified into several types. The darker ones (which are richer in the lighter chemical elements) are generally more distant than the brighter and heavier ones. But just how many of these types are indeed distinct? Why are some types more abundant than others? Are the types correlated with the dynamic families?

The relations among the various properties are so intertwined that, even though we now have about 4,800 numbered asteroids, we do need to measure accurately and study yet more asteroids. It is far from mere data-gathering for the sake of it.

Measuring a Point of Light

Have you ever wondered how we know the sizes of asteroids? After all, most of them are so small that they appear only as points of light even in the largest telescopes. Is a bright asteroid bright because it is big, or merely because it reflects sunlight well? In fact, an asteroid's brightness depends on its distance (which we know, thanks to accurate astrometry!), its size and its reflectivity (technically known as its albedo).

But what happens to the sunlight that an asteroid's surface does not reflect? It is absorbed, and consequently warms the asteroid up. The warm asteroid then emits infrared radiation, which can be detected with special telescopes such as the James Clerk Maxwell Telescope in Hawaii. (Infrared radiation cannot be seen by eye, so an asteroid's orbit must be known with great precision to be sure that the telescope is pointing at it.)

Now the amount of infrared radiation emitted by a warmed-up asteroid also depends on its size and albedo, but in a different way from the optical brightness. Astronomers can measure both the optical and infrared brightnesses simultaneously and *voila*: two equations in two unknowns, which can be solved for size and albedo separately.

Giving Shape to Light

So much for sizes, but have we any hope of determining the shapes of the bodies seen only as points of light? If asteroids are all spherical, then they probably condensed separately from the primordial nebula. But if they are irregularly shaped, they might be fragments from awesome collisions between larger bodies.

Well, indeed, brave attempts are being made to determine asteroid shapes. Asteroids rotate and, as they do so, irregular ones present continuously varying cross sections to the observer. The photometrist is able to see its brightness waxing and waning as the asteroid turns over and over. That is, he or she measures the light curve. Now it is true that an asteroid's shape, as well as any dark and light patches on its surface, determines the light curve. But to deduce asteroid shape from a light curve proves to be a rather difficult business.

There is another way, however, but it depends on the most precise orbital calculations and accurate astrometry possible. We can predict when an asteroid will pass in front of a star and cut off the star's light for several seconds. This is called an occultation and, if it

is observed by several people scattered across Earth, the asteroid's cross-section can be calculated. (See the March/April 1983 and July/August 1984 *Planetary Reports*.) Then we can use the light curve to determine the location of light and dark markings on its surface.

One must not underestimate the difficulty of doing this, but it is astonishing that we can deduce size, shape, mineralogical composition and the locations of surface patches from observations of a tiny, unresolved speck of light!

This is the discovery image of 1991JX, seen here as the faint streak against the background of stars. Eleanor Helin found this asteroid over a month before it made its closest approach to Earth, giving Steve Ostro and his radar team time to get into position at the Arecibo Observatory in Puerto Rico. Their observations allowed astronomers to pin down 1991JX's orbit with great accuracy. *Image: Eleanor Helin/JPL*

No Time to Wait

Much of traditional astronomy is passive in that we wait for radiation to arrive at our telescopes and then we analyze it. Some astronomers are taking a more active role. There is in Arecibo, Puerto Rico, a huge radio telescope some thousand feet in diameter constructed in a natural hollow in the terrain. Steven Ostro of the Jet Propulsion Laboratory and his colleagues have been using this telescope to bounce radar signals off asteroids.

The returning signal is unimaginably feeble, and it falls off inversely as the fourth power of the distance. This means that, if you were somehow to double the distance of the asteroid, the strength of the returning signal would be reduced by a factor of 16! Because of this, the technique is best for those asteroids that pass close by our planet, the near-Earth asteroids.

It is possible that some Earth-born spacecraft have seen an asteroid close up—in an orbit around Mars. Scientists speculate that Phobos and Deimos, Mars' two tiny moons, are actually asteroids captured by the planet's gravity. The US Viking orbiters imaged both moons, and one of the Soviet Phobos craft returned images of its namesake. Mars appears in the background of this Phobos image.
Image: Space Research Institute, Moscow

This poses very special difficulties for observers. Not surprisingly, such objects are usually spotted when they are very close. They then quickly streak across the sky and disappear into the depths of the solar system, not giving anyone much time to carry out the difficult radar experiments. Astrometrists must be particularly on their toes to supply good data to the radar observers.

One now-famous example is the object known as 1989PB (now permanently numbered 4769)—discovered by Eleanor Helin, the leader of the Planet-Crossing Asteroid Survey supported by The Planetary Society. Fortunately, several astrometrists, including Dave and I, found prediscovery images on our photographs and managed to do a lot of rapid follow-up astrometry. As a result of this frantic activity, the radar experiment of Ostro and his colleagues was a spectacular success, revealing that 1989PB is probably a dumbbell-shaped object.

Active observation is not to be limited to radar bounces. Exploratory spacecraft visiting the outer solar system could take close-up looks at asteroids as they travel through the main belt—(204) Ida and (951) Gaspra are scheduled for visitation by *Galileo* on its way to the Jupiter system. What will we see? I'll guarantee there'll be surprises. But only if we do our astrometry right!

Knowing When to Duck

Textbooks tell us that most asteroids orbit the Sun between the orbits of Mars and Jupiter. But in recent years, teams led by Eleanor Helin of the Jet Propulsion Laboratory, Eugene and Carolyn Shoemaker of the United States Geological Survey and Tom Gehrels of the University of Arizona have discovered scores of asteroids that swing close by Earth.

These near-Earth asteroids have a scientific interest all their own. Were they knocked out of the main belt? How could that have happened? Are they extinct comets? Or are they a different class of object altogether?

On the practical side, how often may we expect one to collide with Earth—with obvious disastrous consequences? Was an asteroid collision responsible for the extinction of the dinosaurs at the end of the Cretaceous period? If one is found to be headed our way, what do we propose to do about it?

The scenario makes excellent material for science fiction writers, but it is by no means an impossible occurrence. One reason for "accurate measurement of yet more asteroids and comets" is to make a realistic assessment of just how real the danger is.

But most scientists take a more positive view of asteroids. We could use them—mine them for minerals and metals, relieving a little of the burden from Earth. With their low gravity, little energy is needed to carry materials away from them.

Those of us engaged in astrometry may seem to be far removed from the massive engineering technology that would be needed to bring such dreams to fruition. But if we were ever to stop our humble efforts, these exciting possibilities would never come to pass.

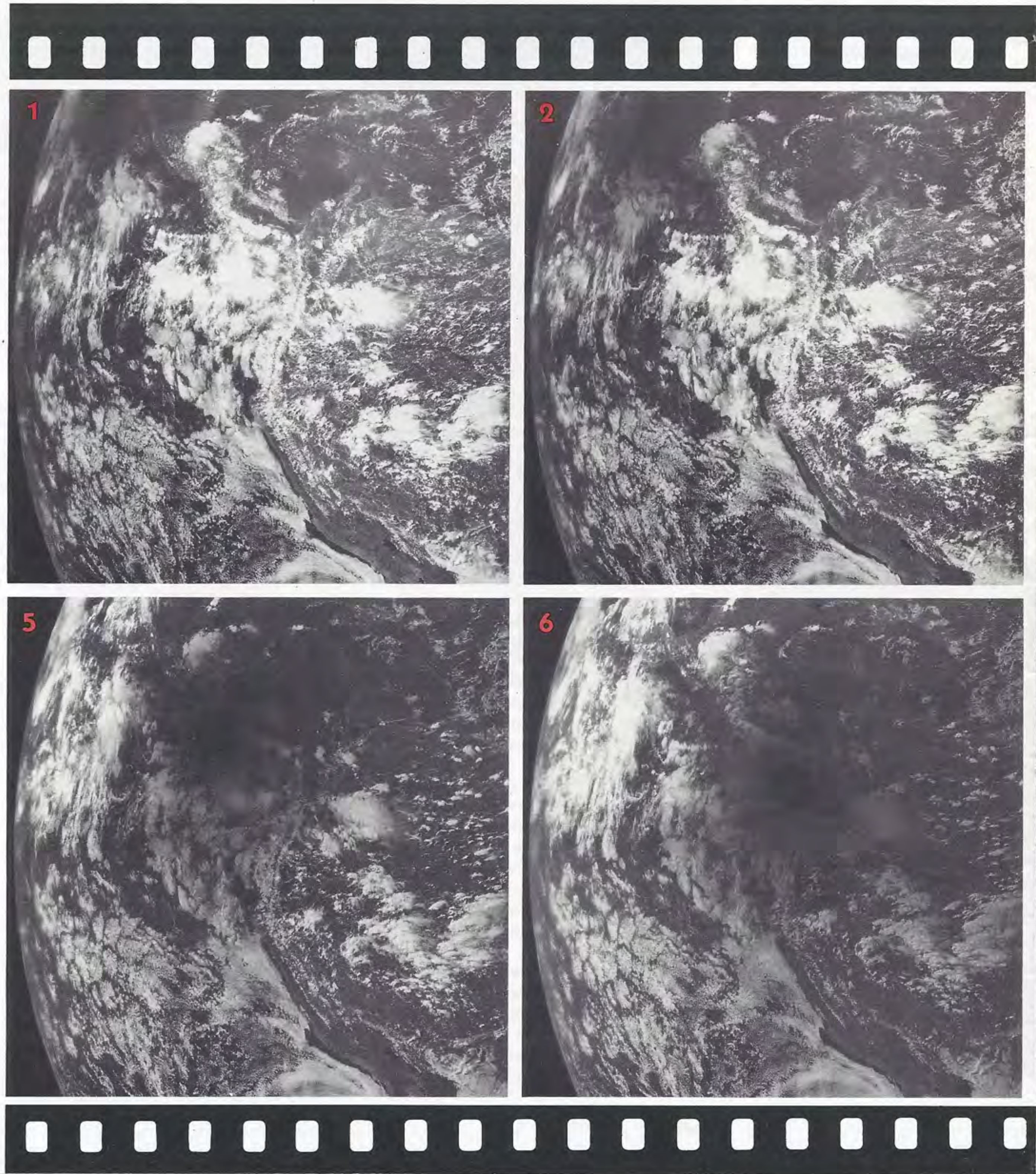
Yes, we enjoy following the asteroids in their paths, and we do it for our enjoyment alone. Yet the scientific and practical applications of our efforts—and I have given but a brief sample—are endless. We make no apology!

Jeremy Tatum is a professor of Astronomy at the University of Victoria in Victoria, British Columbia.

The 1991 Solar Eclipse —

In The Planetary Society we like to think that we view things from a different perspective than most people—that is, we see and visualize solar system places and phenomena from vantage points other than Earth's surface. The great solar eclipse of July 11, 1991, is a case in point.

A few weeks before the eclipse, we received a letter from Bruce Bierman, a Society member from La Mesa, California, asking if any satellites would be making images of Earth during the event. As the Moon passed between our planet and the Sun, it would cast a shadow that a satellite in the right position should be able to see. A series of images showing the transit of this shadow across Earth would have great value, he wrote, "in reinforcing in the public consciousness an awareness of 'Earth as a planet' as well as an enhanced appreciation and understanding of



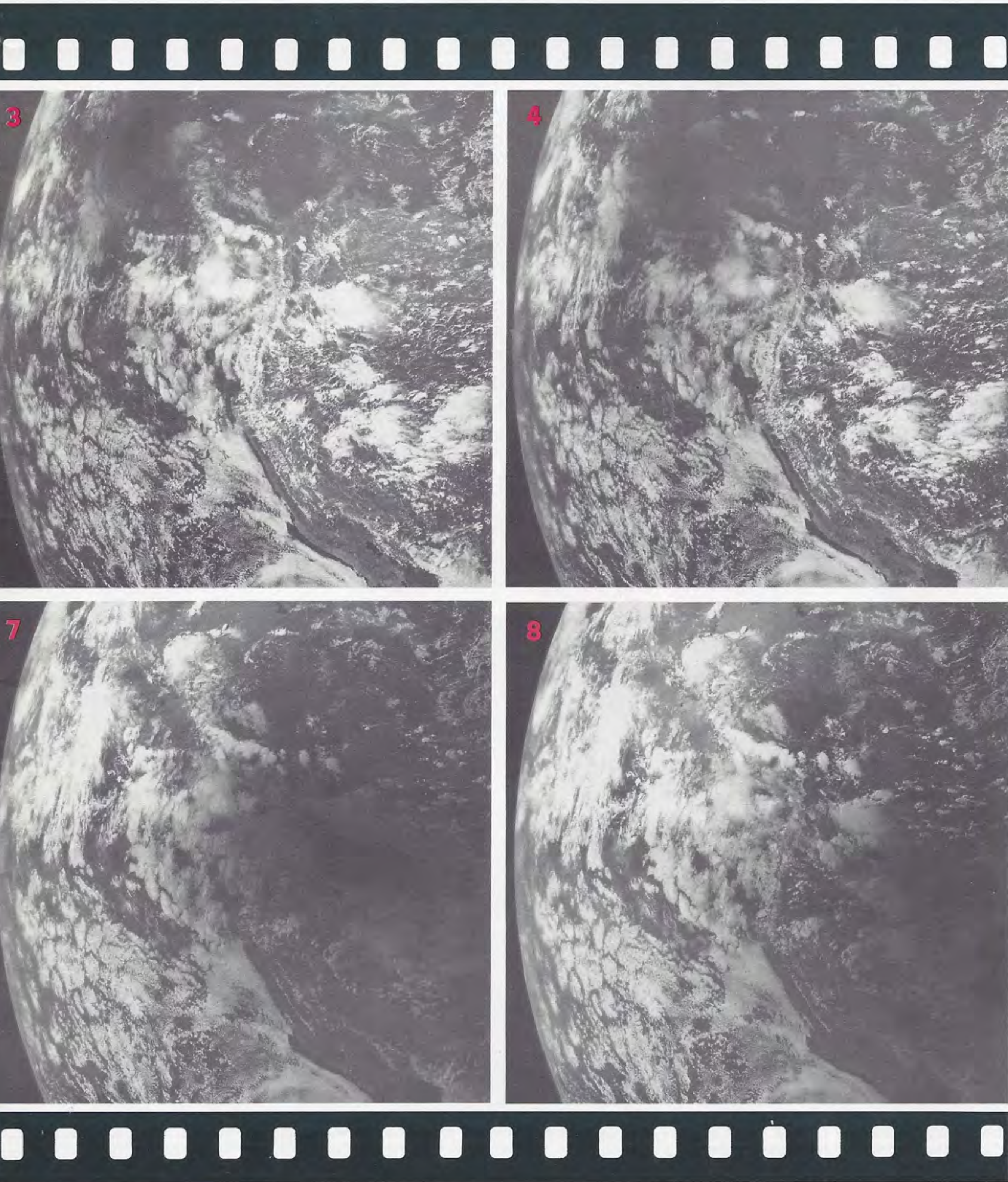
From a Different Perspective

an astronomical phenomenon."

Mr. Bierman's idea excited the Society's staff. None of us had thought of it. We immediately sent a fax to Roger Bonnet, Director of Space Sciences for the European Space Agency, to ask if any of ESA's meteorological satellites would be in a position to see the Moon's shadow. A few weeks later, J. De Waard of the *Meteosat* Exploitation Project sent us this series of images.

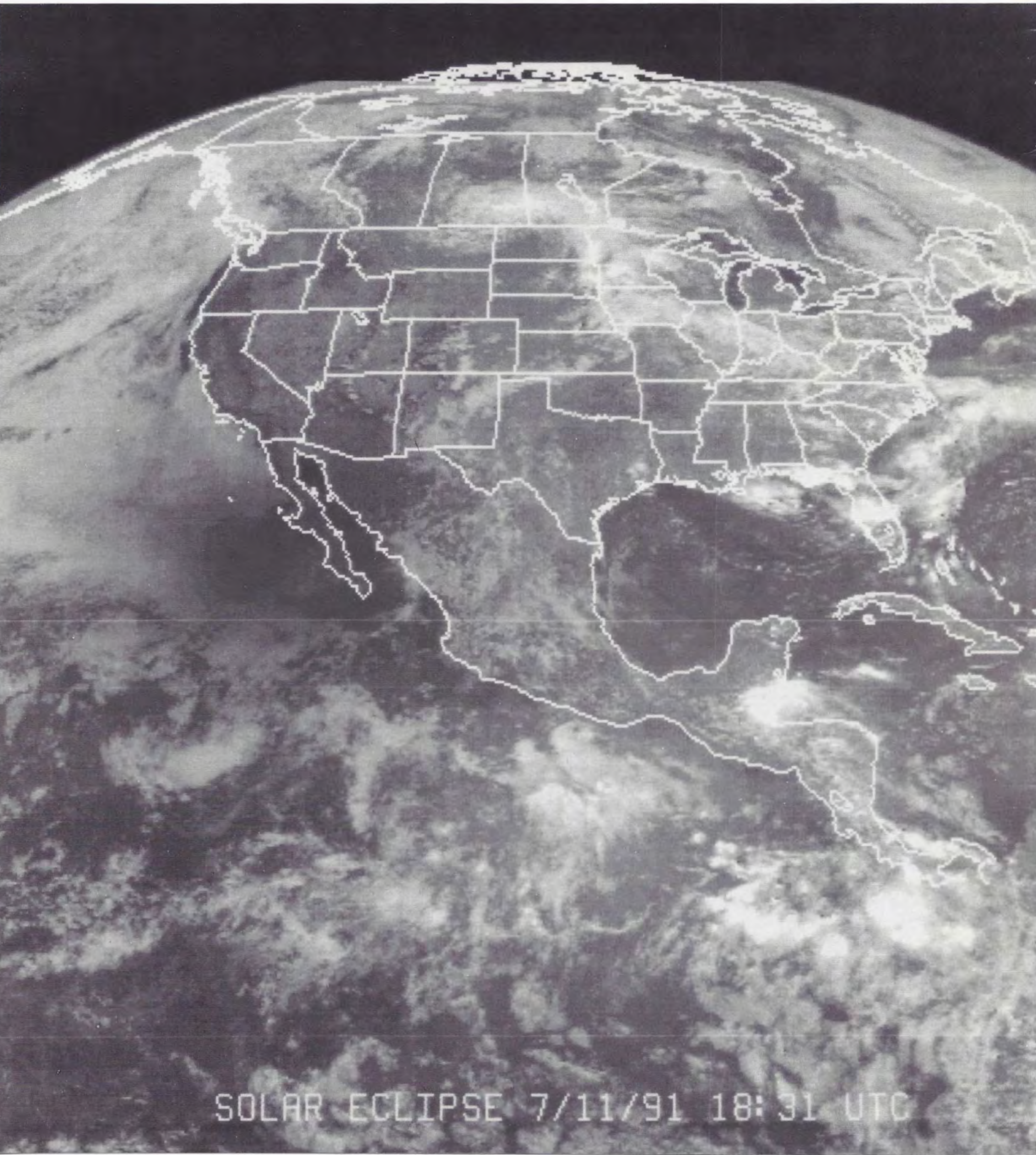
Meteosat 3, operating in a special scan mode, tracked the Moon's shadow as it crossed Mexico and moved across the top of South America. The islands of Cuba and Haiti are visible to the right in these images. If you look closely, you can see that there is a dark central region, the umbra, in the shadow, which is surrounded by a lighter penumbra.

Mr. Bierman also contacted the



United States' National Oceanic and Atmospheric Administration to ask if any of its weather satellites would be tracking the eclipse. At his suggestion, we contacted Richard DeRycke of the National Environmental Satellite, Data and Information Service, who sent us the image on this page, taken by GOES-7, in which the shadow of the eclipse appears off Baja California.

We would like to thank Mr. Bierman for alerting us to the possibility of seeing a solar eclipse from the perspective of Earth orbit, and for making it possible for us to share it with all Planetary Society members.
—Charlene M. Anderson



International Space Year Celebrates Tomorrow's Explorers

by Susan Lendroth

The International Space Year (ISY) of 1992 will celebrate humanity's first tentative steps away from Earth. We have sent robotic spacecraft to the edge of our planetary system, we have walked on the nearest planetary body, and we have looked back on our home planet and seen it, for the first time, from a perspective in space.

The year 1992 was chosen for ISY because it marks the 500th anniversary of another great voyage of discovery: Columbus' first expedition to the Americas. The year also recalls a great exploratory effort only 35 years past: the International Geophysical Year (IGY) of 1957. As part of IGY, scientists around the world undertook far-reaching projects to understand the workings of Earth, and the Soviet Union launched the first artificial satellite, *Sputnik 1*.

Weaving all these threads together, the organizers of ISY have chosen as their theme "Mission to Planet Earth." Programs in many nations will demonstrate our ability, developed since IGY, to study our planet from space. The Planetary Society is joining the celebration with a series of projects focused not only on terrestrial studies, but also on missions to other worlds.

Together to Mars

The launch of *Mars Observer* in mid-September of 1992 will be a centerpiece of ISY. The Planetary Society, working closely with the *Mars Observer* team, is planning a variety of activities at the Kennedy Space Center, including special tours for Society members and events open to the public.

Tomorrow's planetary explorers, whether human or robotic, will need the imagination and talents of a new generation of scientists and engineers. To encourage these young people of today to join in this endeavor, the Society has developed the H. Dudley Wright International Student Contest, "Together to Mars."

By 1992 we will have selected 20 winners from around the world who will receive a prize of $2,500 and a trip to Washington, DC, for the World Space Congress, scheduled for August 28 to September 6. The winners will be honored during the congress, which will be the first joint meeting of the International Astronautical Federation and the International Council of Scientific Unions' Committee on Space Research.

Planetary Rovers to Explore Washington

In Washington during the scientific meetings, the Society will sponsor Rover Expo '92, which is subtitled "An International Space Year Exposition of Planetary Robots and Telepresence Technology for Planetary Exploration." We are coordinating our plans with NASA's Space Exploration Directorate, the Smithsonian Institution's National Air and Space Museum, and the Robotics Committee of the American Institute for Aeronautics and Astronautics. Our members and the general public will be treated to demonstrations of the latest advances in exploratory robotics.

Teaching Tomorrow's Explorers

For the second year in a row, The Planetary Society will co-sponsor the annual convention of the National Science Teachers Association (NSTA). ISY will see the association's 40th annual meeting, held in Boston from March 26 to 29. A Planetary Society Day on March 27 will feature several sessions on space science.

Bruce Bullock of IS Robotics Corporation will demonstrate the microrobot Attila. Paul Horowitz of Harvard University will describe Project META, The Planetary Society's program in the Search for Extraterrestrial Intelligence, and Project BETA, which could greatly expand our search. Marcia Smith of the Library of Congress will review how the turmoil of *perestroika* has affected Soviet space capabilities. Scientist and artist William K. Hartmann will discuss The Planetary Society's new role in the NSTA's upcoming education reform project.

Celebrations Around the World

The International Space Year will provide the theme for an educators' conference in Canberra, Australia. Scheduled for July 1992, this international conference is for invited educators in space science and technology. Thomas O. Paine, former NASA Administrator and now a member of the Society's Board of Directors, will be a featured speaker. [For more information, contact John Nicholas, University of Canberra, P.O. Box 1, Belconnen, 2616 Australia; fax (6) 201-5199.]

Other Society educational activities for ISY now in the planning stages include educator workshops in Colombia and Costa Rica, as well as a symposium in Japan.

We will wrap up our International Space Year activities by celebrating the interwoven themes of ISY: studying our own planet and venturing to new worlds. In December, *Galileo* will swing by Earth on its circuitous route to Jupiter. As it did in December 1990 (see the March/April 1991 *Planetary Report*), the spacecraft will turn its instruments on Earth. We will once again sponsor encounter activities in Pasadena, California—the home of both the Jet Propulsion Laboratory and The Planetary Society.

If you would like more details on these Society events, keep reading *The Planetary Report* and watch your mailbox.

Susan Lendroth is the Manager of Events and Communications for The Planetary Society.

PLANETARY SOCIETY MEMBERS can attend the National Science Teachers Association convention in Boston at the same discounted rates as NSTA members. We will have registration and housing information forms available in November. Please write to NSTA Convention, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

Questions & Answers

In the article "From Siberia to Mars" in the March/April 1991 Planetary Report, *the following is stated: "In the northern hemisphere we find plains with few impact craters, which indicates that they are younger than 2 billion years."*

How can one part of Mars be younger than another part? Once a moon or planet forms into the original sphere, wouldn't all parts have the same age?
—Joubert Malouf, Copperopolis, California

All the planets are continually bombarded with meteorites that form craters on their surfaces. This enables geologists to tell roughly how old a planetary surface is, since an older surface, having been exposed to the meteorite bombardment longer, has more impact craters than a younger surface.

What geologists are really dating, however, is an event that erased all the craters that had previously formed on that surface. For example, lava flows from a volcano might bury all the impact craters around the volcano. If the volcano erupted a billion years ago, we would now see on the lava surface only the impact craters that have accumulated since the eruption. Away from the volcano, we might find many more impact craters because the older ones have not been buried by lava. If there are twice as many impact craters on the pre-volcanic surface as on the lavas, we might conclude that the older surface is 2 billion years old.

As another example, large floods of water on Mars typically destroyed all the impact craters in their paths. A flood can, therefore, be roughly dated by counting the impact craters superimposed on the flood channel.

The technique gives reliable information on the relative ages of surfaces, but it does not give precise information on the absolute age, because we only have rough estimates of the impact rates.

Although it works well on most solid planets, crater-dating does not work well for Earth because the craters are rapidly destroyed by erosion. Compared to other planets, Earth has a very young surface.
—MICHAEL H. CARR, *United States Geological Survey*

Mars' relatively smooth northern hemisphere is sharply delineated from its crater-pocked southern counterpart in this region of Amazonis Planitia.

By counting impact craters on a planetary surface, scientists can get a reasonable estimate of how long that area has been undisturbed by wind, floods or volcanism.

Image: US Geological Survey

Is it possible that the retrograde rotation of Venus [it spins on its axis in the direction opposite to its revolution about the Sun] could be attributed to a collision with a cosmic body? It is theorized that Uranus' tilt is the result of such an event, so couldn't a collision have upended Venus?
—Debbie Lamar, Danville, Illinois

Yes, that probably is the right explanation. Currently fashionable (and quite possibly correct) computer modeling of the formation of Earth, Venus, Mars and Mercury leads to the conclusion that the growth of these planets was marked by giant impacts. The modeling indicates that many bodies more or less the size of the Moon, Mercury and Mars formed first, and that the larger terrestrial planets seen today resulted from the collision of many of these smaller, but still planet-sized, bodies.

This leads to a natural explanation of the origin of the Moon by material from Earth "splashing" into orbit about the planet, followed by the gravitational "clumping" of this debris to form the Moon. It may also explain why Mercury has a large iron-rich core, but only a relatively thin layer of rocky material surrounding the core. These same computer calculations show that giant impacts can almost completely remove rocky mantles from small planets like Mercury.

These large impacts are certain to be at least somewhat off center and will, therefore, cause the planet that is struck to spin one way or the other. One spin direction is about as probable as the other, so it may be just an accident that Venus' spin is retrograde and that of the other three terrestrial planets is prograde. Early in its history, Venus was probably spinning quite rapidly in this retrograde manner, but solar tidal forces have decreased its rotation to the slow rate of 243 Earth-days observed today.

—GEORGE W. WETHERILL, *Carnegie Institution of Washington*

In the January/February 1991 issue of* The Planetary Report*, Eleanor Helin states in "Eureka! The Recovery of 1982DB" that this near-Earth asteroid is "even easier to reach than the Moon." How can this be possible?

—Dennis W. McDonnell, Clinton, Michigan

The accessibility of an asteroid is measured by the amount of energy that would be required for us to rendezvous with it; in the case of the Moon, to land on it. The energy required varies with the orbit of each asteroid and its position relative to Earth at the time of launch. The accessible asteroid mission candidate will have orbital characteristics comparable with those of Earth—in other words, it will be going around the Sun with us.

The energy required to put a given mass into an initial Earth orbit is the same regardless of its ultimate destination. Because of the strength of Earth's gravitational field, this is where most of the energy for such a mission would be consumed. Only a little more energy would be required to go on to the Moon from there because the Moon is simply in a higher Earth orbit. The amount of energy required to go beyond the Moon is also relatively small.

It's the arrival at the asteroid versus the Moon that is different. Although it is less massive than Earth, the Moon still has a large gravitational effect. To soft-land on the Moon, this gravity must be countered with energy—for example, by firing retrorockets. Then it must be overcome again when leaving. The gravitational effect of a small asteroid, say, 1 kilometer in diameter, is negligible from an energy standpoint, so that with carefully chosen arrival and departure times, energy consumption is not significant.

—ELEANOR HELIN, *Jet Propulsion Laboratory*

Why isn't the energy of the Earth-Moon system routinely used as a gravity assist for planetary exploration?

—Joel MacAuslan, Nashua, New Hampshire

Gravity assists using the Earth-Moon system are becoming more commonplace. *Galileo* used Earth gravity assists to help it on its way to Jupiter. The *Cassini* mission to Saturn and Titan will use this technique as well.

The disadvantages of using an Earth-Moon gravity assist are the associated time and navigation constraints—for example, trajectories must be longer and must be precisely aligned in terms of the positions of celestial bodies.

As for a Moon-only gravity assist for an interplanetary trajectory, the amount of extra energy derived is small and rarely useful. The disadvantages of having to precisely time your departure trajectory from Earth would outweigh the gain in energy from the assist. Even Mars, over nine times the mass of the Moon, can supply very little extra energy from this technique.

—LOUIS FRIEDMAN, *Executive Director*

FACTINOS

Astronomers have discovered that the Moon has a tail. A glowing 15,000-mile tail of sodium atoms streams from the Moon, blown away from the Sun by the solar wind—the constant stream of particles flowing from the Sun. The Moon's tail is not visible to the naked eye, but instruments can see the faint orange glow of sodium.

"The scientific community still isn't sure of the source of these sodium atoms," said Michael Mendillo of Boston University, one of the tail's discoverers. It is probable, he said, that sodium atoms are being blasted loose as rocks on the Moon's surface are hit by tiny meteorites. Others argue that sodium is liberated by solar wind particles or by photons of sunlight.

—from the *Los Angeles Times*

Magellan recently found a volcanic flow on Venus that suggests the planet has explosive eruptions like those at Mount Pinatubo in the Philippines and Mount Unzen in Japan. A petal-shaped volcanic flow discovered on a highly fractured portion of Venus' landscape may have been deposited by "an eruption like those that are currently happening in Japan and the Philippines," said James Head of Brown University.

Venus has tens of thousands of volcanoes, and many scientists think it's likely that some are erupting now, though they haven't yet caught one in the act.

—from the Associated Press

Dr. Andrew G. Lyne and colleagues at the Nuffield Radio Astronomy Laboratories at the University of Manchester in England say they've discovered a planet around a distant star. If their report is confirmed, this would be the first established detection of a planet beyond our solar system. They say the object orbits a pulsar, the spinning remnant of a star that collapsed after a violent explosion.

The astronomers reported that they'd observed fluctuations in radio signals from the star and that they believe the fluctuations are caused by the gravitational effects of an orbiting companion about 10 times the mass of Earth. They said the object appears to be as close to the pulsar as Venus is to the Sun. The pulsar itself is about 30,000 light-years from our solar system toward the center of the Milky Way.

—from John Noble Wilford in *The New York Times*

World Watch

As we go to press, the United States Congress is still in its August recess, and the Conference Committee has not yet worked out the details of NASA's 1992 budget. As we reported in our July/August issue, the fates of several planetary missions, the Earth Observing System and new launch vehicle development—among other programs—are hanging in the balance. We will give you final budgetary details and analyze their effects in the next issue of The Planetary Report.

MOSCOW—In July, the French-Soviet Mars mission design team met at the Babakin Center to discuss progress on the *Mars '94* and *Mars '96* projects. The Planetary Society participated in the meeting to report on our SNAKE guide-rope testing and balloon system analysis. We also wanted an update for our members and balloon team on the status of the Soviet program.

Discussions centered on changes to the original *Mars '94* plan due to technical problems with the orbiter and descent module, and financial difficulties within the Soviet space program.

Project managers confirmed the decision to split the mission into two parts, an orbiter to launch in 1994 and an orbiter and descent module to launch in 1996. The Mars Balloon, which the Society has been working on since 1987, will fly on the *Mars '96* mission, along with small meteorological stations and a minirover.

The Mars team is concerned about the potential loss of the *Mars Observer* relay due to the delay in the mission. This device would relay data from the Mars Balloon back to Earth. NASA's *Mars Observer* will launch in 1992, and there are no guarantees that it will still be working when the balloon and rover reach the planet in 1997. The Soviet *Mars '96* orbiter is capable of relaying the data to Earth, but at a much slower rate.

Another problem in delaying the launch until 1996 is that the spacecraft will arrive during the martian dust storm season. It might have to park in orbit for up to six months before the dust clears. Any extension of the mission adds to concerns about equipment reliability. Accidents do happen. During the 1988 *Phobos* mission, both spacecraft were lost. This next generation of Mars spacecraft are derivatives of the basic *Phobos* design. During the meeting, a team of ballistics experts was assigned the task of improving the mission trajectory and timeline to maximize the data return and the probability of success for the balloon.

Meeting participants discussed another concern at length: the sterilization of the entire descent module and its contents. Guidelines laid out by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions require that the chance of a single earthly microbe arriving on Mars should be 1 in 10,000. This is an enormous technical challenge. Sterilization using heat or fumigation with radioactive gas is possible, but either method could damage delicate or sensitive spacecraft parts.

The Planetary Society agreed to act as liaison among the international scientific bodies involved in this question and to provide engineering support to help solve the spacecraft sterilization problem.

The team from France's Centre National d'Études Spatiales reported on the latest flight tests of the full-scale Mars Balloon. They have launched several balloons from Norway to gather data during long flights in Mars-like conditions. They collected some data, but need to conduct further tests to confirm the flightworthiness of the balloon design.

Tests of the latest rover design were also discussed, including The Planetary Society's role in them. As we go to press, Society Executive Director Lou Friedman, the Society's Mars team leader Bud Schurmeier, project consultant Tom Heinsheimer and Jet Propulsion Laboratory engineer Roger Bourke are in Kamchatka, Siberia, for the tests. We are now organizing a new round of rover tests to be held in California's Mojave Desert next spring.

We will keep you informed of further developments. *—Tom Heinsheimer, Mars Team Consultant*

PASADENA—The idea of exploring planets with small, specialized spacecraft, rather than the school-bus-sized, instrument-bedecked platforms of recent design, has been discussed for years. But while the funding for megaprojects was available, "microspacecraft" were regarded as offering too little scientific payback, and so were given low priority.

If this same mentality had been used to build computer chips, we would not have desktop computers today. Indeed, the miniaturization of electronics, mechanical hardware and propulsion systems makes it possible today to build small spacecraft that are more capable than some of the giants of yesterday. It is true that a small satellite cannot carry as many or as powerful instruments as a large one. But a "microcraft" could be simple, built quickly and at much lower cost. In any case, launch vehicles to propel US space vehicles to Mars remain a big problem. Smaller spacecraft require smaller—and cheaper—rockets.

NASA hopes to take a step in this direction with its Discovery Program, in which a spacecraft must be small, simple, and cost less than $150 million. Several mission scenarios that might fit into this program were presented at the recent International Conference on Near-Earth Asteroids, co-sponsored by the Society and NASA.

The Planetary Society is investigating even greater steps toward smaller missions. We've invited the world's experts on small satellites to a Society workshop in Pasadena on September 23 and 24. We will address subjects like small spacecraft, launch vehicle possibilities, microrovers and small penetrating probes of planetary surfaces.

The current budgetary situation in the United States makes it likely that NASA will send no spacecraft to the planets in the decade following the *Mars Observer* launch in 1992. That is, none will go unless we find different and innovative ways to do it. At The Planetary Society we are seekers after innovation. *—George Powell, Microspacecraft Study Leader*

SOCIETY *Notes*

PRESIDENTIAL AWARDS

For the fourth year in a row, The Planetary Society will participate in the Presidential Awards for Excellence in Science and Mathematics Teaching. Each of 216 teachers selected from elementary, junior high and secondary schools throughout the United States will receive a one-year membership in the Society. *—Susan Lendroth, Manager of Events and Communications*

CONTEST WINNER ATTENDS MARS SYMPOSIUM

Eric Choi, winner of The Planetary Society's 1991 Mars Institute Student Contest, was the Society's guest at the "Mars Exploration: Past, Present and Future" symposium, held in Williamsburg, Virginia, July 17 to 19. He also received an award of $500. Eric's research paper on designs for power systems to be used for a human Mars base in the next century was selected from a very impressive field of entries.
—Carlos J. Populus, Volunteer Coordinator

MEMBERS' BEQUESTS

We would like to honor Minnette Luckner of Mill Valley, California, and Marlow Samuelson of West Des Moines, Iowa, two members whose support for The Planetary Society has been continued after their deaths through very generous bequests.

A pamphlet on planned giving, which discusses how members may make estate donations to the Society, either by direct bequest or by naming the Society as a life-insurance beneficiary, is available. Please write me at the address below if you would like more information.
—Lu Coffing, Financial Manager

WE LOVE A MYSTERY

But not when our members are missing. Membership Coordinator Sue Pratt regularly receives membership renewal checks and money orders without names on them, as well as gift memberships without the recipient's name and address. And Sales Supervisor Cosma Norton has a bulging folder of orders that she cannot fill because of similar missing information. Both have become adept at tracking down the information they need, but unsolved cases remain.

Most often overlooked are the little things, like the last four digits on your credit card, the expiration date, a signature. It's especially important to put your name and membership number on money orders and on checks that are not personalized, such as cashier's and organization checks.

Please take a moment to check for missing information before you seal that envelope. Also, be sure to include your fax number when you fax an order to us.
—Cindy Jalife, Membership Services Manager

A GATHERING OF ZERO-G DESIGNERS

Organizers of the University of Illinois Zero-g World Design Project are looking for schools and for interested individuals (especially those having firsthand experience with or knowledge of free fall) to participate in their pilot run this fall.

The project will enable student design teams in schools across the United States, communicating via electronic networking, to focus on the redesign of everyday objects to function in a zero-g environment.

For information, contact James A. Levin, University of Illinois at Urbana-Champaign, 210 Education Building, 1310 South Sixth Street, Champaign, IL 61820-6990; fax 217-244-7620. *—Louis Friedman, Executive Director*

HELP WANTED FOR WORLD SPACE CONGRESS

We are looking for Washington, DC, area members who can help us organize the grand prize for 20 students from around the world who will be selected as winners of our "Together to Mars" International Student Contest, sponsored by the H. Dudley Wright Foundation of Geneva, Switzerland.

The 20 winners and their chaperones will be going to Washington to attend the World Space Congress (August 28 to September 6, 1992). They will need housing, meals, transportation and guides to Washington sites of interest. With their hosts, they will be attending a special Planetary Society reception and awards ceremony.

The World Space Congress is a combined meeting of the International Astronautical Federation and the Committee on Space Research of the International Council of Scientific Unions. Leading space scientists, engineers and policy makers will be coming together for this special International Space Year event.

Most of the Congress' sessions will be technical, but there will be exhibits for the public and other special events—including a Rover Expo sponsored by The Planetary Society.

If you are interested in helping us with the contest winners and the special Society events, please write me at our offices.
—Susan Lendroth

EVENTS CALENDAR AVAILABLE

The Society's worldwide Volunteer Network organizes a great variety of events every year. If you would like to receive a copy of the network events calendar, please write me at the Society's offices.
—Carlos J. Populus

KEEP IN TOUCH

Our mailing address:
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65 N. Catalina Avenue
Pasadena, CA 91106

Call for an updated events calendar:
(818) 793-4328
east of the Mississippi
(818) 793-4294
west of the Mississippi

General calls:
(818) 793-5100

Sales calls ONLY:
(818) 793-1675

CALORIS IMPACT—
Our solar system has a history of violence. One dramatic piece of evidence of this is the Caloris basin on Mercury. In this painting, Rick Sternbach illustrates the explosive confrontation between planet and impactor that formed the basin, which is over 1,300 kilometers (800 miles) across. Our own neighborhood is not safe from such violent events: The Imbrium basin on our Moon looks very much like Caloris, and was created in the same way.

Veteran space artist Rick Sternbach is a founding member of the International Association of Astronomical Artists. He works as the senior illustrator and a technical consultant on Star Trek: The Next Generation.

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