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Galileo—A Final Farewell

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COVER: On December 16, 1992, eight days after its last encounter with its home world,* Galileo *looked back and captured an image of Earth and its Moon from 6.2 million kilometers (3.9 million miles) away. The blue-and-white planet shines three times as brightly as its natural satellite. Still, to make the features stand out, both contrast and color have been enhanced in this image. Antarctica is just visible at the southern horizon of Earth.
Image: JPL/NASA

FROM THE EDITOR

The political world around us is remaking itself at a breathtaking pace, and it's hard to keep up. If you are committed to furthering planetary exploration and the search for extraterrestrial life, which I assume you are as a member of The Planetary Society, you may want to keep track of political developments that are reported in the back pages of the popular press, if at all.

Two recent developments—one overshadowed by the details of President Bill Clinton's economic package, the other reported only in the aerospace press—may have great importance for the future of planetary exploration. One affects the United States space station program; the other, the Russian *Mars '94* mission.

It's our job at *The Planetary Report* to keep Society members up to date on such stories, so after you've enjoyed the latest images from *Galileo*, read the news on the Mars Balloon and pondered the possibilities for extrasolar planets, please be sure to read the two articles on pages 22 and 24.

• **A Last, Long Look Homeward: *Galileo* Sets Off for Jupiter—Page 4**—When the early history of planetary exploration is written, the *Galileo* project to investigate the jovian system will probably become *the* classic example of how political vicissitudes can cripple a planetary mission. Nevertheless, *Galileo* is returning important data about the solar system and, with luck, will continue to do so for years to come.

• **Planetary Prospectors Meet in Pasadena—Page 12**—An exciting new frontier in planetary exploration is the search for planets outside our own solar system. The world's leading searchers met at the California Institute of Technology in Pasadena to share results, devise strategies and plot future courses.

• **News From the Mars Balloon Project—Page 20**—This project so close to Planetary Society members' hearts continues to make progress toward its 1996 launch date. We regularly report on developments in the Snake portion of the balloon system, which the Society has helped design and test. The Mars Balloon itself has passed a major milestone and proved it can survive for days in Earth's turbulent atmosphere.

• **Not Yet to Mars, Together—But Still Working on It—Page 22**—We almost had it—an American lander carried to Mars by a Russian spacecraft. Both sides are new at this cooperation game, and the rules are still to be written. Nearly everyone agrees that, given today's political and economic realities, the best way to explore the solar system is together. There are hard lessons to be learned so that next time cooperation may work.

• **President Directs NASA to Redesign the Space Station—Page 24**—In its previous incarnation, space station *Freedom* was a budget-gobbling behemoth that threatened NASA's smaller scientific missions. The new president has directed NASA's administrator to redesign the station to fit economic realities.

• **Norm Augustine Joins Society Board of Directors—Page 25**—Few other people have had as much of an effect on recent changes in US space policy as Norman R. Augustine. We are fortunate that he has agreed to help steer The Planetary Society as we grapple with a changing world.

• **News & Reviews—Page 26**—A series of definitive books on planetary science and a recent meteorite hit have attracted Clark Chapman's attention.

• **Society Notes—Page 27**—Keep up with our ever-changing activities through these announcements.

• **Questions & Answers—Page 28**—Plate tectonics and life, and finding positions on other planets are topics for this issue's questions.

The Planetary Readers' Service column will return in our next issue.

—*Charlene M. Anderson*

Members' Dialogue

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

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

I am writing in praise of the Second United Nations/European Space Agency Workshop in Basic Space Science for the Benefit of Developing Countries, which The Planetary Society co-organized in Costa Rica and Colombia last November.

I must confess that I approached this workshop with some skepticism, since I wasn't sure it could really accomplish anything very useful. I was happily surprised to find good attendance at the sessions in both countries, with lively interaction from the participants with the speakers and with each other. It was clearly useful for them to learn about the latest results and ideas from the presenters, but they also achieved a better sense of what was happening in the different countries represented at the conference.

This latter aspect was particularly noticeable in Colombia, where there was open discussion of the need for a Central and South American Astronomical Society (I was surprised to find that none existed) and the desirability of a common observatory at a good site. One aspect of that discussion is a proposal from Brazil and Argentina to participate in the funding of the proposed National Optical Astronomy Observatory 8-meter Gemini project. These ideas have certainly been circulating for a long time, but a workshop like this one provides an opportunity to get representatives from all the different countries together to discuss them, something these people clearly appreciated.

I hope it will be possible for you to continue this program. Other logical venues would be Turkey, and Egypt or Saudi Arabia.

—TOBIAS OWEN, *Honolulu, Hawaii (Professor Owen, of the University of Hawaii, was an invited speaker at the workshop.)*

I detected a note of aristocratic, "let them eat cake" sentiment in the News & Reviews column of the January/February 1993 issue of *The Planetary Report*, where *Newsweek* was deemed inappropriate for the discussion of cometary orbital calculations. In this culture that features a horoscope column in most daily newspapers and "psychic hot lines" on television, I welcome the discussion of asteroids in the general press.

A boy of seven was inspired by the *Newsweek* cover story to go to the local library and investigate the books available on the solar system. That little boy is my nephew, and as a result of that story we are building a near-Earth asteroid exhibit for the county science fair. I want science covered by the press. We are in danger of losing our rational heritage in a flood of pseudoscience and New Age nonsense; in just two centuries we have gone from Benjamin Franklin to "channeling," from Thomas Jefferson to cable-television mind readers.

I understand that Chapman was discussing technical material that rightfully belongs in the academic journals, but his sneering reference to *Newsweek* is evidence of snobbism and disregard for democracy. He doesn't trust the people.

If we don't infuse this nation with real science through the general press, how are we to inspire our kids to reach for the stars?

—KREG HUNTER, *Healdton, Oklahoma*

Reading *The Planetary Report*, knowing of your efforts, commitments and achievements concerning space exploration, and reading the interests of the members in Members' Dialogue, it really makes me proud to be a member of such an organization as The Planetary Society.

We are about 100,000 members dispersed all over the world, yet joined in a single dream: curiosity about the unknown and what might be behind it.

—JOÃO MIGUEL MATOS, *Setubal, Portugal*

NEWS BRIEFS

New evidence suggests that comet Swift-Tuttle has virtually no chance of hitting Earth on its next pass through the inner solar system. Swift-Tuttle's orbit, which was poorly understood until now, has been calculated with greater accuracy thanks to a series of new observations and the discovery of previous sightings of the comet.

"We're safe for the next millennium," said Brian G. Marsden of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, who had issued the original alert for the International Astronomical Union.

—from William J. Broad in *The New York Times*

General Dynamics is proposing an innovative human mission to the Moon that is designed to be safer and cheaper by relying on existing technologies, and that could involve Europe as a major participant. The plan foresees a human lunar mission by the year 2000 if work begins in fiscal 1994.

The mission would consist of a series of flights, each using NASA's space shuttle orbiter and an expendable launch vehicle. The shuttle would hoist the lunar payload and lander to low Earth orbit. Then a *Titan 4* or *Ariane 5* would place a modified version of General Dynamics' *Centaur* upper stage into orbit, which would dock with the lunar payload and propel it to the Moon.

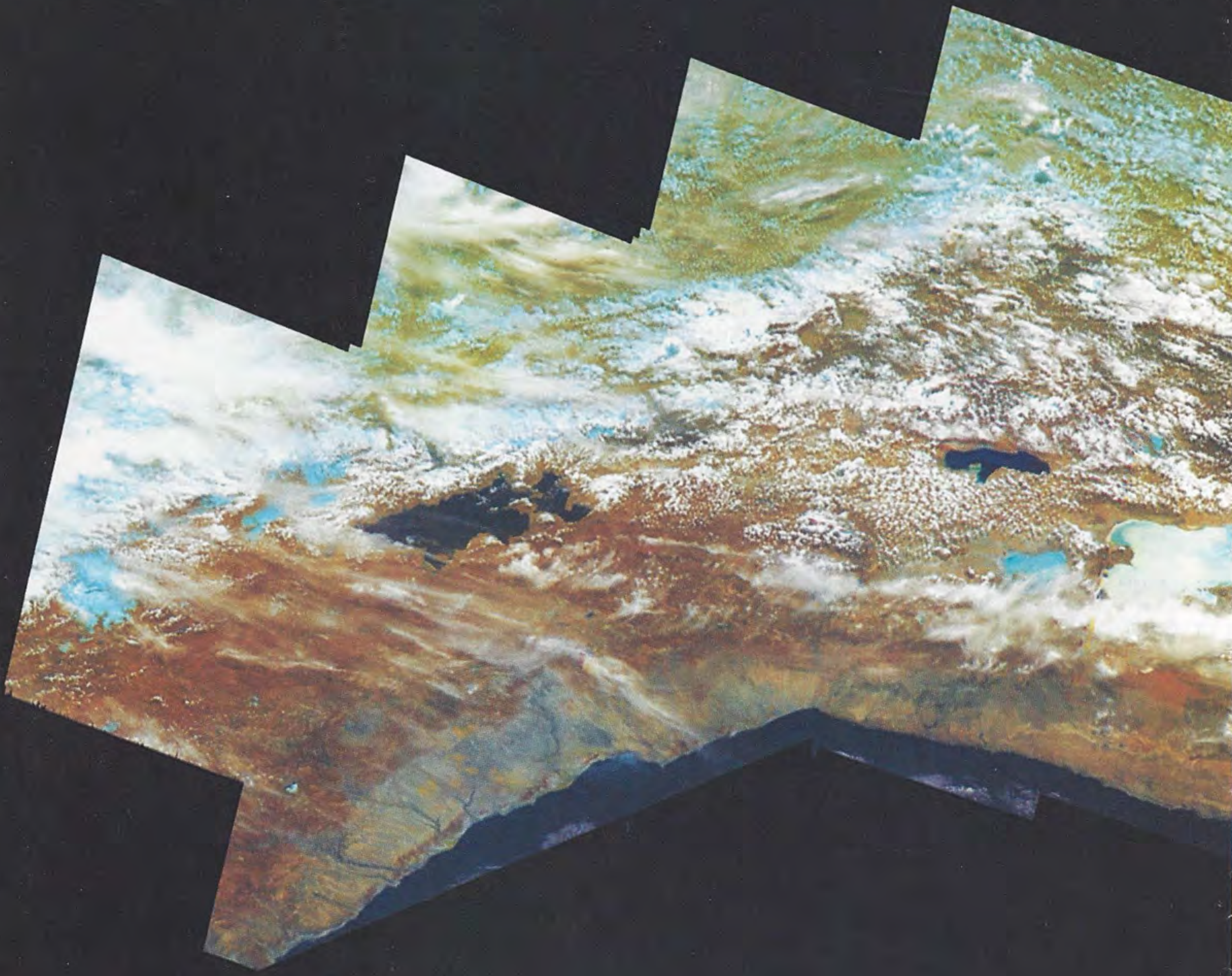
—from Jeffrey M. Lenorovitz in *Aviation Week & Space Technology*

NASA's exploration office is modifying its Mars proposal, should it ever receive funding, into one that agency officials say could make for a cheaper, faster mission. The agency is incorporating a proposal to create fuel from the martian atmosphere into its plan for a human mission. The new concept uses a slower interplanetary speed and a longer exploration period than NASA's first proposal.

When asked about the plan, Mike Griffin, associate administrator for NASA's Office of Exploration, said, "I'm very high on it. Those approaches make the Mars mission more credible and potentially a lot cheaper and easier to pull off."

—from *Space News*

A Last, Long Look Homeward:



The *Galileo* spacecraft is finally on its way to Jupiter, after three years of swinging around the inner solar system, picking up the velocity it needs to reach the jovian system. Last December *Galileo* flew by Earth and received the final push that sent it toward its ultimate goal. It's been a long, difficult, circuitous haul.

This mission was approved in 1977. Its story since then has been compared with "The Perils of Pauline," for the plot twists and cliffhangers are unmatched in the brief history of the Space Age. *Galileo* will not reach its destination until December 1995. Then its probe will plunge into Jupiter's enormous atmosphere and its orbiter will begin a two-year tour of the jovian satellites.

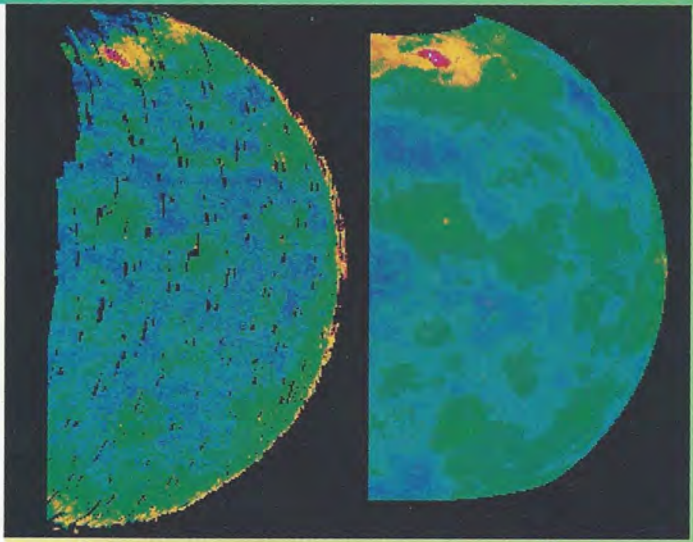
Among the many subplots in *Galileo*'s story is a genuine human tragedy: the 1986 explosion of *Challenger*. This triggered a series of events that changed the launch date from 1986 to 1989 and the spacecraft's previously direct trajectory to Jupiter into a looping perambulation, once by Venus, twice by Earth, with two trips into the asteroid belt. (See the September/October 1986 *Planetary Report* for the full story of the trajectory change.)

On the positive side, the detour through the inner solar system and asteroid belt enabled *Galileo* to visit two planets and two asteroids that had not been on its original

Galileo Sets Off for Jupiter

itinerary. However, because of the launch delay, the spacecraft had to be trucked back and forth across the United States. This particular episode may have impaired the spacecraft: Its powerful parabolic antenna has refused to open, probably because of damage sustained during the truck trips. Without this antenna, *Galileo* will not be able to carry out its mission as planned. (See page 10.)

Despite all this, *Galileo* has still added to our store of knowledge about our solar system, including the planet on which we live. While we await its discoveries at Jupiter, we review here a few of its accomplishments.
—*Charlene M. Anderson*



Venus Glowing in Infrared

ABOVE: *Galileo* carries 11 experiments on the orbiter portion and 6 on the probe that will enter into Jupiter's atmosphere. One powerful orbiter instrument designed to determine the composition of Jupiter's satellites and its atmosphere, as well as to map temperature differences, is the Near-Infrared Mapping Spectrometer, known as NIMS.

NIMS' capabilities were triumphantly demonstrated during the Venus flyby. The thick, sulfuric acid clouds of Venus effectively shroud its surface from imaging systems that see in visible, ultraviolet or many wavelengths of infrared light. As we showed in our March/April 1991 report, NIMS saw 9.5 to 16 kilometers (6 to 10 miles) beneath the cloud tops to map the planet's deep atmosphere.

In this image of Venus' nightside, we observe that NIMS saw even deeper: down to the surface itself. At left is NIMS' infrared data at a wavelength of 1.2 microns; at right is a topographic map from *Pioneer* Venus radar data. The highest mountain on Venus, 10-kilometer-high Maxwell Montes, appears in red on both maps. (Low-lying areas are blue.) Just north of the equator are three green regions 2 kilometers high, which are part of Eisila Regio; the rightmost one is butterfly-shaped. Just above the butterfly is Bell Regio, also about 2 kilometers high. Alpha Regio, some 2 kilometers high as well, is visible in the southern hemisphere. Maps: JPL/NASA

Flying Over the Andes

LEFT: *Galileo*'s camera, called its imaging system, is more advanced than the system carried by the *Voyagers* during their 1979 flights through the jovian system. The older spacecraft carried vidicon systems, similar to the cameras originally used in television studios. *Galileo* carries charge-coupled devices, which will help this next-generation craft obtain images with details 20 to 1,000 times finer than those of images taken by *Voyager*.

This mosaic of images taken during the December 1992 Earth encounter shows the central part of the Andes where Chile, Peru and Bolivia meet. North is to the left, and the Pacific Ocean is at the bottom.

The camera used a combination of visible and near-infrared filters to separate vegetation and soil types. The pale-green areas at the top are the Gran Chaco plains, covered with plant life. The light-blue patches in the mountains to the left are glaciers.

Lake Titicaca is the large, nearly black patch to the left; smaller Lake Poopó appears in the center of the mosaic. The light-blue regions below and to the left of Poopó are dry salt lakes; the largest is Salar de Uyuni, some 120 kilometers (75 miles) across. These lakes lie in the Altiplano, a highland region between the western and eastern Andes. Image: JPL/NASA

Gaspra Rotating As *Galileo* Flies By

BELOW: *Pioneers 10* and *11* and *Voyagers 1* and *2* all traversed the asteroid belt on their way to Jupiter and beyond, but none passed close enough to image an asteroid. This *Galileo* did on its first incursion into this region between Mars and Jupiter, and it turned several of its instruments on the asteroid Gaspra.

In viewing this montage, read it from left to right and imagine yourself riding on the spacecraft. It's October 29, 1991, and you are about to make the first asteroidal encounter. As you approach Gaspra, it gradually grows larger and larger in your field of view, all the while rotating counterclockwise, completing one rotation in roughly 7 hours. You begin your watch when you are 5 3/4 hours and 164,000 kilometers (102,000 miles) from your target. Your last image is taken only 30 minutes before closest approach and 16,000 kilometers (10,000 miles) from Gaspra.

When you first see Gaspra, its "nose" is pointing straight up, then it disappears into shadow, emerges and rotates toward your right. You can pick out several craters on the asteroid's surface, but you note that none of them are very large. Comparing Gaspra with lunar regions of known age, you quickly calculate crater numbers and conclude that this asteroid is quite young.

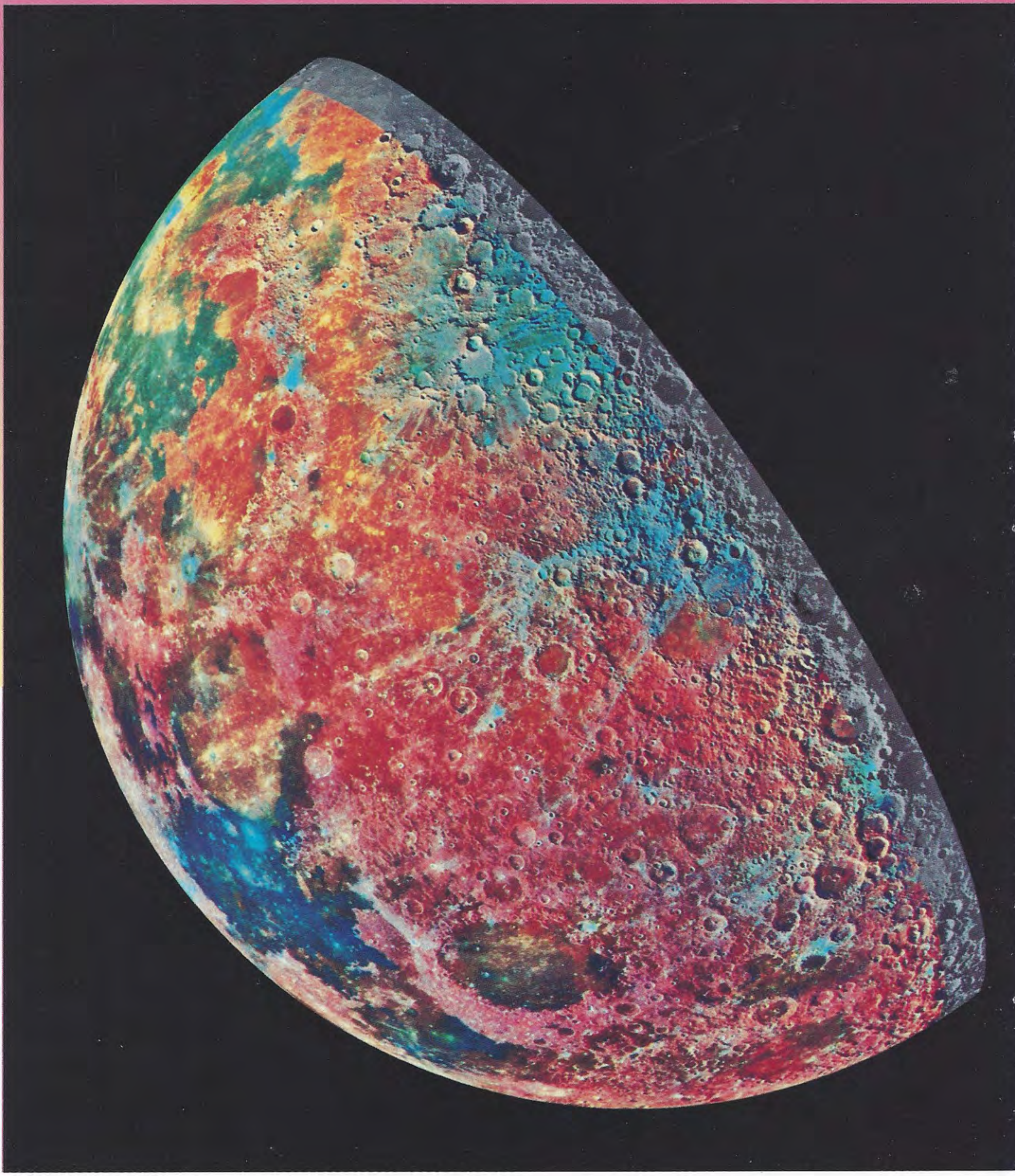
Then, in what seems only a moment, you've flashed by Gaspra, and you're looping back through the asteroid belt for a final swing by your home planet, Earth. Images this spread: JPL/NASA

Viewing a Familiar Face

RIGHT: You may think that this is a most familiar face, but look again. This is a view of the Moon from a perspective impossible from Earth: looking down on its north pole. The Moon rotates with the same face always pointed toward us, gravitationally locked into a simple one-step dance with Earth. Until spacecraft, beginning with the Soviet *Luna 3* in 1959, flew around our natural satellite, no one had ever seen the other side of the Moon. On December 7, 1992, *Galileo* gave us a rare view of its north polar region. The pole itself lies in shadow here, about one-third of the way from the top left lighted region.

Some parts of the Moon visible from Earth appear on the left side of this mosaic of 18 images taken through the green filter of *Galileo*'s imaging system. You can see the dark, lava-filled Imbrium basin at the upper left, Mare Serenitatis at the middle left, and Mare Tranquillitatis, where humans first set foot on the Moon, at the lower left. The Crisium impact basin is the dark circular feature near the bottom, and the lava plains of the Marginis and Smythii basins appear at the lower right.

If you've enjoyed seeing the Moon from a new perspective, turn the page to see it in an entirely new light.



Recoloring the Moon

LEFT: Imaging data taken through one filter can give us the equivalent of a black-and-white photograph. Data taken through several different color filters can give us an entirely different view of a celestial object.

This is the same view of the Moon as on the previous spread, but with data from three spectral filters combined to produce a false-color mosaic. Since materials of different types reflect light in different ways, by gathering light through several different filters scientists can determine something of a planet's surface composition.

Here the bright-pink areas, prominent around the lava-filled Crisium basin near the bottom, are materials typical of the lunar highlands. Blue to orange colors represent basaltic lava flows. To the left of Crisium, the dark blue of Mare Tranquillitatis indicates that this area is richer in titanium than the green and orange regions above it. Thin, mineral-rich soils recently excavated by impacts appear as light blues. The youngest craters have prominent blue rays radiating out from them, caused by rock powder splashed out during the impacts that made them. Image: JPL/NASA

Mapping the Moon

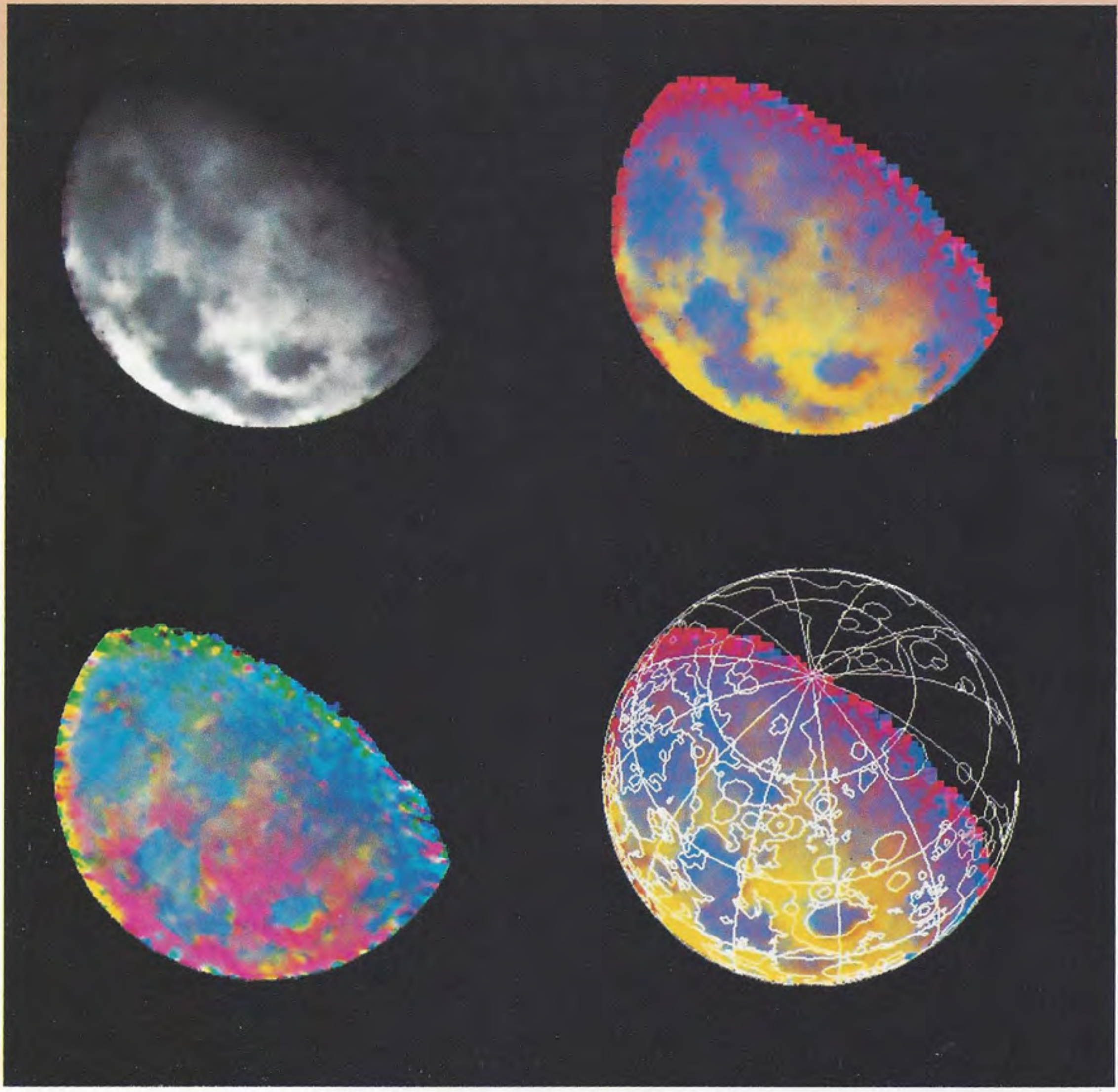
BELOW: Here are four views of the same region of the Moon, this time as seen by NIMS as it mapped the surface composition. The black-and-white image shows the Moon in infrared wavelengths just beyond the visible deep red.

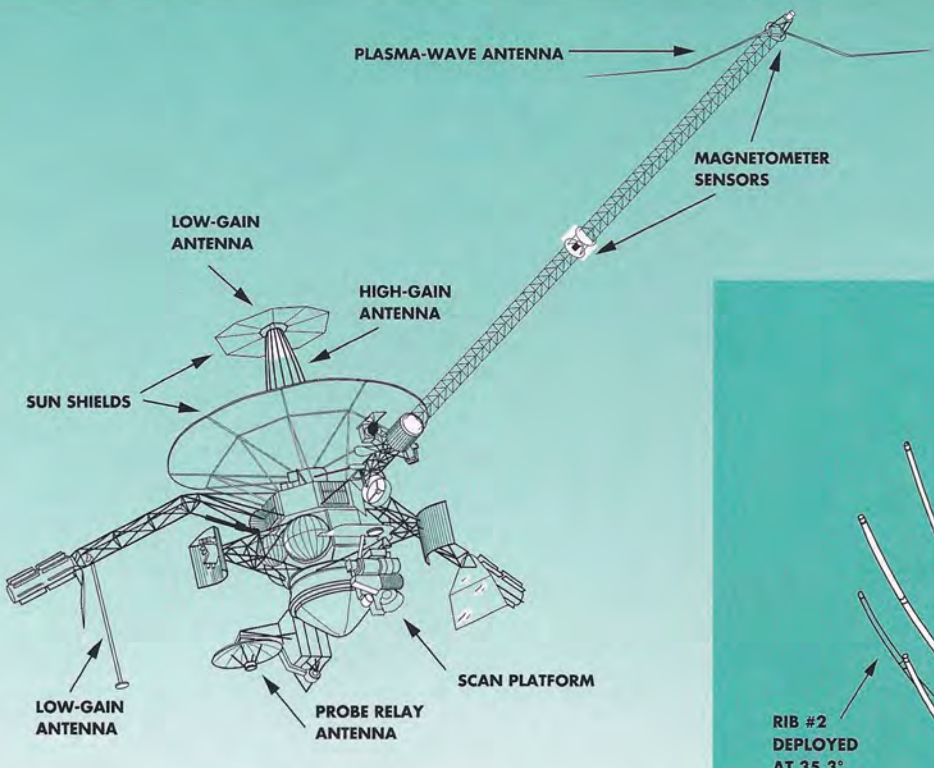
The NIMS team created a false-color map (upper right) that shows the strength with which silicate rocks absorb sunlight in the near infrared. Blue areas strongly absorb light of this wavelength and are made of material rich in pyroxene and olivine, iron-bearing silicates. Yellow areas absorb more weakly, indicating materials of different composition. Young, fresh craters also are strong absorbers, since their materials have not yet been weathered by the effects of meteorite impacts.

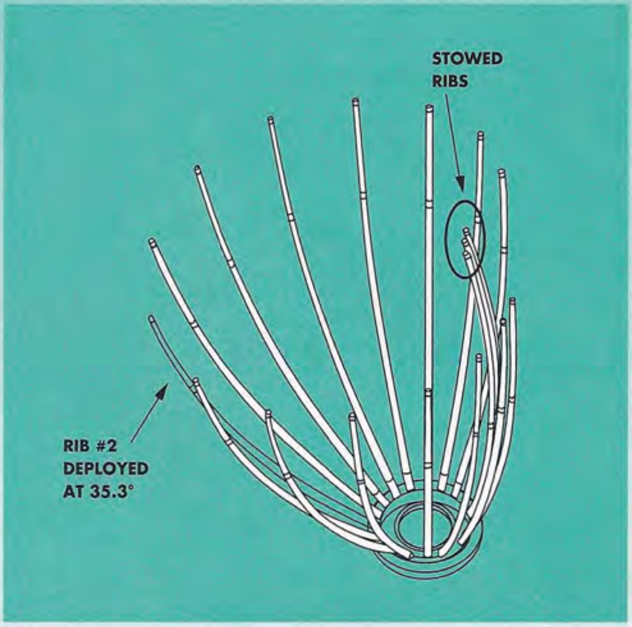
In the map at lower right, the team superimposed the outlines of previously defined geologic units over their false-color map.

In the preliminary mineralogical map at lower left, blue signals regions low in calcium, while green and red indicate areas high in calcium.

From data such as these, researchers may fill in some of the missing pieces of lunar history. Maps: JPL/NASA







The Sad Tale of a Jammed Antenna

On the *Galileo* mock-up, or in the clean room before launch, the high-gain antenna's elegance commanded the viewer's attention. Furled tightly in its launch configuration, it reminded this writer of a crinoid, a delicately beautiful marine creature. Unfurled in its operational configuration, its molybdenum mesh stretched between thin ribs suggested a giant, gold-plated umbrella. You'd hardly notice the rest of the spacecraft.

Unfortunately, the high-gain antenna's troubles have also dominated the story of the *Galileo* mission. As the popular media have reported over and over, this antenna has failed to open completely, seriously affecting the scientific return expected from the mission to the jovian system.

The *Galileo* spacecraft is designed to communicate with Earth primarily through this high-gain parabolic antenna. (*High gain* refers to its great ability to focus a radio signal into a concentrated, narrow beam.) The spacecraft is also equipped with two low-gain antennas, which can transmit data from the spacecraft at a much slower rate. From the distance of Jupiter, the high-gain device is designed to transmit 134,000 computer bits per second back to Earth; the low-gain antennas can send only 10 bits per second, but enhancements to the Deep Space Network and coding schemes will boost the rate to over 100.

Previous interplanetary spacecraft carried rigid antennas that were shaped into parabolas before launch. The *Voyagers'* solid white dishes are familiar sights to those who follow planetary exploration. (And *Magellan* communicates with Earth through a spare *Voyager* antenna.) Because *Galileo* was to be launched on a space shuttle, it had to carry a lightweight antenna that could be collapsed so that the spacecraft could fit into the shuttle's cargo bay—hence the umbrella design.

Antennas of the same design have flown many times on Earth-orbiting spacecraft without problem. But those spacecraft never had to contend with the myriad of obstacles that have faced *Galileo*. (See the May/June 1989 *Planetary Report*.) This particular problem can be traced to the *Challenger* explosion.

In January 1986, *Galileo* was in Florida, being prepared for launch. It had earlier been trucked from the Jet Propulsion Laboratory in Pasadena, California, the project's home. After *Challenger*, when all launches were put on hold, the spacecraft was trucked back to California. When it was again scheduled for launch, in October 1989, *Galileo* was trucked back to Florida. It's doubtful that any other spacecraft has traveled so far on terrestrial highways.

Project engineers think that the vibrations experienced during the cross-country treks wore off the graphite lubricants that were to ease the movements of certain antenna parts. When the command to unfurl was given, 3 of the antenna's 18 ribs refused to move. With the antenna unable to assume a parabolic shape, it is useless.

Galileo project people have made several attempts to free the stuck ribs, first warming and cooling the antenna by turning it into and out of the sunlight, then "hammering" it by turning the antenna drive motors on and off thousands of times. Nothing has worked.

They will make at least one more attempt: In March the spacecraft will be commanded to increase its normal rotation rate of 3 revolutions per minute to 10 revolutions, thus increasing the centrifugal force on the ribs. There is little chance that this will work, and hope is fading for the high-gain antenna.

Project planners have now turned their attention to conducting the mission with one of the low-gain antennas. Through data manipulation techniques, they feel that they can salvage 70 percent of the planned scientific return from the mission. The most noticeably affected investigation will be the imaging experiment. The imaging team had hoped to receive 60,000 images of the jovian system. They may have to settle for less than one-tenth of that amount. The biggest loss will be in studies of jovian weather.

Still, there will be pictures of the large Galilean moons with far greater detail than anything the *Voyagers* sent us. *Galileo* will drop a probe into Jupiter's tumultuously swirling atmosphere and send us the first discoveries from inside that gaseous giant. An array of fields and particles instruments will study the immense jovian magnetosphere. The orbiter will travel through Jupiter's environs for 23 months, gathering huge reservoirs of data about the jovian system.

Even without its lovely high-gain antenna, *Galileo* is a prodigious spacecraft. We can anticipate many wonderful surprises.

Diagrams: JPL/NASA

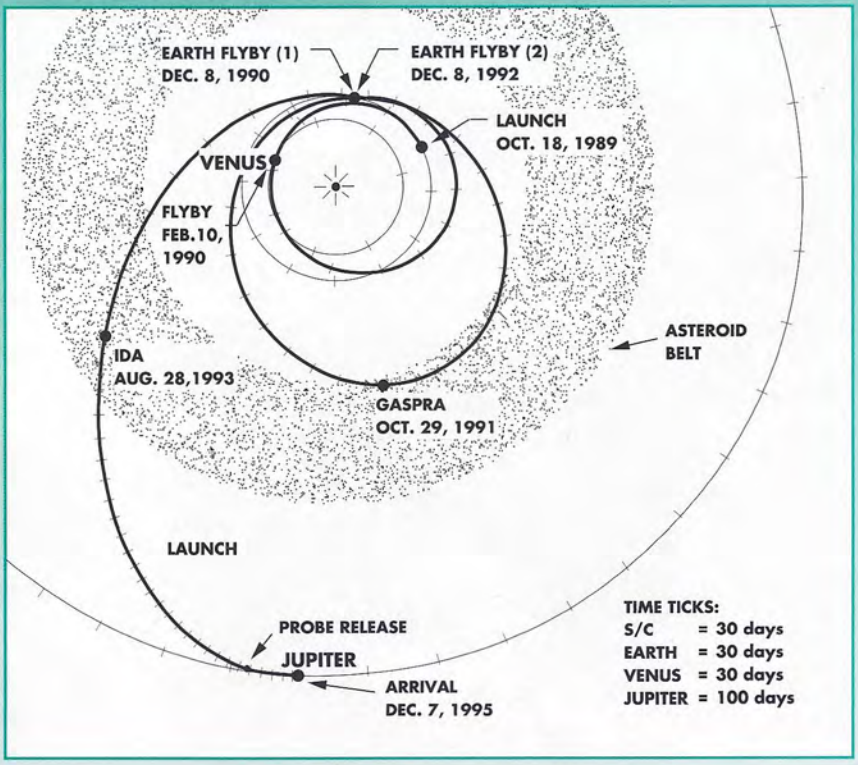
Where Is Our Wandering Spacecraft Now?

After leaving the vicinity of Earth for the last time on December 8, 1992, *Galileo* set off to encounter the asteroid Ida, which it will reach on August 28, 1993. Ida orbits the Sun near the middle of the asteroid belt, while Gaspra orbits near its inner edge. From Earth-based observations, both Gaspra and Ida had been classified as common S-type asteroids, rocky (silicate) bodies that may be the sources of the ordinary chondrite meteorites that often fall to Earth.

But *Galileo*'s observations hinted that Gaspra may possess a magnetic field, which may mean that this asteroid is a fragment of a larger body that once possessed a metal-rich core. This finding surprised scientists, so they are particularly looking forward to investigating Ida.

After Ida, *Galileo* proceeds on the final leg of its six-year journey: It heads to the jovian system. Five months before reaching Jupiter, the spacecraft will release a probe designed to enter the planet's massive atmosphere and relay its discoveries back to Earth.

Meanwhile, the orbiter will make a close flyby of Io, coming within 1,000 kilometers (600 miles) of the satellite's volcanic surface. That's about twenty times closer than the closest flyby made by a *Voyager*. The orbiter will make 11 looping orbits through the jovian system, observing the planet, its magnetosphere, Europa, Ganymede and Callisto as it goes. These studies are scheduled to take almost two years. Chart: JPL/NASA



The Goal of the *Galileo* Mission: Jupiter and Its Moons

Here is Io to the right of the planet, while the shadow of Ganymede falls on the planet's clouds. Image: JPL/NASA

Planetary

BACKGROUND: The "striding winter giant," Orion, is one of the most familiar constellations in our sky, but it looks quite different when seen by the Infrared Astronomical Satellite. Most of the visually bright stars appear dim in infrared; Betelgeuse, however, is easily seen here as a blue-white dot in the upper center. The bright-yellow region in the lower right is Orion's sword, containing the Great Orion Nebula. This has long been suspected to be a region of planet formation. Image: Infrared Processing and Analysis Center, Caltech, JPL and NASA

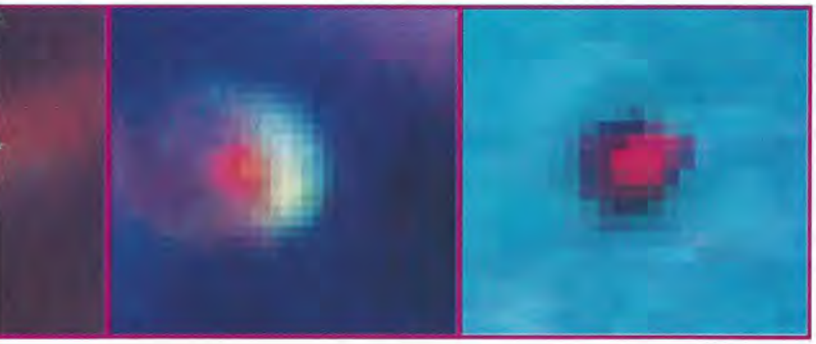
INSET: The Hubble Space Telescope, even with its blurry optics, was able to pick out three protoplanetary disks within the Orion nebula. These thick disks with cool stars at their centers are 1,500 light-years from Earth. Image: C.R. O'Dell of Rice University and NASA

Prospectors Meet in Pasadena

by James D. Burke

Since one of the most wondrous and noble questions in Nature is whether there is one world or many, a question that the human mind desires to understand per se, it seems desirable for us to inquire about it.

—Albertus Magnus, 1200–1280



Are we alone? For at least 2,500 years people have been wondering, and writing, about this question. In ancient Greece it was known that we live on a round ball, and some lights that moved among the seemingly fixed and immutable stars were given the name *planets*, "wanderers." Centuries before the invention of the telescope, humans examined the idea of other worlds; lacking any means of proof, they were free to imagine every kind of cosmos, from a vacant, silent infinity to a heaven teeming with life.

For a long time, we humans arrogated to ourselves the role of rulers of creation, chosen to oversee the universe. This idea eroded as it was found that we are not at the center of anything, we are much like other animals, and our star is ordinary.

Then, as science advanced, theoreticians, observers and creative thinkers began to build understanding of the four phenomena fundamental to the riddle of our existence: the birth and evolution of stars, the origin and evolution of planetary systems, the dawn and evolution of life, and the rise of intelligence and civilizations. Despite the lack of any observed examples other than our own, more and more people became convinced that planets, and perhaps life, may be abundant in the cosmos, and they began to consider ways of finding out the truth.

Conference Reviews Progress

As the latest step in this process, many of the world's leading students of the question of extrasolar planetary systems—planets around stars other than our own Sun—gathered in Pasadena at the California Institute of Technology in December 1992 for the First International Conference on Planetary Systems: Formation, Evolution and Detection. Their purpose was to review progress and chart new projects, and their discussions depicted an enterprise that, though very difficult both technically and politically, is showing enormous promise.

For three days, 130 researchers from the Americas, Europe and Asia exchanged information about their theories and experiments; at the end of the meeting they staged a free-for-all discussion of where we stand in the quest and where we may be able to go. Here we bring you a look at some of the highlights of the conference.

Examining Origins

Much of the conference focused on the first two fundamental phenomena, the birth of stars and thence the birth of planets. A hundred years of observation and theory have given us a persuasive description of how stars come to be. Many details of the picture remain unknown, but we think that a rotating cloud of gas and dust begins to shrink under its own gravity, heating up and spinning faster as it does. At first, particles are moving in all directions, but eventually the turbulent motion becomes organized around one main axis, forming a disk-shaped nebula, a relatively dense cloud of dust and gas. As the collapse continues, the central density and temperature reach thermonuclear ignition levels; the protostar lights up and begins to blow away some of the surrounding material.

For some unknown reason, most such cloud collapses result in the formation of pairs of stars. These are later found chasing each other in all sorts of orbits, and their subsequent evolution may follow a variety of paths. But in a large minority of clouds only a single star is formed, and many—perhaps most—of these single stars are surrounded by disks of gas and dust, remnants of their parent clouds.

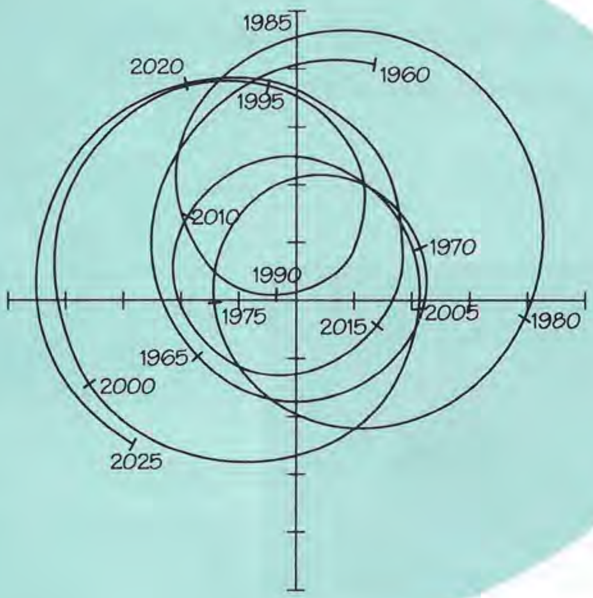


Figure 1. Motions of the Sun induced by the gravity of its planets, as they might be measured by an interstellar observer. Jupiter, in its 12-year orbit, causes the dominant effect.

Diagram reprinted from TOPS: Toward Other Planetary Systems, published by NASA's Solar System Exploration Division

The protostar burns fiercely, at the center of a pancake-shaped mass of spinning debris, with magnetic fields twisting throughout the ionized nebular gases, or plasma. Local condensations of solid matter begin to form planetesimals—thousands or millions of small lumps dragging their way through the plasma or being dragged by it.

At this stage, the process is so complicated that no one can yet claim to know exactly what is going on, but the end result, as shown by the architecture of our one example, the solar system, is highly organized: The final planets, formed by the accretion of smaller bodies, are all orbiting near one plane, traveling in the same sense as the spin of the star, and nicely spaced out at regular intervals from the star.

The star itself is spinning slowly now; most of the protostellar nebula's angular momentum (rotational inertia) has somehow been transferred outward and is carried by the planets. Near what had been the hot center of the nebula, the planets are formed of metal and rock, solids condensible at high temperatures. Farther out from the center, the planets contain water and other low-temperature volatiles such as methane. Throughout the system, bodies bear the scars of impacts, the legacy of great bombardments as the growing planets' gravity cleaned out the spaces between them, and the outer planets have enormous atmospheres of gravitationally swept-up gases.

Life, Intelligence and Civilizations

With the formation of planets, the onset of life becomes possible. Somewhere, in a process not yet understood, molecules made of common atoms found a way to reproduce themselves, creating ever more complicated structures.

For aeons on Earth, the one solar planet where liquid water has been available over geologic time, these structures were microscopic, but they were alive—they metabolized, they reproduced, they evolved. And ultimately they became larger, moving into every environment where life can survive, adapting and creating new ways to dominate and change their world, leading ultimately to Earth as it is today, with an atmosphere containing large amounts of oxygen and other gases that are the signature of our kind of life.

Then, in only a tiny instant of geologic time on Earth, chemistry and biology led to something else; namely, the growth of yet more complex structures, formed through the transformation of matter, energy and above all information by the human mind.

Is the growth of such complexity a natural, universal process driven by the survival advantages of diversity? No one knows. Seen from another star, the signature of this development here and now is a flow of radio emission from the vicinity of the Sun—emission that is not just noise; it carries information revealing the action of intelligent life.

The Search

Finding other planetary systems is difficult, primarily because of the vast distances to even the nearest stars, but participants at the Caltech meeting described several promising ways to attack the problem. In principle, several straightforward detection methods are available, some direct (focusing on the postulated planet itself) and some indirect (focusing on the planet's star), but because the stars are so far away each method requires extreme precision of measurement. Let us examine some of the possibilities.

One indirect approach depends just on gravity: A star and its planets orbit their common center of mass, so even if we cannot see the planets we may be able to detect them by their gravitational pull affecting the motions of their sun. If the planets are orbiting nearly in the plane of the sky, we should see wiggles in the path of the star as it moves relative to the background. If the orientation of the system, relative to our line of sight, is such that the planets are pulling the star toward us, then away, we might observe a cyclic Doppler shift in the spectrum of light from the star—bluer when the star is moving toward us, redder when it is going away.

These two gravity-based search methods are called astrometric and spectroscopic, respectively, and both have now been attempted by a few dedicated observers. To see why great precision and long observing times are needed, examine Figures 1 and 2, which use our own solar system as a model.

Figure 1 shows the Sun's movement around the center of gravity (the *barycenter*) of the solar system, as it would be seen by an astrometric observer at interstellar distances, looking down on the system from above. Because of the observer's great distance, the motion (dominated by the gravity of giant Jupiter in its 12-year orbit) appears to be confined within a tiny range of angles, measured in a fraction of a degree —less than a milliarcsecond. (An arcsecond is 1/3600 of a degree; a milliarcsecond is 1/1000 of that.)

Figure 2 shows how a spectroscopic observer at another star, even if ideally located to view the solar system on edge, would see an oscillation, again dominated by Jupiter's 12-year period, with a maximum toward-or-away speed shift of less than 15 meters (50 feet) per second. This telltale motion would have to be disentangled from motions of comparable magnitude in the atmosphere of the Sun itself and could be confirmed only by decades of observation.

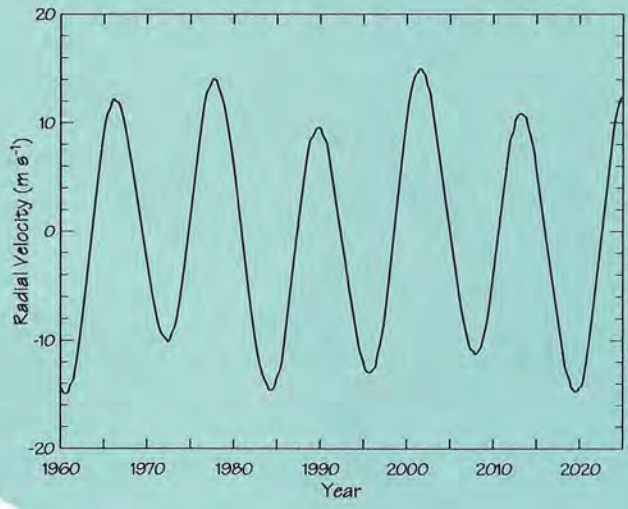


Figure 2. The apparent radial velocity of the Sun as seen by an observer viewing the solar system on edge. The wiggle is due to motion of the jovian planets.

Diagram reprinted from **TOPS**

Thus both methods require great care and the maintenance of instrument calibrations over periods comparable to a human adult lifetime. Looking up through Earth's turbulent atmosphere, ground-based observers contend with disturbances many times greater than the signal they are seeking, but even space-based spectroscopic or astrometric searches will be difficult and slow.

Another indirect detection approach depends on a planet's effect on starlight if the planet passes between us and a star. We see a similar effect with many of the double stars called eclipsing binaries; as one passes in front of the other, brightness varies. Algol is a familiar example whose regular variations can be seen with the naked eye. But a planet, even a large one like Jupiter, would block a much smaller fraction of the light from a Sun-like star, so detecting one would require accurate and prolonged measurement of the star's apparent brightness—that is, precision photometry.

Just using light blockage by planets is not the only possible photometric approach; the phenomenon of gravitational bending of light might also be used. But either method requires close alignment of stars and planets with our line of sight, meaning that the search would have to cover large sky regions in the hope of finding the right geometry for an observable series of events.

Isolating Images

We can also try to observe the planets directly. But because planets are small and shine by reflected light, they tend to be drowned in the glare of their parent stars. Thus any instrument intended to see extrasolar planets must have a way of blocking out that glare.

One possibility is the coronagraph, long used for observing phenomena very close to the Sun. When the Moon blocks the Sun in a total eclipse, we suddenly see the soft, pearly light of the corona. In a coronagraph an occulting disk in the optics serves the same function as the Moon in an eclipse—but because the telescope is on Earth, light is scattered by the atmosphere and makes its way past the disk to contaminate the observations. A coronagraph in space or on the Moon should have much better performance, but even there, scattered light is a problem: The instrument's optical elements must be perfectly shaped and very clean to prevent scattered starlight from reaching the detector. Nevertheless, it now appears possible to build a

(continued on page 18)

A rotating cloud of dust and gas begins to condense—in such a protoplanetary disk a solar system is being born. The large clump at the center will eventually ignite with thermonuclear fire to become a star. Smaller clumps swirling around it collide and stick together until they grow into planet-sized bodies. These small, dark, cold companions to stars are the objects of searches now being conducted in earnest from Earth.

Painting: John Foster

spaceborne instrument that might detect a planet the size of Jupiter if one exists near a star like the Sun.

Another approach to direct detection depends on the principle of interferometry (see sidebar, right), which may be able to isolate the images of the star and the planet even if they are separated by only tiny fractions of a second of arc. Radio interferometers can already resolve radio-emitting celestial sources to milliarcseconds.

Building an instrument that could perform that well at infrared and optical wavelengths is a much tougher task, but it is not impossible. The most advanced current project already has an infrared instrument operating on Mount Wilson in California. The next step will be a larger installation at Palomar Mountain, and there are plans to build a second 10-meter telescope near the existing Keck telescope on Mauna Kea in Hawaii, which with an array of smaller instruments will form an optical interferometer of unrivaled sensitivity with resolution in the milliarcsecond range.

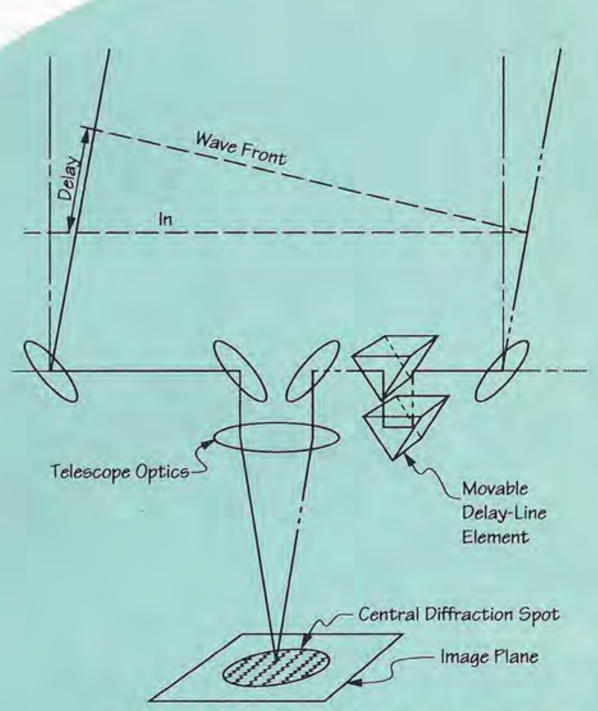
The first interferometric observations are being made in the infrared region because these longer wavelengths are easier to handle in instrument design. But there is another reason why infrared observations are preferred: While a "typical" planet is expected to be millions of times dimmer than its star in visible light, it may be only thousands of times dimmer in the infrared.

If planetary systems like ours are ubiquitous, it is only a matter of time until some are discovered by one or another of the methods just discussed. But there are other possibilities. SETI, the search for evidence of extraterrestrial intelligence, is well launched (see the November/December 1992 *Planetary Report*) and may provide a shortcut by revealing radio signals from an inhabited planetary system. Less dramatic but also possible is the discovery of radio noise like that of Jupiter, originating in a planet's magnetosphere.

Understanding Causes

As the science of cosmogony—the study of the origins and evolution of stars and planets—has matured, theorists have become convinced that many stars must have planets. Observers now seek not only to find planets but also to find answers to more general questions about stellar evolution.

Some of these questions can be attacked by observing star nurseries, those vast clouds of gas and dust in which protostars are forming as we watch. The Orion nebula (page 12), easily seen with the naked eye as the middle jewel in the winter hunter's scabbard, is such a breeding place of stars.



In a Michelson interferometer, the two beams of light alternately interfere destructively or constructively, giving fringes (bright and dark bands) in the image plane. The path lengths are equalized by delay line optics, giving a very precise measurement of the direction to the source of the waves. *Diagram reprinted from* **TOPS**

Only recently have astronomers been able to peer deeply into such clouds and observe what is going on near forming stars. Advances in infrared observing techniques have enabled them to study the spectra of young stars whose emission is strong in the infrared. The Infrared Astronomical Satellite (IRAS), launched in 1983, has been particularly useful. It has found thousands of sources, including many stars showing excess radiation at longer wavelengths —an indication that relatively cool material is orbiting near them. Ground-based follow-up observations revealed dust disks; the most dramatic result is the famous photo of the disk around Beta Pictoris. (See the May/June 1986 *Planetary Report.*) The Hubble Space Telescope, launched in 1990, has observed many more circumstellar disks. Such observations cannot directly show planets, but they do confirm the expectation that circumstellar disks, the probable birthplace of planets, are not rare.

Just seeing a disk is wonderful and exciting, but it is even more rewarding to obtain data showing what is going on as a star and its pancake-shaped nebula evolve. At the Caltech meeting many such new observations were discussed. For example, until recently the predicted cloud collapse was not observed; rather, when astronomers examined protostellar spectra they found evidence only of outflow. But now at last, with persistent effort and improved instrumentation, some inflow examples are coming to light.

As more observational data accumulate, it is becoming urgent to match them with theoretical progress. Modeling a turbulent protostellar nebula is an enormously complex task, because it must include hydrodynamic, electromagnetic, radiative, thermal and chemical effects, all interacting with one another. Supercomputers can come to the rescue—but only if the requisite amounts of time on them are allocated to competent researchers. Because of other priorities this has not happened yet. The confirmed discovery of even one extrasolar planetary system might provide the needed stimulus.

Inferences From Light

An interferometer uses the principle of reinforcement or cancellation in a beam of light or radio waves. Two telescopes receive the waves from a celestial source and send their signals to a detector. If the signals arrive with their waveforms' peaks and valleys synchronous (i.e., in the same phase), they add; if in opposite phase they cancel (see diagram). If the incoming wave makes an angle with the baseline between the telescopes, its times of arrival at the telescopes will differ and so will the phases of the two signals at the detector; hence the combined output signal from the detector is a measure of arrival angle. In modern interferometry this principle can be used, with several pairs of telescopes and many long and precisely controlled baselines, to build an exquisitely detailed image of the object observed. —*JDB*

At the Threshold

The Caltech meeting showed that scientists may be very close to announcing a long-awaited, epoch-making discovery. Several different lines of attack discussed at the meeting are giving evidence that, if confirmed, will show that our home, the solar system, is but one of many such systems. The spectroscopic technique, measuring very precisely the radial velocity of some candidate stars resembling the Sun, has been practiced now for years at several observatories, and the data hint strongly that some of those stars are being pulled toward and away from us by the gravity of unseen planets. Now it is necessary for those observations to keep on running, and for the calibrations and data-reduction methods to remain stable, so that in due time every possible explanation other than the presence of planets is ruled out.

Complementing spectroscopy, another kind of radial velocity measurement was discussed, and it may soon yield the biggest surprise of all—a pulsar with planets. Astronomers think that pulsars are the collapsed remnants of burnt-out stars, crushed by their own gravity to fantastic densities, bearing enormous magnetic fields and spinning fast. Some spin thousands of times per second, earning the name *millisecond pulsars*. These incredible spin rates are observable because pulsars emit radio beams that sweep past Earth regularly, like the beam of a revolving searchlight.

Imagine the astonishment of a radio astronomer whose long-continued observations of a pulsar began to show a variation in pulse arrival time indicating a regular motion first toward, then away from, Earth. The observed motion would at first naturally be thought to be an error, an artifact of the data, since any such bodies would surely have been blown away during the pulsar's violent birth. But, after strenuous efforts at other explanations, scientists are on the verge of announcing that a certain millisecond pulsar, 1257 + 12 (the numbers denote its position in the heavens), is apparently being tugged toward and away from us by the gravity of at least two unseen planets!

Sherlock Holmes knew that, when the impossible has been eliminated, what remains, however incredible, must be the truth. The next step in eliminating the impossible for pulsar 1257 + 12 is conceptually straightforward, but it will take time. If there are indeed two planets, their gravitational signature must show not only motions of the pulsar at the planets' individual orbital periods but also motions governed by gravitational interactions of the planets with each other. Preparations for making the needed observations are under way.

The Future

Despite its profound implications, the search for other planetary systems is not attracting much attention outside the interested astronomical community. Even among astrophysicists, this investigative field is in competition with other exciting prospects, many of them opened up by the advent of spaceborne observatories. For example, there are the violent realms of high energy, enormous scale, and immemorial time, the dominion of galaxies, quasars, black holes, supernovas and the mysterious gamma-ray bursters whose nature is unknown—not to mention the study of the universe in its entirety.

On this grand canvas, the search for planets may be seen as an interesting detail. And yet, according to all our present knowledge, the only places where consciousness can arise are in cool regions, where the signature of nature's hand is written not in gamma rays, X-rays, ultraviolet light or gravity waves, but in the visible, infrared and radio regions of the spectrum. As observational and theoretical techniques advance hand in hand, the study of the universe's cool backwaters may yield understandings even deeper than those of our present sciences, for at last may come the time when we are in contact—not just with knowledge, but with wisdom other than our own.

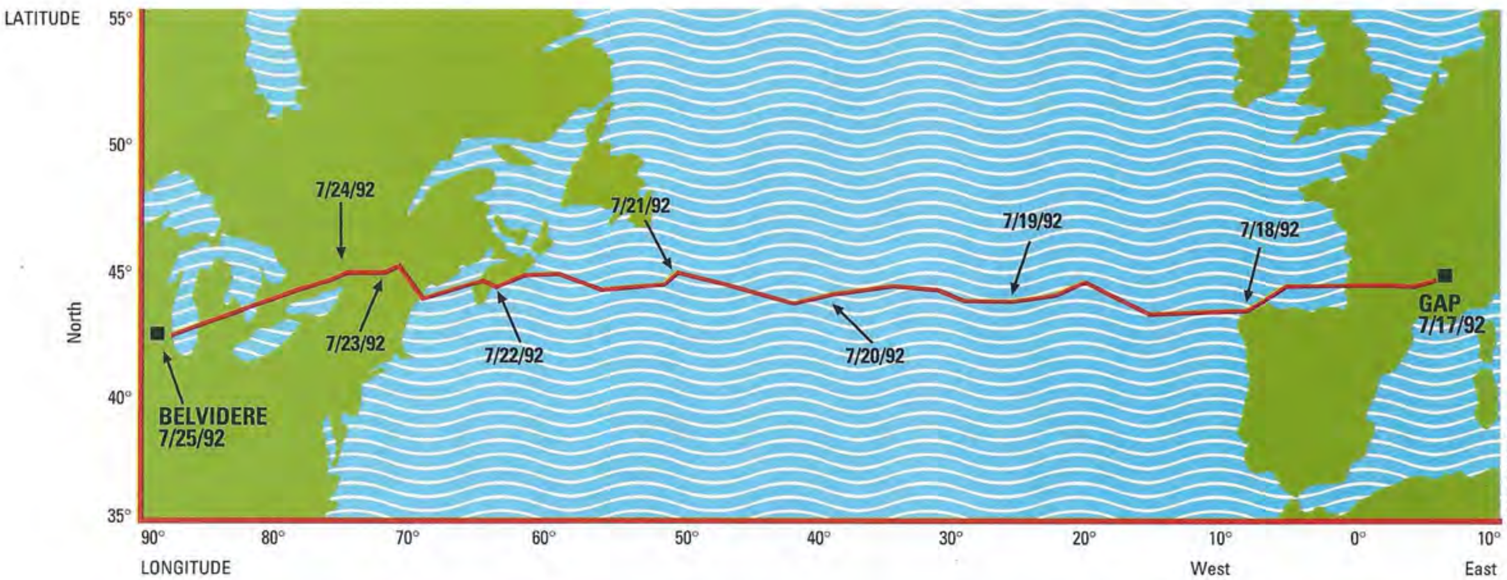
Toward the end of the Caltech meeting, when the gathered scientists reviewed the wonderful plans that await implementation, they asked one another what is keeping the public from being as excited as they themselves are. Several answers were offered, including the one that serious science fiction already portrays an inhabited cosmos, so finding it will be no great surprise. But in the end all agreed that, even without a burst of public enthusiasm, soon we will know much more about the likelihood that we are, or are not, alone.

James D. Burke is a retired Jet Propulsion Laboratory engineer and Technical Editor of The Planetary Report.

News From the

Mars Balloon Project

by Jacques Blamont



Despite the uncertainties created by the unstable situation in Russia, last October the Russian Space Agency (RKA) confirmed that it has given priority to the *Mars '94* and *'96* missions. The original plan stands: a launch in 1994 of a Mars orbiter accompanied by two penetrators and two small stations, and a launch in 1996 of a simpler orbiter, accompanied by one descent module that will carry one balloon and one rover.

At the Centre National d'Études Spatiales (CNES), we have been relentlessly pursuing the development of the balloon, and it is on schedule. As described in previous articles (see the May/June 1987, September/October 1990 and January/February 1991 issues of *The Planetary Report*), the balloon's payload will have two distinct parts: a main gondola carrying scientific instruments and a camera, and a guide-rope—the Snake—designed with the help of The Planetary Society. During the day, the superpressurized balloon will fly at a ceiling around 3 kilometers (about 2 miles) above the martian surface. During the night, the balloon descends (since it is not superpressurized at night) to a point where the guide-rope will slide along the ground and the gondola is at an altitude of 50 meters (about 160 feet).

Some nonspectacular, but very important, technical steps have been taken, such as the qualification of the balloon packaging in a flight container and a long-distance test in which the guide-rope was dragged across 65 kilometers (40 miles) of rugged ground— by a truck.

But our biggest news is that two major flight tests were conducted successfully from the CNES balloon launch base at Gap, France, during July 1992. These constitute a milestone in the progress of the Mars Balloon project.

Falling Inflation

The first flight was devoted to an inflation test under conditions similar to those expected during the descent in the martian atmosphere. This inflation test was crucial, for it showed that we can fill the balloon while it is descending at Mars.

On Earth, balloons are usually inflated on the ground and rise gently into the atmosphere. But during the *Mars '96* mission, the balloon system will be released as the descent capsule enters the martian atmosphere. It will have to inflate as it falls, gaining buoyancy to prevent it from crashing on the surface. While falling, the balloon will flap in the wind like a badly deployed spinnaker. It must be able to survive the atmospheric turbulence.

This method of inflation has been used only once—during the 1985–1986 *Vega* mission, which deployed Soviet-built balloons to study Venus' atmosphere. We have had little practical experience beyond *Vega* in this type of inflation, so we were particularly anxious to prove that it could work.

The 650-kilogram (1,400-pound) payload, carried aloft by a large auxiliary balloon to an altitude of 32.5 kilometers (20 miles; atmospheric pressure, 9 millibars), was very complex. Below the helium tanks and the devices necessary for adjusting the gas pressure, a balloon nearly identical to the martian vehicle was stored in its flight-qualified container. The volume of the test balloon was 5,500 cubic meters (190,000 cubic feet); its fabric was 8 microns thick. Cameras, telemetry transmitters and recovery beacons were added to provide continuous monitoring of all events.

After the container opened, deploying the balloon, inflation took place within the required time. The mass of gas inside the balloon was 7.625 kilograms (16.81 pounds), instead of the nominal value of 7.600 kilograms (16.76 pounds), an acceptable difference. The buoyancy of the balloon was constant for 17 minutes, and we therefore concluded that the balloon was full and leak-free.

Unfortunately, for reasons related to operational constraints, events then took a turn for the worse. The balloon was supposed to separate from the inflation system after 17 minutes and should have reached its nominal flight altitude of 6 millibars. But something went wrong, telemetry was lost, and the balloon was destroyed. Safety precautions imposed at the last minute by air traffic control authorities produced a chain of events that not only ended in the destruction of the balloon, which was not really important, since the most difficult part of the test had already taken place, but also made it impossible for us to obtain the complete set of measurements necessary for a quantitative analysis of the test. For instance, the authorities had decreed that the balloon could not fly during the day, so a night flight was imposed. Therefore no pictures of the inflation could be obtained. (This is why the present report has no photographs.)

From France to Illinois, and on to Mars

In the second test, a balloon identical to the martian balloon (volume 5,500 cubic meters; fabric thickness 6 microns) was launched from the ground and sent up to an altitude equivalent to its ceiling on Mars. The balloon had on board pressure sensors, atmospheric sensors and transmitters for localization by satellite. Launched from Gap in a zero velocity wind on July 17, 1992, it was also carrying a destruct mechanism that was supposed to rip open the balloon's skin after 60 hours of flight.

For some unknown reason, the balloon survived, crossed the North Atlantic and flew to Belvidere, Illinois, 100 kilometers (60 miles) northwest of Chicago, where it landed on July 25. Why did it come down? We know only that it somehow lost buoyancy and was unable to continue its flight.

The flight started at a ceiling of 36 kilometers (22 miles), where the pressure inside the balloon was higher than it will be during the most dangerous situations on Mars. The fabric held together well, and as predicted, the pressure fell during the night and the balloon stabilized at 33 kilometers (20 miles). During the following days, the altitude reached both during the day and during the night decreased, showing a small tendency for the balloon to leak, but it stayed aloft valiantly. After the first 60 hours we lost telemetry, but the localization subsystem worked well, making it possible for us to reconstruct the trajectory (on the facing page).

A lifetime of eight days in the atmosphere of Earth, where the variations of the infrared flux are larger than in the atmosphere of Mars, is comparable to the target value of a 10-day lifetime in the martian environment. We estimate that with a few minor improvements the balloon we have developed will be able to perform the martian mission.

Jacques Blamont is a professor at the University of Paris, chief scientist of CNES, chairman of the French science steering group for the Russian Mars '94 *and* '96 *missions, and a Planetary Society advisor. He conceived the* Mars '96 *balloon experiment.*

The Balloon Stops Here

Russ Garner was driving home through Manchester Township at 2 a.m. on Sunday, July 26, when he first saw the balloon tangled in two trees and a power line on Herman Zick's farm. "As soon as I saw it, I thought it was a weather balloon," he said. "There had been a real bad storm 8 to 10 hours earlier. I didn't get too far down the road before I thought, 'I gotta turn around.' It was partially inflated, and three different bundles of instruments were caught in the trees. There was a lot of fog and the farm had one of those sodium vapor lights, so this bright, bluish glow was coming through the balloon in the fog. You can imagine what it looked like."

The next morning, Russ told his father about what he'd seen, and Mr. Garner promptly called Butch Peters, Herman Zick's son-in-law. (Peters lives on Zick's property, across the street and down the road.) Butch then called Deputy Dennis Reaser from the Boone County sheriff's department in nearby Belvidere, who climbed up a ladder and cut the instrument packages out of the trees.

"When I first got the call about this thing coming down, we all thought it was a weather balloon, so I called the national weather service here and they didn't know anything about it," Deputy Reaser explained. "We'd never seen anything like that before. You find a lot of things by the side of the road when you're out on patrol, but nothing like this. Then we found this note on the balloon asking whoever found it to return it to the French Consulate.

"The only parts that were reachable were some sort of transmitter box on the bottom and this beat-up, foil-covered object that looked like an umbrella" (the antenna). "The balloon part was across the street in Herman Zick's beanfield. The wind had caused it to beat itself to death on the ground. Butch folded it up pretty quickly because he didn't want it to hurt the bean plants."

Although it fell on his property, Herman admitted that he had had no interest in messing with the balloon that morning—he was in a hurry to get to church. When I asked Russ and Herman what they thought about the idea of balloons on Mars, Russ said, "If it works, it seems like the cheapest way to do it—cheaper than a manned mission." Herman simply said, "It'll probably work. You just don't know what they're gonna do."

—Donna Stevens

Not Yet to Mars, Together

by Louis D. Friedman

"The road to hell is paved with good intentions." After 35 years of competition the United States and Russia finally agreed to undertake a bit of planetary exploration cooperatively—a first step "To Mars, Together." It was only a small step, and both sides knew exactly what to do, technically and scientifically. Bureaucratic roadblocks and communication breakdowns prevented them from doing it. If we don't examine how this happened, we're never going anywhere together.

In early June of 1992, as a result of seeing the Russian *Mars '96* rover during the California tests sponsored by The Planetary Society, NASA Administrator Daniel Goldin initiated a plan for the United States to take part in the Russian 1994 mission to Mars. That mission was designed to carry four landers—two small surface stations and two penetrators—in addition to a large orbiter. Goldin proposed adding a lander that would carry US experiments to the Red Planet's surface.

This idea sprang from a Planetary Society proposal that NASA's previous administrator, Adm. Richard Truly, had turned down. Originated by Society Vice President Bruce Murray, it called for adding a penetrator to the mission, with US researchers modifying the Russian technology. By mid-1992, when the idea was resurrected by Goldin, it was too late to consider adding such a new device. In contrast, the surface station, which was being developed by Russia with the participation of Finland, was considered by engineering and scientific specialists to be a more mature design.

Things moved quickly. In just a few days, Goldin got the Jet Propulsion Laboratory to develop a plan that he could present to the Russian Space Agency (RKA) during the US–Russian summit meeting in mid-June. It offered US financial participation in the mission and new science experiments—which would add to the knowledge necessary for the human exploration of Mars—in return for Russia carrying the experiments to Mars. The US would also be given access to the surface-station technology being developed by Russia, Finland and France. Within two weeks, the plan had been agreed to in principle by everyone involved, from spacecraft engineers to the presidents of Russia and the US.

The deal was a good one for all concerned. JPL and its Russian counterpart organizations judged it to be feasible, albeit difficult, and it was accepted by the politicians as mutually advantageous. Because of the short schedule and the complicated engineering interfaces, it was the most challenging joint space endeavor for the two countries since the symbolic *Apollo/Soyuz* test project of 1975. All that was needed was to implement it.

But that did not happen. There will be no American lander on *Mars '94*. In my opinion, both sides are to blame. The best of intentions were no match for bureaucratic misdirection and poor communication. What follows is my interpretation of the events.

Off to a Bad Start

In the US, JPL's engineers and scientists, who had been ready to begin work on *Mars '94* in July 1992, were stymied. Fearful of sending the wrong signal to the Russians, mid-level officials of NASA and the State Department took turns refusing permission for international working meetings.

With NASA encouragement, however, JPL began to consider broader, long-range possibilities for Russian–American cooperation in the Mars program for 1996 and beyond. They even sent a team from the Mars Environmental Survey (MESUR) project, including people cognizant of the 1994 plan, to Moscow to look at the surface-station technology—but then prohibited them from discussing the 1994 mission! This of course mystified the Russians: They were on an extremely tight schedule with the 1994 mission, and they thought the 1996 and later activity could wait.

At the urging of everyone connected with the project, and at the direction of Goldin and his Russian counterpart, Yuri Koptev, head of RKA, NASA's Office of Solar System Exploration moved to expedite the transfer of funds to Russia. The funds were badly needed to meet project requirements, but Goldin and Koptev wanted a contract. Complicated procurement procedures came into play.

Intending to speed up the process, NASA officials decided that a grant would be a good way to get money to the Russians. But then complications arose on the Russian side: Who would get the grant? Would it be RKA, or the Babakin Center, which was responsible for building the station? Or would it be the Space Research Institute (IKI), with its overall mission responsibility and long-established relationship with the West? And would the money disappear into the vastness of the Russian bureaucracy, or would it get used for the intended purpose?

The Russians never got this sorted out, and the internal jockeying about led to protracted negotiations. What I find perplexing is that these negotiations were going on even *after* it had become impossible for the project to be carried out.

Hedging the Bet

In June and July, when asked if the proposed US surface station could be added to the mission, Babakin officials said yes. They had analyzed the spacecraft implications, hardware availability and schedule, and said that they could do it, if work could begin soon. "Soon" was left undefined. Several knowledgeable Americans were surprised. Adding another element to a very complex mission just two years before launch seemed risky, especially in view of the fragility of the Russian space industry. In retrospect, I suspect that Babakin officials really believed that the mission would be postponed, giving them two more years and a new mission design.

What Babakin officials neglected to say was that in the first week of October they had to send the spacecraft specifications to their factory. Any changes after that would result in an official change in the contract—a situation well known in both the US and Russia to increase costs and put schedules at risk. This particular week is significant because Goldin was in Moscow then, meeting with RKA officials about the

—But Still Working on It

US lander. He was embarrassed at not having US funds available because of a snafu in NASA/Congress budget action at the end of the fiscal year. This may have exacerbated the misunderstanding, but Russian officials never mentioned the Babakin specification deadline to him.

Meanwhile, Babakin officials proceeded to send the specifications to the factory—not for three, but only for the original two, surface stations. Why did they do this? The NASA grant had not been made, and Goldin appeared not to have the money. The JPL team had not yet visited the Russians to plan the new surface station. Perhaps the Russians remembered the instance of an American spectrometer once slated to fly on *Mars '94* but abruptly withdrawn by the US. They may have thought the risk of being let down too great, given the scheduled 1994 launch.

This uncertainty made the Russians' decision to specify only two surface stations a reasonable choice. But it was not reasonable to have kept NASA and JPL in the dark about it, especially in October and November when they were working hard on closing the deal. In fact, the Russians were arguing about payment approaches and schedules as if including the surface station was definitely still an option.

Because of the Russians' positive attitude, their NASA counterparts kept informing management (including Goldin), Congress (which had to be consulted about the money), outsiders (like The Planetary Society) and the other participating space agencies in France, Finland and Germany that the deal would soon be official, with money in the Russians' hands. But the targeted date kept slipping—from mid-November to Thanksgiving, to the end of November, to the first week in December, when the international *Mars '94* science team (MNS) was to meet. The Russians were at the same time giving Koptev and other RKA officials the impression that they would accommodate the American station.

Only when JPL project leader Frank Schutz and I forced the issue in Moscow during the week of the MNS meeting did Babakin officials finally say they couldn't do it. The principal reason given was that they did not want to hand their factory and subcontractors an excuse not to meet the 1994 launch date.

At the MNS meeting, it had become clear that the *Mars '94* mission was real. Perhaps encouraged by the prospect of US participation, but also motivated by the significant existing French and German support, RKA officials strongly backed the 1994 launch date. On December 1, they had informed the international team that the mission was "guaranteed" full funding, even in the face of skyrocketing inflation! To be sure, this guarantee is only as good as the Russian government's support of RKA, but it is still an extraordinary statement of priority.

A Silver Lining

The concrete support for the mission, given everything else going on in Russia, is certainly good news. And I believe that by early December the decision to drop the US station was probably the correct technical one. Also, by refusing a $2.6 million deal, the Russians showed that they are seriously committed to the 1994 launch date.

Both the JPL and the Babakin engineers still want to cooperate, as do NASA and RKA. In the aftermath of the decision not to include a US surface station, the Russians offered the US some space on the existing two small stations. The international team of scientists on the mission was very cooperative about accommodating the American experiment —even when it became necessary to adjust existing experiments. JPL is now working on a soil oxidant experiment for the mission.

Beyond *Mars '94*, the commitment to cooperative Mars exploration is growing. Several interesting ideas for the Russians' *Mars '96* and NASA's MESUR are under study, and the space agencies have agreed to hold a multilateral review of Mars mission planning this May in Europe. Throughout the governments and space agencies involved, people do want to work together. Now that we've gone down a dead end, perhaps the next road will take us to our destination—Mars.

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

A Personal Opinion

How can a situation like this be avoided in the future? NASA and the Russian space institutions must:

- Institute regular and frequent teleconferences between cooperating agencies and organizations for the duration of a project.
- Make it easy for individuals to communicate via e-mail and telephone, and *eliminate* existing rules that hinder such communication.
- Streamline procedures for approving and arranging international travel.
- Loosen export control laws and regulations, and simplify dealing with them.
- Exchange technical personnel.
- Have people on each side whose job it is to expedite communications and watch for snafus.

Then, the next time the presidents of the United States and Russia agree to undertake a space mission, and the heads of the two space agencies tell their people to carry it out, maybe it will happen. —*LDF*

President Directs NASA to Redesign the Space Station

by Louis D. Friedman

President Bill Clinton, in his first month in office, has signaled a major change in the United States' space program: He has directed NASA to redesign space station *Freedom* to make it "more efficient and effective."

The Planetary Society has long advocated such a change. If implemented, this redesign of the US space station could give a strong boost to space exploration around the world.

A US space station was proposed in 1984 by President Ronald Reagan. In the years since, it has grown into a budgetary behemoth that has threatened smaller but critical elements in NASA's overall program. Clinton's new proposal would make room in the agency's budget for growth in aeronautics, human and robotic spaceflight, planetary exploration and new technology development.

In response to Clinton's directive, NASA Administrator Dan Goldin pledged that the agency will "introduce broad, innovative thinking" into the redesign process. This means the space station designers will reconsider ideas for making the station a preparatory step for eventual human interplanetary spaceflight, decreasing the number of space shuttle flights needed to build and service the station, making it more modular in design, and broadening international involvement, possibly using existing Russian capabilities and experience with the *Mir* space station.

This is exactly what The Planetary Society has been urging since 1987, with the publication in the July/August *Planetary Report* of "A Space Station Worth the Cost." At technical workshops, in congressional testimony, during committee meetings and in consultations with the administration, Society officers have repeatedly asked for a station that would be capable of supporting studies of the effects of long-duration spaceflight on the human body, which is essential for planning any human missions to another planet.

The new policy is contained in the president's budget request for fiscal year 1994, which he has now presented to Congress. As we go to press, details of that budget are not yet available. Before Congress passes the budget, it will be debated by the committees with oversight of NASA's budget. The outcome cannot be predicted.

It appears that NASA will receive a modest increase in its budget as an expression of the new administration's support for science and technology. The space station will receive funds adequate for its redesign and the transition to a revamped program.

In future years, the station should take a lower percentage of NASA's budget, which will, it is hoped, free up funds for new projects, perhaps including the MESUR Pathfinder to Mars, the Near-Earth Asteroid Rendezvous and a flyby mission to Pluto. Many proposals for low-cost planetary missions in the Discovery program (see the July/August 1992 *Planetary Report*) and other space science missions now have a brighter future. The Mission to Planet Earth program to study and monitor our home environment should also benefit.

It appears that Planetary Society advocacy of a space station worth the cost has been effective. However, the political process being what it is, there is no guarantee that this change to the space station program will actually be implemented.

If NASA is to carry out this new mandate, the agency will need support from its international partners, Congress, the administration, the aerospace industry—and from you, the members of The Planetary Society, and others interested in space exploration.

We will keep you informed as the situation develops.

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

Excerpts From NASA Press Release, February 18, 1993

NASA BUDGET BOOSTS TECHNOLOGY, PROMISES IMPROVED SPACE STATION PROGRAM

President Clinton has directed the Administrator to redesign the space station as part of a program that is more efficient and effective and capable of producing greater returns on our investment. The '94 package provides $2.3 billion for the smooth transition of the program to a streamlined, cost-effective design, assuring stability in the program during the transition and minimizing any potential job loss.

The President also has directed NASA to work closely with the US Congress and international partners to maintain continuity in the program and to assure their participation in producing a space station that is technically challenging and promises the highest possible returns.

NASA's new technology investment package will provide significant funding aimed at new projects that could lower the cost of space research, achieve demonstrable results sooner and be more directly beneficial to the economy. The new plan allows room in NASA's budget for future enhancements to ongoing agency efforts in aeronautics, human and robotic spaceflight and the transfer of technology to new and existing industries.

Norm Augustine *Joins Society Board of Directors*


Photo: Martin Marietta Corporation

Norman R. Augustine, chairman of the board and chief executive officer of Martin Marietta Corporation, has joined the Board of Directors of The Planetary Society. He is the first active member of the aerospace industry to be asked to join our Board. "Norm's presence will broaden our collective vision," according to Bruce Murray, Planetary Society Vice President.

Augustine's list of accomplishments is probably unmatched in the aerospace world today. As Murray points out, "He is one of the most highly respected persons in the entire aerospace industry. Having a distinguished career as head of a very successful aerospace company, he chaired the Bush administration's Advisory Committee on the Future of the US Space Program. The committee's recommendations to the president—the Augustine report, as it has come to be known—have set the direction for NASA in the post–Cold War era." Indeed, both the space policy set by the Bush administration after the December 1990 publication of the report and the recent directives from the Clinton administration regarding the space program appear to have closely followed the committee's recommendations.

Augustine is familiar with the workings of the government beyond his service on many advisory panels, chairing both the Defense Science Board and the Aeronautics Panel of the Air Force Scientific Advisory Board. He spent many years in government service, including the position of undersecretary of the Army.

In a series of lectures and commentaries, Augustine developed a body of "laws" governing the aerospace industry and its relationship to government. In the words of Murray, these pronouncements "have become a part of American engineering folklore." In 1982, they were gathered into the book *Augustine's Laws.*

Consider, for example, Augustine's Law Number 1: "The thickness of the proposal required to win a multimillion-dollar contract is about 1 millimeter per million. If all proposals conforming to this standard were piled one on top of the other at the bottom of the Grand Canyon, it would probably be a good idea."

Augustine has also taken a serious look at the changes in the defense industry demanded by the end of the Cold War. His 1990 book, coauthored by Kenneth L. Adelman, is entitled *The Defense Revolution: Intelligent Downsizing of America's Military.*

An often suggested solution to the crisis facing the defense industry is the conversion to products for the civilian market. This type of conversion, Augustine has pointed out, has a track record "unblemished by success."

Martin Marietta is following a different path. In late 1992, it acquired General Electric's aerospace division, making the new entity the world's biggest supplier of defense electronics. "This Deal Could Send Martin Marietta Into Orbit," read the headline in *Business Week.*

Other aspects of Augustine's business acumen have earned him inches in the weekly business magazines. In 1991, *Forbes* magazine selected him as one of the top 10 underpaid chief executives in America. (His joining the Board at The Planetary Society will not make any change in this regard.)

Augustine also volunteers his time and skills to the American Red Cross, of which he is chairman, and to the Boy Scouts of America, which he serves in the position of executive vice president.

We look forward to Norm Augustine's contributions to The Planetary Society. Murray sums it up: "Norm will bring a broad view of the possibilities of space, the realities of national and international affairs, and the discipline of sound financial management to our Board deliberations."

—Charlene M. Anderson

The *Report of the Advisory Committee on the Future of the US Space Program*, known popularly as the Augustine report, made 15 specific recommendations for NASA. We summarize here those that directly address the programs and policies of The Planetary Society.

• The civil space science program should have first priority for NASA resources.

• The Mission From Planet Earth should be established with the long-term goal of human exploration of Mars.

• The Mission From Planet Earth should be configured to an open-ended schedule, tailored to match the availability of funds.

• NASA, in concert with its international partners, should reconfigure and reschedule space station *Freedom*.

• Technology should be pursued that will enable a permanent, possibly human-tended outpost on the Moon [as] required for the eventual human exploration of Mars, and NASA should initiate studies of robotic precursor missions and lunar outposts. *—CMA*

News & Reviews

by Clark R. Chapman

The most definitive books about the solar system are those in the University of Arizona Press Space Science Series. Nearly two decades after the first volume appeared, the 21st—*Mars*—arrived, in late 1992. As with previous books in the series, nothing compares to this 1,500-page sourcebook on the Red Planet. Written by 114 experts on Mars, this is the most thorough book on its subject ever published and is likely to remain the bible for Mars even after the *Mars Observer* mission is completed.

Although intended primarily for graduate students and professional scientists, this collection of 38 review chapters is a gold mine of information for anyone interested in Mars. Introductory chapters on the history of telescopic and spacecraft studies of Mars, plus parts of other chapters, will be accessible to most *Planetary Report* readers. Other chapters are filled with equations. I have not read all the chapters in this book. Nor, I suspect, has anyone, not even the book's able senior editor, Hugh Kieffer. *Mars* is not bedtime reading, but rather a sourcebook, at many levels. It lists all major books and technical journal special issues ever published on the subject of Mars. Separate geologic and shaded relief maps provided with *Mars* are suitable for framing; they may alone be worth the cost of the book.

The Space Science Series

Since 1974, the Space Science Series has treated (or soon will treat) every object in the solar system (except the Moon, but including the Sun) and every category of object (like asteroids and planetary satellites, but not interplanetary space itself), as well as topics in stellar and galactic astronomy that have relevance to understanding the solar system. Some topics have already been updated in a second book. Only the 1976 Jupiter book is obsolete.

Most of the Arizona books are produced in association with a scientific conference that brings prospective chapter authors together. The fourth International Mars Conference was held in January 1989. *Mars* took nearly four years to appear, an unfortunate trend. Through what series editor Tom Gehrels calls "shotgun weddings," proponents of divergent scientific perspectives often find themselves coauthoring a review chapter. It doesn't always work, but Gehrels' encouragement for the "married" authors to compromise, or at least to understand each other's theories while stating their separate viewpoints in a joint chapter, is very constructive for the increasingly fragmented and specialized process of scientific research.

Some chapters are stronger than others, but *Mars* represents the best possible compilation of Mars science in 1990. *Mars* has a few defects, which it shares with most other volumes in the series. To save a few pages, each chapter's references are grouped at the end of the book, which sharply reduces their utility. The short, 11-page index is awful, typical of most books published today. Spot checks reveal that a topic treated by many sentences or paragraphs in the text is often not in the index. Indeed, whole chapter sections are sometimes missing from the pertinent index category, most unfortunate for an encyclopedic book.

Still, the Arizona Space Science Series provides a unique, indispensable service to planetary science. Tom Gehrels and his capable senior editor Mildred Matthews deserve accolades. I wish the series success for its second two decades.

Peekskill Fireball

We do not yet know, for sure, which asteroid is the parent body for *any* of the thousands of meteorites collected on Earth. We have trajectories for only a handful. Orbits for three meteorites were calculated from photos of meteor fireball tracks obtained by the dedicated, underfunded surveys of three teams of meteor scientists during the 1960s and 1970s, operated in the American Midwest, in Canada and in Czechoslovakia. Each survey resulted in one invaluable pre-atmospheric-entry orbit. Now it may finally be possible to calculate a fourth orbit.

On Friday evening, last October 9, a brilliant fireball was witnessed over much of the eastern United States. Since the meteor exploded during high-school football season, an unprecedented number of videos of the event were taped by football parents and local news photographers. No ordinary shooting star, the responsible asteroid fragment crashed through the trunk of 18-year-old Michelle Knapp's old red Malibu coupe in Peekskill, New York. An enterprising group of New Jersey rockhounds reportedly paid Knapp over $50,000 to buy not only the meteorite but her damaged vehicle as well. In February, I saw both meteorite and car displayed at the annual Tucson Gem and Mineral Show.

Valuable Videos

Meanwhile, George Wetherill of the Carnegie Institution has been trying to collect the videos, in hopes of calculating the meteorite's orbit and perhaps linking the Peekskill stone to a known asteroid. Wetherill has located 17 videos of the Peekskill fireball, six of which are good enough to use for measurements.

If Planetary Society members know the whereabouts of additional videos of this remarkable event, they could aid science by calling George Wetherill at (202) 686-4375, sending a fax to him at (202) 364-8726 or writing to him in care of the Carnegie Institution, Department of Terrestrial Magnetism, 5241 Broad Branch Road NW, Washington, DC 20015.

Clark R. Chapman was coeditor of one of the Space Science Series volumes, the 1988 book on the planet Mercury.

SOCIETY *Notes*

THANKS FOR THE ASTEROIDS

The Planetary Society has regretfully ceased funding the amazingly successful astrometry project of Jeremy Tatum and David Balam at the University of Victoria in British Columbia. (See the May/June 1988 and September/October 1991 issues of *The Planetary Report.*)

As a member-supported organization, the Society cannot provide continuing funding for scientific research. Rather, we seek out projects where a little seed money can help an idea grow into a worthwhile program, or where some wisely placed funds can keep a meritorious program from folding.

In a letter, Tatum wrote, "I fully understand (and even support!) the Society's decision. Continuing research of this nature should be supported by government granting agencies and one should not have to rely on private organizations forever. The Planetary Society helped us out with a most generous grant at a time when we were really desperate, and without that help we wouldn't have been able to keep going. We really appreciated that generosity."

We were very happy to learn that the National Geographic Society has been able to come to the rescue of these researchers. Their asteroid and comet tracking program—and their contributions to this important field of research—will continue.
—Louis D. Friedman, Executive Director

EXPERT PANEL DISCUSSES THE FUTURE OF SPACE EXPLORATION

"The Present and Future of Space Exploration" starts airing on Canadian Broadcast Corporation and Public Broadcasting Service channels the first week of May. Produced by the CBC's weekly show, *Newsworld*, the two-part program (the second part airs the following week) features a panel of space and planetary science experts, such as Louis Friedman and Society Advisors Sergei Kapitsa, Jun Nishimura and Jacques Blamont. The program promises to be a thought-provoking look at what lies ahead in planetary exploration.
—Susan Lendroth, Manager of Events and Communications

SPACE EVENTS

Here's a brief look at some highlights of The Planetary Society's latest space events calendar:

• In Washington, DC, at the National Air and Space Museum, the multimedia exhibition "Where Next, Columbus?" continues. The exhibition examines the prospects for exploration and discovery in space in the next 500 years. Admission is free, and the museum is open from 10 a.m. to 5:30 p.m. daily. For more information, contact the National Air and Space Museum at (202) 357-2700.

• On April 5–7 in Mexico, the La Paz Station of the Solar Astronomy Research Center will hold its second annual solar astronomy convention at La Paz, Baja California. For more information, contact Solar Astronomy Research Center, Calle La Purisima 119, Colonia Bellavista, CP 23050, La Paz, Baja California Sur, Mexico.

The Planetary Society organizes a variety of space-related events every year. If you would like to receive a copy of the regional space events calendar, please contact me at Society headquarters.
—Carlos J. Populus, Volunteer Coordinator

INTO THE RING OF FIRE: EXPLORE KAMCHATKA

Exploring active volcanoes, entering once secret KGB headquarters and visiting the site of the Mars Rover tests on Russian soil are some of the highlights of the Ring of Fire Expeditions' nine-day tour to Kamchatka. Sponsored by The Planetary Society and Future Travel, the tour to the former Soviet state is scheduled for August 14–23, 1993.

The tour begins in Seattle, Washington. From there voyagers will fly to Magadan on the Russian mainland and then to the Kamchatka Peninsula. Tourists will stay in the city of Petropavlovsk–Kamchatskii and see KGB and Communist Party headquarters, visit the black sand beaches and natural thermal pools of the surrounding countryside, fly in a helicopter over many of the peninsula's volcanoes and fly by jet to the site of Kamchatka's Mars Rover testing. Also planned are a side trip to a formerly top-secret military installation and a cruise on nearby Avachinskii Bay.

The tour costs $2,995 per person and is limited to 20 persons. For more information, write to me at Society headquarters, or call 1-800-969-MARS. *—SL*

THE PLANETARY REPORT: FROM AARON TO ZUBRIN

The new *Planetary Report* index is available now. Updated through the November/December 1992 issue, the index includes author, subject and title listings for the magazine's past 12 years. The 26-page publication sells for $3.00. To order, call (818) 793-5100 or write to TPR Index at Society headquarters.
—Charlene M. Anderson, Director of Publications

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Questions & Answers

When asteroid 4179 Toutatis recently zipped past Earth, Steven Ostro of the Jet Propulsion Laboratory and his team used radar signals bounced off the asteroid to create these images. The team used the Goldstone Deep Space Communications Complex in California's Mojave Desert.

These four glimpses (from top to bottom) of Toutatis were caught on December 8, 9, 10 and 13, 1992, when it was an average of 2.5 million kilometers (about 1.5 million miles) from Earth. "It's our first close imaging encounter with an Earth-crossing asteroid," Ostro said.

On each day the asteroid was in a different position, and because the radar illumination comes from the top in each image, some parts of the object toward the bottom of each image can't be seen. The large crater in the December 9 image (second from the top) is about 700 meters (2,300 feet) in diameter.

Ostro reported that Toutatis' jagged, cratered surface indicates a complex history of collisions, but that the binary nature of the asteroid was the most important single finding in the experiment. "Three years ago we were startled by the initial evidence for contact-binary asteroids," he said. "Now it seems that double bodies might be very common in the Earth-approaching population. If so, then their abundance has important implications for theories of the origin and evolution of asteroids and meteorite source bodies."

Over the next few months, the scientists will refine the data to reveal details of surface features less than 100 meters (330 feet) across. Using these details, they plan to construct a detailed, three-dimensional computer model.

Are plate tectonics necessary for the maintenance of a long-term, life-sustaining climate? Would an ocean-covered early Venus have had plate tectonics and, if so, why did its surface become so hot?
—Matt Straznitskas, Cromwell, Connecticut

The answer to the first question is yes —plate tectonics are probably necessary to maintain a stable climate. Take Earth as an example: Its mean surface temperature is basically determined by the amount of sunlight it absorbs and by the greenhouse effect of its atmosphere. Earth's greenhouse effect, an increase of about 33°C (which corresponds to a change of 59°F), is attributable to absorption of outgoing infrared radiation by atmospheric gases, primarily water vapor and carbon dioxide (CO_2). Of these gases, carbon dioxide may be thought of as the "independent variable" because water vapor is constrained to be near its saturation vapor pressure; that is, the air holds about as much water vapor as it can.

On long time scales, the atmospheric carbon dioxide abundance is determined by the balance between the weathering of silicate rocks to form carbonate sediments and the conversion of carbonate sediments into carbon dioxide and silicates. The latter process occurs primarily in areas where carbonate-laden seafloor is being drawn into the mantle as part of the plate tectonic cycle.

Thus, without plate tectonics or some equivalent process for burying carbonate sediments to great depths, there would be no way to recycle atmospheric carbon dioxide. Earth's carbon dioxide would all be tied up in the crust, and the climate would be too cold to support life. (Plants would be unable to photosynthesize in the absence of carbon dioxide, regardless of the temperature.)

Your question about early Venus is more difficult because the process of plate tectonics is poorly understood even for Earth. Water may play an essential role in lubricating plates. An ocean-covered early Venus would have had a cooler surface, and a cooler surface ought to reduce the depth at which the basalt of the seafloor converts into the denser mineral phase eclogite. This transformation is thought to help descending oceanic plates sink down into the mantle. So, an ocean-covered early Venus could have had a plate tectonic cycle similar to that of modern Earth. (Present-day Venus evidently does not have such a cycle, based on observations by the *Magellan* spacecraft.)

On the other hand, geologists are not certain that conventional plate tectonics occurred on early Earth; the modern cycle may have gone into operation sometime after the interior had cooled below some critical temperature. So, the real answer to your question is, we don't know.

Even if plate tectonics did operate on early Venus, the process would not be expected to have stabilized the surface temperature. Remember, its main climatic effect is to inject carbon dioxide back into the atmosphere, thereby making a planet warmer. Since Venus was too warm in the first place, plate tectonics would only have made the problem worse. Climate stabilization by the carbon dioxide geochemical cycle breaks down if the solar energy intensity is too high (or too low) at the planet in question.
—JAMES KASTING, *Pennsylvania State University*

What are the criteria for assigning the locations of longitudes and latitudes on bodies other than Earth?
—Marcel St-Amand, Pembroke, Ontario, Canada

In 1970 the International Astronomical Union defined rules for establishing the latitude/longitude coordinate system for solar system bodies. Latitudes are defined with respect to the direction of the body's spin axis, with north being positive and south being negative. "North" means north of the invariable plane (the invariable plane is the average plane of the bodies of the solar system). The equator (0 degrees latitude) passes through the center of mass of the body; the north pole is 90 degrees latitude, and the south pole is minus 90 degrees latitude.

Longitudes are numbered from 0 to 360 degrees. As the body rotates, the longitude increases with time when observed from a distance (such as with a telescope). Thus if the rotation is prograde (the same sense as the planet's motion around the Sun, as is the case for Earth), west longitudes are used, and if the rotation is retrograde (opposite sense, as for Venus), east longitudes are used. For this reason, longitudes on Mars increase to the west and on Venus they increase to the east. The prime meridian (0 degrees longitude) is often defined by a surface feature, such as the transit circle at Greenwich for Earth, the small crater Airy-O on Mars and the central peak in the crater Ariadne on Venus. The crater Hun Kal defines the 20-degree meridian on Mercury.

Because of tradition, the longitudes on Earth and the Moon do not follow the IAU rules. Their longitudes are numbered from 0 to 180 degrees and designated east or west.
—MERTON E. DAVIES, *RAND*

Why was helium selected for the Mars Balloon? Hydrogen is lighter, cheaper and more plentiful. It is hazardous to handle, but the shuttle launches show that the techniques for safely handling large quantities of hydrogen have been pretty well worked out.
—Dan F. Hays, Mojave Valley, Arizona

Helium was selected because hydrogen causes embrittlement of titanium, the material that Russia uses for the pressure vessels that store the balloon's inflation gas aboard the Mars spacecraft. Hydrogen would otherwise be a good choice. In a United States–designed spacecraft, hydrogen might be used, with storage in nonmetallic pressure vessels. But the net difference in balloon performance would not be very large, and convenience might still dictate the use of helium.
—JAMES D. BURKE, *Technical Editor*

FACTINOS

After 60 years of guesswork, planetologists finally have a firm idea of the mass of Pluto and that of its satellite Charon. George W. Null of the Jet Propulsion Laboratory and two colleagues used the Hubble Space Telescope's Wide Field and Planetary Camera to photograph the Pluto–Charon system repeatedly over three days in August 1991.

After precisely pinning down the positions of the two bodies and noting their motion around their common center of gravity, the team deduced that Pluto's mass is about 12 times that of Charon but only a fifth that of our Moon. Therefore Pluto's average density must lie between 1.8 and 2.1 grams per cubic centimeter, depending on the radius used, and its interior must consist of ice and rock in roughly equal amounts.

However, Charon's density is lower, between 1.2 and 1.3 grams per cubic centimeter, meaning that it has more in common with the water-ice moons of Saturn than with Pluto. More important, it now seems highly unlikely that the two bodies accreted together as a "double planet."
—from *Sky & Telescope*

❖

A team of scientists says it has solved the mystery of what exploded 85 years ago over Tunguska, Siberia, flattening hundreds of square miles of forest: It was a stony asteroid about 30 meters (100 feet) in diameter.

Experts have debated for decades on the cause of the explosion, with the most popular explanation being that a comet plunged through the atmosphere at supersonic speed. In January, Christopher F. Chyba of the Goddard Space Flight Center, Paul J. Thomas of the University of Wisconsin and Kevin J. Zahnle of NASA's Ames Research Center reported their new hypothesis in the journal *Nature*.

In a mathematical simulation of the Tunguska explosion, the researchers show that cometary nuclei and carbonaceous asteroids explode far too high to account for the blast, and that iron-rich asteroids tend to explode low and leave craters. The only logical source, they conclude, is a stony asteroid, the most common type. "This event represents a typical fate for stony asteroids," they wrote.
—from William J. Broad in *The New York Times*

Spring is here! Clean those shelves, closets and tabletops to make room for new and exciting things from The Planetary Society.

We have something new for everyone this spring. And you can still order our regular items. Here's a great bonus for those who love to shop . . . with every purchase of $60 or more you'll receive a free Planetary Society key ring. This offer is good through April 30,1993.

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325 pages (hard cover). 3 lb. **#182 $25.00**

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Dance of the Planets, featured in our previous issue, is here to stay! This software program presents a unique, dynamic model of the solar system. With this innovative program, you can view the assembly of worlds from the perspective of space or from Earth over a period from 4680 BC to AD 10,000—observing all manner of transient events and orbital processes. IBM-compatible software—requires 80x86 CPU, DOS 3.X or higher, 640K RAM, EGA or VGA graphics, hard drive. Math co-processor recommended. Please specify 3 1/2" or 5 1/4" disks. 2 lb. **#715 $170.00**

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