The PLANETARY REPORT

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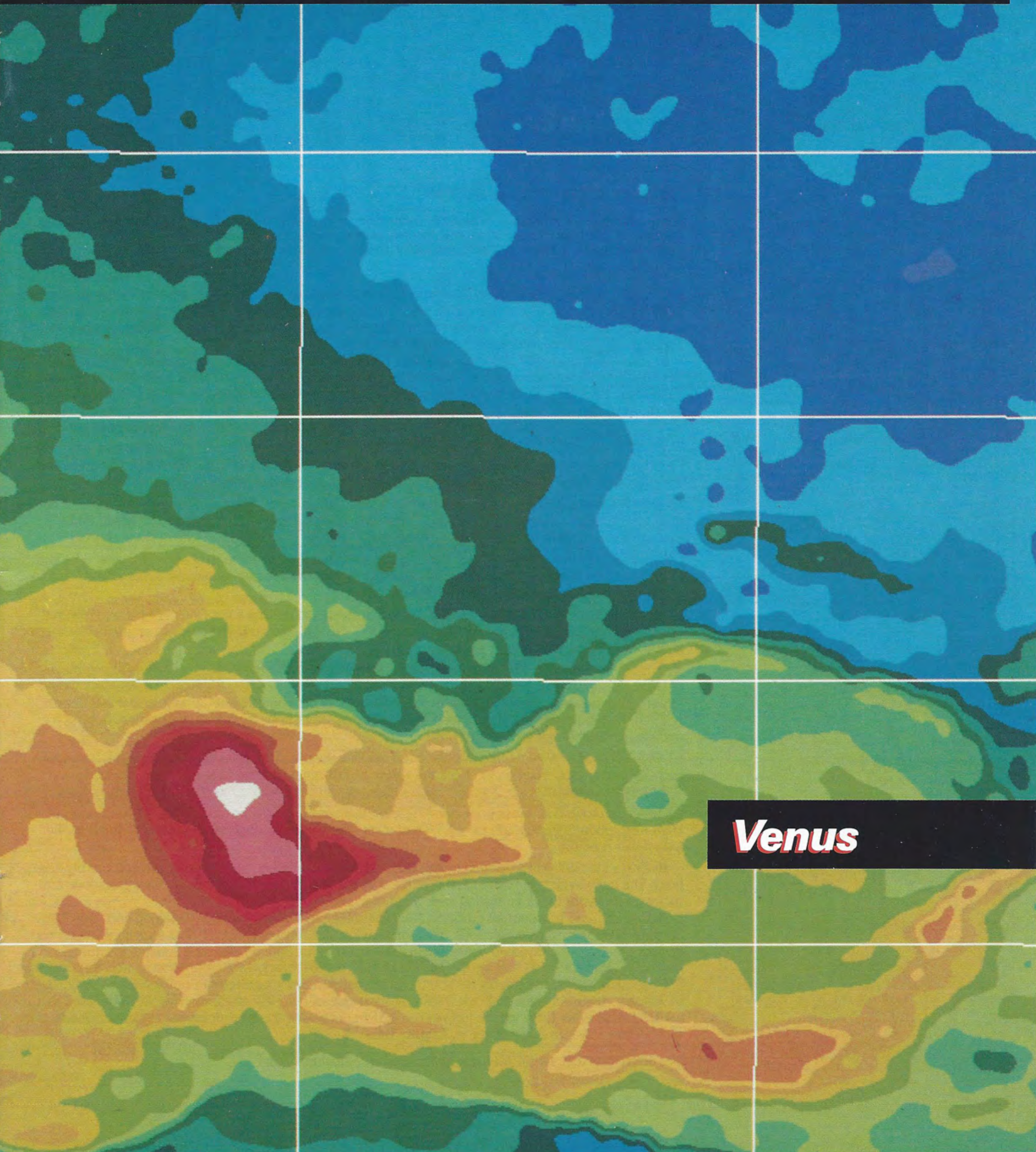

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COVER: Venus' highest mountain, Maxwell Montes, appears in this new map compiled from data returned by the Soviet Venera 15 and 16 orbiters. The main mountain (shown here in red and white) is part of a tectonic mountain belt and spans about 1,000 km from north to south. Maxwell Montes rises 11 km above Venus' mean surface; Earth's tallest peak, Mauna Loa, is only 8 km above the Pacific Ocean floor. Tying strips of altimetric data together to produce this preliminary map was an arduous task; elaborate image enhancement and radar-image mosaics will be completed later. Image provided by Harold Masursky, with computer processing by Laurence Soderblom and Robert Gurule, United States Geological Survey

Letters to the Editor

We encourage our members to write to us on topics related to the goals of The Planetary Society: Continuing planetary exploration and the search for extraterrestrial life.
Address them to: Letters to the Editor, 65 N. Catalina Avenue, Pasadena, CA 91106.

For 10 years astronomers around the world have been looking forward to the remarkable capabilities of the Hubble Space Telescope (HST). With this instrument we will not only be able to see farther into space than ever before, but we will be able to see nearby objects, such as planets, with resolutions available previously only from flyby spacecraft.

In 1981, 1984 and 1987, I used a 330-page NASA publication, "Scientific Research with the Space Telescope," as a text in my course "Astronomy with the Space Telescope" at the University of Houston, Clear Lake. Each time 12 to 15 graduate students were led to believe that HST would be launched by the shuttle within two years. In their term papers, each student presented his proposal for using HST on some important astronomical research, ranging from Neptune's ring-arcs and martian dust storms to evidence of black holes and bridges between galaxies and quasars:

☐ Brian Bird in *Mars Climatology* wants to use the Planetary Camera, the Faint Object Camera and the High Resolution Spectrograph to study the beginning and end of a dust storm.

☐ Robert Carmody in *Jupiter's Great Red Spot* wants to use the Planetary Camera with infrared and ultraviolet filters to monitor the Red Spot over long intervals to check its circulation depth and mathematical models of vorticity and divergence.

☐ James Foster in *Lagrange Points* wants to use the Wide Field Camera to observe dust at the L4 and L5 points of the Earth-Moon system, and he wants to observe an asteroid with the Faint Object Camera at the L4 and L5 points of the Sun-Jupiter system.

☐ Rene Martinez in *T-Tauri and Herbig Ae/Be Stars* wants to use the Faint Object Camera to observe the spectra and possible planetary disks around DG Tau, HL Tau and W90, then go on to check other faint members of this class of stars.

☐ Harold Robertson in *The Neptunian Ring System* wants to use the Planetary Camera to get images of Neptune's rings and possible shepherding satellites before *Voyager 2's* flyby in 1989. This would require 12 exposures. If nothing is detected, he would try the Faint Object Camera, and if that detects nothing, he would use the High-Speed Photometer on stars to be occulted by Neptune, hoping for occultation by the ring-arcs or full rings.

☐ Richard Todd in *Object Chiron* wants to use the Planetary Camera, Faint Object Spectrograph and the High-Resolution Spectrograph to check the nature of this unusual asteroid/comet from its albedo and surface-reflectivity spectrum. The High-Speed Photometer could be used to determine Chiron's rotation.

☐ Brian Zuckowski in *Mass Loss from T-Tauri Stars* wants to use the Wide Field Camera and the High-Resolution Spectrograph on 19 T-Tauri stars. His goal is to improve estimates of input to the interstellar medium.

Because the HST was grounded by the 1986 *Challenger* accident, all observing projects are now on hold. The early launch of HST will be prompted by the fact that to store the flight-ready telescope and maintain its instruments is costing over $1 million per month.

Before HST can be operated properly, NASA's shuttle must launch another Tracking and Data Relay Satellite (TDRS) to geosynchronous orbit for relaying vast amounts of HST data to ground receivers, and eventually to the Goddard Space Flight Center and to the Space Telescope Science Institute near Baltimore. Present plans call for the launch of HST in November, 1988. After checks and tests (of, among other things, the effects of "shuttle glow" on the telescope), research observations may start in January, 1989. As the list above shows, at least one of my 1987 students (Harold Robertson) is wondering whether there will be time to use HST to determine the hazardous ring region around Neptune before *Voyager 2* gets there in August, 1989.

THORNTON PAGE, *NASA Johnson Space Center, Houston, Texas*

Questions & Answers

What is the feasibility of terraforming the planet Mars by using existing technology? If we did supply Mars with an atmosphere, how long would the planet retain its oxygen and water? Can we really turn Mars into another Earth?
— Richard Autry, Adkins, TX

Mars is the planet most like Earth in our solar system, but an unprotected human being could not survive there. Although tropical midday temperatures may be quite nice, the average temperatures are colder than those in Antarctica. The water that Mars possesses, probably enough to fill a shallow ocean, lies frozen in the ground. Mars has plenty of oxygen stored in these water molecules, but has little in its atmosphere. On Earth, photosynthesizing plants release oxygen from water into the air we breathe. The martian atmosphere is so thin (the surface pressure is equivalent to being at an altitude of about 35 kilometers on Earth) that a human's blood would boil. Also, deadly radiation reaches the surface of Mars. Earth's denser atmosphere protects us from high energy particles and the ozone in our atmosphere absorbs harmful ultraviolet sunlight.

What could we do to make Mars more comfortable? First, we need to increase the atmospheric pressure. It would be nice to do this with an inert gas such as nitrogen which composes about 80 percent of Earth's atmosphere. Unfortunately, there may not be enough nitrogen on Mars in available forms. If not, then carbon dioxide is the obvious substitute.

The abundance of carbon dioxide in the martian atmosphere is about 30 times that on Earth, but we need much more. Large quantities of carbon probably exist on Mars in the form of carbonates just as most of Earth's carbon is stored in the sediments as limestone. If all the carbon in the soil could be converted to carbon dioxide the atmospheric pressure might rise to the terrestrial range. Increased carbon dioxide would warm the planet by the greenhouse effect, leading to the release of liquid water. Plants, which love to eat carbon dioxide, could be used to build up oxygen and ozone in the atmosphere, a process which might take millions of years.

What we need then is a mechanism to convert carbonate rocks into carbon dioxide. On Earth, volcanism does this (see James Kasting's article in the Jan/Feb 1985 *Planetary Report*). The only economically practical way I can envision to do this on Mars is to discover an organism that loves to eat carbonate rock and thereby convert it to carbon dioxide. Even then it is unlikely that we would be able to manufacture enough carbon dioxide to warm the planet to Earth-like levels.

An alternative would be to steer volatile rich comets onto orbits which would impact Mars. We need a carbon mass approaching 10^{21} grams, equivalent to at least one million carbon-rich comets of one kilometer radius. The impacts of these comets would completely destroy the martian surface converting some of the soil back into volatiles. Unfortunately, in a warm, moist atmosphere these volatiles would be reconverted to carbonates in a few million years, making resupply necessary. Moreover, high carbon dioxide levels would be poisonous to animals. Humans would have to use respirators when outside.

Clearly, terraforming Mars wouldn't be easy. We won't get far in planning such ventures until we know more about Mars, especially about the amounts and forms of minerals in its soils. Terraforming on small scales will have to be practiced first. I don't expect that humans will walk unprotected on the surface of Mars for a very long time — if ever. However, it wouldn't surprise me if my three-year-old-son were someday able to live there in a terraformed environment not of global scale, but large enough to call home.

— OWEN B. TOON,
NASA Ames Research Center

If you have a question you'd like answered, send it to: *The Planetary Report*, Q&A, 65 N. Catalina Avenue, Pasadena, CA 91106. Please keep the questions short and limit their subjects to planetary exploration and the search for extraterrestrial life.

The Earth orbits the Sun at an approximate speed of 30 kilometers per second or 1,116 miles per minute or 66,960 miles per hour. This comes to an awsome 1,607,040 miles per day.

How can we travel that fast and not feel it? At that speed, why doesn't an airborne, hovering object (such as an airplane) lose its position and proximity with Earth?
— Bryan Farha, Oklahoma City, OK

We are in the same position as a caterpillar on a leaf of lettuce in the salad of an airline passenger. As Earth spins on its axis and whizzes along its orbit around the Sun (and as the Sun and planets move in the galaxy, and the galaxy moves in the local supercluster and so on), we do not feel the motion because we, our immediate surroundings and our atmosphere (with all the aircraft in it) are all moving together, held together by Earth's gravity.

We can, however, easily detect effects of other bodies moving near us — for example, by observing the tides caused by the Moon and Sun. With finer instruments we could tell, even without looking up at the heavens, that Earth is rotating once per day, because bodies appear to weigh a bit less at the equator than they do at the poles due to centrifugal force. But these apparently simple concepts, made clear in mathematical terms by Isaac Newton, George Darwin and other students of classical physics, turned out to contain much deeper possibilities when examined by Albert Einstein, who began by asking what an observer in one moving "frame of reference" sees when he looks at another, and by Ernst Mach, who asked whether or not Earth's spin could be detected if it were the only object in the universe. So, on one level, your question is easy to answer: We do not feel our planet's motion because we share it. But on a deeper level, your question is profound.

— JAMES D. BURKE,
Jet Propulsion Laboratory

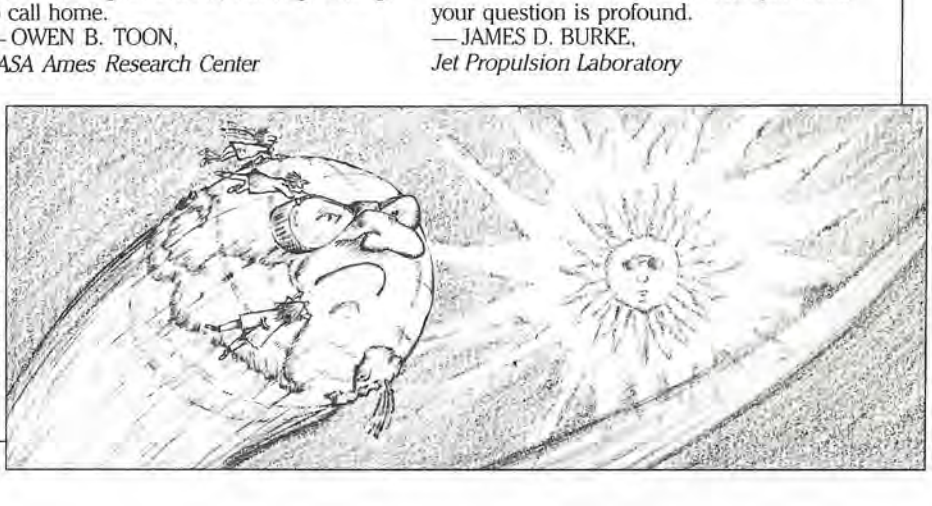
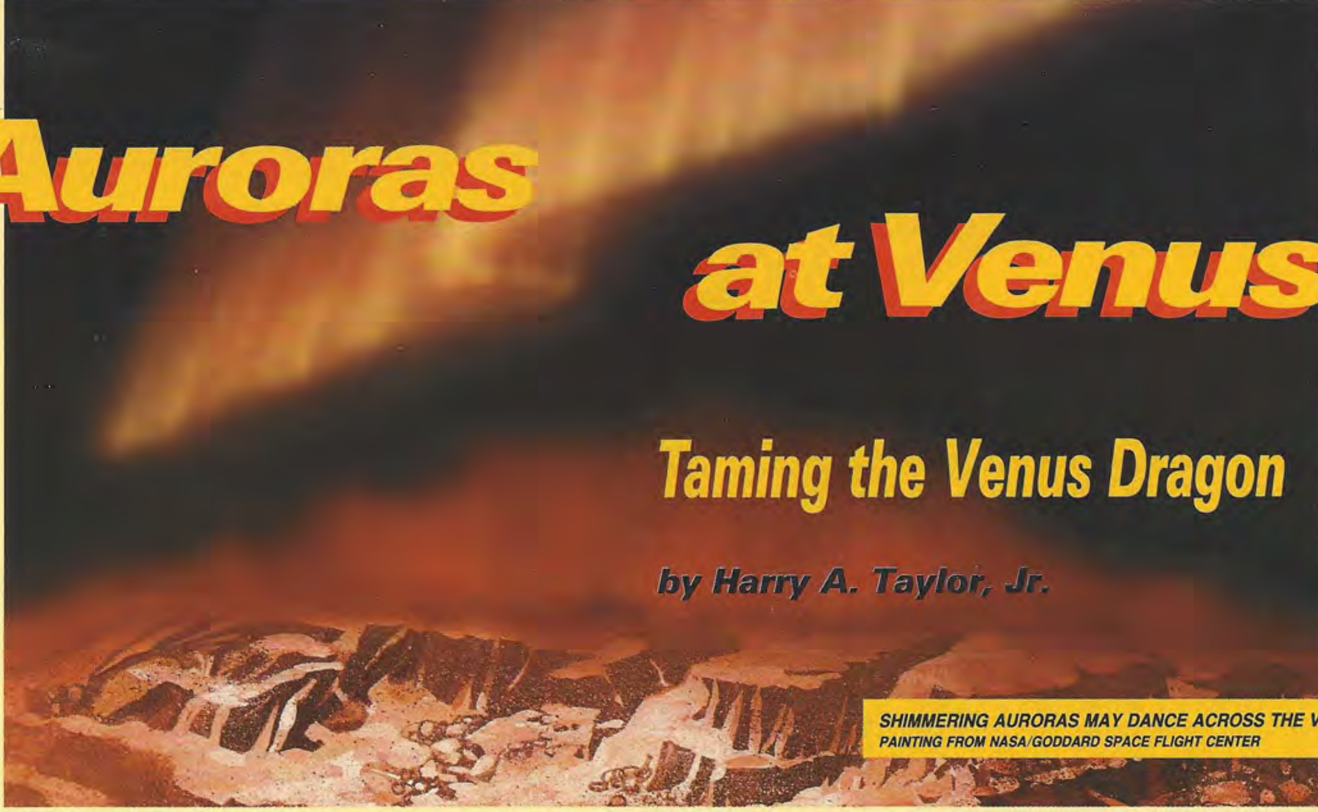


ILLUSTRATION: S. A. SMITH

Auroras at Venus?

Taming the Venus Dragon

by Harry A. Taylor, Jr.



SHIMMERING AURORAS MAY DANCE ACROSS THE VENUS SKY.
PAINTING FROM NASA/GODDARD SPACE FLIGHT CENTER

Does lightning frequently split the Venus sky? Do gigantic volcanos spew clouds of sulfurous gas, triggering the electrical flashes? Or does a shimmering aurora form above the dense, seething atmosphere, resembling the tenuous lights that sometimes girdle Earth's poles? For the past few years, scientists have been hotly debating these two different pictures of Earth's nearest neighbor. Venus is Earth's "sister" planet. It's about the same size as our planet and shares our neighborhood near the Sun. But these two similar worlds have evolved into very different places. Benign nitrogen gas makes up most of Earth's atmosphere; carbon dioxide composes 96 percent of Venus' atmosphere. This carbon dioxide has generated a "runaway greenhouse effect" that has raised Venus' surface temperature to 460 degrees Celsius — hot enough to melt lead.

On Earth, we measure atmospheric pressure in bars; one bar is the pressure at sea level. On Venus, the surface pressure reaches a crushing 90 bars. There winds flow more like deep ocean currents than gentle summer breezes. While most of Earth is covered by water, any water that may have lain on Venus' scalding surface has long since disappeared. The remaining atmospheric water vapor joins with the abundant sulfur dioxide to form sulfuric acid clouds.

Thick sulfuric acid haze completely enshrouds Venus, hiding its surface from optical instruments. But this shroud is transparent to radar, and several radar investigations — from the great radar dish at Arecibo, the Soviets' series of Venera spacecraft and NASA's Pioneer Venus mission — have remotely mapped the planet. Our knowledge of the planet's topography is based on these observations. Several Venera spacecraft have landed on Venus and transmitted images and chemical analyses of surface rocks back to Earth before being destroyed by the temperature and pressure. Their data revealed a primarily basaltic surface, formed by volcanic processes.

But Venus' hostility to Earthly probes has allowed it to keep many of its mysteries. We see evidence of past volcanic activity on Venus, but are volcanos still erupting? The Pioneer Venus Orbiter has detected radio "noises" that appear similar to those generated by lightning on Earth. Does this mean there is lightning on Venus? Or is there an alternative possibility, such as auroral activity, that can explain the data? In this article, Harry A. Taylor presents his side of the controversy, and William J. Boruki offers the opposing arguments. — CHARLENE M. ANDERSON

The vision of a volcanic, lightning-rent Venus has dominated thinking about the planet for the past few years. Some scientists have interpreted electrical noise detected by Soviet and US experiments as evidence of lightning. The most extensive data, taken from more than four years of observations by the *Pioneer* Venus Orbiter, have stimulated arguments for both extensive lightning and massive volcanos, which are asserted to stimulate the lightning and to change the composition of the atmosphere.

But there is an alternative explanation: The noise is stimulated by the interaction of the solar wind (a stream of magnetized charged particles from the Sun) with the nightside ionosphere, in a manner analogous to disturbances in the auroral zones on Earth. The Venus environment may not be quite so hellish as imagined, and the planet may have been volcanically inactive for some time.

The spectre of an infernal environment might well cause future space travelers to avoid visits to Venus. Along with a massively heavy and overheated atmosphere, the suggestion of massive volcanos belching forth volumes of sulfurous gases, stimulating widespread lightning, creates a Dantesque image not likely to encourage tourism, even with budget fares!

How did such an image develop, and is there good evidence to support this frightening perception?

Mysterious Noise

The presence of lightning and explosive volcanos was first suggested by unexplained radio noise detected by the Soviet *Veneras 9* and *10* as they penetrated the atmosphere below the clouds. Although tentatively interpreted as caused by lightning, this noise was observed when the descent probe was in the clear air below the clouds, perplexing the investigators as to the possible source. They referred to the unexplained source as "The Electrical Dragon on Venus." Unable to explain the noise otherwise, the investigators suggested that perhaps volcanic activity, if present, could stimulate the atmosphere to create the otherwise unexpected lightning discharges.

It is not so surprising that the Soviet experimenters used such a colorful analogy for the unexplained phenomenon. Historically, early humans had a similar problem in attempting to explain the mysterious and dramatic heavenly displays that we commonly call the aurora borealis, or northern lights. (The southern hemisphere counterpart is called the aurora australis.) Before the realization that a magnetic field surrounds Earth, before rocket and satellite exploration, and before the discovery of the solar wind, little was known to help us explain those fascinating displays of nature's power.

The biblical writers Ezekiel and Jeremiah provided colorful descriptions of what might well have been auroral displays. Later, even after scientific methods and observation had developed, the auroral lights remained a mystery. Anders Celsius, known for his work on temperature measurement (the Celsius scale is named after him), noted early in the 18th century that the northern lights might be caused by active volcanos close to the north pole.

Taming the Northern Lights

Celsius was not satisfied with his early speculation and remained fascinated by the subject. Later, writing to his colleagues, he stated "it is deplorable that the northern light still has not let itself be tamed by the scientific community." Still later, after investigations of Earth's magnetic field had begun, Celsius and his colleagues observed that northern light activity was accompanied by disturbances in the magnetic field, and thus the door was opened to more serious inquiry into the mystery of the aurora.

As science progressed, we have come to understand that energetic processes generated by the passage of the solar wind through the magnetized environment of Earth are what creates auroral displays. These disturbances tend to encircle the polar regions in both hemispheres. The disturbances affect both the neutral atmosphere and the ionosphere above it, in regions we call the auroral zones.

Within these zones electrical and chemical changes take place in response to solar energy deposited in the form of charged particles and electric fields. These particles and fields alter the natures of neutral and ionized constituents of the lower atmosphere. As a consequence of the shape of Earth's magnetic field and variations in solar activity, these zones expand and contract in latitude and may be quite irregular in longitude. At some longitudes, these zones may coincidentally overlie mountainous terrain, such as the White Mountains of New Hampshire. Thus, while the physics of auroras is still not completely resolved, we understand that it is the solar wind's interaction with our planet's magnetic field, and not the presence of mountains far below, that sometimes results in colorful auroras being seen by persons in New Hampshire.

In the case of the "Venus Dragon," we also have considerable additional evidence that can help us tame this perceived "monster." By far the most extensive set of observations to stimulate the active volcanism-lightning scenario comes from recordings of electrical noise from the *Pioneer* Venus Orbiter. From 1978 to 1984 thousands of static-like noise bursts were recorded on hundreds of nightside orbits. This unexplained noise prompted both US and Soviet investigators to further propose that this noise, like the noise detected earlier by the Soviet *Veneras*, was produced by lightning in the lower atmosphere.

Exploding Volcanos

Fred Scarf and colleagues suggested that the inferred lightning discharges triggered electromagnetic disturbances called whistler mode waves, which propagated up to the Orbiter, thus permitting the remote detection of lightning. These investigators also asserted that the noise signals were much more frequently observed over mountainous terrain. The same mountains had been studied independently, using radar images, and in some cases geologists speculated that certain features may have been produced by once-active volcanos. This in turn prompted the inference by Scarf and colleagues that the mountains were actually exploding volcanos, spewing out hot gases that encouraged the atmospheric charge formation needed to generate lightning. The extent of these data implied that the lightning was very frequent, and that these angry discharges and the volcanic explosions must be continuing over many years.

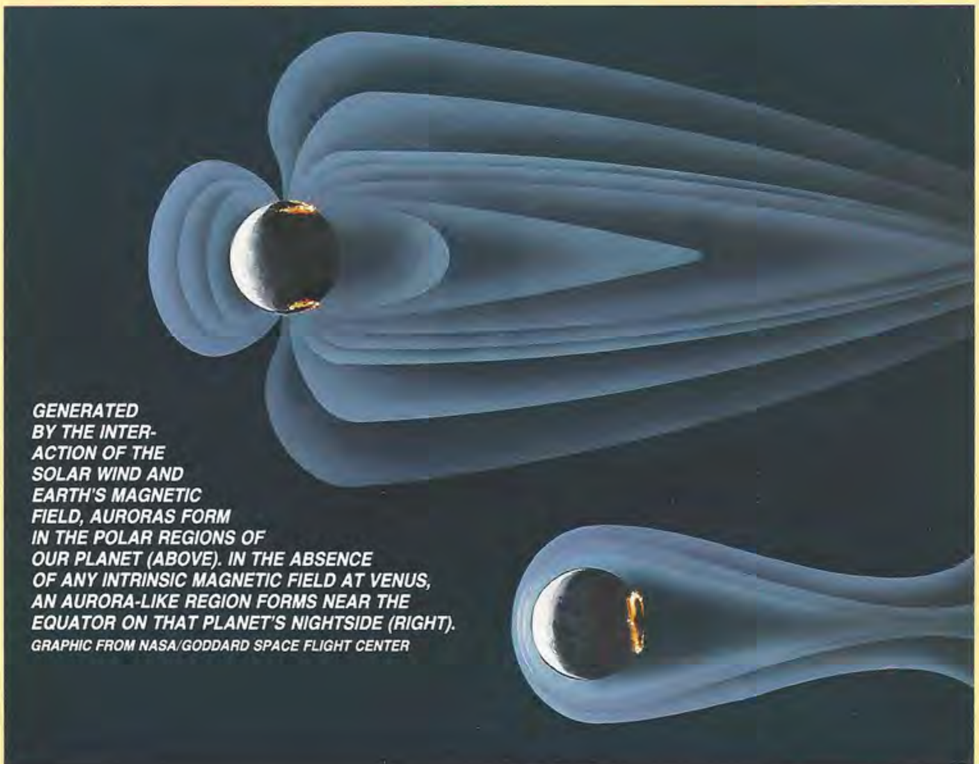
This interpretation of the electrical data was soon joined by University of Colorado scientist Larry Esposito's analysis of remote observations of ultraviolet reflection spectra from the Orbiter. The measurements indicated a large increase in the inferred sulfur dioxide content of the upper atmosphere in December 1978, followed in later years by a return to more normal concentrations. Dr. Esposito interpreted this as indicating that massive volcanos had erupted in late 1978, just before the *Pioneer* Orbiter arrived at Venus. To explain the large initial concentrations of sulfurous gas, Esposito proposed that these explosions must have been 10 times larger than any recorded on Earth.

These interpretations of extensive lightning and massive volcanism have been widely noted in books and films as independently confirming the evidence that the Venus Dragon is alive and well, and capable at any time of creating a most undesirable environment. But just how fearful is this dragon?

Ionospheric Disturbances

First, I have found through independent analysis of hundreds of orbits that the most prominent episodes of electrical noise attributed to lightning invariably occur within regions of ionospheric disturbances which develop as the huge stream of ionized particles — the solar wind — passes the planet. The solar wind and the interplanetary magnetic field embedded within it interact with ionized particles in Venus' environment to produce a fairly distinct nightside region. There disturbances capable of generating the observed electrical noise regularly occur.

As suggested in the illustration, the region of nightside disturbances is roughly analogous to the auroral zones of Earth. In both cases, in these zones energetic processes stimulated by the solar wind's passage noticeably disturb otherwise fairly normal conditions. At Venus, because there is no magnetic field, the auroral-like region is located on the planet's nightside, rather than around the poles as at Earth. In fact, the presence of auroral-type atmospheric disturbances over Venus' nightside has recently been inferred by J. Phillips and colleagues from analysis of remotely detected ultraviolet emissions seen across the nightside by the *Pioneer* Venus Orbiter. Thus, there is further reason to believe that the electrical noise earlier attributed to lightning is actually linked to external conditions, and is totally unrelated to the lower atmosphere. →



GENERATED BY THE INTERACTION OF THE SOLAR WIND AND EARTH'S MAGNETIC FIELD, AURORAS FORM IN THE POLAR REGIONS OF OUR PLANET (ABOVE). IN THE ABSENCE OF ANY INTRINSIC MAGNETIC FIELD AT VENUS, AN AURORA-LIKE REGION FORMS NEAR THE EQUATOR ON THAT PLANET'S NIGHTSIDE (RIGHT).
GRAPHIC FROM NASA/GODDARD SPACE FLIGHT CENTER

It's easy to understand why the electrical noise sometimes occurs as the Orbiter passes over mountains. As Venus orbits the Sun, the spacecraft progressively flies over different longitudinal regions of the planet. Owing to the constant variation of solar energy, auroral-like disturbances of the ionosphere may be observed above low latitudes throughout much of the nightside region. Since the longitude range occupied by highlands and mountainous regions is extensive, observations of ionospheric noise will often simply coincide with the Orbiter's passage over highland topography. At Earth, it is coincidental that auroral-zone ionospheric noise is frequently seen as a satellite passes over mountains. At Venus the topography and the "lightning" signals are physically unrelated.

An Active Planet?

But is the planet really still active? Experts examining radar images from orbiting satellites and Earth-based observatories have found little evidence of past explosive volcanism, and have been unable to identify any surface structures that would indicate very recent or present-day geologic activity. On the other hand, the large amount of sulfur retained in surface rocks, and the very high surface and atmospheric temperatures, have prompted geologists to suspect that slow outgassing of material from the planet's interior may still continue and that future activity may occur. Analysis of much of the higher-latitude surface in high-resolution radar images from *Veneras 15* and *16* indicates that, while Venus was once perhaps very active, its surface features appear to have been unchanged for about a billion years. Thus even if Venus may somehow still be geologically active, we have no direct evidence of any present-day explosive volcanism.

But what of the evidence of dramatic changes in the sulfur dioxide content? A close examination of the published data prompts questions as to whether the data really provide convincing evidence of any sustained long-term trend. For example, the observations indicate that the concentration of sulfur dioxide was relatively low during 1983, but that year many "lightning noise" signals were recorded. This runs contrary to the inferred association.

Also, the concentration of these sulfurous clouds changes greatly from week to week. We now know from the Soviet *Vega* balloon investigations that there is considerable strength and variability in vertical winds up to the cloud levels. It seems quite likely that natural atmospheric circulation may produce the observed variations in sulfur dioxide. This view has been reinforced by independent analysis showing that even large explosive volcanos, if they exist, could not inject enough gas to explain the variations seen.

So, is our sister planet volcanically active, or has the dragon long since retired? In my view, the most influential data promoting the possibility of current activity are readily explained as consequences of natural causes from the interaction of the solar wind and the ionosphere. I also believe the noise in question is unassociated with any geological activity. I understand that from existing information, geologists have not reported, and probably cannot report, any compelling evidence for recent volcanism. Consequently, I suspect that, as regards exploding volcanos and incessant lightning, Venus may well have been inactive for quite a long time. I suggest that the auroral-like behavior at Venus has, as in ancient times on Earth, been hastily interpreted as the exhalations of the "Venus Dragon."

Harry A. Taylor, Jr. is a senior scientist at Goddard Space Flight Center. He specializes in atmospheric physics and has flown experiments on numerous satellites and sounding rockets.

Lightning on Venus—An Alternative View

by William J. Borucki

Although some people have questioned that lightning exists on Venus, an examination of both the radio and optical data from the *Venera* and *Pioneer* Venus missions leads to the conclusion that lightning is widespread.

When you turn on your AM radio and tune it between stations, you hear a crackling sound. This radio static comes from lightning flashes hundreds or thousands of miles away. Receivers designed to operate at frequencies lower than the AM band can detect lightning from almost anywhere on Earth. The powerful radio waves emitted by the lightning flash are trapped between the ionosphere and the ground and suffer little absorption, and so are easy to pick up.

Clearly, putting a low-frequency radio receiver on a planet's surface is an excellent way to search for lightning. So the Soviet *Veneras 11* through *14* missions to Venus carried low-frequency (10 to 80 kilohertz) radio receivers. All the receivers picked up static after they had descended below the Venus ionosphere. Just as on Earth, the signals were strongest at the lowest frequencies.

Although low-frequency radio waves strongly reflect off ionospheric layers, and so do not escape into space, ultra-low frequencies (100 hertz) can travel along magnetic field lines and so be detected by orbiting spacecraft. The Electric Field Detector aboard the American *Pioneer* Venus Orbiter detected ultra-low-frequency radiation many times while on Venus' nightside during the low-altitude portion of its orbit. Unfortunately, the source of these ultra-low frequency waves is ambiguous. They might be caused by lightning or they might be caused by variations of the ion concentrations in Venus' upper ionosphere. Although researchers are vigorously trying to understand these results, no one has yet found a fully acceptable explanation.

Another way to search for lightning is to look for its light pulses. Such flashes are so bright that Earth-monitoring satellites have sometimes confused them with thermonuclear weapons tests. Calculations show that lightning should be visible through the clouds that cover Venus.

On October 26, 1975 at 7 p.m. Local Venus Time, the spectrometer aboard the *Venera 9* orbiter detected many strong light flashes over 70 seconds. This detection was the only one obtained from three optical searches made by the *Venera* and *Pioneer* Venus Orbiters. Analysis of this event, assuming that it was indeed lightning that had been seen, showed that Venus lightning radiates about 30 million joules per flash — about 15 times brighter than the average terrestrial lightning flash. Because the instruments view only a few millionths of the area of Venus at any time, the chances of finding a lightning storm are quite small. This single detection was a matter of luck.

To summarize the data, the instruments most sensitive to lightning — the low-frequency radio receivers — always picked up lightning activity. The optical systems — designed for other purposes — detected a lightning storm only once. The evidence, I believe, is there: Lightning occurs so frequently that whenever a suitable instrument is deployed, lightning is detected.

Although it is clear that lightning exists on Venus, we are uncertain as to its source. Some researchers have suggested that the lightning originates in thunderstorms or is caused by hundreds or thousands of volcanic eruptions. Because the ash and aerosols from so many volcanic eruptions have not been observed, a volcanic source for the lightning appears unlikely. Thus, in my view, Venus lightning, like terrestrial lightning, is probably produced by very local, strongly convecting clouds, that is, thunderstorms.

William J. Borucki is a research scientist at NASA Ames Research Center. His main areas of study are planetary lightning and detection of other solar systems.

(Editor's note: For another view of Venus, see "Lightning, Clouds and Volcanos" by Leonid V. Ksanfomaliti in the November/December 1984 Planetary Report*).*

How the Planetary Sciences Struggle Toward the Truth

by James D. Burke

Puzzle-solvers enjoy a special thrill when whole islands of knowledge, laboriously built up bit by bit, suddenly are seen to join in a larger synthesis. The new big picture "must" be right because so many of its elements fit. But often it isn't right; in the better puzzles and in detective novels, one must sometimes dismantle and rearrange, perhaps even start over from a different point of attack.

For at least three thousand years, humans have made what modern scientists call *models* of the cosmos: mental images connecting observations with a concept of their causes. Around 500 B.C. Hipparchus, observing a circular arc of shadow on the Moon during lunar eclipses, concluded that the Earth is round. He and Aristarchus of Samos guessed the true nature and measured the dimensions of the Earth-Moon system. But then 20 centuries elapsed before the Copernican model replaced all earlier models for explaining the apparent motions of the Moon and planets.

In modern times science is able and is encouraged to move faster. New models can be invented, tested and accepted or rejected during a human lifetime. Consequently some people come under pressure to abandon not only previous generations' teaching but also their own convictions — possibly even their own earlier publications. Naturally they resist. This increases the rigor of testing new models, brings forward alternatives, and could even result in a reversal and triumph of the old.

Paradigm Shifts

In the planetary sciences, the 20th century has seen several of these grand paradigm shifts. On Earth, geological and geophysical observations have led to the theory of plate tectonics, whose dramatic success tells us much about the human side of science. Before 1900, Earth's mountain chains were thought to be like wrinkles on the skin of an old and shrunken apple. Then, early in this century, the hypothesis of continental drift arose to explain things such as the jigsaw fit of Africa and South America. For decades the theory was scornfully rejected, but then in the 1950s, exciting syntheses began to come together.

Exploring the ocean bottom, scientists found volcanic activity and young volcanic rocks along mid-oceanic ridges. Then, going in both directions away from a ridge, the rocks' radioactive clocks gave older and older ages and the overlying sediment layers became deeper, as though the basement rocks had originated at the ridge and then moved slowly away, being buried by a steady rain of sediments as they went.

The clincher came with the discovery of magnetic stripes parallel to the mid-oceanic ridges, with magnetic patterns on one side of the ridge the mirror image of those on the other. As the geomagnetic field fluctuates and reverses at varying intervals during millions of years, any rock that cools from a molten state will acquire a slight magnetization characteristic of Earth's field at the time of cooling, and once the rock is cold this magnetization does not change. The stripes thus showed that the ridges were spreading centers, their mirror-image pattern suggesting that molten rock, emerging along a ridge, had cooled and then been transported in both directions away from the ridge. For millions and millions of years, Earth's sea floors have been a giant, slow-moving magnetic tape recorder!

From seafloor spreading, earthquake and volcano locations, rock ages and types, animal and plant fossils, and other evidence including more elaborate jigsaw geographics, there then emerged the picture we now see in every popular text about Earth: A picture of crustal plates that split apart, slither around on the slimy asthenosphere, collide and rumple up the margins of continents, and founder in the deep ocean trenches.

This motion of continents, until recently supported by overwhelmingly strong but still circumstantial evidence, is in the process of being confirmed directly: By measuring differences in the arrival times of noises from distant quasars, the relative positions of radio telescopes on different continents can be determined with fantastic precision. Also, the relative positions of ground laser sites can be determined exactly using the LAGEOS satellite, a heavy ball of optical corner reflectors that lasers can track with extreme precision. If such measurements are made over a period of years, not only will contemporary motion have been proven, but also episodic changes in that motion (many are observed in the geologic record) will be confirmed.

So persuasive is the grand synthesis of plate tectonics — at some level it accounts for nearly everything we can see on our own planet — that it has been universally embraced by Earth scientists, and only a tiny rear guard of outcasts holds forth the possibility of other models. This is exactly the reverse of the situation only 30 years ago, when proponents of continental drift were ignored or even reviled by their "scientific" colleagues.

In lunar science there have also been paradigm shifts, but none so dramatic as the plate-tectonics revolution on Earth. For most of the 17th to 19th centuries (a great age of telescopic lunar mapping) the cratered lunar surface was thought to be volcanic. Then the impact hypothesis supervened. Today, all observers agree that most lunar craters are the scars of giant impacts. But they also agree that volcanism must have had a major role in shaping the lunar surface (See "Origin of the Moon" in the November/December 1986 *Planetary Report*), and they have yet to reach a consensus on the actual history of the Moon.

Grand Synthesis

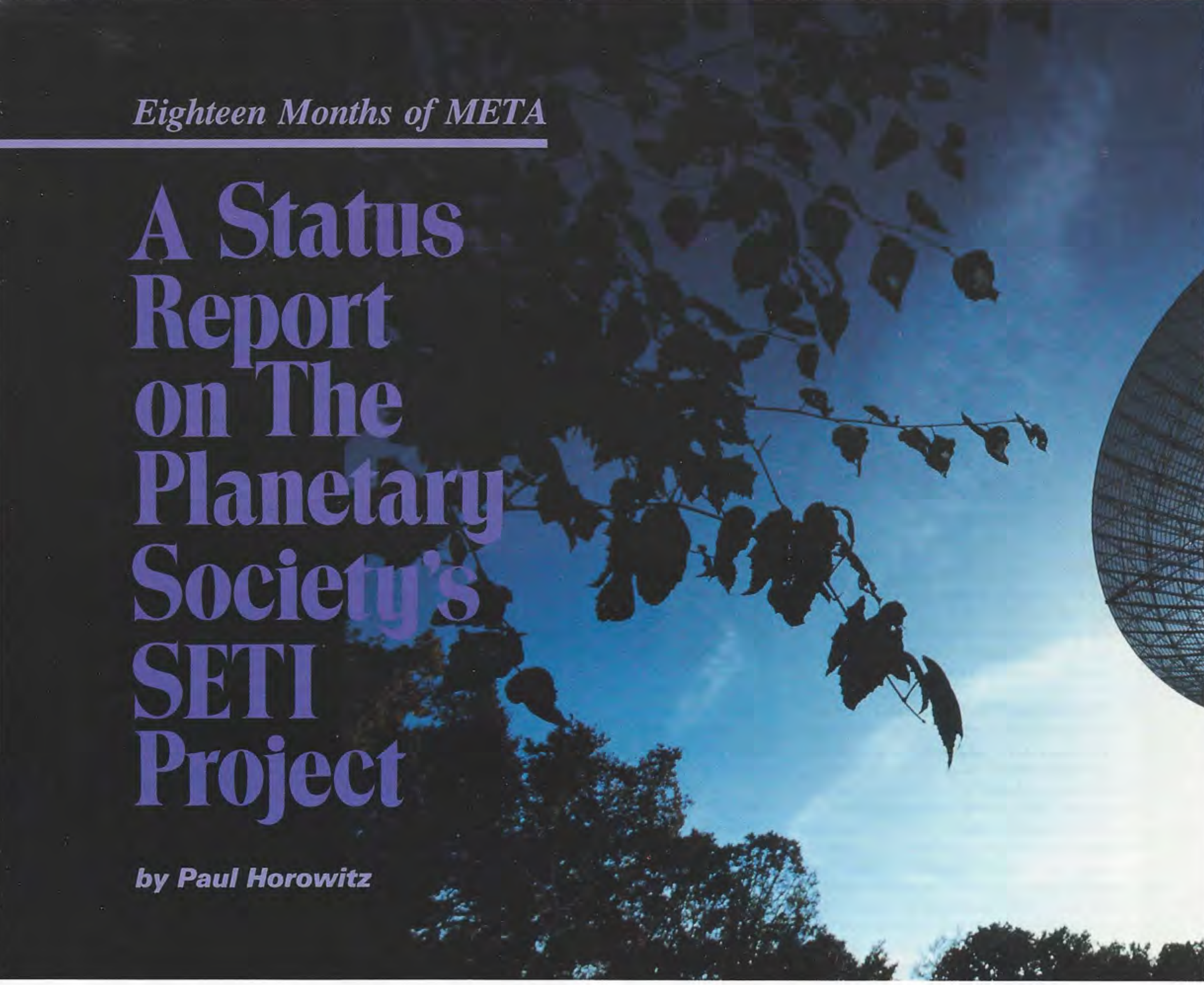
Farther out toward the frontiers of knowledge, competing hypotheses continue to flourish simply because the data are insufficient to kill any of them off. The idea that Venus might be a lush, tropical swamp with oceans of water (or even of oil) survived until it was demolished by spacecraft observations — but those same observations suggest to some scientists that Venus may have had an ocean in the distant past.

The possibility of present-day volcanos and lightning on Venus (see "Lightning, Clouds and Volcanos" in the November/December 1984 *Planetary Report*) has sparked another scientific controversy: One group believes that the *Pioneer* Venus Orbiter has detected lightning-generated "whistlers" (strange musical tones caused by electromagnetic waves traveling in the plasma surrounding the planet), while another group attributes the observed plasma waves to local disturbances originating near the spacecraft. The dispute seems likely to rumble on for a while in the pages of the *Journal of Geophysical Research*, and even if the *Magellan* spacecraft's radar shows details of volcanic landforms, the lightning question may not be settled.

The idea that Mars may harbor life (or may once have done so), though dealt a blow by *Viking* observations, continues as a stimulus to future research. The idea that Mars once had large amounts of water, and may still have a lot in the form of permafrost, is gaining ground.

And all the while a grand synthesis is slowly forming — one in which our solar system may prove to be representative of a whole class of such objects in the cosmos, with millions of planets out there waiting to be observed. The proven discovery of even one extrasolar planet would suddenly join our island of knowledge to another: It would connect the planetary sciences into the rich and fast-growing store of information on the evolution of the stars. *When* that happens (hardly anyone now says *if*), humans will share one of puzzle-solving's greatest moments.

James D. Burke is a member of the technical staff at the Jet Propulsion Lab. He is also technical editor of The Planetary Report.



Eighteen Months of META

A Status Report on The Planetary Society's SETI Project

by Paul Horowitz

A year and a half ago we switched on the power to The Planetary Society's Project META, a powerful 8-million channel receiving system dedicated to the Search for Extraterrestrial Intelligence (SETI). META, for Megachannel ExtraTerrestrial Assay, was built at Harvard University with Steven Spielberg's $100,000 gift to The Planetary Society. It uses an 84-foot radio astronomy dish, picturesquely sited on a Massachusetts ridge amid apple and peach orchards, in a full-time, full-sky effort to listen for microwave radio beacons from possible advanced civilizations in our galaxy.

META evolved from two earlier Planetary Society SETI projects, paid for by contributions from Society members. Suitcase SETI was a portable 131,072 channel digital receiver that looked for (and archived) any unusual signals coming from the 200 stars we observed with the giant 1,000-foot Arecibo radio telescope. Project Sentinel was its successor — Suitcase SETI put to work in a full-time search at our Harvard antenna. With a champagne send-off, and Society President Carl Sagan's "Let the search begin!", Sentinel came to life in March 1983.

Although Suitcase SETI and Sentinel were the most advanced searches of their time, they were still quite restricted in the kinds of signals they could detect. In particular, they required the continuous transmission of a guessable radio frequency (for example, the celebrated 21-centimeter line), transmitted so that it arrives in our solar system at the true frequency. Astronomical objects really zip along, and typical stellar velocities of 10 kilometers per second or more produce substantial doppler shifts of received frequency (the train whistle effect), enough to shift the signal completely out of the receiver's limited bandwidth. As a consequence, these searches were only sensitive to transmissions deliberately aimed at our solar system, and they would have missed an omnidirectional galactic beacon. In spite of this restriction, Suitcase SETI and Sentinel showed that it was possible to carry out

Researchers in the search for extrate radio frequencies as "magic" beca as we know, are the same everywhere in to any technological civilization.

Two such frequencies are 1420 megah the neutral hydrogen atom, and 1667 m OH^- molecular fragment, the hydroxyl nents of the water molecule on which all as well as a scientific one for searching Oliver, head of the SETI program at NA The Planetary Society:

"Nature has provided us with a rathe spectrum that seems especially marked spectral lines of hydrogen (1420 meg megahertz). Standing like the Om and t emissions of the dissociated products of for its kind at the age-old meeting place
— JAMES D. BURKE

LEFT: For The Planetary Society's Project META the radio telescope at the Harvard-Smithsonian Oak Ridge Observatory searches the sky full-time for microwave beacons. **Photograph by Frank Siteman**

ABOVE: Computer equipment jams META's control room. The paneled rack at left holds the 144 processors comprising the 8.4-million-channel receiver. The control computer is to its right, with radio-frequency and housekeeping hardware extending to the right of the picture. **Photograph by Paul Horowitz**

trouble-free and inexpensive searches for radio signals from extraterrestrial intelligence. They also eliminated the possibility that the sky was full of 21-centimeter signals directed at us.

rrestrial intelligence (SETI) refer to certain use they are constants of nature that, so far the universe and would probably be known

rtz, a characteristic oscillation frequency of egahertz, a frequency characteristic of the radical. Since H and OH^- are the compo- known life is based, there is a poetic reason in this region. In the words of Bernard M. SA's Ames Research Center and advisor to

narrow quiet band in this best part of the for interstellar contact. It lies between the ahertz) and the hydroxyl radical (1667 he Um on either side of a gate, these two water beckon all water-based life to search of all species: the water hole."

META was our answer to the doppler problem. By expanding to 8.4 million simultaneous frequency channels, we were able to cover a band of 400 kilohertz, enough of the frequency spectrum so that a beacon, transmitted by an extraterrestrial civilization on a guessable "magic" frequency, will fall within our receiver bandwidth in spite of doppler shifts caused by relative motion. Creating META was a major task — a custom supercomputer, containing 144 fast parallel processors, 20,000 backplane connections, and a half-million solder joints (all done by hand!). By the end of September 1985, everything was ready. We celebrated with a gala switching-on ceremony, presided over by Spielberg and Sagan.

Doppler Shifts

You need to know two additional facts about astronomical doppler shifts to appreciate fully the zoo of META oddities we've collected over the past 18 months.

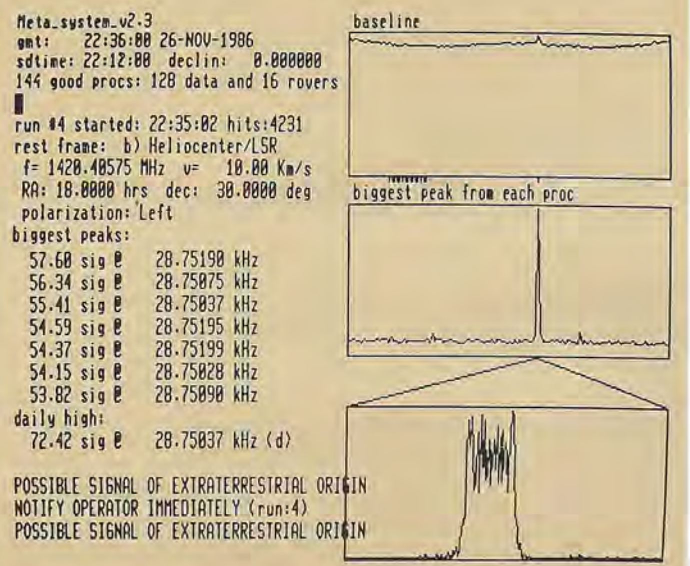
First, Earth's rotation produces a doppler shift — an exactly calculable *changing* doppler shift. META knows about this and uses this unique doppler "chirp" signature to discriminate a true celestial radio signal from earthly radio interference.

Second, an elegant solution to the large doppler shifts encountered in interstellar communication is to choose a common reference frame, with both sender and receiver making appropriate adjustments of frequency according to their known motions. In other words, the search problem is simplified if a strategy of "guessable reference frames" is used to eliminate doppler shift ambiguities. There are only a handful of such frames — the galactic center, the cosmic blackbody rest frame, the local standard of rest. The META strategy, stated compactly, is to look for properly chirped narrowband signals at guessable frequencies in guessable rest frames. We are currently finishing our second pass of the sky at the 21-centimeter "hydrogen hyperfine" frequency, in the three frames just enumerated.

First Results

The first 18 months of META have been, unfortunately, uneventful. META's ever-vigilant computers have sifted through nearly 2 million independent spectra, each consisting of 8.4 million numbers representing the received radio power in those separate channels. Altogether that's about 15,000 gigabytes. META is kind to dumb animals and throws out most of these data, preserving

FIGURE 1



FIGURES 2, 3, 4, 5, & 6

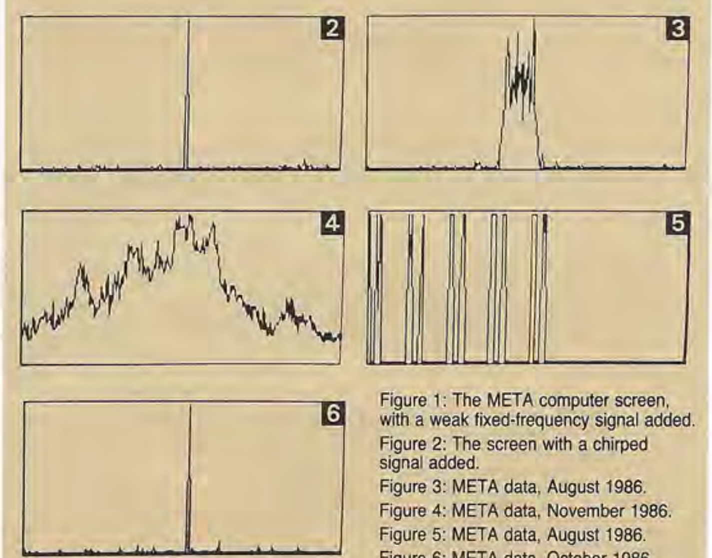


Figure 1: The META computer screen, with a weak fixed-frequency signal added.
Figure 2: The screen with a chirped signal added.
Figure 3: META data, August 1986.
Figure 4: META data, November 1986.
Figure 5: META data, August 1986.
Figure 6: META data, October 1986.

roughly a megabyte per month of "META's greatest hits." (If you like, you can think of META as the world's biggest garbage can!).

We look carefully at these preserved treasures. They generally fall into four categories:

1) Just plain noise, a little louder than usual;
2) Radio interference (which some cite as evidence of intelligent life on Earth);
3) Equipment malfunction (evidence of lack of intelligent life on Earth); and
4) Other signals.

Noise "events" dominate the archive; in fact, we can predict their number according to our chosen threshold above which they are archived. Our threshold is low — about 98 percent of the archived events are simply noise. Of the remaining archived events, most are due to radio interference. Although we can't generally identify the offending transmitter, the nature of these signals reveals their pedigree.

To see how this works, look at the figures. Figure 1 shows the full META screen as it appears during normal running. The screen is redrawn every 20 seconds — the collection interval for each 8.4 million-channel spectrum. The screen lists the telescope's target, time and date, and reference frame (in this case the local standard of rest, which is the average motion of stars in our region of the galaxy). It also lists the run's seven largest peaks by size and frequency.

The top graph shows the full megachannel spectrum, compressed by averaging adjacent blocks of 65,536 channels to form each displayed point. The middle graph is similar, but with the *highest* point of each 65,536 channel block displayed. The bottom graph is a high-resolution blowup of the 256 channels centered on the largest peak; individual channels here correspond to frequencies separated by only 0.05 hertz, about 30 trillionths of the observing frequency.

In this case we have intentionally introduced an interfering signal. It shows weakly in the top graph (which is what a 128-channel receiver would see), but quite strongly in the middle graph. The most information comes from the bottom graph, however, where the signal is spread out in a "mesa" shape. This is the characteristic of a fixed-frequency terrestrial signal, smeared out by the intentional chirp of the receiver as it looks for similarly chirping celestial signals.

The other figures show the bottom (high-resolution graph) for some other kinds of signals. Figure 2 is an artificial signal, intentionally chirped in precisely the way an intentional extraterrestrial signal would be received on Earth. This signal is nicely collected into one channel only, thanks to the receiver's corresponding antichirp.

The last four graphs are real data from META during 1986. Figure 3 shows the characteristic mesa shape of highly stable fixed-frequency interference. Graphs like this occur perhaps once a week. Figure 4 is more broadly and erratically spread out in frequency. It is the signature of a less stable transmitter with a stability of "only" one part in 100 million (0.000001 percent). Figure 5 resulted from an occasionally intermittent META processor during one of its off-the-wall moments (it has since been reprimanded and had its brain reeducated).

Finally, Figure 6 is real data from October 10, 1986 at 17:57 Greenwich Mean Time. It looks for all the world like the real thing. The peak is way above average noise. However, during many re-observations of that sky position, it has never repeated.

Graphs like this last one have a tendency to get the adrenalin flowing and bring color to one's cheeks. In 18 months of META we have seen three peaks like this. But many re-observations have failed to confirm these signals. Perhaps even more significant, in each instance the signal did not recur even during adjacent 20-second intervals. Irreproducible science is not science at all; thus we are obliged to discard these events, without a good explanation of their cause.

New Search

This summer, META begins searching on a new wavelength — 2841 MHz, the second harmonic of the 21-centimeter line. This wavelength is nearly as magic as 21 centimeters, and does not have the liability of doing violence to the sending civilization's radio astronomy programs at that important wavelength (by international agreement on Earth the 21-centimeter band is protected). Furthermore, the cosmic noise background is lower.

Perhaps in assessing our chances of early success it is worth noting that 1987 has already had two astounding scientific discoveries — the first nearby supernova since the invention of the telescope, and materials that are superconducting above liquid nitrogen temperatures. Astounding discoveries ought to come in threes.

Harvard physics professor Paul Horowitz's studies range between the very large and very small: SETI, ground-based interferometry and tunneling microscopy (which can image individual atoms).

META owes its existence to the talented contributions of John Forster, Mal Jones, Ivan Linscott, Brian Matthews and Mike Williams, along with a small army of student solderers: Suzanne Amador, Mike Coughlin, Teddy Kim, Elaine Kuo and Carl Quillen. In addition to funding from The Planetary Society, the Dudley Observatory and the Hofheinz Foundation provided small supplemental grants.

News & Reviews

by Clark R. Chapman

The "literature" about space science includes books, magazines and technical scientific journals. In past columns, I have also reviewed newspapers and other reading material available in libraries. And I have noted the so-called gray literature: the untold tons of technical reports, preprints and other jargon-filled writings of scientists who never got around (or never dared?) to have them officially reviewed or formally published. Several decades ago, the gray literature was uncommon, but with the encouragement of the Xerox machine and its ever-cheaper clones, whole forests were felled to serve scientists' ever-increasing desires to distribute their words to all who might, just possibly, read them.

Now, in the rapidly dawning age of desktop publishing, two other kinds of space science literature are weighing down the shelves in my office: newsletters and brochures. So much arrives, in fact, that even a packrat like me is forced to consign much of it to the venerable "circular file." The first new products of desktop publishing were — and remain — the innumerable newsletters. I get them regularly from countless projects, offices, programs, institutions and individuals.

Four that have recently crossed my desk exemplify the diverse traits of this portion of the gray literature (which is not actually gray: one is printed on yellow paper, another on blue, and a third is blue and black ink on glossy white paper!). Perhaps the most incomprehensible is the glossy one: the March 1987 issue of the *OSSA Information Systems Newsletter* runs 36 pages. Although the first page carries a photograph of four smiling people, the tone of the publication is best exemplified by the leading headline: "New Roles for NSSDC and PDS Defined in MOU." This quarterly publication is about the use of computers, data archiving, telecommunications and so on, in the service of NASA's science office. We should be glad to know that NASA is participating in the computer revolution, but we may hope that the communication eventually becomes more effective over NASA's high-speed data lines than it is likely to be through this newsletter.

A newsletter that could be of wider interest to *Planetary Report* readers is *The Lunar & Planetary Information Bulletin*, published several times a year by the librarian of the Lunar and Planetary Institute, 3303 NASA Road One, Houston, Texas 77058. It deals with computers, electronic mail and so on, in vogue with the trends of modern library science. But its May 1987 issue also carries book reviews, announcements about slide sets and NASA art, pinpointers to publications of interest to school teachers, news about Spaceweek, a calendar of forthcoming planetary science meetings and a bibliography of recent articles and publications about the solar system.

Most surprising to me, the innocuous blue-papered *V-Gram* for April 1987 (available from Carolynn Young at JPL) contains readable articles about the planet Venus written by some of the foremost American space scientists. Jim Head reviews venusian geology. Jerry Schaber addresses the question "How old is the surface of Venus?" (He thinks it's about half a billion years old — pretty young by the standards of most rocky planets — but Schaber looks to the *Magellan* mission to provide a more secure answer.) Blue-faced pictures of both authors adorn their respective articles, with accompanying chatty biographies. (Jim Head, we are told, "collects beer bottles and postcards.") There's nothing stuffy about *V-Gram*, which exists to keep all interested parties up-to-date on the Magellan Project.

Even chattier is Jim Loudon's *Michigan Spacelog*, a monthly publication of the University of Michigan, which supplies words about astronomy for possible use by newspapers and other news media around Michigan and North America. It focuses on anniversaries of astronomy and space-related historical events and on forthcoming celestial events, visible with the naked eye.

Selling CRAF

Some things are too important for the mimeograph machine or offset printing press and require fancier treatment. One of these is the would-be Comet Rendezvous Asteroid Flyby mission (CRAF). Official approval had been expected — and promised — in years past but CRAF is still awaiting the government's go-ahead. This highly recommended mission is now facing its last chance to begin America's exploration of the small bodies, for if it isn't announced as a "new start" in the President's budget message in January, there's no way it can make its early 1993 launch date to Comet Tempel 2. And nobody has found another comet it could get to for three more years after the 1997-1999 time frame for CRAF's close-up studies of Tempel 2.

Scientists and engineers have been planning missions to asteroids and comets for decades (I just got a copy of a three-pound Lockheed report about a prospective asteroid mission dated February 1965!). With a queue of small bodies and outer planets missions lined up behind CRAF, the first of the *Mariner Mark 2* spacecraft enterprises, some NASA-watchers fear that the whole house of cards may come tumbling down if the Solar System Exploration Committee program isn't finally put into effect with a CRAF new start.

Most space scientists feel that the top priority for preserving a viable planetary science program in NASA is to sell CRAF. Otherwise we are left with a shaky group of already approved missions waiting to fly, but no future program other than vague hopes that the next President may actually approve (since the current one seems unlikely to) the Mars initiative that The Planetary Society has been pushing. Selling CRAF is a multistep process. First, it must be sold to NASA scientists and administrators who have big problems and thin budgets. If that is successful, by August or September, then NASA must sell CRAF to the OMB (Office of Management and Budget), which wields a dangerous budgetary axe on behalf of the President. Finally, next spring, the Congress must agree to fund the mission, which will be an uphill battle if the President hasn't proposed it.

One marketing approach, which has become more sophisticated lately, is to produce glossy brochures. In past years, two CRAF brochures have failed to win support for the mission even within NASA, so JPL has just released a new one: "The CRAF Mission: A Search for Our Beginnings." The document is rich with scientific questions, facts and figures about Comet Tempel 2 and asteroid 46 Hestia, descriptions of the spacecraft's 14 scientific instruments, and an outline of CRAF's prospective journey. Somewhat technical in content, this brochure was intended to attract some key scientists and NASA officials to CRAF. But not to be caught short, JPL has printed 5,000 copies. If this colorful appeal to NASA proves successful, another brochure in the works will help to articulate CRAF's broader goals. It will be aimed at the wider group of opinion-makers and political leaders who must help if CRAF is ever to get into the interplanetary realm.

Clark R. Chapman, who himself has been drafted to write some NASA brochures, also edits a homeowners' association newsletter in Tucson, Arizona.

A Space Station Worth the Cost: The Planetary Society Proposal

by Carl Sagan, Bruce Murray and Louis Friedman

More than money, more than launch vehicles and more than a space station, NASA needs a goal. The tragedy of *Challenger* dramatized that sending people into space is dangerous as well as expensive. To justify risking lives and money, the purposes of spaceflight with human crews must be clearly stated and found worthy. Voyages to explore our neighboring planet, Mars, constitute such a worthy, long-term goal — and, we believe, an optimal goal.

The prospect of human exploration of Mars is ecumenical — remarkable for the diversity of opinion it embraces. It is justified among other reasons:

— As a human adventure of high order, able to excite and inspire the most promising young people, and to convey that high technology can be consistent with a hopeful future.

— As a potential scientific bonanza — for example, on climatic change, on the search for present or past life, on the understanding of enigmatic martian landforms and on the application of new knowledge to our own planet.

— As an aperture to enhanced national prestige and technological development.

— As a realistic and possibly unique opportunity for the United States and the Soviet Union to work together, and with other nations, in the spotlight of world public opinion on behalf of the human species.

— As an in-depth exploration of the only other planet that may someday sustain human life.

If we start soon on a long-term program to investigate Mars, culminating with humans landing on the Red Planet sometime in the first quarter of the next century, we can: revive a dispirited NASA; provide it with a focus and sense of purpose on an appropriate timescale; and establish a standard by which to judge proposed major NASA activities and their subsequent progress.

But NASA's space station, as now envisioned, is not a practical stepping stone to Mars. With it, we would learn little of the effects of long-duration spaceflight on humans — something our species will have to understand before setting out for Mars. Nor will it enable us to assemble propulsion stages in orbit and build the ships that will take us to other worlds.

The Microgravity Rationale

Instead, the rationale behind the now $20 billion space station rests largely on the vague notion that space holds great potential for manufacturing — of pharmaceuticals, alloys, ball bearings and the like. Yet outside the aerospace industry itself and, beyond verbiage, no large commercial concern advocates the space station strongly enough to share the costs of its development. No one has offered compelling arguments that space industrialization would be economically competitive with manufacturing on Earth when a comparable capital investment is made. Nevertheless, the key and often unstated assumption that products manufactured in space can be commercially profitable continues to permeate US space station planning.

In particular, a severe microgravity requirement has been levied on the current station design to permit development of microgravity processing. This introduces at least three inconsistencies: First, the priority on microgravity processing precludes emphasis on other needed developments, such as in-orbit rocket assembly, life-science research in variable gravity, and very-long-duration human flight. Second, it dictates a set of demanding and expensive requirements solely to maintain the large microgravity capability and to provide high power levels for its operation. Third, microgravity is intrinsically incompatible with a human presence; such experiments are better done in dedicated recoverable or revisitable automated facilities.

Some assert that a microgravity capability is important for American competitiveness in the world market. But by investing precious dollars in an uneconomic space facility, US competitiveness in space applications will go the way of its once undisputed competitiveness in launch vehicles. Others argue that international agreements based on anticipated commercial benefits have already been negotiated and therefore must be followed through. Does this mean that there is a set of foreign industries poised to profit from the station? No. The only identified interests, foreign or domestic, with a serious commitment to the station are the organizations that stand to profit from building it. Japan and Western Europe are willing, for political and space technology reasons, to pay for 5 to 10 percent of the development costs. But where is the participation in the space station of AT&T, IBM, GE, Texas Instruments, Johnson & Johnson, or their foreign counterparts? Their unwillingness to invest significant capital funds is a clear indication that a coherent commercial justification for the space station has not been made.

In a letter to US Secretary of State George Schultz, Secretary of Defense Caspar Weinberger has expressed a "national security" interest in the space station, although the Department of Defense has yet to offer to help with the funding. A quasi-military space station built by a civilian space agency would profoundly conflict with the 1958 National Space Act and with the NASA Charter. (However, as a result of negotiations mediated by the National Security Council, military applications will now be played down.) In contrast, a space station that would enable planetary exploration is fundamental to and consistent with NASA's congressional mandate.

Mars and Long-Duration Human Flight

The task of sending humans to explore the solar system — particularly Mars — has been largely ignored by NASA since the death of Wernher von Braun. It certainly has not been a significant factor in the current design of the space station. Yet NASA's own Advisory Council has recommended that the agency adopt the goal of Mars, as did the President's National Commission on Space. The goal of Mars has been endorsed in many recent editorials in major newspapers, including seven in the *New York Times*, and others in the *Los Angeles Times*, the *Christian Science Monitor*, the *Denver Post*, and the *Washington Times*. The Mars goal has also been endorsed in a congressional resolution initiated by Sen. Spark Matsunaga and co-sponsored by Sen. William Proxmire, among others. It has been publicly supported by many other members of Congress.

The Planetary Society has witnessed another sort of endorsement of Mars exploration. Our members voted for Mars in a very real way — by donating, bit by bit, over $200,000 to enable the Society to advance the prospect of humans on Mars.

Even so, no requirements for Mars exploration have been seriously considered for the space station. Despite repeated rhetorical references by NASA officials to the proposed station's relevance for interplanetary flight, the technical specifications and planned capabilities do not address planetary exploration.

Perhaps only modest changes in the present program would be sufficient to provide the crucial knowledge we need to send humans to Mars. Or perhaps not. No one really knows because NASA has never seriously studied the necessary requirements. Key questions must be answered:

☐ *Will the space station provide crucial data about:*

— Supporting human life in space for long periods?

— The competing effects on crews of arti-

ficial (spinning) gravity, versus adapting to zero-gravity?
— The necessary scale of life-support systems for interplanetary flight?
— Closed ecological systems?
— Deep-space radiation hazards to humans, including solar flares and the utility of spacebased proton shelters?

☐ *Will the space station provide the experience we need to design interplanetary vehicles, particularly:*
— Launch vehicles?
— Orbital transfer vehicles?
— Assembling propulsion stages in orbit?

☐ *Will the space station satisfy requirements for:*
— Quarantine of samples returned from Mars?
— Possible coordination with the Soviet Mars program?

Our examination of NASA's planned space station forces us to conclude that these questions must be answered, for the most part, in the negative.

For example, engineers continue to debate the benefits of "weightlessness" versus artificial gravity on flights between the planets — but these arguments are based mainly on faith, not data. From the beginning of human spaceflight, most have presumed that crews can somehow adapt to weightlessness. But the extensive Soviet efforts in zero-gravity long-duration flight seem to have stalemated after reaching an eight-month limit — far short of the time needed for a realistic mission to Mars and back. The space station plan must include a systematic way to acquire the needed comparative data, including tests of humans in large rotating structures in Earth orbit, which would provide artificial gravity.

We also need more ground-based and Earth-orbital research on closed-ecological life-support systems before the space station goes into operation. That research could begin now, on the ground, even while space station requirements are being redefined.

The current space station schedule calls for developing physical structure first, with most *in situ* applications postponed to some indefinite later time. This is a mistake which becomes even more severe in NASA's newly revised two-step plan. We suggest instead a more flexible modular approach, in which some early low-power applications and research could be carried out while facilities for long-range objectives are built up gradually. This would give the United States an earlier return on its investment. The modular, step-by-step approach has served the Soviet Union well, and could also benefit the US.

An obviously desirable function for the US space station will be the capability to assemble large payloads in low orbit, and then to send them on to geosynchronous orbit and interplanetary trajectories. An easy, reliable way of reaching beyond low Earth orbit must be developed soon. However, the current space station plan does not include such a capability or even permit it. This capability is far more important for the United States, and has a much more favorable cost-benefit ratio, than the competing objective of developing a microgravity environment. Maintaining the microgravity requirement requires that there be few disturbances on the space station; such disturbances would be unavoidable while assembling rocket stages.

If the space station is developed to prepare for an expedition to Mars, can it still fit more general needs for space development? The goal of landing humans on the Moon, so successfully met by the *Apollo* program, also gave us a stable of capable launch vehicles, a small but effective space station (*Skylab*), a series of successful spacecraft that initiated the golden age of planetary exploration, and advances in space communications, power, propulsion, data processing, computing, materials and life-support capabilities.

An overriding and compelling single-purpose goal, when sufficiently broad and challenging, need not be a single-benefit program. If the space station is developed to provide responsible support for a human mission to Mars, it will also advance the United States' abilities to:

— Build structures in space,
— Support life in space,
— Understand low-gravity and vacuum technologies,
— Lower costs and provide reliable access to space,
— Advance aerospace engineering and space science, and
— Explore the solar system.

What's the Rush?

Today, the American space program is a shambles, despite generous funding for many years. The enormous past investment in the shuttle program, plus the large new investments required to restore it even to a minimally operational state, threaten the viability of the entire civilian space program. Funding a space station and timing its construction become critical to everything else NASA would like to do. How much will it cost? Why build it now? The goal of landing humans on Mars sometime during the first quarter of the next century could provide a coherent and reasonably paced objective against which to match space station development and schedule.

A human mission to Mars will require the United States to develop new expendable launch vehicles (as will anything more than a rudimentary space station), to send precursor robotic missions, to research life support, and to develop life-supporting vehicles. A well-designed national program would address these requirements, and see that they are carried out in parallel and at a reasonable pace, and that they meet the political and economic conditions imposed by the goal of exploring Mars.

It would also allow American space sciences to reverse their present decline. The Space and Earth Science Advisory Committee Task Force on Scientific Uses of the Space Station recently told NASA that the space station should be reevaluated and reformulated or the United States could lose an entire generation of space scientists.

It is impossible to start a responsible space station program until the true payload capability, flight frequency and, especially, cost per pound of cargo for the shuttle have been demonstrated, rather than over-optimistically guessed at — as has been the common NASA practice in the past.

In the early 1990s, NASA must gain genuine experience and maturity in shuttle operations. In parallel it can begin research soon on life support in space by lengthening shuttle missions from a few days to weeks. The shuttle can be used in this way for a broad array of experiments and activities. Many scientists believe that it is more effective to use the shuttle as an experimental facility than as a "space truck." It may prove wiser to let the space station implementation wait for more appropriate expendable launch vehicles to become available, just as the Soviet successes with its *Mir* space station and other facets of human space flight are built upon a solid foundation of routine expendable launch vehicle use.

Take the Time Now and Do the Job Right

NASA should reconsider the space station design. Its new focus instead should provide (1) a more mature definition of the station requirements, (2) consideration of how to support the goal of landing humans on Mars, and (3) critical assessment of the prospect of spending tens of billions of dollars in the short term to permit extremely dubious space manufacturing endeavors sometime in the next century. Most important, taking more time in defining the space station will permit now-budgeted resources to go into fixing the shuttle, into buying expendable launch vehicles, and into prompt implementation of important science and applications programs that are now languishing. Only then can the United States begin to earn back its place in space.

Our aim is neither a smaller nor a larger NASA budget. Nor is it a smaller or larger human spaceflight program. Instead, we advocate a NASA budget and a human spaceflight program that *are worth the cost and risk*. The only way to measure that worth is to establish a coherent long-term NASA goal. We urge the President and the Congress to commit the United States now to join with all other spacefaring nations in preparing to send explorers to Mars early in the next century. Human exploration of Mars at the beginning of the new millennium is a goal worthy of the promise of the space age and the aspirations of the human species. A space station designed to help implement that goal would be well worth the cost.

Carl Sagan, President, Bruce Murray, Vice President, and Louis Friedman, Executive Director of The Planetary Society, gave this testimony before The Senate Appropriations Committee on May 1, 1987.

SOCIETY Notes

GREAT PLANETARY GIVEAWAY

It was an attic sale to end all attic sales. Lu Coffing, the Planetary Society's financial manager, decided that she'd had enough. Extra back issues of *The Planetary Report* and miscellaneous obsolete sales items had accumulated in every nook and cranny of the Society's turn-of-the-century headquarters in Pasadena. Lu announced that we had to clear the decks — and so we did.

After offering boxes of *Reports* to students, teachers, schools and volunteers, Lu threw a "Great Planetary Giveaway" and invited the world to come and share the excess. Some 400 enthusiastic people showed up and carted off stacks of magazines and handfuls of leftover merchandise. Lu is now much happier.

CELEBRATING SETI

Never let it be said that The Planetary Society is a dull, stodgy organization. Not when we can come up with events like the Great Planetary Giveaway and the Celebrating SETI picnic, which was held last May at the Oak Ridge Observatory in Harvard, Massachusetts. Dr. Paul Horowitz, chief scientist for Project META (Megachannel Extraterrestrial Assay — the Society-sponsored radio search for extraterrestrial intelligence, or SETI), hosted about 450 members and guests at a picnic at the radio telescope site.

According to reports from the picnickers, the day was a splendid success. Our hats are off to Gail Abend, Regina Mitchell and their volunteer crew who dealt with the myriad of logistical details involved in pulling off such a large caper. Gail is our volunteer coordinator for Massachusetts; Regina recently challenged members to give school and community libraries gift subscriptions to *The Planetary Report*. We greatly appreciate their hard work and enthusiasm.

The picnickers heard from some of the most distinguished scientists involved in SETI: Dr. Philip Morrison, Society Advisor and professor at the Massachusetts Institute of Technology; Dr. N.S. Kardashev, Director of the Samarkand Radio Observatory in the Soviet Union; Dr. Masaki Morimoto, Director of the Nobeyama Observatory in Japan; and our own Paul Horowitz.

Photograph by J. Kelly Beatty, *Sky & Telescope*

Society members enjoy a picnic at the META telescope.

HALLEY'S COMET REVISITED

One of the scientific projects funded by Planetary Society members was a University of Notre Dame study to detect rapid changes in Halley's Comet on its last swing through the inner solar system. Led by Terrence Rettig of Notre Dame and Alan Bambaugh of Fermilab, the study's scientists have published their findings: "Preliminary Results Using a New Technique to Search for Very Rapid Variations in the Spectra and Shape of the Coma of Comet Halley" (20th ESLAB Symposium on the Exploration of Halley's Comet, European Space Agency, Special Publication 250, Vol. III, pp. 93-97.)

RENEWING MEMBERS MAKE PROJECTS POSSIBLE

Although Society members enjoy lighthearted events like the Great Planetary Giveaway and the SETI picnic, they also have a deep and serious appreciation of Society programs and projects that encourage the exploration of the solar system and the search for extraterrestrial life. In 1986, our members contributed *over $215,000* at renewal beyond their annual membership dues.

These funds are critical in supporting important projects, among them SETI and the Mars Institute. Your contributions are allowing us to reach out into the Third World, as at the recent Society-sponsored educators' conference in Mexico City. Your contributions have enabled Society officers to testify before Congress and fight for a strong US planetary program. Your contributions have made possible scientific studies that may determine the future of humans as explorers of other worlds. Your continued support demonstrates how an alliance of individuals, sharing common goals, can make our world a better place.

VOLUNTEER NETWORK

Our members make other valuable contributions — of the time and energy that make Society activities and programs successful. One in every 400 members has filled out a volunteer application form, officially joining the volunteer network. One in every 200 members has offered to help out when the need arises. That is a remarkable indicator of our members' dedication to Society goals.

To join the volunteer network, write Lyn McAfee, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

INVENT AN ALIEN

The challenge went out to Canadian students in grades 4 to 9: Design and build a three-dimensional model of a lifeform that could survive in the hostile (to humans) environment of Mars. The National Museum of Science and Technology in Ottawa held the "Invent an Alien" contest last spring. The Planetary Society helped sponsor the contest and provided the first prize for the intermediate level group — an Earth-satellite station for the winners' school.

At the junior level, the winners were Patrick Hayden and Blair D. Isaac of Knoxdale Public School in Ottawa; at the intermediate level, the winners were Jean-Claude Naugler and Rose Smith of New Germany Rural School in Halifax. "I love this kind of project because I get to use what I learned and not just write it down and hand it in. I got to put ideas to work," said winner Hayden.

Prizes in the "most artistic creation" category went to Aaron Stavert and Lyle Waugh of Kensington Intermediate School, and to Peter Burke and Sidney Lunn of Elliot River Elementary School, all in Summerside, Prince Edward Island.

Planetary Society Executive Director Louis Friedman, who helped judge the contest, was enthusiastic about the event as a learning experience for tens of thousands of young people. "The work of the young people demonstrated their curiosity about other worlds, and the cleverness of their projects showed their ability to relate it to our own," Dr. Friedman commented.

Astronaut Marc Garneau and artist Jon Lomberg joined Dr. Friedman in judging the contest.

TOGETHER TO MARS?

The Planetary Society has led the call for human exploration of Mars and has vigorously advocated that the United States and the Soviet Union undertake Mars exploration as a joint effort. As we go to press, the Society is organizing a July "spacebridge" between Soviet and American scientists and engineers. During the Case for Mars III conference in Boulder, Colorado, American scientists will be linked by satellite with Soviet scientists meeting in Moscow. The meeting, called "Together to Mars?", will be broadcast over PBS stations this fall.

Overseeing the science groups (on mission design, life science and Mars science) will be Society President Carl Sagan in the US and Society Advisor Roald Sagdeev in the USSR. Astronauts, cosmonauts, social commentators and other leading scientists will observe the meetings and comment on their significance.

The Solar System in Pictures and Books

Books

ORDER NUMBER	Books	PRICE (IN US DOLLARS)
105	**Atlas of the Solar System** by Patrick Moore and Garry Hunt. 464 pages. **Soft Cover**	$20.00
108	**Beyond Spaceship Earth: Environmental Ethics and the Solar System** edited by Eugene C. Hargrove. 336 pages. NEW	$20.00
110	**Comet** by Carl Sagan and Ann Druyan. 398 pages.	$20.00
115	**Cosmic Quest: Searching for Intelligent Life Among the Stars** by Margaret Poynter and Michael J. Klein. 124 pages.	$ 9.00
120	**Earth Watch** by Charles Sheffield. 160 pages.	$20.00
135	**Nemesis: The Death-Star and Other Theories of Mass Extinction** by Donald Goldsmith. 166 pages.	$14.00
137	**New Worlds** by Heather Couper and Nigel Henbest. 144 pages.	$11.50
140	**Out of the Cradle: Exploring the Frontiers Beyond Earth** by William K. Hartmann, Ron Miller and Pamela Lee. 190 pages. **Soft Cover**	$11.00
145	**Pioneering the Space Frontier** by the National Commission on Space. 211 pages.	$12.00
150	**Planetary Exploration through Year 2000: An Augmented Program** Part two of a report by The Solar System Exploration Committee of the NASA advisory council. 239 pages.	$10.00
155	**Rings — Discoveries from Galileo to Voyager** by James Elliot and Richard Kerr. 209 pages.	$16.00
159	**The Case for Mars** edited by Penelope J. Boston. 314 pages. **Soft Cover** REPRINT	$18.00
160	**The Case for Mars II** edited by Christopher P. McKay. 700 pages. **Soft Cover**	$26.00
165	**The Grand Tour: A Traveler's Guide to the Solar System** by Ron Miller and William K. Hartmann. 192 pages.	$ 9.00
170	**The Mars One Crew Manual** by Kerry Mark Joëls. 156 pages.	$10.00
175	**The Mars Project** by Senator Spark Matsunaga. 215 pages.	$15.00
180	**The Planets** edited by Byron Preiss. 336 pages.	$22.00
183	**The Search For Extraterrestrial Intelligence: Listening For Life In The Cosmos** — by Thomas R. McDonough. 256 pages.	$18.50
185	**The Surface of Mars** by Michael Carr. 232 pages.	$16.00
187	**To Utopia and Back — The Search for Life in the Solar System** by Norman H. Horowitz. 168 pages.	$11.00
190	**Voyager: The Story of a Space Mission** by Margaret Poynter and Arthur C. Lane. 152 pages.	$ 8.00
195	**Voyage to Jupiter** by David Morrison and Jane Samz. 199 pages.	$11.00
196	**Voyages to Saturn** by David Morrison. 227 pages.	$14.00

Videotapes

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410 VHS 411 BETA	**Comet Halley** (60 min. videotape)	$15.00
420 VHS 421 BETA	**Mars, the Red Planet** (30 min. videotape)	$30.00
430 VHS 431 BETA	**The Voyager Missions to Jupiter and Saturn** (28 min. videotape)	$30.00
440 VHS 441 BETA	**Universe** (30 min. videotape)	$30.00
450 VHS 451 BETA	**Uranus — I Will See Such Things** (29 min. videotape)	$30.00

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315	**Earthrise** photograph of Earth from the Moon (16" x 20" Laser Print)	$ 8.00
320	**Halley Encounter** — 2 pictures from Vega and Giotto missions.	$ 2.50
321	**Uranus Encounter** — 4 pictures from Uranus and its moons.	$ 4.50
322	**Jupiter** laser print of southern hemisphere (16" x 20")	$ 8.00
323	**Mars** laser print of landscape from Viking Orbiter (16" x 20")	$ 8.00
325	**Other Worlds** (23" x 35" poster)	$ 7.00
330	**Planetfest '81** — Saturn and the F-ring (Two 23" x 35" posters)	$ 5.00
333	**Saturn** photograph of full view (16" x 20")	$ 8.00
335	**Voyager 1 at Saturn** (set of five posters)	$16.00
337	**Uranus** laser print of sunlit crescent (16" x 20")	$ 8.00
340	**"You Are Here"** (23" x 29" poster)	$ 5.00

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205	**Chesley Bonestell's Vision of Space** (40 slides with sound cassette)	$15.00
210	**Halley's Comet** (20 slides with description)	$10.00
215	**The Solar System Close-Up, Part One** (50 slides with booklet)	$35.00
216	**The Solar System Close-Up, Part Two** (50 slides with booklet)	$35.00
220	**Viking 1 & 2 at Mars** (40 slides with sound cassette)	$15.00
225	**Voyager 1 & 2 at Jupiter** (40 slides with sound cassette)	$15.00
230	**Voyager 1 Saturn Encounter** (40 slides with sound cassette)	$15.00
231	**Voyager 2 Saturn Encounter** (40 slides with sound cassette)	$15.00
235	**Voyager Mission to Uranus** (20 slides with description)	$ 7.00
240	**Worlds In Comparison** (15 slides with booklet)	$12.00

Other Items

ORDER NUMBER	Other Items	PRICE (IN US DOLLARS)
003	**Membership** — Please list each new member's name and address on a separate sheet of paper. **each**	$20.00
505	**An Explorer's Guide to Mars** (color map of Mars)	$ 4.00
510	**Back issues** of THE PLANETARY REPORT – Each volume contains six issues. (Vol. 1, #5 & 6; Vol. 2, #1 & 6; Vol. 3, #1 & 2 and Vol. 4, #6 have been sold out.) Specify the issues you are ordering by volume and number. **each**	$ 2.00
515	**Bookmark** — blue with logo (6" x 2", 2 for $2.00)	$ 1.50
520	**Calendar 1987** — last chance sale.	$ 3.50
530	**"I Love Mars, That's Why I Joined The Planetary Society" T-Shirt** — burnt orange **S M L XL**	$ 8.00
535	**Mars Model** by Don Dixon and Rick Sternbach	$65.00
540	**Men's T-Shirt** — white with blue logo. **S M L XL**	$ 9.00
541	**Women's T-Shirt** — navy with white logo. **S M L XL** (sizes run small)	$ 9.00
545	**Planetary Report Binders** — blue with gold lettering. (2 for $16.00)	$ 9.00
550	**TPS Buttons** — blue with logo (2 for $2.50)	$ 1.50

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PLUTO — Although very little is known about Pluto, the outermost planet in our solar system, its small size and other characteristics have caused scientists to wonder if it is really an asteroid in planet's clothing. But new findings from the Infrared Astronomical Satellite (IRAS) and from ground-based observations show that Pluto holds a significant methane atmosphere, making it distinctly planetary. In this painting, artist Ron Miller depicts Pluto's cold, rocky surface and its companion moon, Charon.

Ron Miller lives and works near Fredericksburg, Virginia. His latest book, Cycles of Fire *(co-written with William K. Hartmann) is due out in September.*

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