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Venus—Retaining Her Mystery

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COVER: Venus as seen through a telescope is a fuzzy yellow planet completely enshrouded by sulfuric acid clouds. Only with radar can we penetrate the thick, obscuring layers to discern surface features. Earth-based radars, the **Pioneer** ***Venus orbiter and*** **Veneras 15** ***and*** **16** ***all helped to reveal Venus' surface, but couldn't match the detail of*** **Magellan*'s observations. This global view was created from data gathered by* Magellan*. Areas missed were filled with coarser* Pioneer *data, and the colors were based on data returned by the* Venera 13 *and* 14 *landers.*** *Image: JPL/NASA*

FROM THE EDITOR

A WARNING FROM YOUR EDITOR
You may soon be getting a phone call from me. No, I won't be asking you for donations or nagging you about a missed deadline (a common fear among planetary scientists). Instead, I will be asking for your opinion about *The Planetary Report.* Each month our computer will randomly select several members whom I will call to discuss the contents of our latest issue—or any other topic related to our publications. I want to make sure that The Planetary Society is providing the magazine you want, so be prepared to let me know what you think of it. The next phone call you get may be from me.

Here's what we've gathered for you.

—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 have been a Planetary Society member for several years, and I eagerly await each issue of *The Planetary Report*. I strongly believe in the Society's goals and objectives, and I donate what I can, knowing that however small my contributions may seem they are one more step on the road to humankind's exploration and colonization of space. I also believe that as more people join The Planetary Society, it will become a stronger and more vibrant organization.

This belief prompted me to give a gift membership. The only problem I had was deciding whom to give this gift to. I wanted it to go to someone who would fully appreciate what the Society stands for. I decided to donate it to my local library. It's my hope that as people read the issue they might decide to become members themselves. The magazines will also serve as a terrific resource for anyone researching space or planetary science.

Thus, the real reason for this letter is to propose to all other members that they try to donate a gift membership also. It can be to a library, or a school, a college or a personal friend. Imagine the benefits to the Society as it gains access to new ideas as well as growing both financially and politically with each new member.
—DOUG BURDEN, *Lacombe, Alberta, Canada*

As my final semester in college begins, it is necessary to thank all of those who enabled me to pursue my education. Without the National Merit Scholarship from The Planetary Society, my dreams of a college education would have been unaffordable.

Again, thank you for your generous support over the past four years. Best wishes to your organization.
—JENNIFER L. AVEGNO, *Notre Dame, Indiana*

I am a charter member of The Planetary Society, and I have finally been moved to write this letter about a subject that has been bothering me almost since the beginning of my connection to the group. Why is there this fixation on a human trip to Mars? The Planetary Society should be concerned with the best way to do science in the entire solar system, not just on the Red Planet of Edgar Rice Burroughs' dreams.

I would like to see a forum in the magazine on this obsession with a human trip to Mars. Underlying this drive to colonize Mars is a theme expressed by Robert Zubrin and Christopher McKay in their article, "A World for the Winning: The Exploration and Terraforming of Mars," where they state, "Terrestrial life could go forth and multiply into realms of diversity unimagined." This theme also needs serious examination, yet it seems to be an article of faith at The Planetary Society.

The underlying belief that terrestrial life-forms somehow deserve to rule the universe—or at least colonize portions of it—needs to be discussed. The science fiction many of us grew up on was great fun, but it should hardly be the basis for what might be the most important policy decision in the history of the species.

That same scrutiny must be applied to a human mission to Mars, which seems to me to have been fueled primarily by Ray Bradbury, Burroughs and a host of other brilliant writers. But reality is different than stories where the hero always wins—and it would be tragic if we let our fantasies poison our future.

The duty of The Planetary Society extends beyond blind boosterism, and I think it is incumbent on the board and editorial staff to present a balanced view of the dangers and glories of exploration of the solar system. I hope that balance will be more evident in the future.
—CLAY KALLAM, *Antioch, California*

NEWS BRIEFS

This May the *Magellan* team will test the technique of aerobraking as the spacecraft orbits Venus, using money left over from getting the baseline mission done under budget. Aerobraking would use the friction from the planet's atmosphere to slow the spacecraft. The technique is of engineering interest as an economical alternative to burning propellant to get to lower orbits. It hasn't been done before because of the unknowns of alien atmospheres and fear of spacecraft damage.

The aerobraking will also start to circularize *Magellan*'s orbit. However, the orbit will only be partially circularized, because the meager leftover funds will limit the operation to five or six weeks.

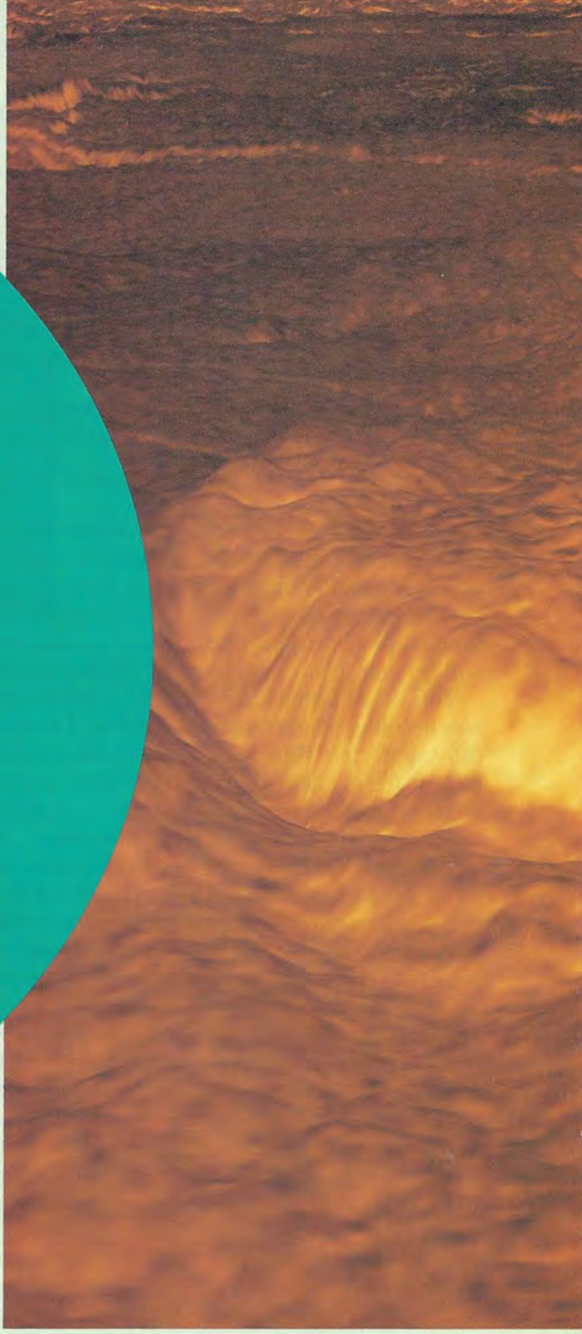
A circular orbit is desirable because it would improve resolution of gravity field measurements. These high-resolution measurements are important for understanding the processes that drive the planet's geology, and would complement radar maps of the surface.
—from Michael A. Dornheim in *Aviation Week & Space Technology*

In March, scientists at the Jet Propulsion Laboratory began a three-week quest for the subtle and elusive gravitational waves that stretch and shrink the fabric of space-time.

When Einstein formulated his general theory of relativity, he predicted that accelerating bodies should produce gravitational "waves" that travel at the speed of light, making objects in space bobble like corks on a pond. But no one has ever directly measured them until now.

The researchers used the *Mars Observer*, *Ulysses* and *Galileo* spacecraft to help conduct their search, as well as the antennas at the Deep Space Network sites in Goldstone, California; Australia; and Spain. The antennas sent radio signals to the three spacecraft, which in turn bounced the signals back to Earth. If the scientists are lucky, some relatively recent or nearby astronomical debacle created gravitational waves, buffeting both the spacecraft and Earth.

Analyzing the reams of data from the project will take about a year, according to JPL scientist John Armstrong.
—from Elizabeth Wilson in the Pasadena *Star-News*



Venus

After *Magellan*, She Still Has Her Mysteries

by R. Stephen Saunders

Magellan has now completed its mission to map Venus. With its radar, the spacecraft was able to penetrate the thick sulfuric acid clouds that enshroud the planet, and it revealed to us surface features as small as a football stadium. We have a global map of Venus that is actually more complete than any comparable view of Earth's surface.

Yet, despite the success of the *Magellan* mission and the many questions it answered about this planet, many new questions have appeared.

To find answers, we will have to continue to study this planet that has been called Earth's sister world. Venus is the closest planet to ours, and it is most like Earth in size, mass and distance from the Sun. But it is a vastly different world. It rotates only once every 243 Earth days, and in a direction opposite to that of most planets in our solar system. Its primarily carbon dioxide atmosphere, with those sulfuric acid clouds, is 90 times denser than Earth's nitrogen-based air laced with clouds of water vapor. The ultimate greenhouse effect has taken hold on Venus, trapping solar radiation and resulting in a surface temperature that hovers around 480 degrees Celsius (900 degrees Fahrenheit).

Clearly these two sister worlds appear to have followed different evolutionary paths, and by comparing Venus with Earth we should learn more about our own planet. One of the most important differences, for life-forms such as ourselves at least, is the relative abundance of water.

Did Water Ever Flow on Venus?

Before *Magellan* reached Venus, a few optimists had hoped that within its radar images we would find evidence of ancient shorelines or long-dry riverbeds—some sort of indicator that Venus may once have had enough liquid

The pancake domes on Venus are among the most distinctive geologic features discovered by Magellan. *Three of them are shown in this computer-generated view, which was created by combining radar images with altimetry data to produce a three-dimensional map. These volcanoes were found adjacent to the highland of Alpha Regio and may have formed when thick, viscous lava erupted from vents in level ground, allowing the lava to flow evenly in all directions. Their average diameter is 25 kilometers (15 miles), with maximum heights of 750 meters (about 2,500 feet).* Image: JPL/NASA

water to cause rain, flowing rivers or oceans. There was a precedent for such hopes: The *Mariner 9* images of Mars, taken in the early 1970s, had revealed channels almost certainly cut in the martian surface by flowing water.

But *Magellan*'s radar images have not shown us any such evidence. On the contrary, what we see argues that the presence of liquid water was not likely, at least within the past 500 million years, which seems to be the age of most of Venus' surface. From *Magellan*'s images, we've learned that the planet lacks small impact craters, indicating that small meteorites burn up in the dense atmosphere before they can reach the surface. If some of the older-looking terrains had many small craters, we could conclude that the atmospheric shield was down at an earlier time. This is not the case. So, since the dearth of small craters seems to extend as far back in time as the surface indicates, this tells us that over the past 500 million years the atmosphere has been about as dense as it is today. In such an atmosphere, liquid water cannot exist for long.

In fact, the fundamental issue in the evolution of Venus' atmosphere is the abundance of water over time. We estimate that the atmosphere and surface currently hold no more than one-thousandth of the amount of water present in Earth's atmosphere and oceans. Whether Venus once possessed more water is a hot topic for debate among planetary scientists.

One hypothesis holds that Venus formed as a relatively water-rich world, with an early ocean that it lost through a greenhouse effect gone wild. Solar heat would have been trapped in the thick carbon dioxide atmosphere, and the ocean would have evaporated, its water breaking down into its component atoms, hydrogen and oxygen. The lighter hydrogen would have then escaped into space.

The alternative hypothesis holds that Venus formed relatively dry, and that the little atmospheric water we do detect is in a steady state. That is, whatever water evaporates and is lost to space is replaced by water released by volcanic activity or delivered to the planet by infalling comets and asteroids. (For more details of this dispute, see the November/December 1988 *Planetary Report.*)

Magellan's radar has not settled this debate, and scientists are now following several avenues of further research. To make the necessary measurements, we will have to send probes into the atmosphere carrying gas chromatographs and mass spectrometers, which will be able to give us details of the atmospheric composition. Earth-based and Earth-orbital telescopes could also contribute to the answers, as could additional laboratory and theoretical work.

What Is Going On in Venus' Atmosphere?

While the low water abundance in Venus' atmosphere is the major unsolved problem in understanding its composition, we have to work out other aspects of atmospheric dynamics and thermal structure.

An intriguing observation is the super-rotation of Venus' cloud-level atmosphere. That is, the clouds rotate almost 60 times as fast as the planet's surface. Clues to the mechanisms of this phenomenon may be contained in the atmospheric composition and in the thermal structure of the atmosphere near the surface. From Earth-based radio and spacecraft observations, we've known the surface temperature for years, but we have only a few observations on how temperatures in the lower atmosphere change with height.

Our pursuit of the atmospheric dynamics issue might involve entry probes that could directly measure wind and temperature as they fall through the atmosphere. Long-lived balloons could travel with the winds and would be the best way to track their motions. Orbiters carrying cameras sensitive to ultraviolet and infrared, which could see through to different atmospheric layers, would be very helpful in analyzing cloud-layer circulation as well as circulation in the upper atmosphere.

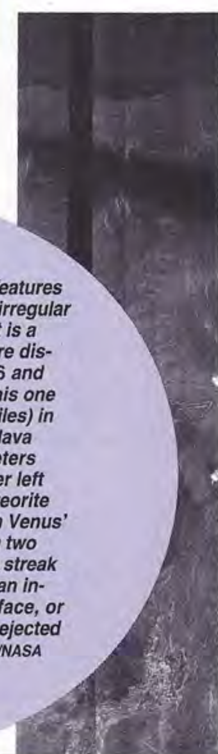
We know that sulfur plays a major role in Venus' atmosphere. The clouds that hide the surface from telescopes and cameras that see in visible light, but which *Magellan*'s radar can see through, are made primarily of sulfuric acid. Sulfur gases can help to weather surface features and may contribute to the greenhouse effect that keeps Venus so hot. To understand Venus, we need to know more about how these sulfur gases are distributed and concentrated, and what changes occur over time.

Spacecraft have measured variations in sulfur gas concentrations, and these may indicate that recent volcanic eruptions are releasing the gases into the atmosphere. Measurements of another atmospheric gas, methane, may also point in the direction of active volcanoes on Venus: The *Pioneer* Venus orbiter detected an amount of methane that can be explained by volcanic eruptions. These links between atmospheric composition and volcanism lead us to another major set of questions.

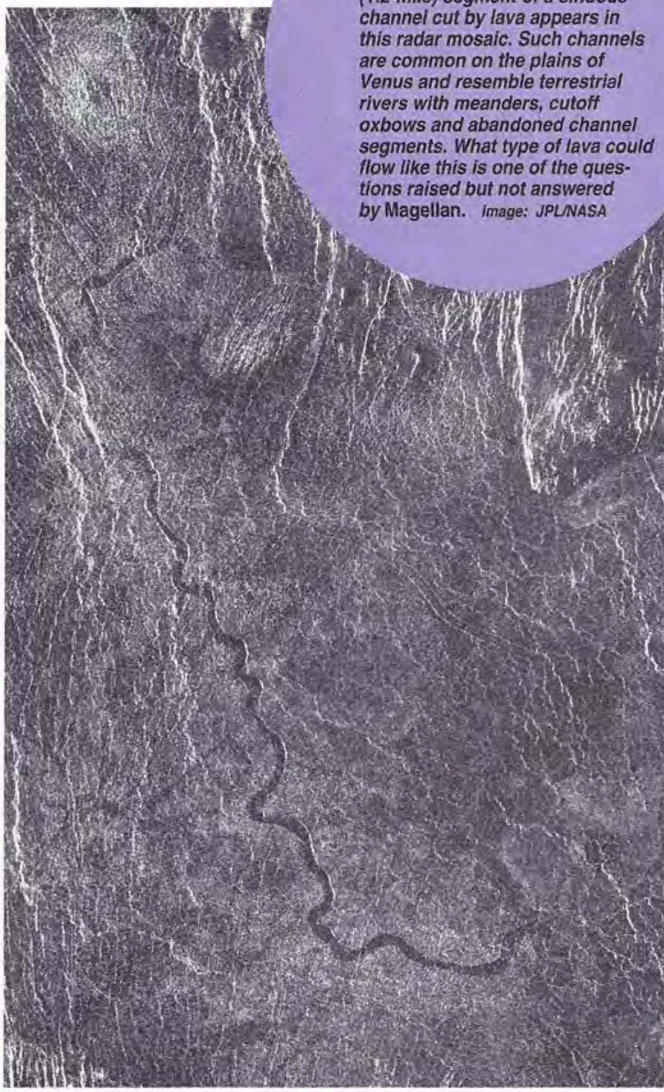
What Shapes Venus' Surface?

Volcanism is one of the dominant processes shaping the surface features on Venus. There are many volcanic puzzles, such as the nature of the venusian "pancakes" and domes. These enormous volcanoes, some of which are about 65 kilometers (40 miles) in diameter, seem to have

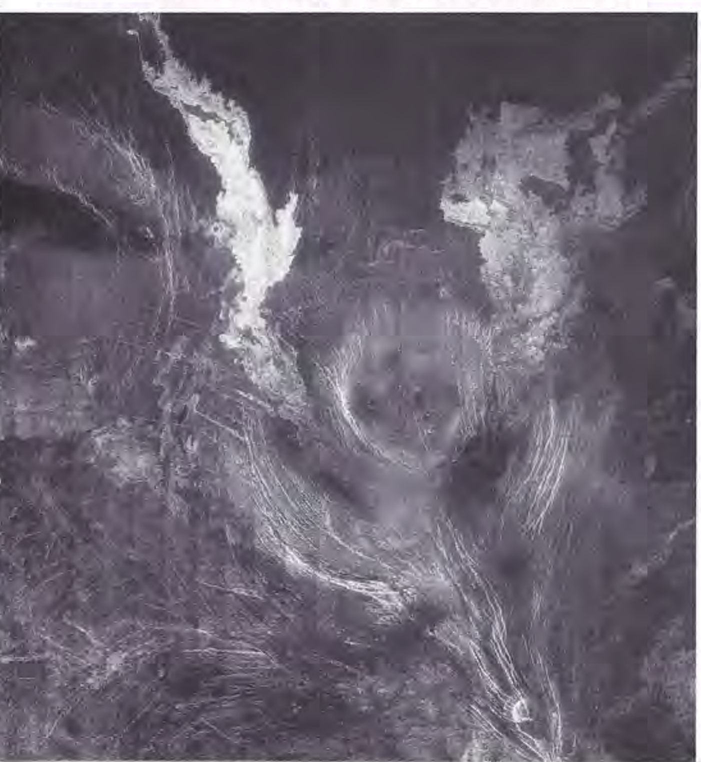
Scientists can learn something about Venus' low-level atmospheric circulation from images such as this, which shows what may be a dune field. The orientation of the dunes and the wind streaks indicates the direction of the prevailing winds. In the southern part of this region, the winds appear to blow from the southwest to the northeast, then shift to a westward flow in the northern part of the field. This mosaic of Magellan *images covers an area 340 kilometers (211 miles) long and 190 kilometers (118 miles) wide.* Image: JPL/NASA



Several distinctive venusian features are shown in this image. The irregular circular feature at center right is a corona, a type of ring structure discovered by Veneras *15 and 16 and seen in detail by* Magellan. *This one is about 100 kilometers (60 miles) in diameter. It is flanked by two lava flows several hundred kilometers long. The dark streak at upper left may have formed when a meteorite broke up as it passed through Venus' crushing atmosphere, leaving two small craters where it hit. The streak itself may have formed when an intense shock wave hit the surface, or as fine-grained material was ejected during the impact.* Image: JPL/NASA



It appears that lava on Venus sometimes flows the way water flows on Earth. A 200-kilometer-long (124-mile), 2-kilometer wide (1.2-mile) segment of a sinuous channel cut by lava appears in this radar mosaic. Such channels are common on the plains of Venus and resemble terrestrial rivers with meanders, cutoff oxbows and abandoned channel segments. What type of lava could flow like this is one of the questions raised but not answered by Magellan. *Image: JPL/NASA*



oozed up through ruptures in the crust. There are similar features on Earth, but on much smaller scales. What kind of lava made these giant features? What do they tell us about the evolution of Venus' crust?

Perhaps the most intriguing volcanic features are the sinuous channels. Most of them are about 1 1/2 kilometers (about 1 mile) wide and very shallow, perhaps 150 to 300 meters (500 to 1,000 feet) deep. The longest runs 6,800 kilometers (more than 4,200 miles), surpassing the Nile, the longest river on Earth. If we saw similar features on Earth or Mars, we'd probably assume that they were cut by flowing water. But on Venus, liquid water cannot exist. On Venus, the only viable alternative is liquid rock—some sort of very thin, very fluid lava.

Most lavas, even in temperatures around 480 degrees Celsius, would become sluggish and freeze after flowing several hundred kilometers at most. What molten material could possibly flow for thousands of kilometers? Possibilities include a form of carbonate—the material of limestone—or perhaps sulfur. There are difficulties in explaining how these materials could accumulate into flows, so the mystery remains.

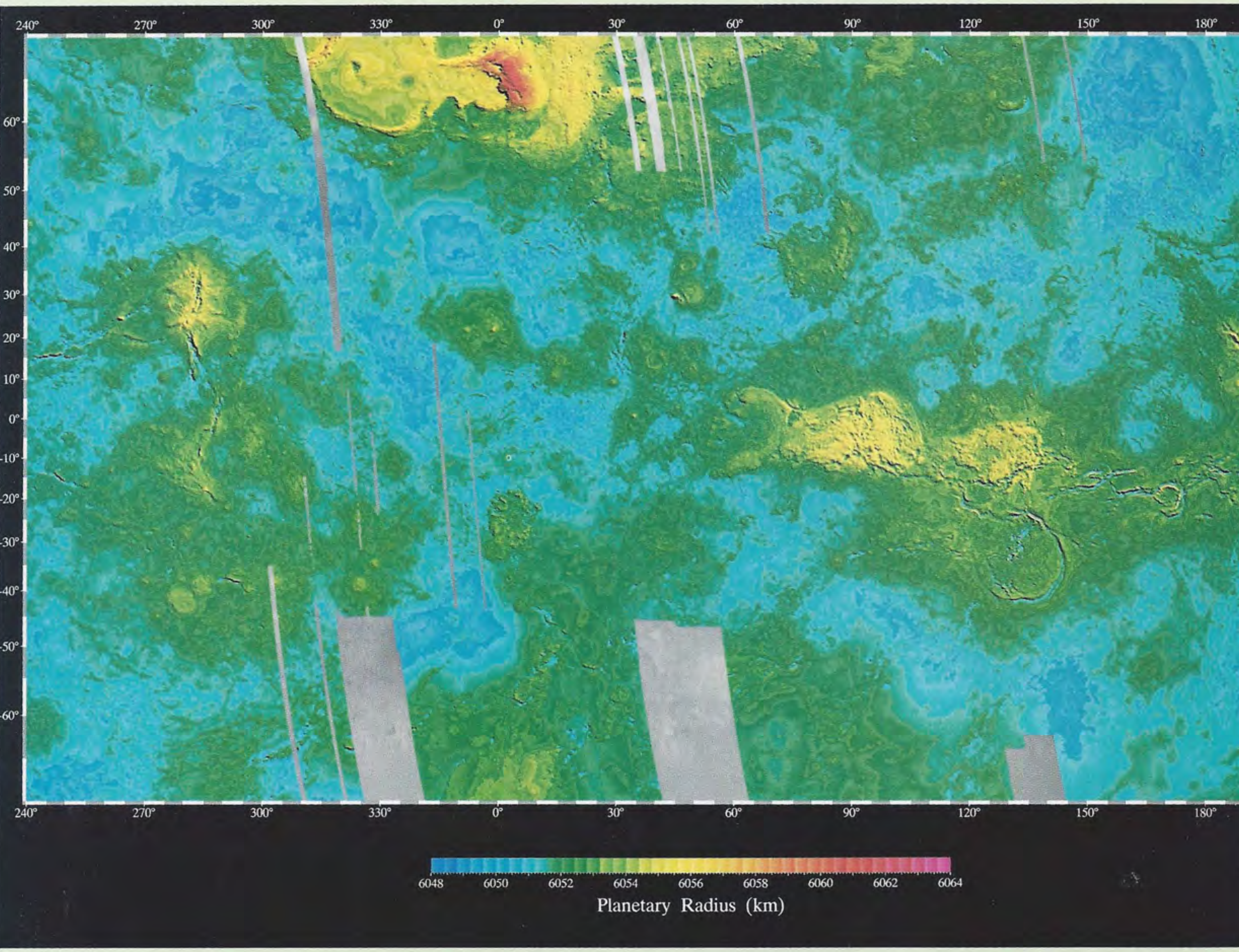
Magellan's images revealed a wide range of volcanic features, such as "ticks," large plains and "festooned" flows. Our continuing study of these features may tell us how the magma rises to the surface and erupts. They may reflect variations in surface composition, in how the rocks form and in their content of volatile substances, such as water. We believe we can work out the modes and rates of crustal formation from *Magellan* images—for example, the origin of the plains lavas and the sequence in which they were laid down.

However, we still have not answered key questions about the subsurface structures of the various volcanic edifices. We know that heat from the planet's interior provides the energy to melt rock within the mantle and crust to drive the volcanism, but we don't yet know how this process manifests itself.

Magellan has completed three mapping cycles, and by searching the images for volcanic features that might have changed between cycles, such as a lava flow whose size or shape is different, we may be able to finally say that there are active volcanoes on Venus. This would go a long way toward explaining some of the atmospheric mysteries, such as the abundances of sulfur gases and methane. It would also settle a long-running dispute about whether there is volcanically generated lightning on Venus. (See the November/December 1984 and July/August 1987 issues of *The Planetary Report.*)

While *Magellan*'s radar is an excellent tool for describing volcanic forms, landers would tell us much more about the composition of the surface and the forces that shape it. In situ measurements would also help establish the link between volcanism and the atmosphere.

Closely related to volcanism is the process called tectonics, evident in the faulting, fracturing and folding of surface rocks. On Earth, the dominant surface-shaping process is plate tectonics, so called because our planet's surface seems to be broken up into moving plates. On one edge of a plate, new crust erupts through rift zones, pushing the plate along until it



collides with another plate. Where plates collide, one is pushed up, forming mountains, while the other slides under and is subducted—pulled back down into the molten mantle beneath the crust.

Before *Magellan* began its mapping mission, hopes ran high that we would be able to determine Venus' tectonic style from the radar images. But so far, there is no definitive answer. The Soviet *Venera 15* and *16* orbiters discovered large features called coronae that are distinctive tectonic forms. We've seen no evidence of global spreading zones like those we see on Earth, where crust is created, but there are smaller features that display some rift-like features. Local tectonics, where subduction and rifting have "failed," may be a contender, but debate is continuing.

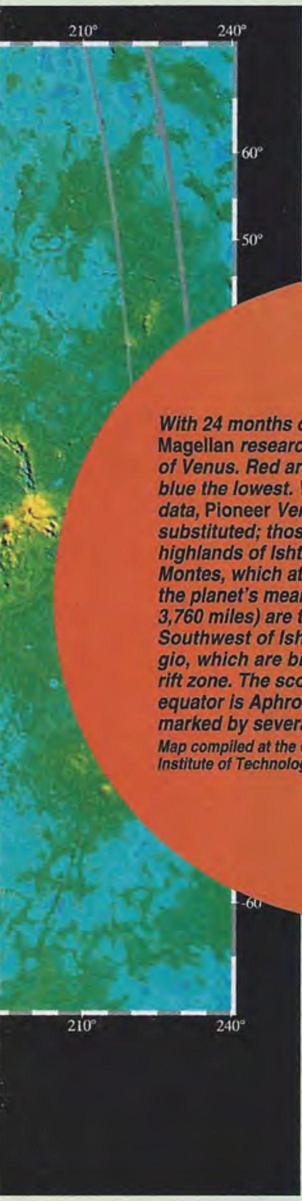
Key to understanding the forces that shape a planet's surface is its heat budget. On a dynamic planet such as Venus or Earth, heat is held in its interior, left over from its formation or generated by the decay of radioactive elements. This heat tends to flow outward and to escape through the crust—providing a driving force for volcanic eruptions, fractured features and folded rocks.

A planet's internal heat also determines the structure of its interior. At Venus, we have still to answer questions such as these: Is there a molten outer core? Is the mantle surrounding it layered? How does the magma affect the crust and account for changes in elevation and crustal thickness?

A planet's interior dynamics are linked to surface processes and atmospheric evolution. For example, the dynamics determine where and to what extent volcanoes will erupt, which surface areas will rise and which will sink, and what gases will be released from the molten interior rock into the atmosphere.

Tectonics on Earth have played a particularly important role in atmospheric evolution, for the subduction of crustal material carries carbon dioxide, much of it in the form of carbonate rocks, back into the planet's interior, thus removing it from the atmosphere. In other processes, however, such as volcanism, that infamous greenhouse gas is released from the rocks and goes back into the atmosphere. This recycling of carbon dioxide is one reason that the greenhouse effect on our planet is so mild. (See the January/February 1985 *Planetary Report.*)

There are many questions relating to tectonics on Venus that we are seeking to answer with *Magellan*'s radar data. But we have another technique to apply. *Magellan* is cur-



With 24 months of radar altimeter data to work with, Magellan *researchers created this topographic map of Venus. Red areas are the highest in elevation, blue the lowest. Where* Magellan *was unable to obtain data,* Pioneer *Venus and* Venera *15 and 16 data were substituted; those areas are gray. In the north lie the highlands of Ishtar Terra, dominated by Maxwell Montes, which at 11 kilometers (36,000 feet) above the planet's mean elevation (6,050 kilometers, or 3,760 miles) are the highest mountains on Venus. Southwest of Ishtar lie Beta Regio and Phoebe Regio, which are bisected by a north-to-south-running rift zone. The scorpion-shaped feature along the equator is Aphrodite Terra, a continent-like highland marked by several spectacular volcanoes.*

Map compiled at the Center for Space Research, Massachusetts Institute of Technology, and released by JPL/NASA

rently producing a global map of Venus' gravity to complement the radar map of surface features. The gravitational tug on the spacecraft increases over regions of high density, and decreases over regions of low density. This should tell us more about the structure of the planet's interior.

Can Craters Date a Planet's Surface?

One of the biggest debates to arise from the *Magellan* mapping concerns the age of Venus' surface. On other worlds we have used the density of impact craters on the surface to measure the relative age of that surface—in general, the longer the surface has been exposed to random bombardment from space, the more craters it will retain. On an airless world like the Moon, with a relatively inactive crust, we can see a lot of craters. On a world with a thicker atmosphere and a crust that is recycled, like Earth, we find fewer craters. From this we can deduce that the lunar surface is ancient compared to Earth's.

Venus has few craters and appears much more like Earth than like the Moon. This low crater count suggests that the average age of Venus' surface is about 500 million years. There are at least two ways to interpret this.

One is that Venus was inundated by floods of lava in a great global catastrophe 500 million years ago, and since then not much has happened, except for about 900 random impacts. We know something similar occurred on the Moon about 3 billion years ago, when the lunar maria, the dark basaltic features that look like seas, were formed in lava floods.

An alternative interpretation is that there is an equilibrium between fairly small volcanic events that flood and bury craters and the rate at which craters form. In this view, Venus' surface would look about the same at any time in its history.

Our increased knowledge of Venus' gravity and atmosphere, courtesy of *Magellan*, helps us understand the impact process and place better constraints on the surface age. We can link the abundance, location and preservation state of impact craters to the estimated flux of impacting bodies, and thus estimate the ages of different regions of the planet's surface.

One of the surprises of the *Magellan* data was the pristine appearance of most of Venus' craters. On Earth, those impact craters that haven't been destroyed by plate tectonics have been weathered by water, wind, volcanic eruptions and other processes, making them hard to recognize as impact features. On Venus, as we've seen, water is not a factor at the present. We have, however, seen craters partly buried by younger lava flows, torn apart by tectonic processes and weathered by the wind. Streaks of material blown back from a crater by the wind, as well as other eolian features, help us understand the circulation patterns of the lower atmosphere.

We have a lot of ways to study these processes. We have three data sets from *Magellan* that can be integrated to give us a more complete picture of the surface: the radar images, altimetric measurements of surface height, and gravity information. We can continue theoretical and experimental work on the physics of cratering processes, and we can model the way that radar is affected by the type of surface it reflects off. Plus, in the laboratory we can examine rocks and minerals under Venus-like conditions, which should help us understand their behavior on that planet.

Of course, sometime in the future we may develop the technology to build a spacecraft that could survive the hellish conditions of Venus' surface for a long time to make on-site measurements and, perhaps, to return samples to Earth.

In our future exploration of Venus, we must attack the question of how the lower atmosphere behaves and how the atmosphere helps shape the surface. But to make any real progress in understanding Venus as a terrestrial planet, to get deep into its interior structure, we must place instruments on its surface. On Earth, researchers measure the speed and strength of shock waves from earthquakes to deduce the nature of our planet's interior. Seismographic instruments on Venus may someday enable us to do the same for that world. We will continue to plan the exploration of Venus, for an understanding of how that planet works is crucial to our understanding of Earth.

R. Stephen Saunders is the project scientist for the Magellan *mission and has been pursuing the exploration of Venus for over 20 years.*

A Hopeful Gathering of

For several years now it has been evident that solar system exploration is in jeopardy. In both the United States and the former Soviet Union the glory days are past. The great argosies of the *Viking, Voyager, Venera, Vega* and *Phobos* spacecraft are history; the American comet and asteroid mission, the Comet Rendezvous Asteroid Flyby (CRAF), has been canceled; the international *Cassini* and *Mars '94/'96* missions are threatened; and no high-profile follow-on to them is in prospect.

This sad state has been long in coming, long foreseen but masked by the continued success of missions born decades ago, such as *Magellan* and *Galileo* (which, despite its antenna fault, is expected to return a good harvest of data from the jovian system beginning in 1995).

The causes of the problem are not hard to divine. As missions became more ambitious (the easier ones having been done) and budgets more constrained, demands increased for each new mission to carry out a broad variety of science investigations and to be highly insured against failure. The management and engineering systems responded by designing complex, technically conservative, costly and infrequent ventures, until finally each single flight could consume a scientist's whole career and opportunities for new participants and innovation became rare.

A New Focus

At length the solar system exploration community passed from worrying about the problem to trying to do something about it. A serious attempt a few years ago led to the Planetary Observer concept, a plan for using already-developed spacecraft in a series of modest missions, taking advantage of economies by repetitive use of proven designs. But the Observer "series" degenerated into just one mission—that spacecraft is now en route to Mars—and most of the intended cost savings did not occur.

Meanwhile, a similar disease beset NASA's astrophysics program. Of its four "great observatories" only two, Hubble and Compton, are flying. The other two, the Advanced X-ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF), languish in the limbo of downsizing and delay. But because astrophysics can be done from Earth orbit, it was possible to plan smaller missions, thus continuing the tradition of earlier ones named Explorers. The Infrared Astronomical Satellite (IRAS), the Cosmic Background Explorer (COBE) and the Extreme Ultraviolet Explorer (EUVE) have, despite development difficulties and growth beyond Explorer-class budgets, been great scientific successes, encouraging astrophysicists to seek faster and more economical missions in the future.

Can solar system exploration follow an analogous route? Clearly it will be more difficult, because most planetary ventures require leaving the vicinity of Earth. This adds to both launch and operations costs—not to mention the demand for increased reliability of long-lived spacecraft and the likely need in some missions for expensive and controversial onboard nuclear energy sources.

In spite of these handicaps, planetary scientists are rising to the challenge. The failure of the Planetary Observer program plan did not daunt those who visualize a fast-paced series of missions with focused scientific objectives. They came up with fresh ideas for a new class of missions called "Discovery," which would use streamlined management and new technology (with some consequent and accepted risks) to enable small spacecraft, launched on lower-cost rockets, to return limited science results of high quality. And when Dan Goldin took over NASA these people gained an energetic ally.

The latest step in the search for a solar system program that fits today's needs and constraints occurred in late November of 1992. In response to a NASA invitation, 246 scientific investigators, engineers and managers gathered at San Juan Capistrano, California, to review more than 70 concepts intended as Discovery candidates. Their willingness to participate, knowing that the chances of any one concept's acceptance are minuscule, showed their commitment to solving the problem. And the meeting displayed much innovative thinking. A summary of some highlights follows.

Ground Rules

NASA's present solar system exploration plan, the result of numerous planning exercises over the past several years, includes two Discovery-class missions. One is a small Mars lander called MESUR Pathfinder, intended as a step toward a MESUR (Mars Environmental Survey) mission; the other is an asteroid mission called NEAR (Near-Earth Asteroid Rendezvous).

The people gathered at the San Juan Capistrano Research Institute had been asked to come up with additional mission concepts scaled to a $150 million development cost and a three-year development schedule, with the object of producing a suite of follow-on candidates. According to Geoffrey Briggs, who chaired the evaluation panel, the results of this workshop would aid NASA in allocating advanced-programs resources (the funding used to prepare projects before they are proposed for execution) and would aid proposers in getting ready for NASA's next planetary Announcement of Opportunity, expected in about two years.

Though most of the participants had taken this plan into account in preparing their concepts, at the meeting itself the ground rules came up for lively discussion. At one point this was stimulated by a surprise visitor. Realizing how well the group's goals agreed with his own, NASA Administrator Dan Goldin added the San Juan Capistrano Institute to a crowded California itinerary, grabbed a quick lunch there and then stood up to tell everybody what he thought. He said this was exactly the kind of initiative he hoped to see, mentioned his strong belief in using new technology with some accepted risk and asked for questions. At once he was challenged to explain how a quick-paced program could get started if people had to wait two years even to propose the first new mission. Goldin did not dodge. He urged the scientists to question authority, to work with the responsible

Planetary Scientists

by James D. Burke

NASA managers and find a practical path toward starting sooner.

Some Ingenious Ideas

Clearly this article can't cover all of the mission concepts described at the November meeting. Also, I do not propose to comment on the review panels' evaluations. Instead, I hope to give readers a sense of the zest and ingenuity with which the presenters approached their task, evincing their commitment not to let the present dreary situation get them down.

Many of the presenters considered not only technical ways to get good science at lower cost, but also new managerial approaches. In NASA's present large projects, scientific investigators have the role of important and often competing passengers. For a Discovery-class project, with narrowly focused scientific objectives and only a single experimenter team, competition among scientists for the project's resources is reduced. Also, with greater acceptance of risk it can be practical for a principal investigator to take full charge of the project. Among other advantages, this provides more opportunity for university people, including students, to participate.

Naturally such proposals make some NASA people nervous because they place the project's system designers and its quality-and-reliability risk-controllers in a subordinate position. But a simplified management does offer the prospect of quicker decisions and lower costs.

Let's tour the solar system now, sketching some approaches that the gathered scientists thought might enable faster, cheaper, highly focused missions.

Mercury

The group's attention naturally focused on the surprising recent discovery of what appears to be ice at both poles of this hottest of planets.

Four different scientific teams presented concepts for small Mercury orbiters intended to investigate the planet and its surroundings, accepting the difficulty of reaching the planet and going into orbit around it. In contrast, Paul Spudis of the Lunar and Planetary Institute in Houston developed a concept just using repeated flybys. As shown during the mission of *Mariner 10* in 1974, it is possible to place a spacecraft in orbit around the Sun in such a way that it comes back again and again to Mercury. Spudis' mission concept takes advantage of this. It also minimizes the demand for launch energy from Earth by repeatedly obtaining gravity assists (see the Questions & Answers column in the January/February 1991 issue of *The Planetary Report*) from Venus and Earth en route to Mercury. Using these celestial-mechanics tricks, Spudis and his colleagues from the Jet Propulsion Laboratory and several universities believe it possible to fit a multi-instrument mission into the Discovery program's $150 million, three-year box.

A different approach to Mercury, and one perhaps more in keeping with the Discovery idea of narrowly focused science, was presented by Duane Muhleman of the California Institute of Technology, a discoverer of Mercury's polar ices, who described a way to investigate them from a highly eccentric mercurian orbit using radar.

Venus

Venus got a lot of attention at San Juan Capistrano. Earth's nearest-neighbor planet is the easiest to reach and hence offers good opportunities for exploration by spacecraft launched on relatively inexpensive rockets. But Venus also holds challenges: Its surface, completely shrouded by clouds, is hot enough to melt lead. Heavily insulated landing probes, launched by both Soviet and American rockets, have survived there for only minutes up to an hour or so—but scientists would like much longer survival times for geophysical experiments such as seismology.

Several teams avoided the heat problem by using only remote sensing from orbit, with instruments carried by small orbiters similar to *Pioneer 12*. However, some investigators accepted the thermal challenge. Charles Counselman of the Massachusetts Institute of Technology described a mission with many small probes, scattered in an array over the whole Earth-facing side of the planet, with high-temperature electronics whose radio signals would be analyzed to give data on atmospheric motions and the rotation of Venus.

In a very different approach to squeezing into the Discovery box, an international team led by James Head of Brown University described a mission in which the Americans would supply a payload, which would be integrated into a *Venera*-class spacecraft to be built and sent to Venus by Russians. Head's former student Ellen Stofan of JPL described another idea, one responding to Dan Goldin's call for the use of advanced technology with acceptance of more technical risk: Three seismic probes would be landed on Venus, with their longtime survival provided by active refrigeration! How can one expect to operate room-temperature electronics in the hellish conditions on Venus, where a refrigeration system must reject its waste heat at a temperature above 450 degrees Celsius (about 850 degrees Fahrenheit)? Well, with modern advances in tiny machinery it may indeed be possible. In the Stofan team's concept a little Stirling engine, a reciprocating machine invented a hundred years ago, would run continuously to pump heat away from the insulated instrument compartment in each small landed probe. Each engine would be powered by an almost incandescent radioactive heat source.

Earth and Moon

Investigation of Earth as a planet was not emphasized at the San Juan Capistrano meeting, but the presented concepts did include several solar system missions that can be conducted from near Earth. As Earth orbits it encounters, at tens to hundreds of kilometers per second, the interplanetary medium, a tenuous mix of gases and particles from the Sun, from comets and asteroids, and from interstellar space. Some meteor streams are identified with comets along whose paths tiny particles are dispersed. By collecting and examining dust particles in Earth's upper atmosphere, scientists have already gained some clues to solar-system phenomena elsewhere. Fred Hörz of NASA's Johnson Space Center described a dust-collection experiment to be carried on a space station, while W. Hayden Smith of Washington University and J. Derral Mulholland, formerly of the University of Texas, described collectors that could be carried on small satellites. Stopping a fast particle without destroying it has recently become possible through the invention of a new material called silica aerogel, a cobwebby substance that can be made in densities so low that it almost isn't there. In other techniques the particles are allowed to hit thin metal foils and the resulting plasma burst is observed.

The Discovery Advanced Study Review Group has announced its selection, from the concepts presented at the San Juan Capistrano workshop, of 11 that it believes are most promising. The chosen presenters will receive small amounts of NASA funding in 1993 to develop their ideas. The selections include a Mercury flyby and orbiter, two probes of Venus, a mission to Mars' upper atmosphere, two missions to comets, one mission to both an asteroid and a comet, one near-Earth asteroid sample return, an Earth-orbiting telescope to study Jupiter, and a solar wind sample return.

The review group also singled out three concepts presented at the workshop that it considers to be prime candidates for further study in 1994. In this group are a rendezvous with a main-belt asteroid, a comet nucleus penetrator, and a lander in the martian polar region. —JDB

Several teams attacked the problem of exploring the Moon, or its tenuous atmosphere, within Discovery program constraints. In some instances the investigators contemplated just scaling down existing concepts such as remote-sensing geochemical or geophysical orbiters. However, two teams described lunar surface payloads. Jeff Plescia of JPL assumed delivery by penetrators of the kind now being prepared for a lunar mission by the Institute of Space and Astronautical Science in Japan, while Peter Bender of the University of Colorado described a seismic-and-heat-flow mission with instruments landed by the controlled-impact technique attempted in the *Ranger* missions of 1962.

Mars and Phobos

Though Mars is harder to reach than Venus, some martian missions may be achievable within Discovery limits. Several small orbiter missions were described, including one, by Daniel Lyons of JPL, that would include repeated dipping into the planet's outer atmosphere for in situ measurements. David Paige of UCLA outlined a Mars polar lander mission to investigate the layered ice deposits found by the *Mariners* and *Vikings*. In addition to cameras, the small lander would carry a thermal probe designed to melt its way down into the ice. Tom Duxbury of JPL described a concept combining Russian and American strengths: A Russian *Phobos* spacecraft would visit Mars' little moon Phobos, and a miniaturized American spacecraft, riding piggyback, would return a sample of Phobos material to Earth.

Asteroids and Comets

Several concepts dealt with investigations of other small bodies. Eugene Shoemaker of the US Geological Survey described a mission designed to return several samples from a near-Earth asteroid, using a quick-in, quick-out punch. Michael Belton of the National Optical Astronomy Observatory outlined a mission that could visit several comets and asteroids using small spacecraft with advanced, miniature imaging cameras. Joseph Veverka of Cornell University presented a concept for visiting three different short-period comets over a period of 15 years, using repeated swing-bys of Earth to direct the spacecraft to each new target. Daniel Britt of the University of Arizona described an unconventional concept: A spacecraft would be launched into lunar orbit, where it would wait for a suitable comet to appear, at which time it would be directed to the comet. Marcia Neugebauer of JPL considered a comet mission derived from missile defense: In her concept, a "Star Wars"-type kinetic kill vehicle would be fired from a comet flyby craft, impacting the comet and causing formation of a plasma and dust cloud to be observed from the spacecraft and from Earth.

Outer Planets

Going to Jupiter and beyond might be considered outside the range of possibilities defined by the Discovery ground rules. Nevertheless, some scientists at San Juan Capistrano accepted the challenge and came up with concepts for continuing exploration in the outer solar system. Bruce Murray of Caltech presented a Pluto–Charon flyby mission using a small spacecraft designed to avoid the costly and controversial use of nuclear radioisotope power. With just solar power for cruise and a one-shot lithium battery for the encounter phase, Murray showed the possibility of returning the first images of the enigmatic Pluto–Charon system. To attain the high speed required to depart Earth on such a mission, Murray assumed the use of a Russian *Proton* rocket with added upper stages.

Shared Programs

Murray's and Duxbury's concepts, as well as a few others presented at the conference, took advantage of the possibility of US–Russian collaboration to bring missions within the compass of the Discovery program. Jacques Blamont of the Centre National d'Études Spatiales, the French national space agency, went further, suggesting that a much fuller integration of international efforts is possible now that the Cold War is over and the rationale for large US-versus-Soviet competitive efforts has vanished.

In sum, the San Juan Capistrano meeting was a happy, invigorating sign of lively interest and unselfish collaboration in a large community of planetary scientists who are determined to work their way through present adversity and open up an exciting future for us all.

James D. Burke, Technical Editor of The Planetary Report, *is a retired JPL engineer and a longtime enthusiast for small missions using microspacecraft.*

Bringing People Together Through Planetary Science

Workshop participants hiked to the caldera of Poas, an active volcano, following the Costa Rican portion of the space science program. The trip gave them the chance to apply the concepts of comparative planetology they had just heard described.
Photo: Adriana Ocampo

by Adriana C. Ocampo and Rosaly Lopes-Gautier

The Space Age was born in a technological struggle between two superpowers who saw space as an arena in which to compete for the leadership of the nations of Earth. In the first few decades of that new age, science flourished, but it was largely the product of the citizens of the United States, the Soviet Union and their closest allies. Access to the results of planetary exploration and space science was possible only in technologically advanced nations.

But the world of 1957 no longer exists, and in the next few decades more and more nations will come of age technologically and economically. Many developing nations are already claiming roles in the exploration of space.

The Planetary Society, as a worldwide organization, has sought ways to bring planetary science to the citizens of developing nations. Our first full-scale effort was the enormously successful 1987 workshop in Mexico City. (See the May/June 1988 issue of *The Planetary Report*.) In 1992, the Society reaffirmed its commitment to the process by cosponsoring the Second United Nations/European Space Agency Workshop on Basic Space Science for Developing Countries, a two-week affair held in Costa Rica and Colombia during November.

The governments of Costa Rica and Colombia had invited the Society to organize educational workshops in their countries for the purpose of informing scientists there about the latest advances in planetary and space science, and they hoped to duplicate the success of the Mexico City workshop. The serendipitous confluence of the Society's efforts and a new program sponsored by the United Nations and the European Space Agency helped bring the idea to fruition. The UN–ESA program called for an annual space science workshop for the benefit of developing countries; the first one had been held in Bangalore, India. The merger of our planetary program with their broader focus on astronomy and astrophysics worked beautifully in the Costa Rica–Colombia endeavor.

Sharing the Excitement of Science

Leading scientists from around the world traveled to San José, Costa Rica, and Bogotá, Colombia, to share their discoveries and expertise with researchers whose countries are just beginning to set their sights on space. The 122 participants represented 19 nations: Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, Czechoslovakia, Germany, Guatemala, Honduras, Mexico, Peru, Sweden, Trinidad and Tobago, the United Kingdom, the United States and Venezuela.

It was an amazing gathering. The workshop was conducted in an informal atmosphere, and participants were encouraged to mingle at meals and social events. One could overhear animated hallway conversations covering topics as diverse as planetary magnetospheres, the origin of life and gamma-ray astrophysics. A sense of camaraderie grew among people of very different backgrounds.

We were also able to raise a feeling of excitement among the public in both cities. Workshop presenters gave public lectures, and simultaneous translation was provided to make the lectures accessible to a large local audience. Arcadio Poveda of Mexico spoke on how stars are made, Mario Acuna of the US discussed the exploration of Mars, Guillermo Lemarchand of Argentina and the US considered the search for other civilizations, Tobias Owen of the US covered the origin of life and Adriana Ocampo of the US described the *Mars Observer* mission.

Diverse Discussions

The scientific program was tailored to the wishes of the host institutions, which were the University of Costa Rica, the

Costa Rican Ministry for Science and Technology, the University of the Andes (Colombia), the International Center for Physics in Colombia (CIF), and Colciencias (the Colombian equivalent of the US National Science Foundation). The governments of both countries closely cooperated in organizing the workshop.

During the first week of the workshop, held in San José, registered participants covered a broad spectrum of planetary science. They heard lectures on such topics as the formation of the solar system, planetary magnetospheres, asteroids, comets, surface processes on terrestrial planets, solar physics, formation of the giant planets, and planetary atmospheres. A special session to discuss international planetary science activities proved particularly lively.

The week was capped off with a field trip to Poas, an active volcano. Volcanologist Eduardo Malavassi, from the Costa Rican Volcanology Observatory, led the participants on a hike part of the way down into the caldera, an area normally off limits to all but research volcanologists. This trip gave them the chance to apply the concepts of comparative planetology they had heard described by workshop speakers Ronald Greeley and Rosaly Lopes-Gautier.

In Bogotá, the second week of the workshop concentrated on astrophysics and radio astronomy, covering such topics as the detection of neutrinos, gamma-ray astrophysics and the structure of the universe. The radio mapping of the galaxy attracted special interest, since it is the objective of a joint project of Colombia, the University of California at Berkeley and the Brazilian Space Agency.

Looking to the future, participants discussed ways they could cooperate on planetary science projects. They outlined their national capabilities in space science and suggested steps they could take to improve their programs. Some urged major space agencies to encourage developing countries to participate in future missions, and others proposed exchanging researchers. Still others pointed to the simple need to make scientific journals widely available in libraries. Their recommendations were presented to the UN General Assembly on January 20, 1993.

Some of the presentations prepared for this workshop will find a larger audience when they are published in the journal *Earth, Moon, and Planets.*

The success of this workshop was based on many factors, not the least of which was the active participation of students, who were encouraged to contribute to the program. Many students in Latin America clearly have a great desire to pursue careers in planetary science.

Playing a Continuing Role

During the workshop discussions, it became evident that nonprofit international organizations such as The Planetary Society are essential in keeping the general public interested in and informed about advances in scientific fields.

The Society plans to continue its involvement in this successful program. The next workshop will be held in Africa, probably in November of 1993. Colleagues in Nigeria and Egypt have expressed interest in having their countries act as hosts. Either China or Sri Lanka will be the site of the 1994 workshop, and in 1995 it will return to Latin America, probably to Argentina.

The most important message to come out of the workshop is that through programs like this we can all share the dream of space exploration, regardless of race, culture, politics or economic standing. Space is a common link that can unite us all.

Adriana Ocampo is a special consultant to The Planetary Society and is presently conducting research on the K/T Yucatán impact crater. She is a science coordinator for the Galileo *mission and the* Mars Observer *mission. Rosaly Lopes-Gautier, a specialist in planetary volcanology, is a science coordinator for the Near-Infrared Mapping Spectrometer on* Galileo. *The authors would particularly like to acknowledge the invaluable efforts of Walter Fernandez, of the University of Costa Rica, and Sergio Torres, of the University of the Andes in Colombia, in organizing the workshop.*

Mexico City Workshop Still Inspiring Students

The Planetary Society's 1987 workshop in Mexico City inspired one of its participants, architect and teacher Socorro Velasco, to find an imaginative way to bring the wonders of space to the children of San Cristobal de las Casas, Chiapas, Mexico. Here she shares her success with Society members.

Early every Sunday a constellation of bike riders known as Amigos del Sol wends its way through the streets of San Cristobal and out into the countryside. Its mission combines the study of the universe with the very down-to-Earth goal of litter cleanup.

Its stars are young, ranging in age from 6 to 16. But their fascination with the realm of space leaves little doubt that they are future members of The Planetary Society.

I founded Amigos del Sol three years ago as a means of expanding the horizons of children caught between practical scholastics and nighttime video. They never looked down or around. And they never looked up.

The club has grown now from 10 children to upwards of 250. Their accomplishments have won the cooperation of the city, which provides a police escort and a disposal truck at the pick-up site. This is no small triumph in an area hard-pressed for services.

When the day star goes down and the night stars appear, Amigos del Sol shifts its focus to the solar system. The children pass the club's two pairs of binoculars from hand to hand to observe the wonders of the universe.

They love space. They love to plant trees, but they'd rather go to Mars.

Amigos del Sol is a club without entry fees, without dues. It is open to any child of any religious, social or economic group, from city residents to the Maya people who live in the surrounding mountains.

The only requirement is a willingness to help preserve and enhance the beauty of the Chiapas highlands, to understand the beneficence of the Sun, whose energy and light give life to our Earth, and to appreciate the unimaginable opportunities that lie ahead in space.

These children invite you to San Cristobal de las Casas. The club can provide you with a bike—but, please, bring your own binoculars. Better yet, bring a telescope! —*Socorro Velasco*

"Together to Mars" Contest Reaches Its Goal

Another of the Society's education efforts, the "Together to Mars" International Student Contest sponsored by the H. Dudley Wright Foundation, reached its climax in August 1992 when 20 students met in Washington, DC, to participate in the World Space Congress. The following report, written by one of the contest winners, Caitlin Arden of the United Kingdom, eloquently describes the ultimate achievement of the contest.

The "Together to Mars" competition has affected the lives of nearly 1,000 students, all of whom put a tremendous amount of effort into their entries, and all of whom gained immeasurably from their work.

The competition has served to inspire these students and to provide many with a glimpse of the kind of life and career they may soon be able to enjoy. If its purpose was to boost enthusiasm for science and learning, then it has certainly succeeded in its aim.

I spent several months reading around my chosen discipline, space psychology and medicine, and obtaining a broad understanding of a subject that would never be touched on at my school.

Because the contest required work more advanced than that required at most schools, it provided a very useful stimulus for students interested in space science. It also gave us the opportunity to discuss topics with distinguished scientists and to use facilities that would not normally be available to us.

The competition perhaps proved most inspiring to the fortunate 20 who were able to visit Washington, DC. At the World Space Congress, we were able to mingle with scientists and astronauts alike, and to experience the esprit de corps of the event. We were able, on more than one occasion, to participate in discussions on an equal basis with scientists of international repute, and we were able to attend seminars delivered on forefront research.

Writing this report some months after my visit to Washington, I can cite two notable effects.

The first is that I made a great many friends from all over the globe while in Washington, and I have been keeping a running correspondence with a number of them. I have received invitations to visit from several fellow students, and so I hope that the Washington event is just the start of some long and fruitful friendships.

The second is that I have experienced increasing self-confidence and motivation, which has had a noticeable effect on my work. I will be entering a good university this coming September, and I look forward to being able to commence space research in a few years' time.

I sincerely hope that there will be many more competitions like "Together to Mars." They are well worth the investment, and I believe that they greatly benefit all who take part, not just those who have won. —*Caitlin Arden*

Planetary Society Joins Education Reform Effort

The Planetary Society has moved in a new direction by becoming a partner in a program to reform science education in the United States. Our effort kicked off with a December 1992 workshop at our headquarters in Pasadena. Thirty-three educators and scientists, including Society President Carl Sagan, joined representatives of NASA and the National Science Teachers Association (NSTA) to begin the development of materials to be used in integrating planetary science into high-school curricula.

Bill Aldridge, executive director of the NSTA, is leading the reform movement, known as Scope, Sequence and Coordination (SS&C). One of the objectives of the program is to get away from an authoritarian presentation of science. Rather than just telling students, "This is the way it is," Aldridge says, teachers should encourage students to ask, "How do we know?"

Workshop participants brainstormed about planetary science topics, such as climate change and the greenhouse effect, and how these topics could be integrated into a larger program of science teaching. This led to our drafting a list of basic concepts that all US high-school graduates should understand—such as the ideas that scientific laws are universal and that all the planets in our solar system move about the Sun—and scientific observations they should have made by that time—for example, tracking changes in sunset and sunrise positions on the horizon as the seasons change. Specific topics will be developed in more detail.

A report on our workshop will be available in June 1993. For a copy, or for further information, contact the Society Education Office at (818) 793-5100.

—*William K. Hartmann, senior scientist, Planetary Science Institute, and Gayle G. Hartmann, editor,* The Kiva, *and Planetary Society consultant.*

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Conversing With the Planets: How Science and Myth Invented the Cosmos

By Anthony Aveni; Times Books, New York, 1992, 255 pages.
Retail price: $21.00
Member price: $18.50

Before electric lights obscured the night sky, most people lived in awe of the lights moving through its blackness. Tracing the changing positions of the constellations, the phases of the Moon and the paths of the planets, early astronomers predicted celestial events, from lunar eclipses to the transit of Venus across the face of the Sun.

In *Conversing With the Planets*, Anthony Aveni, who has worked at Kitt Peak National Observatory in Arizona and taught astronomy at Colgate University, recounts the history of human observation of the planets.

Aveni explains that he "became interested in the possibility that each of the 200 generations of astronomers who lived before [him] might have looked at the same stars . . . and seen a different light." This led him to study anthropology, especially how civilizations remote from one another, like those of the Maya, Aztecs, Chinese and ancient Greeks, made sense out of the night sky.

Each planet played a special role, but none as interesting as Venus, the brightest planet in the sky. With its dual role of morning and evening star, and its 584-day cycle of returning to the same spot in the sky, Venus was an object of worship by many civilizations. Aveni attributes this to its apparent death, as it sinks below the horizon, and subsequent rebirth, which accounts for the association of Venus with resurrection, rebirth and fertility.

Predicting the return of Venus enhanced the prestige of early astronomers. For example: "The date is June 26, 884, shortly before noon, and the dark new moon has just bitten into the disk of the sun—the start of a total eclipse in Yucatán. . . . As the thin, bright solar crescent gives way to the diamond-ring flash of the last gleam of sunlight—there, appearing just off the western edge of the sun, is bright Venus. . . . The planet actually had vanished from the nighttime sky only a few days before, and it was not scheduled to reappear for at least another month. . . . But today the people were offered a rare glimpse of their descending deity while he lay in hiding." This rare phenomenon was recorded in a Mayan codex. Aveni suggests that the ability to predict such events made Mayan astronomers the social equivalents of contemporary heart transplant surgeons.

Using pictures of Babylonian, Greek, Chinese and Mesoamerican calendars, Aveni shows how each of these astronomically sophisticated civilizations interpreted the heavens in the light of their own particular world views.

As astronomers they marked the stellar positions and as astrologers interpreted their impact on the lives of mortals. The partnership between the two approaches, Aveni says, began to falter with the ancient Greeks. The Greeks, unlike astronomers and astrologers in other prescientific civilizations, charted horoscopes—the life predictions for individuals—as well as the future of the state. Aveni says that this sowed the early seeds for the rise of humanism.

Later, Galileo shattered the astronomer–astrologer partnership altogether when he looked through his telescope and saw that Venus passed through phases, just like Earth's Moon, and followed laws of physics rather than directives from invisible gods.

Although Aveni writes with sympathy about ways earlier civilizations regarded heavenly bodies, at times he falls into trendy New Age thinking, which, for me, detracted from the otherwise important contributions of his writings about the role of astrology in the development of astronomy.

Unlike Aveni, I prefer to look toward a planet like Mars as a destination for explorers rather than as a mythic god of battle. Nonetheless, this is a highly enjoyable and provocative book.
—Reviewed by Bettyann Kevles

Still Available:

From Stone to Star: A View of Modern Geology, *by Claude Allègre. Clues to the origin of Earth are found in rocks from space in this adventure tale of modern science.*
(Reviewed November/December 1992.)
Retail price: $39.95
Member price: $32.00

Angle of Attack: Harrison Storms and the Race to the Moon,
by Mike Gray. Relive the tragedy and triumph of the Apollo *program, in a tensely written tale focusing on one of the unsung heroes of the space program.*
(Reviewed January/February 1993.)
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WORLD  WATCH

BY LOUIS D. FRIEDMAN

PASADENA/SAN FRANCISCO— In late January and early February, the Russian Mars Rover again visited the United States. This time its destination was not the rugged hills and dunes of Death Valley, but the high-tech facilities of American industrial and space centers.

This trip was hosted by the McDonnell Douglas Corporation, which has begun exploratory talks with Russian space organizations about a joint rover development program that would involve NASA, the US aerospace industry and academia.

This link was an outgrowth of The Planetary Society's 1992 rover test program. We provided opportunities for Americans and Russians to meet and discuss common interests in planetary exploration.

International partnerships and joint ventures are becoming more common—taking advantage of Russian space capabilities and helping American industry find lower-cost ways to develop space hardware. Lockheed's recent agreement to license and develop the Russian *Proton* launch vehicle for international use is another—and very different—example of US–Russian cooperation.

To further promote discussions between groups working on planetary rovers, the Society coordinated a series of visits for the McDonnell Douglas–sponsored group to the Jet Propulsion Laboratory (JPL) in Pasadena and the NASA Ames Research Center outside of San Francisco.

At JPL the Russian rover went through its paces before a large crowd of lab employees and members of the press. Joining it was JPL's Rocky 4, a microrover being developed for use in the MESUR (Mars Environmental Survey) Pathfinder mission set for 1996.

The impressive display suggested technical possibilities for the approximately 90-kilogram (200-pound) Russian rover and the 7-kilogram (15-pound) Rocky to work together on the surface of Mars.

Following the demonstrations, the two rover teams spent an afternoon discussing design philosophy for mechanical and electronic systems, as well as areas of common development.

The Planetary Society has urged Russian and American officials to consider placing Rocky on the Russian *Mars '96* mission as part of the rover package. With a rover–microrover combination, the mission would gain a mobile hand for the big rover and additional sampling and imaging capability, making possible additional scientific measurements of the surface.

This could provide the basis for more extensive US–Russian interactions, leading to more ambitious Mars missions in the years to come.

The Russian team's visit to Ames was even more spectacularly successful. The rover was set up in a test area strewn with sand, gravel and boulders. This time it was controlled not only by the Russian teleoperation software, but by state-of-the-art virtual reality and telepresence software developed at Ames.

In less than one day, the two software teams connected their programs, wrote interfaces and integrated their operations. Ames scientist Butler Hine created a virtual environment in which a software rover operated. As he commanded the virtual rover to move through its environment, the commands traveled out to an Ames computer at the test site, to the Russian command computer, and finally to the real rover.

This impressive display of both navigation possibilities for the rover and the advantages of working together may lead to pooling the capabilities of these two leading groups in telerobotic research.

The McDonnell Douglas group and the people at Ames and JPL, with the help of The Planetary Society, are investigating ways to go from these demonstrations to a long-range, continuing research and development program leading to robot operations on Mars.

Planetary Society members can take a great deal of parental pride in our rover project, not only for the success of our test program, but for spawning international teams that may someday explore Mars together.

PASADENA/MOSCOW—Following the snafu we reported in our March/April issue ("Not Yet to Mars Together"), NASA, the Jet Propulsion Laboratory and Russian space officials produced a silk purse from a sow's ear. They overcame the failure to add a small US lander to the Russian *Mars '94* mission and reached an agreement to accommodate an innovative Mars Oxidant (MOX) experiment on the two Russian landers. The experiment would determine the nature of suspected oxidizing agents in the soil.

NASA will also gain an engineering model of the landers, which the Russians refer to as "small stations." In return, the US will contribute about $1 million to the *Mars '94* mission.

Finnish, French and German scientists helped make it possible to accommodate the US experiment on the small stations. Wesley Huntress and John Schumacher of NASA Headquarters, Frank Schutz of JPL, Viacheslav Linkin of the Space Research Institute, and, we are proud to say, The Planetary Society were all instrumental in finalizing the agreement.

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

News & Reviews

by Clark R. Chapman

Almost a quarter of a century ago, scientists met in Houston to consider Moon rocks. During that first Lunar Science Conference, astronauts were poised for further lunar exploration. Then the *Apollo* flights were abruptly called off, and NASA began its decline.

Annual conferences at the Johnson Space Center (JSC) continued, organized by Pam Jones and her capable staff at the Lunar and Planetary Institute, then housed in the "Diamond Jim" West mansion near JSC. The conference's purview has expanded to cover the whole solar system, and astronomers and geologists now mingle with the original cosmochemists and physicists.

Times are changing for the renamed Lunar and Planetary Science Conference. The Lunar and Planetary Institute now occupies modern offices—efficient and functional, but lacking the charm of the old digs. Pam Jones herself will leave, for Washington (and marriage), this summer. And a perennial Cold War–era attendee was absent from the 24th conference this past March: Russian Academician Valery Barsukov, who died in July of 1992. Some old-timers fondly recalled one of his birthday dinners at the Crazy Cajun, when the Muscovite made music.

Why Venus Died

With upwards of a million million bits of information in hand, *Magellan* scientists at this year's conference grappled with the profound mysteries of our sister world. Something changed on Venus nearly 500 million years ago. Most subsequent craters remain nearly pristine, rather than being eroded, buried or wrenched apart, as would happen on Earth and apparently happened also on Venus prior to the change. In Houston, some scientists proposed that Venus, which lacks the efficient plate tectonics and volcanism that liberate Earth's internal heat, episodically overturns its crustal layers. Venus' current quiescence (despite local continuing volcanism) would be just an interlude before the planet again turns itself inside out.

Sean Solomon, new director at the Carnegie Institution's Department of Terrestrial Magnetism (succeeding George Wetherill) and husband-to-be of Pam Jones, dissents. At the conference, he proposed that Venus' surface was continually contorted and wrenched until 500 million years ago, when its thinner crustal regions cooled and stabilized. The last gasps of venusian volcanism flooded the lowlands, while the rare, geologically complex, but increasingly less active highlands ("tesserae") record a tableau of what once was ubiquitous on Venus. Years from now, once all data are interpreted, a consensus may emerge about how Venus came to look the way it does, and whether Venus is an exceptional planet for lacking plate tectonics or if, instead, our own planet is the anomaly.

Are Jupiters Rare?

George Wetherill thinks our planetary system may be anomalous. In *Nature* (February 18, 1993), J. Laskar and colleagues proposed that Earth may have its comparatively stable climate, which nurtured the evolution of life, because we have the Moon. Otherwise, the Parisians' calculations show, the polar axis might wander chaotically. They speculate that the resulting seasonal havoc would have made it unlikely for us ever to have evolved to notice that we lacked a Moon.

At the conference, Wetherill outlined his frustrations in trying to understand how giant Jupiter and Saturn could be the natural, inevitable result of the formation of the Sun. He suggested, akin to Laskar, that the solar system is an anomaly: Without the gas giant planets, we wouldn't be here. Wetherill calculates that Jupiter and Saturn impeded the growth of comets early in solar system history. (It takes smaller planets, like Uranus and Neptune, to propel comets in their vicinity out to populate the Oort cloud and Kuiper belt of comets.) Furthermore, the huge gravity of Jupiter has protected us from many of the intruding comets that did form.

In short, lacking Jupiter, Earth would be pummeled by 10-megaton cometary explosions like the 1908 Tunguska, Siberia, blast every month or so instead of every few centuries. And Earth would be scorched by a Cretaceous/Tertiary holocaust every few 10,000 years instead of once in 100 million years, leaving inadequate time for evolution to proceed to intelligent beings before the next impact.

Jupiter exists not because our solar system is typical, but because we wouldn't be here to observe it if it wasn't —just as the French scientists speculate that we would be absent if Earth lacked its Moon. What other attributes of our solar system, indeed of the Milky Way galaxy, are explicable because intelligent observers couldn't evolve and survive to witness them if they weren't exactly that way?

What a difference from the concept that Earth is a middling planet around a random star! Planetary scientists pondered such lofty questions, as well as the politics of NASA, as they drank green beer at the chili cook-off in Houston on St. Patrick's Day.

Clark R. Chapman's life is evolving, as well: He recently married Lynda McGoon in a small ceremony near Sedona, Arizona.

SOCIETY *Notes*

MAKING SPACE FOR INTERNATIONAL SCIENTISTS

The Division for Planetary Sciences (DPS) of the American Astronomical Society will hold its annual conference in Boulder, Colorado, on October 18-22, 1993.

Scientists from around the world will attend the DPS conference, including participants from the former Soviet bloc and other nations whose currency cannot easily be converted to US dollars.

DPS organizers are looking for Planetary Society members in the Boulder area who can host visiting scientists whose funding constraints prohibit their staying in hotels. The host will need to pick up a participating scientist at the Denver airport and provide him or her with accommodations and a few meals during the conference. Most participants will arrive on Sunday, October 17.

DPS also needs people who can assist with shuttling these scientists to and from the conference each day. Volunteer drivers do not necessarily have to be hosts as well.

DPS sessions are conducted in English, so these visitors will have some command of that language.

If you are interested in opening your home to one of these international guests, please contact Reta Beebe of New Mexico State University at P.O. Box 3458, Las Cruces, NM 88003; telephone (505) 646-1938. *—Susan Lendroth, Manager of Events and Communications*

OFFERING HELP TO AMIGOS DEL SOL

In the Chiapas highlands of Mexico, a group of children are working to keep their environment clean and to learn more about their solar system. For the past three years, Amigos del Sol, a multicultural collection of children aged 6 to 16, have been bicycling through the streets of San Cristobal de las Casas in Mexico, planting trees in the surrounding countryside and learning about the universe (see page 14 of this issue).

The group is open to all children and charges no entry fees. Students are not even required to own bicycles. The Amigos do not have a large budget to purchase or maintain the materials the children need—the bicycles they use to travel to their observation sites or the binoculars they use to gaze at the stars. If you can donate your old binoculars, telescopes, bicycles, astronomical publications (such as posters or books in Spanish) or other materials, please contact Socorro Velasco, Amigos del Sol, Ap. Postal 1, Santiago de las Casas, Chiapas, Mexico; telephone (525) 598-2172; fax (525) 598-2993. *—Charlene M. Anderson, Director of Publications*

KEEPING UP WITH SPACE EVENTS

The Planetary Society organizes, sponsors and cosponsors numerous events every year, and the Society is committed to keeping its members informed of upcoming planetary and space happenings. You can get an updated listing of these events simply by writing to Carlos J. Populus at Society headquarters.

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

• In Richmond, Virginia, at the Science Museum of Virginia, the "Decade of Discovery" continues through June 6. This planetarium show reviews the milestones of the past 10 years in astronomy and space exploration. For more information, contact the Science Museum of Virginia, 2500 Broad Street, Richmond VA 23220; telephone (804) 367-1013.

• Astronaut Sally Ride, *Magellan* project scientist Stephen Saunders and Jet Propulsion Laboratory scientist Stephen Edberg are among the featured speakers at Universe '93 on July 10-11. Cosponsored by The Planetary Society, Universe '93 is a weekend-long astronomy fair featuring exhibits, workshops and nontechnical talks and seminars by scientists and amateur astronomers.

Universe '93 will be held in the Aztec Center on the campus of San Diego State University, 5300 Campanile Drive, San Diego, CA. For more information, contact the Astronomical Society of the Pacific, Event Registration Services, 655 Redwood Highway, Suite 309, Mill Valley, CA 94941; telephone (415) 337-1100.

• On July 29-31 in Madison, Wisconsin, the Madison Astronomical Association hosts the 47th Astronomical League Convention (ALCON '93) at the Sheraton Hotel and Convention Center. Among the program events are seminars, workshops, contests and star parties. For information, contact MAS/ALCON '93, P.O. Box 14747, Madison, WI 53714-0747. *—Carlos J. Populus, Volunteer Coordinator*

PLANETARY SOCIETY ANNUAL AUDIT

The firm of Stanislawski and Company recently completed its yearly audit of The Planetary Society. The firm determined that the Society's 1992 financial statement was in conformity with generally accepted accounting principles. Copies of the financial statement, which includes a report on member donations restricted to special use, are available on request. *—Lu Coffing, Financial Manager*

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Questions & Answers

How did water arrive, or form, on Earth? And when?
—Roger C.S. Clarke,
London, England

The Isua rock formation in Greenland provides evidence for standing bodies of liquid water on Earth by 3.8 billion years ago. Since these are the oldest sedimentary rocks we have, there is no direct geological evidence for the existence of water on Earth prior to this time. However, our understanding of planetary formation leads us to believe that the vast bulk of water on Earth is nearly as old as Earth itself.

It is now widely accepted that Earth, like the other inner planets, formed from the accretion of smaller planetesimals beginning about 4.6 billion years ago. If these planetesimals contained water, Earth would, from the very beginning, have had a supply of water. However, models of the temperature distribution in the cloud of gas and dust that swirled around the early Sun, and out of which the planetesimals themselves formed, indicate that at Earth's distance from the Sun conditions were simply too hot for water to be incorporated into these particular planetesimals. If this were the whole story, Earth would have accreted dry.

However, models of planetary formation show that a great deal of "mixing" of planetesimals occurred early in solar system history. Water-rich planetesimals from farther away from the Sun would have been scattered in great numbers throughout the inner solar system. It seems likely that early Earth acquired its water from this source. The comets we observe today, which are nearly 50 percent water ice, represent the vestige of the most water-rich part of this early outer planetesimal population.

When was most of the water on Earth today collected? This question is difficult, because much water may have been destroyed on Earth early in its history. The putative giant-Moon-forming impact, the formation of Earth's core, and the atmospheric escape of hydrogen could all have destroyed or stripped from Earth whatever water collected prior to 4.5 to 4.4 billion years ago. If this is the case, then Earth's present oceans were accreted after this date, during the time of heavy bombardment by comets and meteorites—which we know about from the lunar, mercurian and martian cratering records. We can estimate the time scale for the input of water, and other volatile elements, from the lunar cratering record. In this version of the story, about half of our oceans would have been delivered by 4.3 billion years ago, three-quarters by 4.2 billion years ago, and so on.

This story can be partly checked by estimating the amount of mass falling to Earth as implied by the cratering record on the Moon. These estimates are consistent with estimates from certain elemental tracers of meteoritic bombardment on Earth subsequent to core formation. If these estimates are right, only a few tenths of a percent of the lunar cratering record need to have been due to comets for Earth to have acquired its entire ocean of water from this source. Of course, water-rich asteroids falling to Earth during the heavy bombardment would have contributed as well.

—CHRISTOPHER CHYBA,
NASA Goddard Space Flight Center

These bleak and barren rocks in Greenland harbor the earliest direct geological evidence of standing bodies of liquid water on Earth. Akira Shimoyama of the University of Maryland's Laboratory of Chemical Evolution climbs the Isua formation.

Photograph: Cyril Ponnamperuma

Would it be possible to grow desert plants on Mars since the atmosphere is mostly carbon dioxide and water vapor? Would photosynthesis take place and oxygen be released?
—Jeff Prentice,
Silverdale, Washington

Even the most hardy desert plant would almost certainly die if planted on Mars today, owing to the low atmospheric pressure and temperature and the general lack of liquid water. How much thicker and warmer would the martian atmosphere have to be before plants could be introduced? Right now it is more than 100 times thinner than the sea level atmosphere on Earth. There is actually both relatively and absolutely more carbon dioxide in Mars' atmosphere (95 percent) than in Earth's (only 0.3 percent). So Mars has enough carbon dioxide, but plants also require liquid water.

If Mars' atmospheric pressure were to be high enough to be saturated with water vapor as well as the present amount of carbon dioxide, it would need to be about twice or three times what it is now. The temperature would also have to be increased from the average of minus 60 degrees Celsius (minus 76 degrees Fahrenheit) that we see there today. It would have to be high enough so that during the warmest part of the year, at least, the daily average remained above freezing.

Climate models suggest that this would occur when the annual average temperature is about minus 40 degrees Celsius (minus 40 degrees Fahrenheit). To get this high a temperature from the carbon dioxide greenhouse effect would require an atmosphere about 15 times thicker than Mars' present one—this would be more than thick enough to contain the carbon dioxide and liquid water necessary. If we did produce this minimally thick and warm atmosphere on Mars, then some hardy vegetation (desert and arctic plants) might be able to survive. If they did they would certainly photosynthesize and produce oxygen.
—CHRISTOPHER P. McKAY,
NASA Ames Research Center

If the Moon started rotating tomorrow, what immediate and long-term effects would we on Earth see?
—Kieran Sala,
San Francisco, California

The Moon is rotating now, once per revolution about Earth. If it began to spin faster, nothing much would happen here except that we would regularly view its far side. Over time, however, measurable gravitational effects would occur because the Moon is slightly lopsided. Ultimately we would observe small irregularities in the rotation of Earth; offhand, I do not know if such effects would be swamped by Earth's present uneven spin rate due to atmospheric and other geophysical phenomena.
—JAMES D. BURKE, *Technical Editor*

FACTINOS

Earth's rapid spin may have been caused by collisions with Mars-sized worlds early in its formation, says Luke Dones of NASA's Ames Research Center. "When these objects strike a forming planet, they can make it spin, just as you can make a globe spin by pushing it with your finger," Dones said.

Dones and his research partner, Scott Tremaine, of the Canadian Institute of Theoretical Astrophysics in Toronto, studied the history of collisions during the formation of early Earth to see what the "spin speed" would have been. They conclude that without the large impacts Earth would rotate every 200 hours instead of the 24 hours it takes today.
—from Ames Research Center

❖

Last summer scientists using the Hubble Space Telescope determined that the atmosphere on Mars is even colder and drier than it was when spacecraft last surveyed the planet.

Todd Clancy and Steve Lee of the University of Colorado used the Hubble's ultraviolet imaging system to map the ozone distribution in the atmosphere surrounding Mars. They discovered that the ozone was more heavily concentrated at the planet's poles, because water vapor that normally destroys the ozone was frozen there.
—from *Space News*

❖

Scientists now suggest that, of all the profound influences on Earth's delicate climate, the most important may be the Moon. In a February issue of *Nature*, Jacques Laskar and Philippe Robutel of the Bureau des Longitudes in Paris reported that the Moon apparently acts as a sort of gravitational gyroscope to stabilize the 23-degree tilt of Earth's axis, the slight skew that gives the planet its seasons.

The scientists assert that without the Moon, Earth—like the other inner planets—would tilt as much as 85 degrees. A radical tilt would be catastrophic because—as other scientists have suggested—a mere 1.3-degree change in Earth's tilt may have resulted in ice ages.

Carl A. Murray, an astronomer at the University of London, noted elsewhere in *Nature* that a tilt greater than 54 degrees would give the equator less sunshine than the poles. "Given that," he concluded, "the forecast for a Moon-less Earth would have been bleak."
—from Mark A. Stein in the *Los Angeles Times*

❖

Now that some planetary scientists have had time to digest the first, along with the most recent, images of Gaspra returned by *Galileo*, they are seeing a very different sort of asteroid. Rather than a single rock, *Galileo* imaging team member Clark Chapman of the Planetary Science Institute in Tucson says, Gaspra might consist of two or more giant lumps of rock loosely held together by their own feeble gravity. Referring to the most recent sequence of Gaspra images returned to Earth, Chapman says, "From almost any direction, it looks lumpy, kind of like you might have assembled two lumps of clay into a peanut shape."
—from *Science*

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Volcanoes have played an important part in sculpting the surfaces of several planets and moons. While Mars' volcanoes now seem dormant and scientists are still not sure if Venus' volcanoes are active, there is no doubt about Jupiter's moon Io.

"Jupiter from Io" is Kazuaki Iwasaki's vision of the giant planet filling the sky of Io—the most volcanically active body known in our solar system.

Kazuaki Iwasaki lives in Yokohama, Japan. In 1951, at the age of 16, he began to paint planets and stars. After discovering the art of Chesley Bonestell in the book, The Conquest of Space, *he decided to become the "Chesley Bonestell of Japan."*

Although Iwasaki completed his thousandth painting in 1980, his astronomical art is an avocation. He is also a successful industrial designer.

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