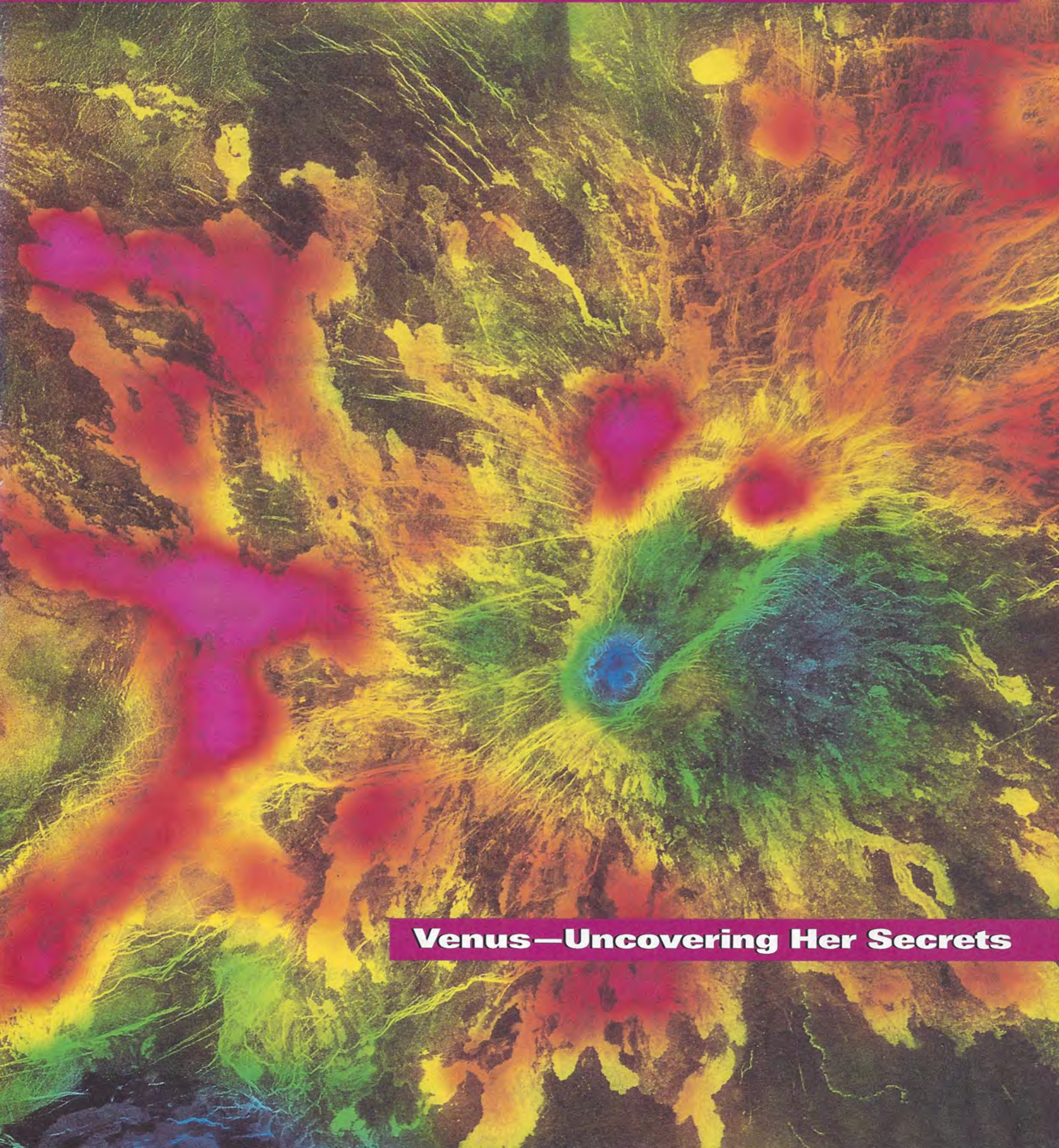
The PLANETARY REPORT

Volume XIV Number 2 March/April 1994



Venus—Uncovering Her Secrets

On the Cover:

The *Magellan* spacecraft returned many different types of data. Researchers on Earth can manipulate these data to produce spectacular images that tell them much about the planet—but bear little resemblance to how the planet would appear to a human looking down upon it. This image of an unnamed volcano in the equatorial region of Venus combines a radar map with measurements of the radio emissions from the surface. These measurements contain clues to the nature of the surface materials; red here corresponds to strong emissions; blue, to weak. By comparing topographic features with these data, scientists can begin unraveling some of the mysteries of Venus. Image: JPL/NASA

Table of Contents

Volume XIV
Number 2
March/April 1994

Features

4 No Space for NASA
The United States space program was conceived as a weapon of the Cold War, but was justified as an expression of a national drive to explore and understand the universe. Now the Cold War is over; what reasons are left to continue the exploration?

6 Orbital Maneuvers: *Magellan* Aerobrakes Into Venus' Atmosphere
With the radar mapping of Venus now completed, the spacecraft team has undertaken a daring aerobraking experiment to launch *Magellan* on a new mission, to map the planet's gravity.

14 Laurel Wilkening Joins Planetary Society's Board of Directors
A distinguished planetary scientist and university administrator is now contributing her talents to the Society's Board of Directors.

15 Mining the Air: How Far Have We Progressed?
In situ propellant production, making rocket fuel from a planet's atmosphere, could be one of the technologies that will make human travel to Mars possible. Here's a look at progress in this exciting technology.

Departments

3 Members' Dialogue
Our members continue to challenge the Society to achieve even more.

16 News and Reviews
Our faithful columnist wrote this on the plane while returning from a workshop on the predicted collision between comet Shoemaker-Levy 9 and Jupiter. This is literally the latest word on the coming crash.

17 World Watch
The planetary programs of both Russia and the US face tremendous budgetary challenges. *Mars '94* has just received a vote of support from the Russian Space Agency, but *Cassini* and other US missions are facing a tough fight in Congress.

18 Readers' Service
It is the nature of humans to try to impose order and predictability on the world, and science is one of our more successful attempts. We offer here a book of essays exploring the nature of that science.

19 Society News
The Planetary Society endeavors to give its members an array of opportunities to participate in our many activities. We have a number of exciting events coming up, and you are invited to join us.

20 Questions and Answers
Saturn's moon Titan is one of the most fascinating bodies in our solar system. We answer a question about its atmosphere and also discuss using radar to search for signs of life elsewhere in our universe.

From The Editor

Many, many of the pieces we print in *The Planetary Report* are variations on a theme: the challenges—political, economic and social—that face planetary exploration. While we would prefer to cover only the triumphs of the planetary community, the continuing struggle to find support and funding to launch missions to other worlds consumes much of our energy.

It's not always easy to articulate a rationale for spending great sums of money on interplanetary spacecraft and scientific research. But if we believe that exploratory endeavors are worth the struggle, then we should be prepared to say why. A recent essay in *The New York Times Magazine* tackled the question, "Should NASA be retired and its budget put to better use?" We've reprinted the essay on pages 4 and 5 in the hope that it will provoke discussion among our members.

Let us know why you think planetary exploration is valuable. Lay out your reasons and send them to our office. Thank you for your help.
—*Charlene M. Anderson*

The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, (818) 793-5100. It is available to members of The Planetary Society. Annual dues in the US or Canada are $25 US dollars or $30 Canadian. Dues outside the US or Canada are $35 (US). Printed in USA. Second-class postage pending at Pasadena, California, and at an additional mailing office. Postmaster: Send address changes to The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106. Canada Post Agreement Number 87424.

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A Publication of
THE PLANETARY SOCIETY

Members' **Dialogue**

Broaden Our Scope?

Abe Gomel has presented the Society's Board of Directors with an enormous challenge—to broaden the Society's charter to encompass the very reasons that human society explores the unknown: "continued life, adventure, prosperity, happiness, harmony, knowledge, hope, freedom and time." (The words "continued life," "happiness" and "freedom and time" were mistakenly omitted from Dr. Gomel's letter in the January/February 1994 issue of *The Planetary Report*.) It is clear that The Planetary Society must continually evaluate the rationale for exploring other worlds.

But, should The Planetary Society, as Dr. Gomel proposes, become more involved as a citizens' group in promoting the values implicit in the Society's charter over the spectrum of social issues? For example, we understand and deal with Earth as a planet, but should we become involved in environmental issues that affect future life and the quality of life on Earth? Similarly, our Mars Rover program puts us at the cutting edge of information and robotic technology. Should we become more involved with non-space applications that could shape the 21st century's economy?

To accept Dr. Gomel's challenge would require broadening the Society's scope. The Board of Directors has been discussing this and is not of one mind on the issues. Environment, international cooperation, advanced technology, and cosmology are all related to our issues—but should they be in the mainstream of Society activity?

The Board welcomes our members' views and hopes that Dr. Gomel's will provoke more.
—LOUIS D. FRIEDMAN,
Executive Director

Standardized Spacecraft

Every planetary exploration probe that gets launched looks like it was designed from scratch. Then, when a large probe like *Mars Observer* is lost, so is a lot of money, something NASA can't afford, but also a lot of time—something the public has no patience for. Finally, NASA looks foolish and uncool, something it cannot do if it is trying to inspire younger generations.

I would like to see smaller, lighter, *standardized* spacecraft. Maybe two or three models to handle different jobs. They should be designed to carry, at most, two or three pieces of equipment. To learn about Mars, we could send five probes, each carrying different equipment with, perhaps, some redundancy. If one probe got lost, the entire mission wouldn't be.

We all know that production in mass quantities cuts costs. Why can't this be used for planetary exploration?
—ERIC VANDERNOOT,
Brookfield, Connecticut

More Members on Mars

I just read the January/February Members' Dialogue and found that you are planning to send our names to Mars. I am so happy! We joined The Planetary Society because we all dream of going to the planets. You have done what no one else could. You have filled some space in your members' hearts with the reality that one of their most precious dreams will come true. Thank you for being so humanitarian! It is as if you are giving that spacecraft a soul. You have my support and membership for the rest of my life.
—LAURA S. FLEISCHMAN,
Los Angeles, California

I love the new look! I just read the January/February 1994 issue of *The Planetary Report* and I couldn't put it down! This is by *far* the best overall issue I have ever read (and I have been a member for many years).

I thought that "Bodies at the Brink" was very educational. "Jupiter Watch: The Celestial Necklace Breaks" made me want to go out and buy a telescope so that I can witness this "once-in-a-thousand-lifetimes" event first-hand. The regular columns were of their usual high quality. And George Powell's "A Rover's Journey: Linking Two Worlds" was absolutely captivating. As Charlene Anderson's letter to George directed, it certainly was "personal" and conveyed the excitement that the team felt. It made me feel that, as a member, I *really did* have a personal stake in this.

I'm also thrilled that my name will be going to Mars on a microdot. As a person who longs to actually travel in space, I know that the closest I'll ever get to space is during a one-week "mission" at Space Camp. I may not make it to Mars, but my "spirit" will. Thank you, TPS!
—KAREN GOLUBIC, *Edinboro, Pennsylvania*

Space Station Pioneer

I was very interested in Hans Mark's informative article on the rise and fall of the space station ("The Space Station: In the Beginning") in the November/December 1993 issue of *The Planetary Report.* I'm rather surprised that Hans didn't mention the most amazing book ever written on the space station, *Das Problem der Befahrung des Weltraums*, by Herman Potocnik (Richard Carl Schmidt and Co., Berlin, 1929).

I had never seen the book until recently. Imagine my astonishment in finding that Potocnik specifically mentions the use of the space station for communications, using short radio waves! If television had been around in his time, he certainly would have been the first to point out the value of geostationary satellites for global telecasting!
—ARTHUR C. CLARKE,
Colombo, Sri Lanka

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

No Space for NASA

by Nicholas Wade

The Mars Observer is a spacecraft designed to map our neighboring planet in exquisite detail. NASA spent $1 billion but failed to make the mission foolproof. In August, just as the delicate craft neared its target, some accident disabled its communications gear, probably condemning it to snap endless postcards of Martian vistas that no one will ever admire.

The futile outcome mirrors the general state of space exploration, which also has come far with little to show. The universe is waiting, but NASA can think solely of plumbing and aluminum, the chief ingredients of its much-redesigned space station. The project's only evident purpose is to make work for space contractors and NASA's erratic fleet of space shuttles. Its feeding has long starved the agency's more promising ventures.

Thus, the Hubble Space Telescope, designed to peer back close to the universe's edges and the dawn of time, was put into orbit with a flawed mirror and dishearteningly fuzzy vision. The Galileo spacecraft, now en route from Earth to Jupiter, cannot report the full wonders of its journey because its main antenna won't unfurl.

These failures could not come at a worse time for space exploration and its supporters. There is no longer any urgency to beat the Soviet Union to the moon or Mars. NASA cannot claim that it spins off critical technology for industry, which surpassed it years ago in materials and computers. Viewers have tired of astronauts' weightless and often witless antics in space.

Given its recent performance, shouldn't NASA be retired and its $15 billion annual budget be put to better uses?

Suppose for a moment that there were no NASA, no enormous investment in the clunky hardware of manned spaceflight. Would we need to venture into space? What arguments could anyone make for starting a new civilian space agency from scratch?

One is that there's a lot out there to be discovered. The solar system holds amazements that we have only begun to sample, from the watery blue orb of Neptune, a giant bubble floating in the twilit edges of the sun's demesne, to the tiny shepherd moons that tend the rings of Saturn. "And since, my soul, we cannot fly/To Saturn nor to Mercury," concludes a Housman poem I had to learn for some schoolboy offense, "Keep we must, if keep we can,/These foreign laws of God and man." Missions that record these extraterrestrial geographies offer escape, even if only in imagination, from laws, conventions and the banal.

Besides discovery, another reason to go to space is what might be called the insurance option. Aren't two planets better than one? Mars is probably the least difficult place in the solar system to make hospitable. But it would take decades to get ready, so those who foresee a human settlement of Mars urge starting soon. As our planet edges ever closer to its carrying capacity, Malthusians could one day prove right for a change, especially if there should be some sudden shift in the conditions for agriculture. What if the long-threatened greenhouse effect at last arrives?

There's also the matter of historical imperative. Humankind will inevitably spread beyond Earth to exploit the opportunities of the solar system, this argument goes. So why not start soonest, lest later generations judge us fainthearts who faltered at a decisive turning point in history? "Like the Alexandrian Greeks, who discovered the motive power of steam but used it to open temple doors instead of initiating an industrial revolution in the first century A.D.," some future Gibbon may scold, "Americans of the late 20th century first reached the moon but then turned back home, too discouraged by the vastnesses ahead to grasp the new worlds they had brought within reach."

Then there is the agenda of science. Origins are among its most intriguing questions. But many of the answers now seem to lie beyond Earth's boundaries. The geology of other planets may bear the records, long erased from Earth's, about the conditions that prevailed when life began. The solar system surely holds clues as to whether the first chemical building blocks of life, or even the seeds of life itself, arrived aboard meteorites to fecundate the primitive Earth. Since it now seems that the stately process of evolution was brusquely diverted from time to time by asteroids or comets that wandered into collisions with Earth, there is much to learn about the history of these celestial visitations.

Gaining scientific knowledge is perhaps the most tangible reason for a serious and immediate space program. Research with no practical purpose in view is an accepted function of government, not least because it often yields unexpected gains. Planetary exploration is not cheap, but if abolishing crime and poverty were the preconditions for anything of lesser priority, governments would never subsidize opera, protect the landscape or hunt for quarks. And space exploration is the kind of thing governments do well. Project Apollo, to land men on the moon, was a brilliant success; had the nearly $25 billion it cost been poured into social programs, where money is seldom decisive, the results would have disappeared long ago.

Grant, then, that a civilian space effort of some size is warranted. A magnificent space program could be mounted for something closer to $5 billion a year, instead of $15 billion as at present, simply by keeping people on the ground and sending computer-driven vehicles to roam the solar system. It's providing for astronauts' safety that takes up the lion's share of NASA's budget. Though humans may live beyond Earth some day, no logical program requires them to do so this soon.

It's even possible to imagine a space program that would cost almost nothing. The Department of Energy has on its payroll several outstanding national laboratories with nothing much to do now that nuclear power is in eclipse and the cold war over. At Los Alamos and Livermore, two of the world's finest teams of physicists and engineers are desperately looking for a worthy intellectual challenge now that the development of nuclear weapons has pretty much achieved perfection. Let the two labs compete in building spacecraft as vigorously as they once did in designing nuclear warheads. Their scientists would embrace the challenge, and their skills would produce superb machines for exploring the mysteries that lie beyond Earth.

Recently, the Galileo, crippled as it is, radioed back a snapshot of a passing asteroid known as Ida in the astronomers' catalogues. Shaped like an Easter Island statue, with a meteor crater for an eye socket, it stretches 32 miles from crown to chin. To some, Ida may look like just another rock; to astronomers, it is an untouched piece of the solar system's building material, the dust of stars that died before the sun was born. Next July, Galileo should witness an eye-catching series of multimegaton explosions as the pieces of a stricken comet plow into the red clouds of Jupiter.

For 20 years, NASA's political masters in the White House and Congress have let the agency drift. One day, maybe, something will rekindle the desire to explore and understand.

Nicholas Wade is the science editor of The New York Times. *This article is a reprint of his November 14, 1993, "Method and Madness" column in* The New York Times Magazine.

"To Explore and Understand"—An Endangered Objective

In his essay, Nicholas Wade postulates that the rationale for NASA's existence is the desire to explore and understand. This proposition is about to be tested: The budget-cutters in Washington have in their sights the *Cassini/Huygens* mission to explore Saturn and its mysterious moon, Titan. As was described in the July/August 1993 issue of *The Planetary Report*, this is a mission of great scientific promise, with the potential to thrill earthbound explorers with its discoveries.

The *Cassini* spacecraft will launch the European Space Agency's *Huygens* probe into the organic-rich atmosphere of the giant moon Titan, possibly illuminating the processes that long ago led to the origin of life on Earth. The majestic saturnian rings, having beguiled astronomers for centuries, are targeted for intense study. Saturn's smaller satellites—such as Mimas, nicknamed the "Death Star," and Iapetus, with its strange, organic-marked surface—will give up much of their secrets to *Cassini*.

This mission takes on added importance when we consider its international significance. If the United States cancels *Cassini*, effectively abandoning its European partners, there will be profound repercussions among all the spacefaring nations. The US could be labeled, perhaps irrevocably, an unreliable partner. The fallout could reach beyond the planetary program, extending to the space station, which the US has just agreed to build in partnership with the Russians, the Europeans, the Canadians and the Japanese. Repercussions could reach well beyond the space program.

The US Congress and the administration have already begun considering the 1995 budget, and The Planetary Society is very concerned about the fates of *Cassini* and *Huygens*. This is, however, an expensive mission: $1.4 billion for development, over $400 million for launch and more than $1 billion for operations and data analysis over its 11-year lifetime. This last should be and probably will be reduced. Although budget cuts may be required, *Cassini* deserves support in its journey through Congress.

We urge our members to write to their senators and representatives, to members of the congressional budget committees, to NASA Administrator Dan Goldin, and to President Clinton himself to express support for this mission to Saturn. Write frequently and show the Washington policy-makers that the desire to explore and understand still burns within the hearts of people around the world.

—Louis D. Friedman

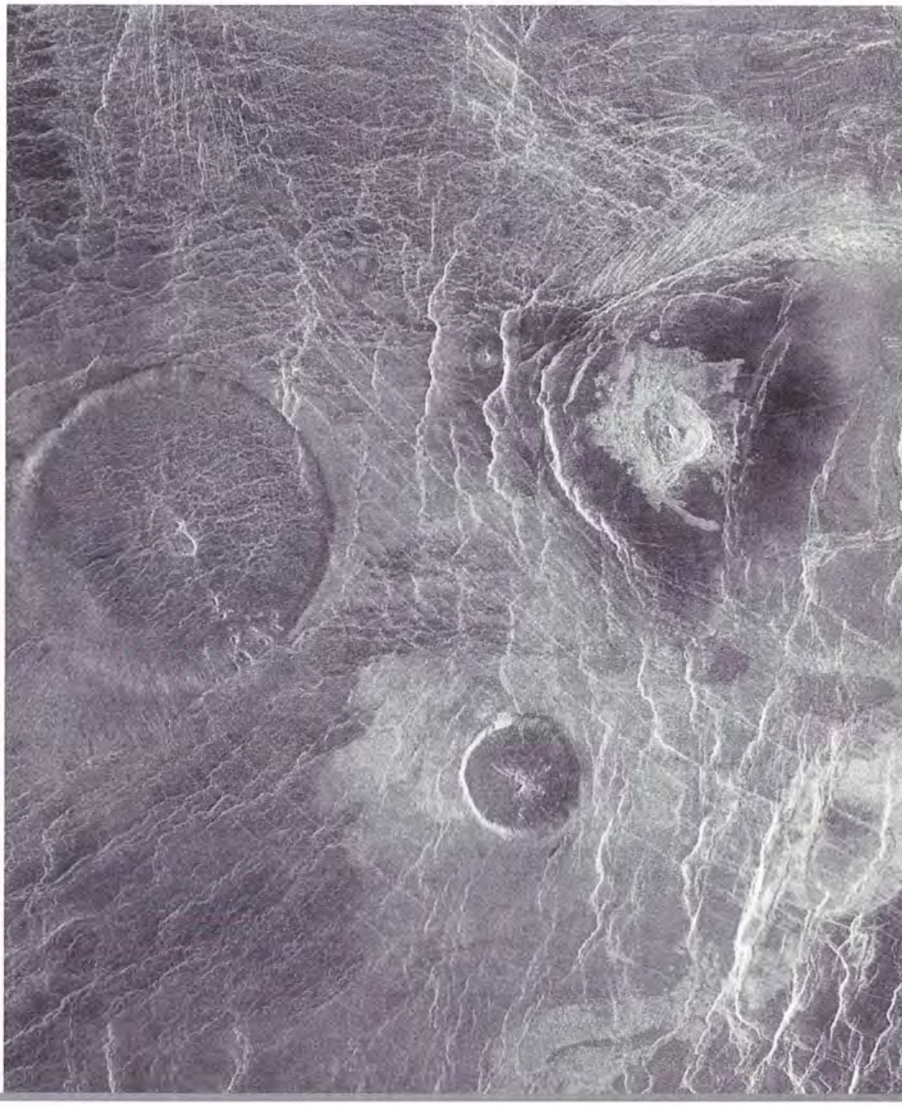
MAGELLAN AERO INTO VENUS'

In the science fiction film *2010*, based on Arthur C. Clarke's novel, a piloted spaceship named the *Leonov* arrives at Jupiter. Crew members inflate a huge shield, which they call a *ballute*, in front of their spacecraft, which then enters the upper reaches of the gas giant's atmosphere. Atmospheric friction decelerates the spacecraft, reducing its momentum so it can be captured into orbit by Jupiter's gravitational field. Although it leaves a fiery trail, the ballute withstands the heat and aerodynamic stresses of aerobraking, and Clarke's heroic explorers carry out their mission.

Aerobraking at another planet is no longer science fiction. In May of 1993, NASA's *Magellan*, in orbit around Venus since August 10, 1990, became the first spacecraft to demonstrate that this technique could be used to significantly alter the shape of an orbit at another planet. Its original mission was to map the planet from a safe distance in orbit, and it did not carry a ballute. In fact, *Magellan* was never designed to undertake aerobraking at all.

Magellan conducted its initial mapping of Venus from a highly elliptical, nearly polar (that is, north–south) orbit. At its point of closest approach, called periapsis, Magellan came within about 200 kilometers (125 miles) of Venus' surface at 10 degrees north latitude. It then climbed out to its farthest point, called apoapsis, about 8,500 kilometers (5,200 miles) above the

Before undertaking its gravity-mapping mission,* Magellan *completed three cycles of radar mapping. This repeated coverage allowed the spacecraft to see some of Venus' intriguing geologic features from different viewing angles. Being able to see the planet from more than one perspective broadened scientists' understanding of its surface forms. Here we see a few of Venus' now famous volcanic pancake domes, some 65 kilometers



BRAKES

ATMOSPHERE

BY DAVID DOODY

(about 40 miles) in diameter and less than 1 kilometer high. The image on the right was taken on the first mapping cycle; the one on the left, on the third cycle. These unique features probably formed when thick, viscous lava erupted slowly through the surface, then cooled and cracked as the lava below it subsided.

If you have access to a standard stereoscope, you should be able to view this pair of images in stereo. *Images: JPL/NASA*

surface on the planet's opposite side. Completing a whole orbit took about three and a quarter hours, while the planet rotated very slowly below.

From this orbit, *Magellan* mapped the surface of our sister world, using radar to peer through the dense cloud cover. This was our first view of the whole surface of Venus in great enough detail to permit close scrutiny by geophysicists, geologists and investigators from other scientific disciplines. (See the May/June 1991, May/June 1993 and September/October 1993 issues of *The Planetary Report*.) The radar mapping ended September 4, 1992, after Venus had rotated three times below *Magellan*'s fixed orbit. Each rotation period is about eight months, slightly longer than Venus' year. On the *Magellan* team, we call each eight-month rotation period a cycle.

Magellan then spent the fourth cycle surveying the gravity field near the equator of the planet. We measure minute variations in Venus' gravity field by studying how the speed of the spacecraft changes while it is in orbit. It speeds up ever so slightly (a handful of millimeters per second) as it approaches an area where mass is more concentrated on or below the surface. Thus a gravity field survey gives important clues to understanding the features visible in the radar images. Geologists use gravity maps of Earth to search for subsurface oil and mineral deposits.

Rounding Out an Orbit

While in its original, highly elliptical orbit, the spacecraft was too high above the surface to measure the gravity field effectively except when it was within about 30 or 40 degrees latitude from the planet's equator. To better our understanding of Venus, we wanted to measure the gravity field at the high latitudes near the poles as well. There are some very interesting features there—including Maxwell Montes, the highest mountain range on Venus, which towers 11 kilometers (about 7 miles) above the mean terrain elevation. The only way we could survey the gravity field over the whole planet, from north pole to south pole, would be by lowering the apoapsis altitude and thereby creating a more circular orbit. But to do this would require dissipating a lot of energy.

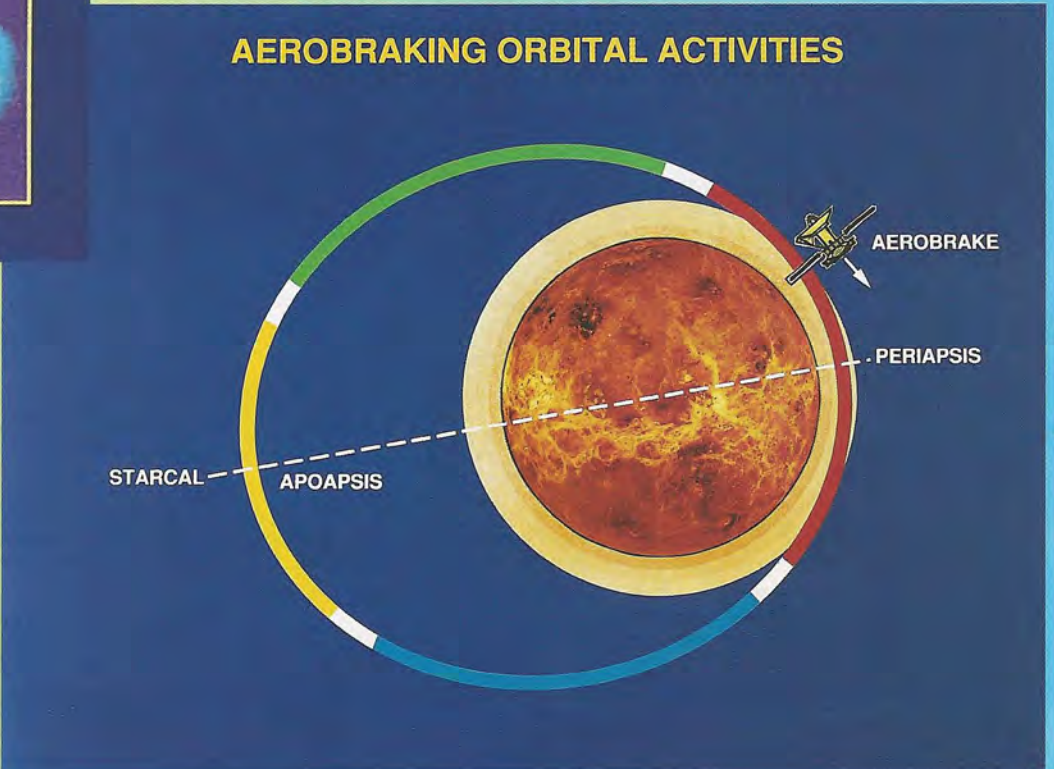
Picture the spacecraft speeding in over Venus' north pole, toward its 9-kilometer-per-second (20,000-mile-per-hour) closest approach to the planet near the equator. It begins to slow as it climbs out over the south pole and on toward apoapsis, where it is moving at its slowest speed. The robot then begins to speed up again as it "falls" back in toward periapsis. The process repeats itself every three and a quarter hours. All of this happens as *Magellan* is coasting, free-falling in orbit around the planet.

Now, if the spacecraft's thrusters (tiny rocket engines) are fired to slow it down as it coasts through periapsis, then it would have less momentum to counteract gravity as it climbs back out toward apoapsis, and it wouldn't travel quite as far as it did during the previous orbit. Apoapsis altitude would be lowered! And if it's lowered enough, the orbit would become nearly circular, a fine vantage point for collecting gravity data.

Using this procedure to slow the spacecraft down enough to reduce apoapsis altitude from the original 8,500 kilometers to about 500 kilometers (300 miles)—a drop of about 1,200 meters per second (2,600 miles per hour)—would have consumed around 900 kilograms (2,000 pounds) of propellant in *Magellan*'s thrusters. (A target altitude of 500 kilometers was chosen as a compromise: The science team wanted as low an altitude as possible, but the spacecraft engineering team needed a higher altitude so a longer orbit period would keep the solar arrays out of Venus' shadow long enough to charge the batteries.) But *Magellan* had only about 95 kilograms (210 pounds) of propellant at that point. If all of this had been used up, *Magellan* would not have been able to control

Left: As it braked through Venus' atmosphere, Magellan *was subjected to great aerodynamic pressures. The effect of the atmosphere on the spacecraft is illustrated here, with the greatest flow indicated in red, decreasing to green and blue. The solar panels sustained half or more of the total dynamic pressure load.*

Below: The goal of aerobraking was to circularize Magellan*'s orbit. To do this, the team set out to lower the spacecraft's apoapsis, or orbital high point, by sending it into Venus' atmosphere during passage by periapsis, or the lowest orbital point. Friction from atmospheric molecules effectively braked the spacecraft. During the aerobraking, it was critical for the spacecraft to keep close tabs on its position. Every other orbit it locked on to two target stars to determine its attitude (starcal) and relayed the information back to Earth.* Images: JPL/NASA



its attitude for more than another few orbits. So we had to find another way to circularize the orbit.

We decided to try aerobraking, since all of *Magellan*'s primary scientific objectives had been completed. Besides, the new NASA administration had been asking for innovative and daring ideas. After much planning, designing, calculating and reviewing by members of *Magellan*'s mission planning and spacecraft engineering teams, at both the Jet Propulsion Laboratory in Pasadena and Martin Marietta in Denver, we reloaded the spacecraft with a new set of programs. On May 25, we sent a command that caused the spacecraft to execute a small propulsive maneuver called an orbit trim maneuver (OTM), slowing it down slightly while it was coasting near apoapsis. Each OTM used a few teaspoons of propellant.

With slightly less momentum to counteract gravity now as it fell toward periapsis, it would pass closer to the planet. In fact, it would pass through the upper reaches of Venus' atmosphere! This would cause drag on the spacecraft as it passed periapsis, slowing it down, robbing it of the momentum it needs to counteract Venus' gravity on its climb out to apoapsis, and reducing apoapsis altitude slightly.

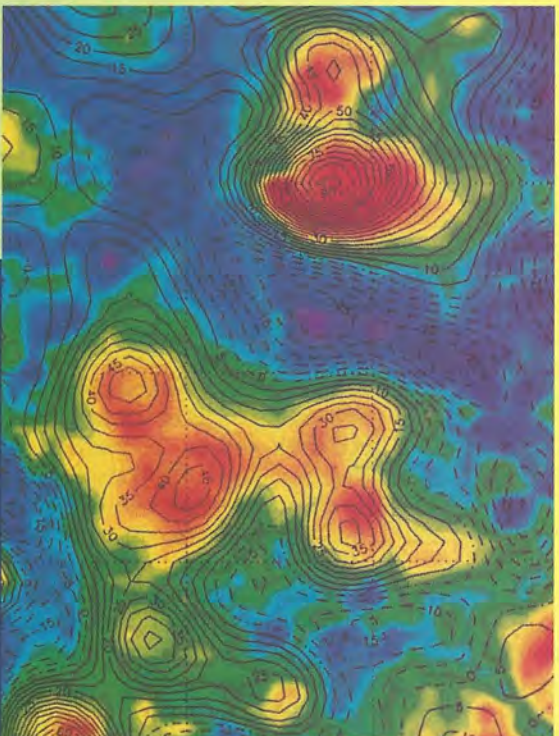
Making a Brake

We programmed the spacecraft to turn its two large, square solar panels so they'd be flat to the airflow, and also programmed it to steer itself to keep its high-gain antenna dish trailing in the wind. To our delight, this turned out to be an aerodynamically stable orientation; if the spacecraft began to wobble off in one direction, the aerodynamic drag on the structure caused it to slowly turn back toward its original attitude, with the high-gain antenna trailing. This was fortunate, because without proper attitude control the spacecraft would certainly have flailed about and overheated in the atmosphere.

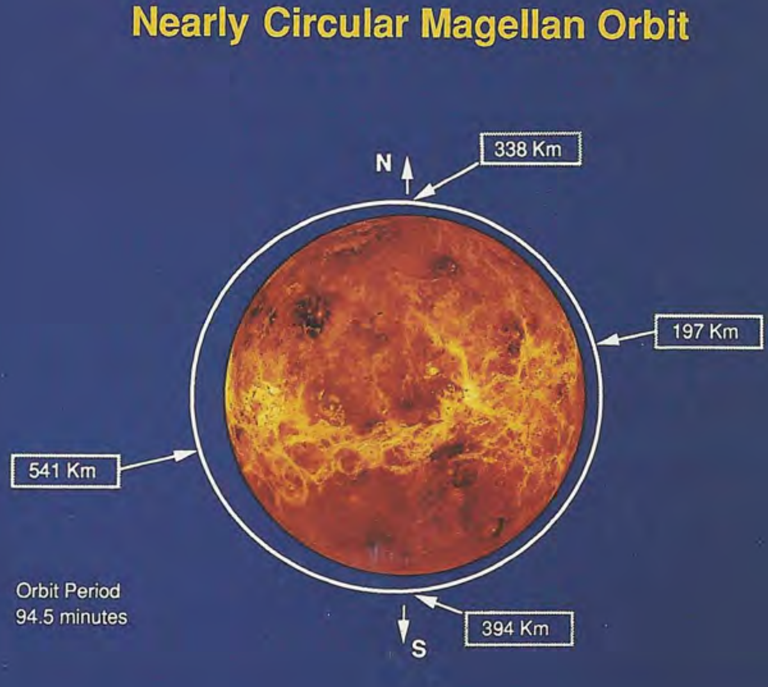
Each pass through the atmosphere produced only a small amount of drag (since we didn't have a ballute, we couldn't aerobrake all at once). The aerodynamic pressure limit we set for the experiment was 0.35 newton per square meter; the total force on the spacecraft was about what you might feel extending your hand—fingers together, flat to the wind—out the window of a car traveling down the highway at 55 miles per hour. It took 730 passes through the atmosphere, one pass per orbit, to reduce apoapsis to the desired 500 kilometers. The aerodynamic pressure limit was slightly exceeded only a few times.

Right: By braking the spacecraft into a nearly circular orbit, the Magellan *team was able to provide scientists with a different data set to deepen their understanding of what's going on beneath Venus' surface. Here gravity field data from the* Pioneer *orbiter and* Magellan *are displayed as contour lines over a color-coded topographic map showing elevations. You can see that the gravitational peaks closely match the highest points in this region, Bell Regio. This correspondence is helping scientists figure out what processes shape the surface of Venus.*

All the Magellan *data have shown that Venus behaves very differently from Earth. For example, our planet's face is shaped primarily by plate tectonics, and peaks in surface gravity do not always correspond with topographic highs. On Venus, we've found no evidence of plate tectonics, but as you can see, the gravity highs correspond to the topographic highs.* Map: W. Sjogren, JPL/NASA



Below: Here, superimposed over a radar mosaic of Venus, is the final, nearly circular orbit resulting from the months of aerobraking. From this improved orbit, the spacecraft is already enhancing our knowledge of Earth's sister world. Image: JPL/NASA



Aerobraking was a 70-day affair. It required constant monitoring. If the temperature and aerodynamic pressure got too high from friction, we were ready to execute an OTM to raise periapsis and get *Magellan* up out of the atmosphere, lest the excess drag send the spacecraft down to fiery destruction. If there wasn't enough atmospheric drag, we were ready to do an OTM to lower periapsis down to where the atmosphere would be denser, so that aerobraking wouldn't take forever. Each of these OTMs would be executed near apoapsis, either speeding up or slowing down the spacecraft slightly while it coasted in its orbit.

In the beginning of the aerobraking adventure, we didn't know exactly how dense the atmosphere would be at the planned altitudes, so we "walked" the spacecraft in slowly over the course of a few days, much the way you might wade slowly into the cool surf if you didn't know how deep it was going to get. It turned out that we could go slightly deeper into Venus' atmosphere than we had originally planned. The lowest altitude we took the spacecraft to was about 130 kilometers (80 miles) above the surface, still about 65 kilometers (40 miles) above the sulfuric acid cloud tops.

Tagging Along on a Typical Orbit

A typical aerobraking orbit went like this: Flying over Venus' north polar region, the spacecraft turned to its aerobraking attitude, with its high-gain antenna dish trailing, solar panels flat on. Communications were lost as soon as the antenna turned away from Earth. Normally, in the vacuum of space, to turn the spacecraft clockwise, for example, we'd have it drive an internal reaction wheel counterclockwise and leave it spinning; the torque turns the spacecraft. Later, to turn the spacecraft counterclockwise, we'd just slow or stop the wheel's spin. The spacecraft has three wheels mounted at right angles to each other so it can rotate to any attitude. But once in the presence of atmospheric drag, the reaction torque from these wheels wouldn't have been strong enough to overcome the wind. So the thrusters were brought into use for the atmospheric drag portion of each orbit. Mounted on booms jutting out from the spacecraft, they had enough leverage to maintain control.

While the spacecraft was encountering the atmosphere, data such as its attitude variations and the all-important temperature of the solar panels were stored in the onboard computer's random access memory.

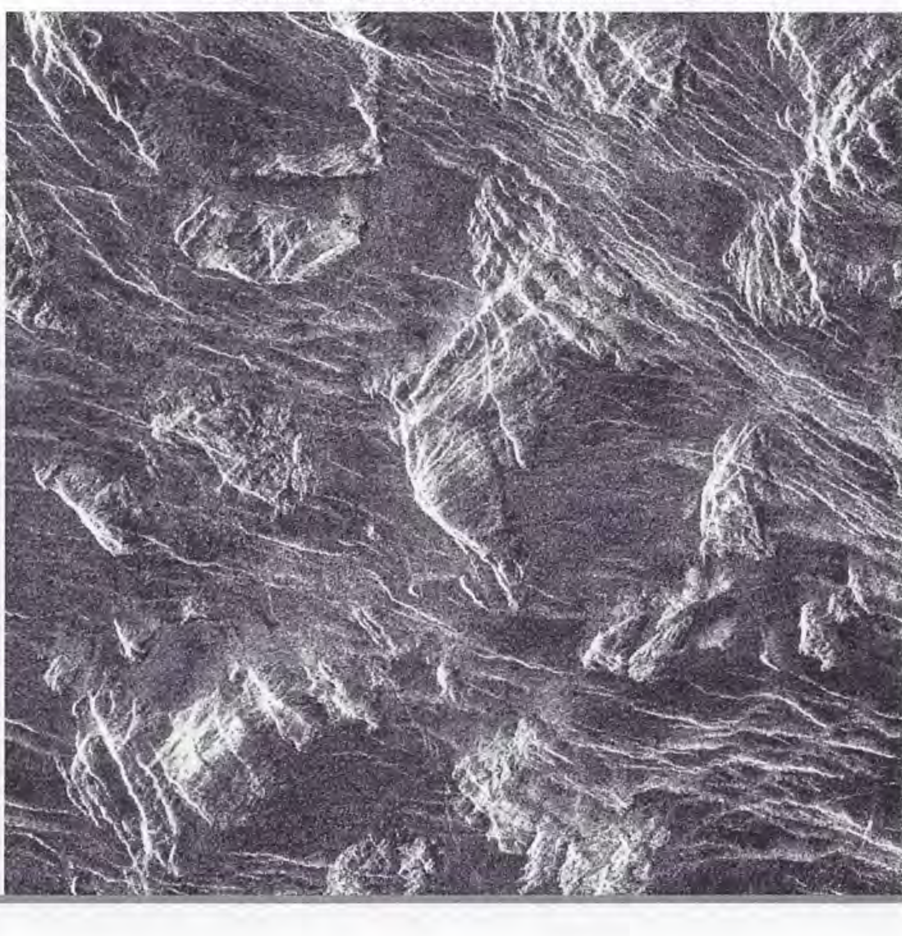
After about 30 minutes, the pass through the atmosphere was over. *Magellan* went back on reaction wheel control and turned to point its high-gain antenna toward Earth. The memory was read out, transmitting the critical temperature and attitude data taken during the previous drag pass. Controllers at JPL immediately checked the data, ready to "push the button" to command an emergency bailout OTM at the next apoapsis opportunity if things got too hot. They never did. The highest temperature we had decided to permit the solar panels to reach was 110 degrees Celsius (230 degrees Fahrenheit), way below the temperature at which the solder on the panels would melt. Fortunately, the hottest they ever got was 90 degrees Celsius (194 degrees Fahrenheit). The big high-gain antenna dish was expected to tolerate up to 180 degrees Celsius (356 degrees Fahrenheit), although some analysts at JPL suggested it might delaminate (literally, come unglued) at temperatures below that.

Attitude Adjustment

On odd-numbered orbits, the spacecraft performed a star calibration near apoapsis. This maneuver rotated the spacecraft so that its star scanner could take a fix on the locations of two widely separated bright stars and thus update knowledge of its own attitude—in effect telling it exactly which

This set of stereo pairs shows another geologic feature diagnostic of Venus: tessera, from the Latin for "tile." This strange pattern of crisscrossing cracks in the crust is found in all regions of Venus. Scientists speculate that tesserae are the scars of an era of planet-wide deformation when tectonic forces reshaped the planet's face.

In this region in western Aphrodite (a "continent" near the equator), later lava flows have filled in the tessera, leaving only isolated hills and ridges to hint at its history. Seen with a stereoscopic viewer, these images, covering an area 77 kilometers (48 miles) wide, will appear as three-dimensional. *Images: JPL/NASA*



way was up. The spacecraft needs to know what its attitude is for communication purposes, so it can know, to a fraction of a degree, which way to point to Earth, at that distance just a bright speck in a huge black sky.

This design displays a terrible pun on carpe diem, *"seize the day," with its* carpe atmospherum, *literally "seize the atmosphere."* Magellan *flight team members wore T-shirts with this design during the aerobraking maneuvers. It also serves as a good diagram of the spacecraft, showing the high-gain antenna dish, the solar panels and the thrusters.*

Artwork: Dan Lyons, JPL/NASA

Attitude knowledge is also important for the spacecraft to have so it can guide itself through the atmosphere in a stable orientation to avoid tumbling out of control. After each star calibration, the spacecraft aligned its medium-gain antenna with Earth and continued to communicate until a few minutes before passing over the north pole again. On even-numbered orbits, we had the opportunity to execute an OTM near apoapsis if it became necessary to raise or lower periapsis altitude.

The plane in which *Magellan* orbits Venus remains fairly fixed in space while the planets move about the Sun. Therefore, as the seasons progress, *Magellan*'s periapsis occurs sometimes on the sunlit side of Venus, sometimes on the dark side and sometimes in between. As the aerobraking marathon continued past 50 days, the nightside of Venus was approaching. The atmosphere became less dense there (it settles in the absence of sunlight), and we lowered the periapsis even more. On several occasions, waves of atmospheric density slapped at the spacecraft, and it recorded peaks in temperature and aerodynamic pressure.

Shrinking Orbit, Shrinking Time

In the beginning of *Magellan*'s Venus adventure, we had three and a quarter hours to accomplish all the activities associated with each orbit. But as the days of aerobraking passed, there was less and less time in each orbit. The controllers' reaction time for responding to any anomaly grew shorter, and it became critical to avoid accidental losses of data. With the shorter orbit, the spacecraft had less time to catch both stars for its attitude knowledge update before they went behind the planet from *Magellan*'s point of view. Also, as the orbit shrank, the time spent in the atmosphere increased, causing more drag, and the orbit shrank ever more quickly.

The people who operate JPL's Deep Space Network (DSN), which tracks interplanetary spacecraft such as *Magellan* by means of stations in Spain, Australia and the Mojave Desert, always need to know the exact times to acquire *Magellan*'s signal when the spacecraft turns to point to Earth. They also need to know the exact radio frequency to send up to it, and the exact radio frequency to expect to receive back down from it. But with *Magellan*'s shrinking orbit, the times were constantly changing.

A change in an event time also means a change in radio frequency, since the Doppler shift differs depending on whether the spacecraft is moving more or less toward or away from Earth at any particular point in its orbit about Venus. To send commands to the spacecraft, as we frequently had to do, we had to know exactly when to send them, planning so that the spacecraft had rotated to point to Earth right before the radio signals completed their 12-minute trip. This meant that hundreds of "back of the envelope" updates needed to be constantly calculated and sent to the three DSN stations.

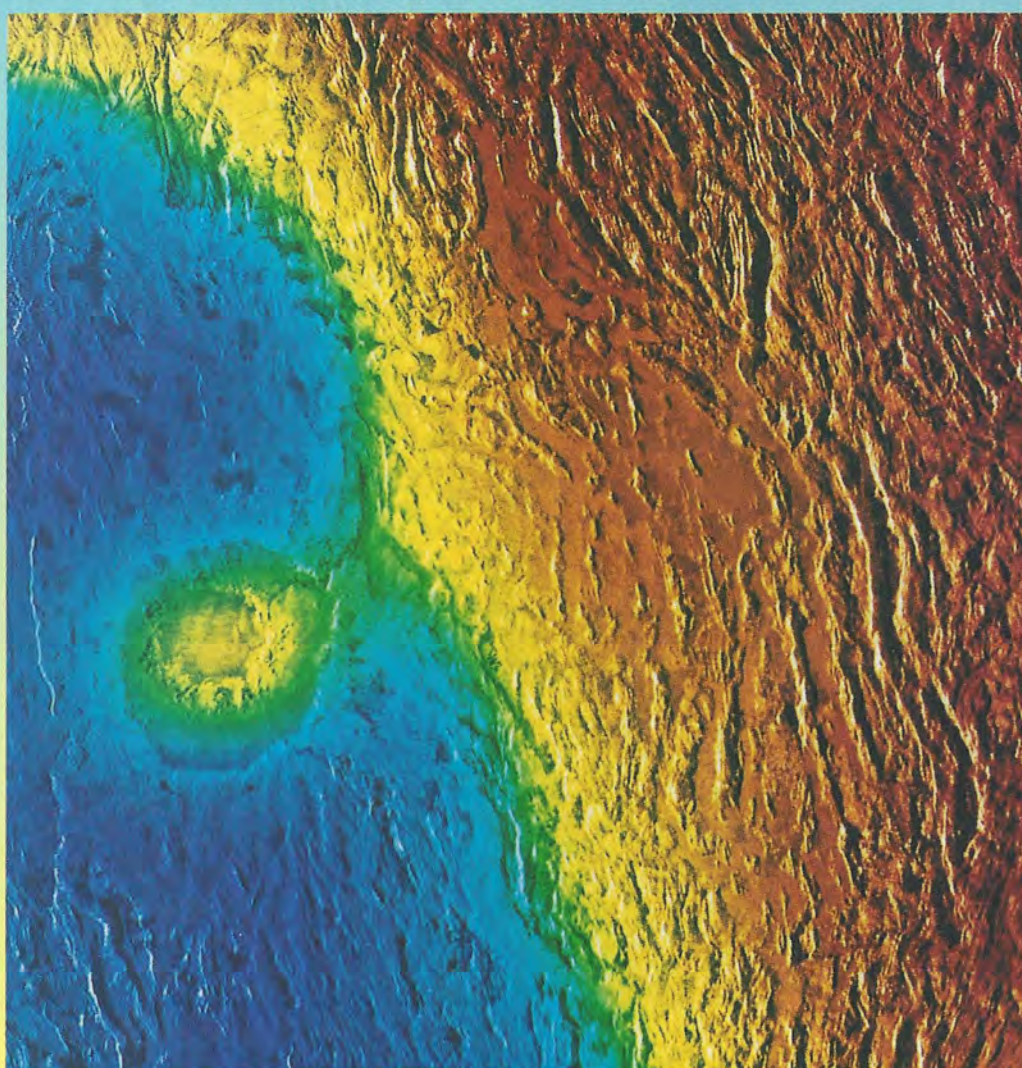
By the end of 70 days, the apoapsis altitude had decreased to the desired 500 kilometers, and the orbital period was only about an hour and a half. The spacecraft was still healthy, but the flight team members were completely exhausted.

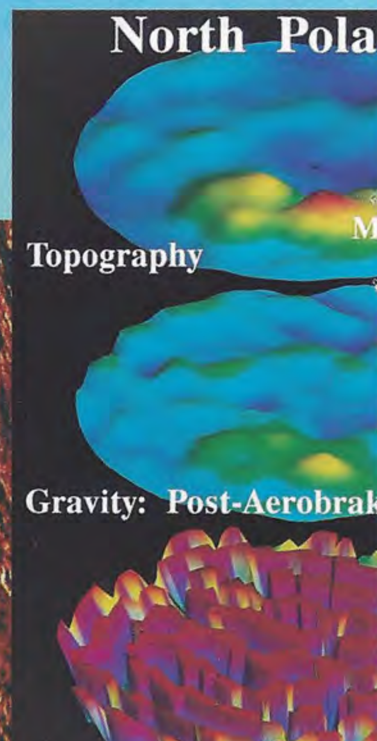
The Circle Completed

The DSN had dutifully kept up with our multitude of last-minute changes and updates, with never a word of complaint. With the shortened orbit, the star calibrations were beginning to fail to catch both stars before they disappeared. (Attitude knowledge becomes degraded if this happens too often, with possibly disastrous results.) DSN resources were beginning to be needed to support *Mars Observer*'s planned orbit insertion. The time had arrived to stop aerobraking.

In the early hours of Tuesday, August 3, a command was sent to *Magellan* to perform an OTM raising the periapsis up out of the atmosphere. This was done by speeding up the spacecraft slightly while near apoapsis; the added momentum caused it to climb to a slightly higher periapsis altitude on subsequent passes. The OTM was successful, and the marathon was over. Many of the *Magellan* flight team mem-

Below: Maxwell Montes, the highest mountain range on Venus, was a particular target for Magellan *researchers. A portion of Maxwell, colored blue, appears in this false-color image made by combining radar data with measurements of the amount of heat radiated by the surface. This thermal radiation is an indicator of surface composition and texture. Indigo represents the lowest values; red, the highest. The mountains are bordered by Fortuna Tesserae, a region of crisscrossing ridges. Both the mountains and the tesserae help tell the story of Venus' tectonic past, but the circular feature to the left in this image tells of another process that scars the planet's surface: impacting meteorites. This is Cleopatra, a 105-kilometer-wide (65-mile-wide) crater on the mountain slopes.* Image: JPL/NASA





Magellan *completed its aerobraking m 1993 and by early December JPL was a illustration of how the new orbit had in Venus. The top image is a topographic data of the polar region, with Maxwell as the red peak. The middle image was the new data showing that the gravity to the topography. The bottom image s the data before the spacecraft's orbit w* Image: JPL/NASA bers were able to take a day off for the first time since aerobraking had begun. I spent the day gardening.

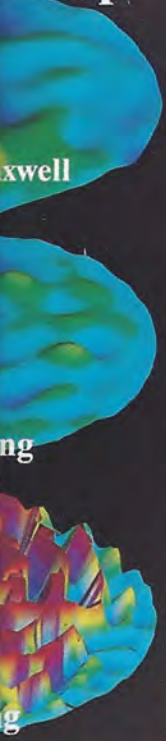
Two more OTMs were executed in the next couple of days, bringing the periapsis altitude back up to 200 kilometers. With an apoapsis now at 500 kilometers, the orbit was so close to circular that high-resolution gravity-field survey data could be acquired all the way from the north pole to the south pole on every orbit.

A Polished Performance

Magellan is now in its fifth cycle, doing its gravity field survey, as well as carrying out some additional experiments. The spacecraft's health is in fact slightly better than it was before aerobraking. It seems that its brush with Venus' atmosphere may have cleaned and polished the spacecraft a bit: The performance of its thermal-control reflectors is better, and the spacecraft is keeping cooler than previously expected. The flight team has been reduced to a "lean, mean gravity team" of 32 women and men (during radar mapping operations, we were over 200 strong), and the project now has funding through April 1994. If the spacecraft's health continues, we are hopeful of remaining funded long enough to complete the collection of a high-resolution gravity map of the entire planet by the end of cycle 6 in October 1994. The data would then be available to assist researchers for decades to come, as they work to understand the puzzling nature of Earth's sister planet.

David Doody is deputy chief of the Magellan *mission control team, which orchestrates the project's real-time operations, at the Jet Propulsion Laboratory. He was previously a member of the* Voyager *flight team.*

. Cap



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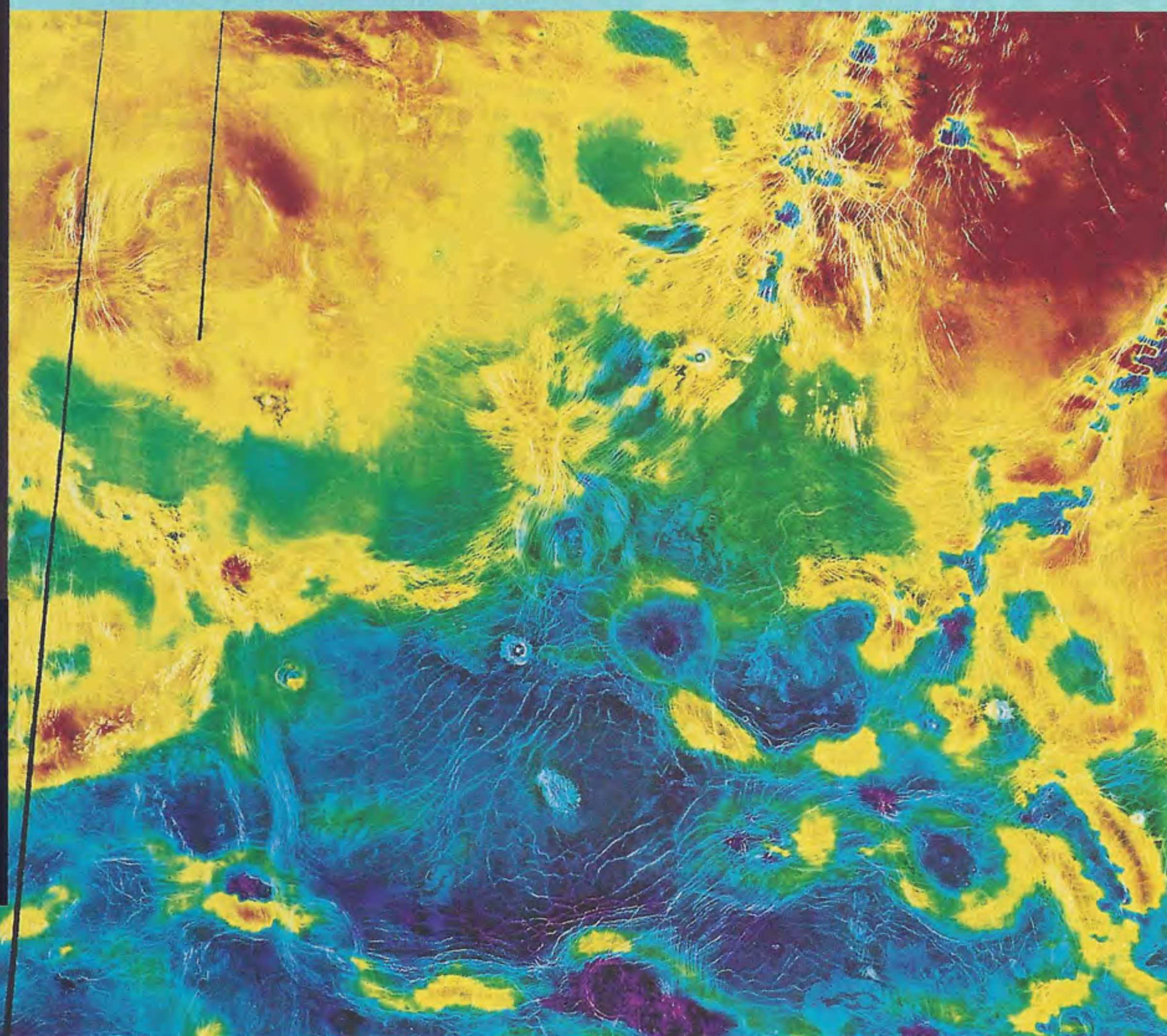
Below: Radar data are combined with altimetry data in this false-color map of Venus. Red areas are the highest; purple, the lowest. This part of Bereghinya Planitia is made up of lowland lava plains crisscrossed by chains of arachnoids, spider-like features seen in several regions of Venus. The arachnoids have raised rims that surround central depressions. Both concentric and radial fractures extend out from them. This image covers an area 1,842 by 1,613 kilometers (1,145 by 1,000 miles). *Image: JPL/NASA*



Laurel Wilkening Joins Planetary Society's Board of Directors


Photo: Kerrie Clayman

by James D. Burke

Laurel Wilkening, chancellor of the University of California, Irvine, has added The Planetary Society to the long list of her activities and concerns. We can confidently expect that she will be a lively, energetic participant in our affairs. Few people in this generation of American scientists have shown such a combination of originality, talent, devotion and managerial ability.

I first met Laurel when she was a young assistant professor at the University of Arizona, doing research on small bodies in the solar system by examining the mysterious compositions of meteorites. Even then, though appearing reserved, she was strong in her convictions and aware of the world beyond her own specialty.

She recognized early in her career that, if solar system exploration is to continue, scientists must persuade decision-makers of its value, so she began serving on the endless succession of committees and advisory panels that clutter the American landscape of government and science. And she did this superbly. Those of us who, from our various perspectives, were also trying to keep deep-space exploration alive came to admire her logical thinking and straight talk.

Graceful and strong, charming and funny, self-deprecating but never lacking confidence, she is just as much at ease among engineers, managers and bureaucrats as she is among her scientific colleagues.

Between 1977 and 1985, she worked on or chaired a series of working groups setting forth objectives for the scientific investigation of comets and asteroids. In 1985, she served as vice chairman of the National Commission on Space. This presidentially appointed panel, chaired by the late Thomas O. Paine, mapped out a future for humanity among the planets. Then she joined the Advisory Committee on the Future of the United States Space Program, whose 1990 road map is known as the Augustine report.

The chairman of that group, Norman Augustine, famous for his own no-nonsense approach to life and now the head of the Martin Marietta Corporation, says of Laurel: "She is one of the few people who understand both planetary science and how Washington works. Laurel possesses a great capability to work at the leading edge of knowledge, yet communicate ideas to students. Through her accomplishments, she has been highly respected in government, academia and industry." In 1992, she chaired a task group of the vice president's Space Policy Advisory Board, producing a post–Cold War assessment of US space policy whose impact is already being felt throughout America's space enterprise.

It's hard to see how she has had time for all those different achievements, acquiring such a reputation as researcher, teacher, academic administrator and advisor to government. But once you have the pleasure of knowing Laurel a bit, you can see that she makes it look easy. For one thing, she listens. She is a natural consensus-builder without giving in on principles. Now, faced with the challenge of leading a large university in very difficult times, she still puts energy into something else that she really cares about—namely, finding out more about the mysteries of the solar system. We are most fortunate to have her with us in this quest.

James D. Burke is Technical Editor of The Planetary Report.

This demonstration plant is capable of producing 1 kilogram (2.2 pounds) of oxygen per day.
Photo: Kumar Ramohalli

Mining the Air: How Far Have We Progressed?

by Kumar Ramohalli

For decades it has been known that the only practical way to enable large-scale space missions is to use extraterrestrial natural resources. Permanent lunar habitats and extended martian expeditions must use local materials and energy sources if they are to prosper, because it is simply too expensive to haul everything up out of Earth's deep gravity well.

Lengthy treatises have been written on the subject, study groups have convened in pleasant locales and pondered the problem, and always the answer is the same: We must learn how to live off the land if we are ever to establish a real human presence on other worlds. What has been missing is the actual laboratory work to begin finding out how to live off the solar system's resources away from our home planet.

Some early initiatives did occur: In 1978, G.K. O'Neill founded the Space Studies Institute at Princeton; one of its goals was exploring the problem both in theory and by experiment. And in various universities and industries, interested people carried out small experimental projects, demonstrating how to win metals and oxygen from simulated lunar soils.

By about 1985, the various possible avenues had been explored enough to justify a more focused attack. With NASA and some local sponsorship, a group at the University of Arizona in Tucson set up a new laboratory called the Space Engineering Research Center (SERC), with the primary goal of developing and demonstrating ways to use extraterrestrial resources.

In this article, Kumar Ramohalli, the head of the engineering faculty at SERC, gives us a progress report on one promising line of research: exploring ways to extract oxygen from the martian carbon dioxide atmosphere. The principles used are being adapted for lunar resource extraction and also for applications on Earth. –James D. Burke

The principle of the oxygen-extraction apparatus is simple but subtle, and its mechanism requires advances in materials and process technique (see the January/February 1991 issue of *The Planetary Report*). Carbon dioxide (CO_2) gas is passed through a hot ceramic electrochemical cell, where some of the carbon dioxide molecules are broken down into carbon monoxide (CO) and oxygen (O_2). The spent stream is passed through a copper- or nickel-based adsorption unit that separates carbon monoxide from the residual carbon dioxide. The carbon monoxide can be used as a fuel, and the carbon dioxide can be combined with hydrogen (H_2) produced by water electrolysis, yielding methane (CH_4) and higher hydrocarbons. A small demonstration plant, after operating successfully at SERC for hundreds of hours, has been sent to the NASA Lewis Research Center in Cleveland for further tests.

Meanwhile, at SERC, research has moved on to the goal of designing a plant having a mass of less than 2 kilograms (4.4 pounds) that could produce, from carbon dioxide input at martian conditions, 0.05 kilogram (0.11 pound) of oxygen per day. Such a plant could be used for early demonstrations on Mars. Larger plants are possible but their realization depends on the refinement of the ceramic disks or tubes that perform the electrochemical separation. A cell cluster with a mass of 10 kilograms (22 pounds) could produce its own mass in oxygen daily, if supplied with about 4 kilowatts of electrical power and 200 watts of thermal power for heating the gases. Including a solar and/or battery power supply, such a system would have a mass of about 300 kilograms (660 pounds).

Some of the same principles can be applied to lunar resource extraction. Lunar oxygen factories have been examined at various research centers; usually they require preprocessing of selected ores or the transport and use of quantities of chemicals from Earth. A major breakthrough at SERC has shown that any iron-bearing silicates, of types known to exist on the Moon, when mixed with a small amount of carbon powder (possibly transported from Earth) and heated, yield a CO/CO_2 gas mixture, which can then be treated by the electrochemical method described earlier to yield oxygen and recover the carbon.

This lunar oxygen production scheme, already demonstrated in gram quantities, is currently the focus of intensive development moving toward a complete, scaled-up plant. Thus at SERC we are readying the next steps toward automated demonstration of in situ resource recovery on both Mars and the Moon.

Kumar Ramohalli is the co-director of the University of Arizona/NASA Space Engineering Research Center and directs all of the engineering at the center; he is also a professor in the aerospace and mechanical engineering department at the University of Arizona.

News and Reviews

by Clark R. Chapman

At least 21 pieces of a broken comet are accelerating toward dramatic encounters with Jupiter in just a few months (see the January/February 1994 *Planetary Report*). They will streak down at 60 kilometers (37 miles) per second and disintegrate below Jupiter's clouds with energies of maybe tens of millions of megatons of TNT. In a five-day period, comet Shoemaker-Levy 9 (SL9) may dump as much energy into Jupiter's southern latitudes as the Yucatan impact 65 million years ago, which dramatically changed the course of evolution of life on our own planet.

The comet crash is unprecedented in the history of astronomy, and astronomers have been responding to a fascinating challenge: to prepare, with just a year's warning, for a once-in-a-lifetime opportunity and milk it for all it is worth. Most astronomers realize that there will probably never be another chance. Such million-megaton impacts hit Earth only every million years (fortunately!).

In mid-January, University of Maryland astronomers Michael A'Hearn and Lucy McFadden held a workshop. The goal was to exchange results about the comet, which had only recently been reacquired since it approached the Sun's glare last August. The workshop also facilitated coordination of observing plans and opened lines of electronic communications among observers.

Ordinarily, workshops are small gatherings. The meeting in College Park, Maryland, however, drew nearly 200 researchers, reporters and comet enthusiasts. SL9's discoverers, Carolyn and Gene Shoemaker and David Levy, were there. An unexpected attendee was Harvard University's George Field; during his last appearance at a planetary meeting, 16 years ago, he forecast the demise of planetary science in its competition with funds for the Great (astrophysical) Observatories. Just two of these orbiting telescopes have been launched; one is the Hubble Space Telescope, whose blurry vision has been fixed and which will be taking the most important pre-crash pictures of SL9 this spring.

Good news was reported at College Park. First, the impacts are now certain to happen over a five-and-a-half-day period beginning July 16. And they will happen only *just* around the edge of Jupiter as seen from Earth. A few months ago, it was even doubtful that the *Galileo* spacecraft would see the impact sites. Newly measured positions of the comet fragments have changed forecasts of SL9's trajectory: *Galileo* will certainly get fine views of the impact explosions; it is even remotely possible that the later impacts may eject some material high enough to be seen from Earth-based telescopes above Jupiter's morning horizon. (The revised orbit also shows that SL9 passed just one-tenth of Jupiter's diameter above its cloud-tops in July 1992. No wonder tidal forces ripped it apart!)

Theoreticians like Mordecai-Mark Mac Low of the University of Chicago are now more confident that the mighty planet will not simply swallow up SL9 fragments without a ripple. Fragment sizes are still not securely known, but the consensus in Maryland was that the larger ones are a kilometer—possibly 3 kilometers—across. Mac Low predicts that they will blow up not far below Jupiter's deep water clouds, and huge fireballs of gas, thousands of degrees hot, will ascend through the clouds as ejecta spread thousands of kilometers in all directions.

The spectacle will be extraordinary for *Galileo*'s instruments, but the bigger explosions should also be bright enough to be seen *by reflection* from Jupiter's inner satellites and rings. The impact sites will rotate within view of earthbound telescopes just half an hour after each explosion. During subsequent hours and weeks, new haze layers and perhaps vortices should be visible not only to Hubble, but even to advanced amateur observers, familiar with Jupiter's normal appearance, using their backyard telescopes.

Jupiter is a million billion times more massive than an SL9 fragment, so why should it be affected by a gnat? Because Jupiter's stratosphere is very tenuous: Injection of just a few cubic kilometers of comet ices and similar amounts of gas dredged up from Jupiter's atmospheric depths will overwhelm the dynamics and chemistry of the stratosphere—and it is the stratosphere that we can study most readily through telescopes. (Lower regions are hidden by cloud layers.)

An intriguing but especially difficult goal is to look for periodic waves generated by the explosions. Seismic waves may be detected during the first hours after the impact. Atmospheric gravity waves—excited by the fallback and splashing of material ejected by the explosion and fireball—may be tracked for days following each impact. However, it is doubtful that the tiny temperature changes produced by the waves (only hundredths of a degree) will condense visible clouds, permitting visibility from Earth.

Many observatory directors are still deciding what to do. New instruments are being built. Collaborations are being arranged with astronomers in far-flung corners of the globe. The hard-pressed *Galileo* project has postponed most SL9 planning until March 1, awaiting a funding augmentation from NASA headquarters. With excitement building, I predict that few astronomers will be indoors during evenings in the middle of July. The planning sessions in Maryland now seem to have ensured that whatever happens to Jupiter will be thoroughly documented and archived for posterity.

Clark R. Chapman will be planning Galileo*'s imaging of the comet crash.*

World Watch

by Louis D. Friedman

Moscow—The *Mars '94* mission remains scheduled for launch this coming October, despite widespread concerns about its survival. At a December 1993 meeting of the project's international science steering committee in Moscow, representatives of the Russian Space Agency and the Russian government affirmed their support for the mission and said that it has received full financial backing.

Following this strong endorsement, Russian industry and science personnel undertook an all-out push to complete the hardware in time to meet the launch schedule. Many of the science instruments and parts of the spacecraft were behind schedule, in part due to the great uncertainties in the Russian program.

Spacecraft manager Roald Kremnev emphasized that there was little time left and most contingencies in the schedule had evaporated. The science instruments must be tested and delivered as soon as possible.

Two mission parts are particularly shaky: the penetrators and the Argus scan platform. However, the mission could still fly without either one. The experiments on the penetrators would be lost, but the instruments planned for the scan platform could be attached to the spacecraft body itself. (An Argus *Mars '94* commemorative calendar is available to Society members; see the sales pages.)

The election of a new Russian parliament and uncertainty about the new government have engendered fears about timely funding for the space program. However, the support for *Mars '94* has made the mission's political and financial problems secondary to its technical ones.

If the hardware and software cannot be completed and tested in time, Kremnev has suggested a backup plan: Two identical spacecraft, complete with orbiters, penetrators and landers, could be launched in 1996. This would presumably mean that the *Mars '96* mission, carrying the rover and balloon, would slip to 1998.

At the time I write this, however, all is still on schedule for *Mars '94* to launch this year.

Washington, DC—Once again the United States federal budget cycle begins. In late January, President Clinton presented his fiscal 1995 budget to Congress. While most federal agencies saw their budgets reduced below 1994 levels, NASA's budget remained approximately level. This represents a victory for NASA Administrator Dan Goldin. Before the budget was finalized, there had been rumors of cuts of up to $1 billion for NASA programs.

The budget for the newly planned international space station was no surprise, since the redesign and its budget had been agreed to last year, and President Clinton and Vice President Gore had both endorsed the new plan to include the Russians as major partners. Europe, Canada and Japan have now also approved the inclusion of the Russians in the space station program.

In preparing for this new international station, American astronauts will fly on the Russian space station *Mir* and Russian cosmonauts will fly on the space shuttle. In several missions, the US shuttle will dock with *Mir* as practice for the rendezvous with the space station.

Planetary exploration fared well in the president's budget, and the *Cassini* mission to Saturn and Titan received full funding. But because this is a very large and ambitious mission, congressional budget-cutters already have *Cassini* in their sights. (See page 5.)

The new budget also contains initial funding for a Mars program that would launch a series of small missions to recover from the loss of *Mars Observer*. A small orbiter and lander would be launched at every opportunity, beginning in 1996 with *Pathfinder*, which would put a small station carrying a microrover on the martian surface.

Pathfinder is part of the Discovery program, which includes the Near-Earth Asteroid Rendezvous (NEAR) mission. NEAR is also scheduled for a 1996 launch.

We will keep you informed as NASA's budget travels through Congress.

Washington, DC—The remarkable success of the shuttle *Endeavour* mission to repair the Hubble Space Telescope has restored NASA's image as a "can-do" agency. Early tests indicate that the repairs were successful and the new equipment is working superbly. We've been critical of the agency in the past, but today we say: Congratulations, NASA!

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

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Universe Down to Earth

By Neil de Grasse Tyson; Columbia University Press, New York, 1994, 236 pages.
Retail price: $29.95
Member price: $25.00

The periodic table and the zodiac both represent the efforts of human beings to impose order and predictability on nature. The periodic table of the elements is a remarkable synthesis of research in physics, chemistry and astronomy. The zodiac, remarkable in an altogether different way, is a monument to the stubborn adherence of people today to the religious cults of long-dead Chaldeans and Babylonians.

In *Universe Down to Earth*, Princeton astronomer Neil de Grasse Tyson offers a clear description of many of the elements in the table, along with explanations of how we know what we know about them. He also takes on the zodiac, explaining in the same reasonable tone how the signs of those constellations familiar to every reader of a daily newspaper were codified in the second century AD by the Greek philosopher Ptolemy, who added to them not only names, but "quirky behavioral traits."

Tyson explains the premise of modern astrology—that the relative positions of the Sun, Moon, planets and constellations at someone's birth affect that person's life forever after. These positions, he continues, are based on the sky as Ptolemy knew it, with the astrological year beginning with the vernal equinox, the first day of spring in the northern hemisphere.

On this day, the Sun begins its journey through the 12 constellations of the zodiac. In Ptolemy's time, this coincided with the constellation Aries. Alas, the heavens have shifted since then, so the vernal equinox is now in Pisces and is moving toward Aquarius. Because Earth wobbles on its axis, the equinox will continue to drift through the entire zodiac over the next 25,000 years, pushing all of us into different signs than the ones we were supposedly born under. In other words, the zodiac no longer makes sense even in its own terms. If "Horrorscope" were the only chapter, *Universe Down to Earth* would be worth having.

But other treasures abound in these collected essays. There is a terrific explanation of the meaning of the scientific method, with examples of how some of the greatest thinkers wobbled on their own axis when they rejected evidence in favor of personal bias. Aristotle, for example, said it was self-evident that a 100-pound iron ball would fall to Earth faster than a 1-pound iron ball, and left it for Galileo to disprove. And Einstein, unhappy with the unpredictability of quantum mechanics, doubted its accuracy because he was uncomfortable with the idea that God plays dice, which is too bad, Tyson tells us, because the evidence is that "God *does* play dice."

Members of The Planetary Society will enjoy "Electromagnetic Spectrum: The Astronomers' Family of Photons," a chapter that describes the realms of radio, microwave, infrared and optical astronomy that enabled us to see cloud-shrouded Venus.

Unlike most of the books we recommend, *Universe Down to Earth* is about the stars beyond our planetary system. Tyson is an excellent guide to the constellations for readers who have never connected the dots beyond Orion and the dippers. Mixing literary allusions and down-home humor, Tyson leaves his readers wiser for the journey.
—Reviewed by Bettyann Kevles

Still Available: *Tales of the Earth: Paroxysms and Perturbations of the Blue Planet*

By Charles Officer and Jake Page. Reader-friendly, with just the right mix of solid data, anecdote and humor, this well-illustrated volume examines some of the cataclysmic events in Earth's tumultuous history. (Reviewed November/December 1993.)
Retail price: $24.00
Member price: $21.00

Newton's Clock: Chaos in the Solar System

By Ivars Peterson. This 2,000-year sweep of humanity's efforts to predict celestial movements gives us a look at chaos theory as applied to astronomy and raises the disquieting question of how stable the solar system really is. (Reviewed January/February 1994.)
Retail price: $22.95
Member price: $20.00

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Society News

Keeping Up With Planetary Events

Here's a sample of some of the events The Planetary Society has planned for this summer.

• Cairo, Egypt, is the site for the United Nations' and European Space Agency's Fourth Space Science Workshop on Basic Space Science for Developing Countries. Cosponsored by The Planetary Society, the workshop will take place from June 27 to July 1, 1994. There is no registration fee for the workshop, but the number of participants will be limited. For more information, contact the Society by April 29, 1994.

• In Washington, DC, from July 16 through 23, 1994, Society members can take part in the Jupiter Watch Tour, an event that celebrates the anniversary of *Apollo 11* and the expected collision of comet Shoemaker-Levy 9 with Jupiter. Tour highlights include speeches by Carl Sagan and Louis Friedman and a chance to view Jupiter from the US Naval Observatory. For more information, call Sam Shah at the Travel Syndicate, 1-800-292-0650 or (818) 999-3696.

—Susan Lendroth, Manager of Events and Communications

Planetary Society Looks Up From Down Under

Australia is becoming the center of important work in the Search for Extraterrestrial Intelligence (SETI). In September 1993, the United States Congress canceled NASA's SETI program—the High-Resolution Microwave Survey (HRMS). The SETI Institute in Mountain View, California, is raising funds to continue some of the NASA project.

Fortunately, engineers and scientists at Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) plan to complete a portion of the HRMS project. They will use CSIRO's radio astronomy facilities to scan the skies for signals from extraterrestrial civilizations.

This news follows a number of successful Planetary Society SETI seminars in Australia, further indicating that support for SETI remains strong down under. Held in Sydney, Melbourne and Canberra in October 1993, the three seminars focused on SETI in the southern hemisphere. Attendees at the Canberra seminar, which featured Society speaker Guillermo Lemarchand and five others, heard how enough equipment has already been completed to allow a reduced sky survey program to proceed at CSIRO.

In late April 1994, CSIRO Fellow Roberta Vaile will deliver further news of Australian efforts. She will speak at the next Society SETI lecture, to be held as part of the Second Australian Science Festival in Canberra. For more information, contact the festival at (61)-6-207-6477.
—Matthew James, Australian Volunteer Coordinator

Raise Your Voice: Help the Society Talk Back on Space Issues

Numerous articles about space programs appear every day in newspapers and magazines around the world. Many are positive, supporting planetary exploration or the Search for Extraterrestrial Intelligence. But many others are negative, and some contain misleading or obsolete information.

The Planetary Society would like the opportunity to respond to some of these pieces, and we need your help. Please clip any appropriate articles you find and send them (with the name, date and city of publication) to the Society. As needed, we will respond with the Society's perspective on issues that can help shape space policy.

We also encourage you to respond as a citizen of the community in which the publication is circulated. Let's not allow these pieces to go unchallenged. As issues arise, start writing to publications, and send clips to me at Planetary Society headquarters. *—SL*

Russian Mars Rover Tests in US This Spring

In a late-breaking development, the Russian Mars Rover will be tested in southern California between March 23 and April 2, 1994. The tests will include a demonstration of telepresence technology at the National Science Teachers Association convention in Anaheim, California (see Society News in the January/February 1994 *Planetary Report*). To learn more about the rover tests, call the Society at (818) 793-4294. *—SL*

New Millennium Committee Welcomes Youngest Member

The Planetary Society welcomes the newest and youngest member of its New Millennium Committee—one-year-old Richard Weisman, Jr. His membership was a Christmas present from his father, longtime committee member Richard Weisman of Seattle, Washington, who is now leading the restructuring efforts of this special group of Society donors.

The committee's donations go toward creating projects that will last into the new millennium, that is, into the 21st century. In 1994, the committee will emphasize developing an active donor group that can help advance the work of exploring the solar system and searching for extraterrestrial life.

We thank the Weismans, and all the New Millennium Committee members, for their support. For more information about the committee, contact me at Planetary Society headquarters.
—Louis D. Friedman, Executive Director

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Questions and Answers

What are the names of Titan's atmospheric and surface layers? In which layer would we most likely find life?
—Jorge A. Alba, Chihuahua, Mexico

Most of what we know today about Saturn's moon Titan comes from data gathered by the *Voyager 1* spacecraft when it passed the satellite in 1980. We learned that the atmosphere is substantial, 90 to 95 percent nitrogen, with a remainder of mostly methane. Besides a number of gases produced from these two main molecules, there are aerosols (dust particles) that form haze layers at different altitudes.

Unfortunately, *Voyager 1* couldn't get a glimpse of the surface because Titan is covered with thick, orange-brown clouds. We can only speculate on the satellite's lower atmosphere and interior, but we have models of their structures based on available pressure and temperature data.

Like our planet's atmosphere, Titan's is subdivided into four main layers controlled by the temperature variations with height or pressure and characterized by two temperature inversions (locations above which the temperature increases with altitude, while the opposite takes place underneath). The boundaries of the different layers are identified by terms ending with "pause" (from the Greek word for "end").

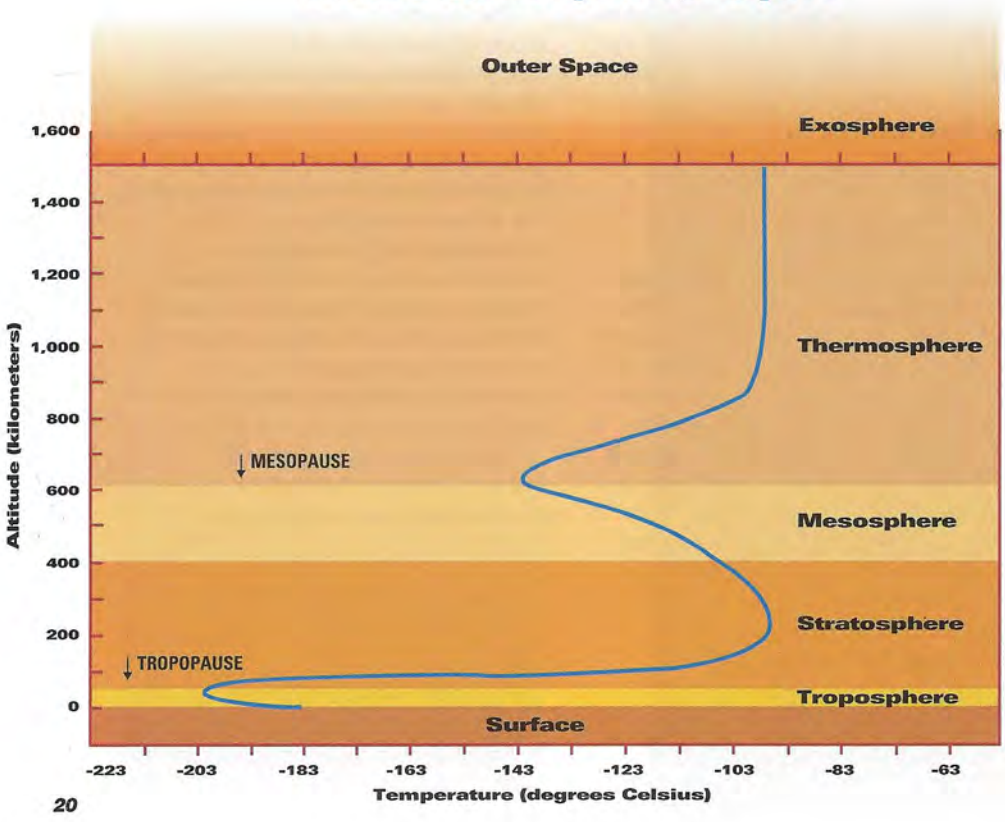
The outer part of the atmosphere, which grades from outer space to about 1,500 kilometers (about 930 miles) altitude, is the *exosphere*, from which light elements escape the planet's grip and are lost to space. Below it lies the *thermosphere,* the largest part of the atmosphere. The thermospheric temperatures regularly increase with altitude from about minus 140 degrees Celsius (minus 284 Fahrenheit) at the mesopause, around 600 kilometers (about 370 miles) up to minus 90 degrees Celsius (about minus 135 Fahrenheit).

The mesopause marks the end of the *mesosphere*, a part of the atmosphere in which temperatures decrease with height. On Earth, the mesosphere begins about 50 kilometers (31 miles) above the surface, whereas on Titan it occurs between 400 and 600 kilometers (about 250 and 370 miles). Due to the absorption and conversion of ultraviolet radiation by different gases and aerosols in the *stratosphere*, the atmospheric layer beneath the mesosphere, the temperature rises again with altitude from a minimum of about minus 200 degrees Celsius (about minus 392 Fahrenheit) at around 40 kilometers (about 25 miles), where the second temperature inversion occurs, up to minus 98 degrees Celsius (plus or minus 5 degrees) at around 300 kilometers.

From the surface up to about 40 kilometers, we find the *troposphere*, where energy transport is performed through convection (that is, since the temperature decreases with altitude, the warmer air lying under colder air is unstable so it rises while the colder air sinks). Ninety percent of the incoming solar radiation is absorbed in the higher atmosphere, allowing only 10 percent to reach the ground, which warms up to about minus 180 degrees Celsius (minus 356 Fahrenheit) and reradiates heat that is absorbed by methane and other hydrocarbon clouds at the tropopause.

The increase in temperature as one nears Titan's surface is due to a modest greenhouse effect similar to that on Earth due to water vapor. Methane and nitrogen photodissociation (the separation of molecules due to absorption of

Titan's Atmospheric Layers



radiant energy like light and ultraviolet rays) takes place in the higher parts of Titan's atmosphere, where sunlight triggers a series of chemical reactions leading to the production of a large number of constituents. Hydrocarbons (such as ethane, acetylene, ethylene and propane) and nitriles (such as HCN and CH_3CN, prebiotic molecules believed to have been among the starting materials that led to life on Earth) are created from the parent molecules and dominate the composition of Titan's atmosphere.

The minimum titanian temperature at the tropopause (also known as the "cold trap") may be cold enough for methane and other hydrocarbons to condense and form clouds that eventually rain out on the surface. In such a case, liquid hydrocarbons could cover Titan's surface.

One model predicts that the hydrocarbon ocean may be stored in a porous, uppermost few kilometers of methane or water ice "bedrock"; 250 kilometers (155 miles) beneath it, a water–ammonia ocean could occupy another 200 kilometers, hiding in turn an ammonia–water ice mantle situated right above the rock core.

Because of condensation, if life exists on Titan, we would expect it to be on the surface (as on Earth). However, a major chemical link is missing: oxygen, which is scarce because water remains trapped in a frozen state on the surface, is lacking in the atmosphere and cannot interact with the other components.

So in spite of all the similarities between Titan and Earth, the cold temperatures (which slow chemical reactions), the feeble sunlight (about 1 percent of that at Earth) and the lack of sufficient amounts of oxygen should prevent the miracle of life from happening on this distant satellite. Nevertheless, Titan's environment does provide significant insight into the conditions that prevailed on Earth during its early history and into the chemistry that then gave rise to life.
—ATHENA COUSTENIS, *Observatoire de Paris-Meudon, France*

Several years ago, Russian scientists claimed to have seen a human television broadcast from space, as if reflected by an object. We probe planets with radar; could we look for other stars with planets? Might some of the noise that we detect from space be alien interstellar radar?
—Robert Kirkman, South Miami, Florida

I haven't heard about this Russian claim. It sounds suspiciously like the kind of story the tabloids invent, in which they quote nonexistent "experts" as their sources. Or, it could be a distortion of a legitimate report. For example, TV signals usually travel in a straight line, unlike the longer radio communications that are reflected by the ionosphere, enabling them to travel thousands of miles. But once in a great while, there are unusual ionospheric conditions that can even allow American TV signals to be picked up in England, or vice versa. We can also detect Earth's radio signals reflected off the Moon.

We do bounce powerful Earth-based radar off Mars, Venus, near-Earth asteroids, the moons of Jupiter and the rings of Saturn. (The bodies of the giant planets absorb radar, so they aren't good reflectors.) The trouble with radar, though, is that it obeys an *inverse fourth power* law. Where radio signals decrease their intensity as the square of the distance, the *reflected* signal also decreases as the square of the distance, so the *received* signal decreases as the fourth power of the distance instead of as the square. This means that it takes fantastically powerful transmitters and very sensitive receivers and antennas to get even a feeble reflection off the nearby planets.

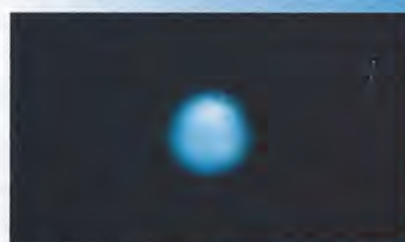
It's unlikely that anyone would use radar to detect planets around another star. You get far more energy by looking at the planet with a telescope, taking advantage of the fact that nature put a gigantic energy "transmitter," a star, next to the planet.

However, one of the strongest signals of intelligent life from our planet that could be detected by another civilization is the military radar of the United States and Russia. It's possible that some of the noise we pick up from SETI, the Search for Extraterrestrial Intelligence, is from some alien's radar. But if it isn't strong enough, it will be washed out by galactic noise. This is one of the frustrations of SETI!
—THOMAS R. McDONOUGH, *SETI Coordinator*

Factinos

Recent images of Neptune show that the planet has taken on a surprising new look. Last summer, as Heidi Hammel of the Massachusetts Institute of Technology was studying Neptune with the University of Hawaii's 2.2-meter telescope, she discovered that the planet's northern hemisphere looked significantly brighter than its southern hemisphere (see image below). A feature or two had shown up occasionally in past images, and *Voyager 2* revealed some faint, wispy structures there, but they were always accompanied by bright features in Neptune's southern half.

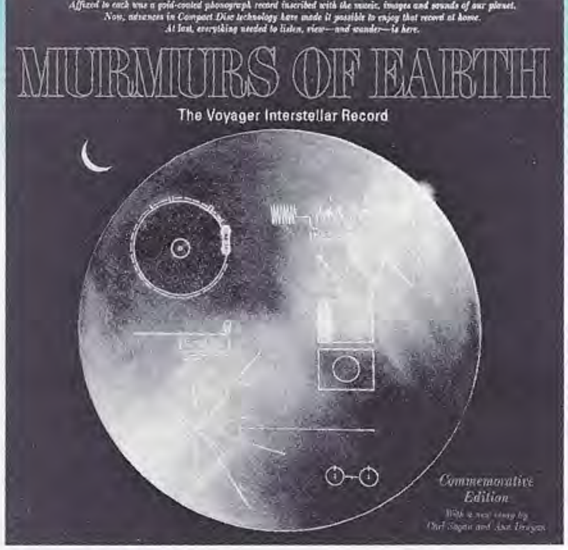
"These new images are strikingly different from anything I've ever seen before," says Hammel, who has been studying Neptune for nearly a decade. One thing is certain: Images captured during a spacecraft's flyby provide only snapshots of atmospheres and systems that can later change dramatically.
—from the Massachusetts Institute of Technology



This image showing Neptune's new look was captured with the University of Hawaii's 2.2-meter telescope atop Mauna Kea on July 12, 1993. The only clearly visible feature is the bright area in the planet's northern hemisphere. *Image: H.B. Hammel and R.P. LeBeau*

In early January, an independent board of investigators reported that the failure of *Mars Observer* was most likely due to a sudden rupture of the spacecraft's fuel pressurization system.

Timothy Coffey of the Naval Research Laboratory, who headed the investigation, said the board concluded from considerable circumstantial evidence that leaking fuel very likely sent *Mars Observer* into a rapid, uncontrollable spin. This would have triggered an emergency shutdown and prevented the craft from pointing its antennas for communications with Earth. In addition, the spin probably shook loose antennas and almost certainly led to battery failure.
—from John Noble Wilford in *The New York Times*



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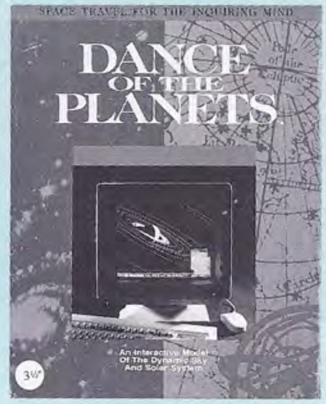

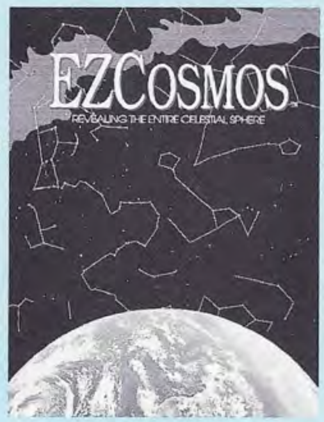

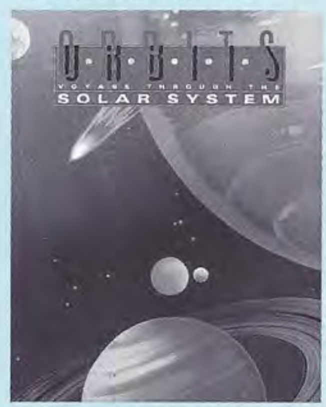

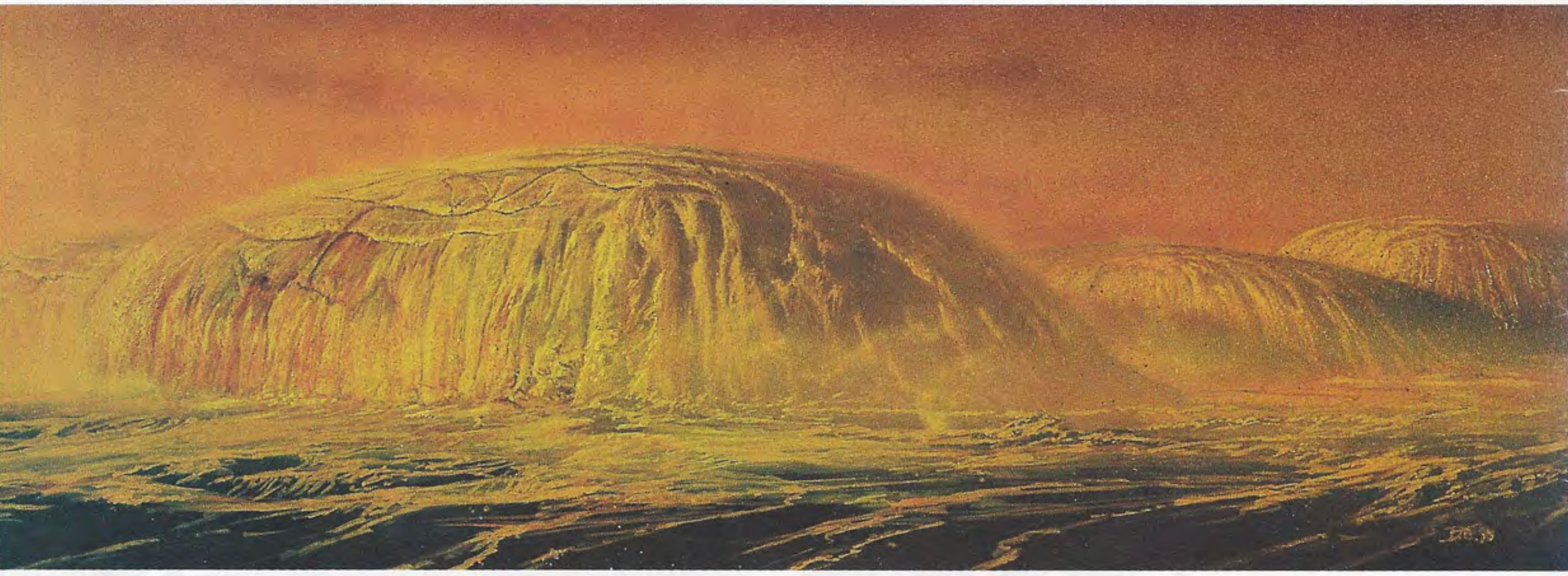

An early *Magellan* image served as the basis for "Venus Domes." Bob Eggleton simply imagined how the mysterious features, which so closely resemble pancakes from above, might look from the planet's surface. These pancake domes are volcanic features formed when thick, slowly erupting lava oozes onto the surface. When the lava cools and the magma beneath the surface withdraws, the dome subsides and cracks.

Bob Eggleton's award-winning artwork has appeared in books, prints and calendars around the globe. He resides in Rhode Island and makes his living as a space and science fiction painter.

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