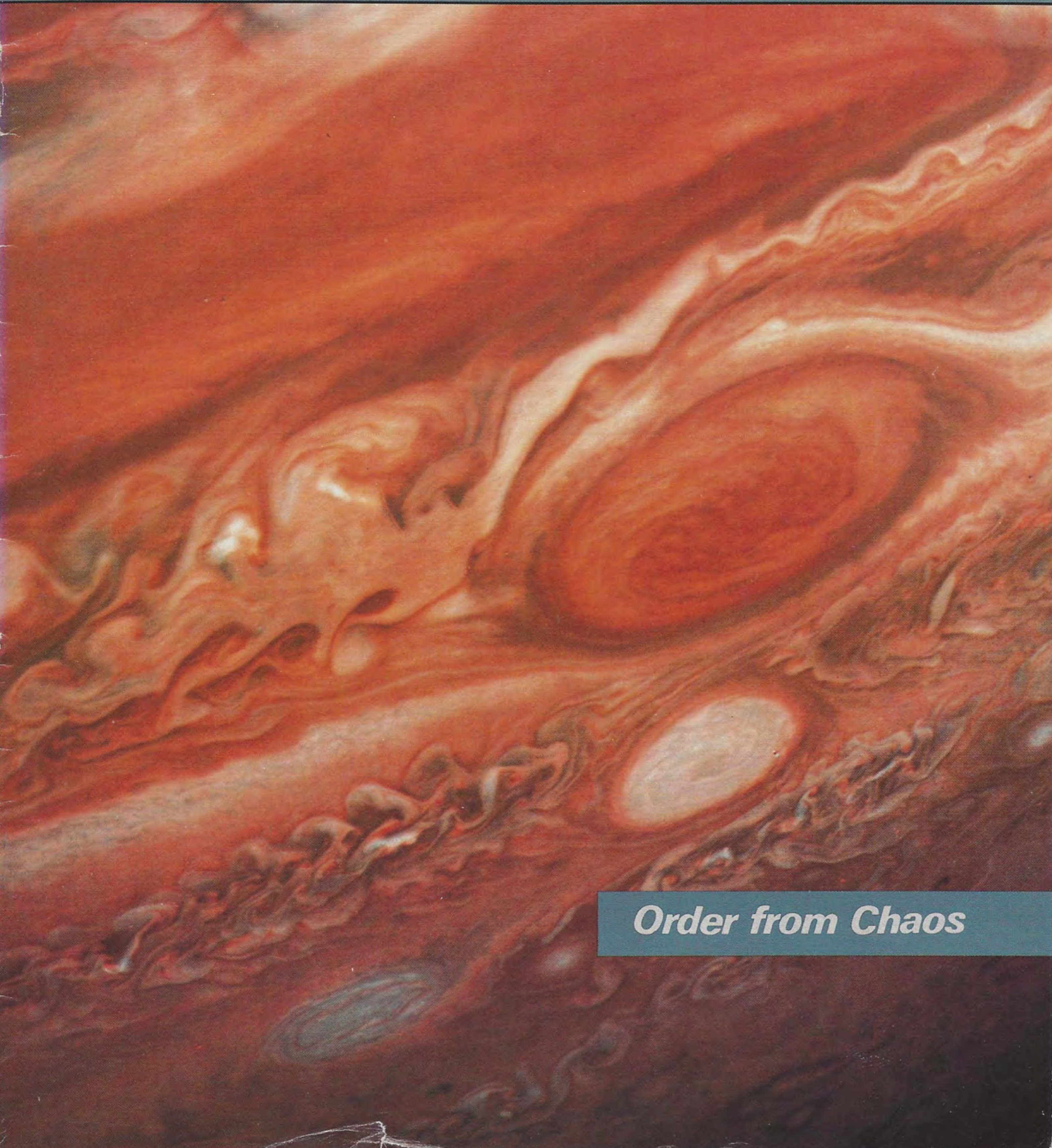
The PLANETARY REPORT

Volume IV Number 3 May/June 1984



Order from Chaos

A Publication of
THE PLANETARY SOCIETY

The Planetary Report (ISSN 0736-3680) is published six times yearly at the editorial offices of The Planetary Society, 110 S. Euclid Avenue, Pasadena, CA 91101.

Editor, Charlene M. Anderson;
Technical Editor, James D. Burke;
Editorial Assistant, Lyndine McAfee;
Art Director, Barbara Smith

COVER: The Great Red Spot dominates Jupiter's southern hemisphere, where it has been watched by Earth-based observers for 300 years. Turbulent eddies, such as the Great Red Spot and the white ovals seen here, are characteristic of giant planet atmospheres. They lie within and between the zonal winds, blowing east and west, that give Jupiter and Saturn their banded appearances.
IMAGE: JPL/NASA

Letters to the Editor

We encourage our members to write us on topics related to the goals of The Planetary Society: continuing planetary exploration and the search for extraterrestrial life. Letters intended for publication should be short and to the point. Address them to: Letters to the Editor, P.O. Box 91687, Pasadena, CA 91109.

EDITOR: After reading about the proposed space station in your January/February 1984 issue, I couldn't help wondering if the US government and NASA weren't missing a perfect opportunity to start defusing the tension and mistrust which exists between East and West.

If the Society has any lobbying power whatsoever, now is the time to push for an international space station, in which Americans, Soviets and all other interested nations contribute in every aspect to the building of our first home-away-from-home.

It would also seem, to me, a positive step toward creating the trust which is so lacking in East-West relations.

PAUL ALBERT, *New Brunswick, Canada*

EDITOR: Upon renewing my membership in The Planetary Society for a second year, I wish to let the Society's staff know that I am excited by the efforts you are making to support and encourage cooperative and international human involvement in space. I am a firm believer in the need for an active and progressive space program (manned or unmanned, commercial or scientific) for the human race as a whole.

I hope the various projects the Society is involved in will yield fruitful, encouraging results.

G. DIANNE LEBONVILLE, *Charlotte, North Carolina*

EDITOR: I read with great interest Dr. Chapman's assessment of the potentials of a permanent space station in the January/February issue of *The Planetary Report.* While I agree that the $9 billion requested by NASA for the project would buy a lot of IRAS and *Voyager* spacecraft, I think we should raise our sights toward doing the kinds of scientific studies that a space station will allow, rather than grumble about how much it will cost.

Think of having a base in orbit for exploring the solar system! A base that can house permanent laboratories and observatories that are always free from Earth's obscuring atmospheric effects. A base where truly sophisticated planetary spacecraft can be assembled, checked out, and sent on their mission. A base where, eventually, men and women can start the *human* exploration of the planets. That's what a space station can provide us, if we make those requirements felt clearly by the decisionmakers in Washington. Instead of trying to repeat past successes, we should be looking forward to future challenges.

I realize that the cost of major programs such as *Apollo,* the Space Shuttle, and now a space station can squeeze funds for planetary exploration. But my reading of the attitudes in Washington (and Peoria, for that matter) is that without the big, politically sexy major programs, NASA would be disbanded and *all* planetary exploration would come to a halt in the United States.

A wise politician once said, "When handed a lemon, make lemonade." The space station is no lemon. But neither should it be a goal in and of itself. We should work our hardest to see that it becomes a beachhead in space, from which new expeditions can be launched. Future generations of scientists, who will carry on the work of exploring the solar system, will thank us for our effort.

BEN BOVA, *West Hartford, Connecticut*

[Editor's Note: Mr. Bova is President of the National Space Institute as well as a member of The Planetary Society.]

Asteroid Project Discovers Ten New Asteroids

1984 HAS BEEN A GOOD YEAR FOR ASTEROID HUNTERS; Eleanor Helin and her co-worker, R. Scott Dunbar, discovered ten new asteroids—four of them planet-crossers—within the first two months of this year. In the Asteroid Project, supported by The Planetary Society and the World Space Foundation, they have been searching the skies with the 1.2 meter Schmidt telescope on Mount Palomar. They are helped in their work by Steven Swanson, a graduate student at the California Institute of Technology, who is funded by The Planetary Society.

The new asteroids belong to two unusual families. Eight are members of the special dynamical groups known as the Hungarias and Phocaeas, which circle the Sun near the inner edge of the main asteroid belt, between the orbits of Mars and Jupiter. Helin said that these regions might be sources of asteroids which cross the Earth's orbit, if perturbed from their present orbits.

Planet-Crossers

Planet-crossing asteroids move around the Sun in orbits that intersect the orbits of planets. They may have been deflected from main-belt orbits or formed in different parts of the solar system. Some may be the remains of comets that condensed in the solar system's outer reaches. Discovering what these small, dark bodies are and where they came from is important to understanding the origin and life history of our solar system. Studying their orbits may have vital relevance to us as well; some scientists speculate that a collision with a large Earth-crossing asteroid may have caused the extinction of the dinosaurs.

Possibly the most exciting new discovery is 1984BC, a planet-crossing asteroid that travels in the same sort of orbit a short-period comet might follow. Project scientists speculate that they may have found the burnt-out nucleus of an ancient comet. Another find, 1984AB, travels in an orbit remarkably similar to that of Mars.

The Asteroid Project's discovery of 1984BC could be particularly important because it has given the scientists a rare chance to study a possible comet nucleus. When Helin and Dunbar first sent the observed positions to Brian Marsden of the Minor Planet Center of the Harvard-Smithsonian Astrophysical Observatory for orbit determination, he was moved to say that 1984BC was "*very* interesting."

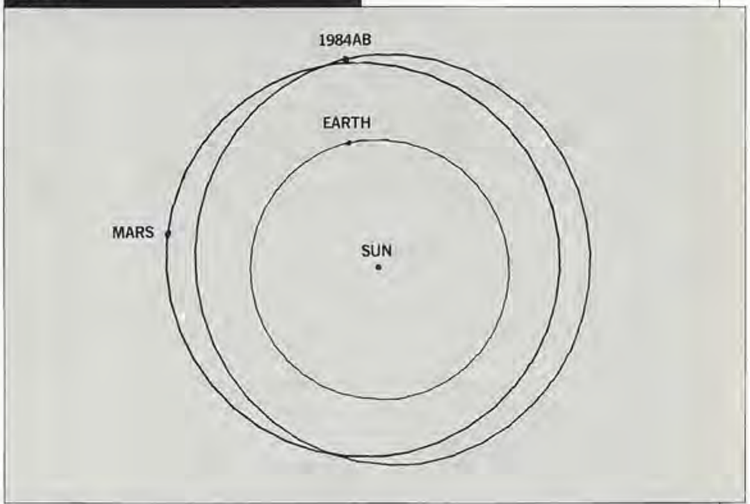
1984BC's orbit swings it close to the Sun every six years (its *orbital period*), crossing the orbits of both Mars and Jupiter. This orbit suggests that 1984BC might be the missing link between asteroids and short-period comets such as Comet D'Arrest, which follows a similar orbit.

Sizing Up a Comet

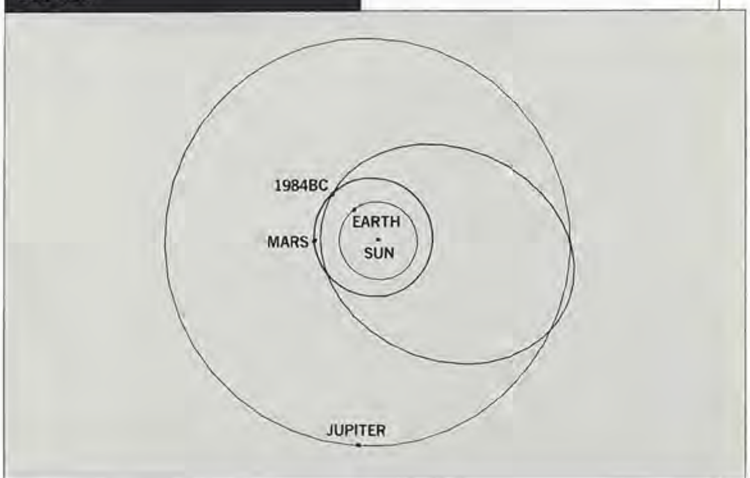
When Asteroid Project scientists make a discovery, they routinely alert researchers at other observatories, enabling as many observations as possible. Immediately after determining the positions of 1984BC from the Palomar Schmidt, Helin and Dunbar sent them to Larry Lebofsky at the Infrared Telescope Facility in Hawaii. He picked up 1984BC with the infrared instrument and added to our information about the new object. 1984BC appears to be very dark, as we would expect of a comet nucleus that has lost its gas and dust. It has a diameter of about four kilometers, which, according to Helin, "really sizes up a comet nucleus."

The asteroid scientists are also excited by Helin's discovery of 1984AB, which she found on the night of January 3–4. From Helin's preliminary measurements, and those of Dr. Edward Bowell of Lowell Observatory, the scientists speculated that this asteroid might be a Mars Trojan. (Trojans precede or follow a planet in its orbit at a *Lagrange point*, a place where the orbiting objects can maintain a constant distance from the planet.) However, further observations and analysis showed that 1984AB was not a Trojan, but it follows an orbit remarkably close to Mars'. The similarities suggest that the planet and the asteroid may eventually collide.

1984AB



1984BC



Asteroids, especially Earth-crossers, are particularly fascinating to many scientists and engineers because they would be easy targets for spacecraft missions and space resource development. Louis Friedman, Executive Director of The Planetary Society, commented, "Both the number and the diversity of these recent discoveries emphasize the importance of this work to finding objects for future space missions. A close-up examination and analysis of near-Earth asteroids is an important step in finding out what space resources may exist." —*CHARLENE M. ANDERSON*

The Next

Seen through a telescope, Mars is a reddish disk marked by dark blotches and crisscrossing lines. In the past, more imaginative astronomers had been tempted to identify the blotches as vegetation and the lines as canals. The more hopeful among them believed that the Red Planet supported life, similar to that covering our blue planet, Earth. Limited by what we could see from Earth, it was difficult to determine what Mars was like, or if Martian plants and animals created the patterns we watched from 78 million kilometers away.

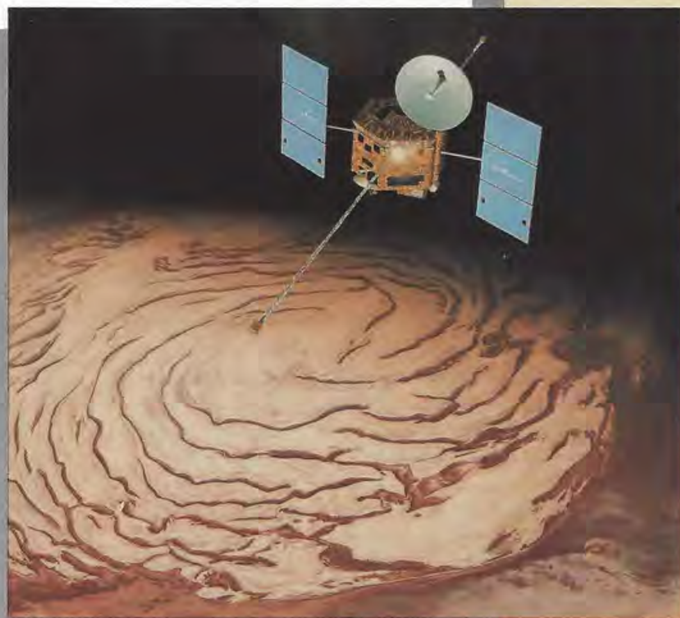
Then, by the mid-1960's, we were able to send spacecraft armed with robot sensing devices to Mars. Mariners 4, 6 *and* 7 *relayed to Earth images of an apparently dead and cratered landscape looking much like our Moon, except for a thin atmosphere and icy poles. They saw no evidence of vast fields of seasonally blooming vegetation, and no network of interconnecting canals built by a technological civilization.*

Mariner 9 *followed them in 1971 and from an orbit about Mars mapped most of the planet with television. This spacecraft saw massive volcanos, immense canyons, planet-engulfing dust storms, and channels remarkably similar to riverbeds on Earth. The Mars seen by* Mariner 9 *was a dynamic and mysterious planet very different from Earth, yet in many ways strangely similar.*

Meanwhile, several Soviet spacecraft had been sent to Mars but most of their missions failed. Then in 1973, the USSR launched a massive assault with four spacecraft— two orbiters and two landers. All of the missions again had some failures but one spacecraft, Mars 5, *did return significant scientific data from orbit, including measurements of the planet's natural gamma-ray radioactivity and measurements of its magnetism and interaction with the solar wind.*

Finally, in 1976, the Viking *mission reached Mars to conduct the most ambitious robot reconnaissance of another planet. The two orbiters imaged the surface in great detail, while two landers took up residence on rocky and sandy plains. The* Vikings *studied the geology and climate of Mars and also tried to determine if any life existed on the Red Planet. Orbiting spacecraft had seen no artifacts of technological civilization, but might there be microbes flourishing in the soil?*

Unfortunately, the results of the biological experiments were ambiguous and the question of whether or not there are Martians of any sort will have to await a rover, a sample return mission or a human expedition. But there is still much we have to learn about the planet itself. Scientists and spacecraft designers have recently begun work on a new mission to Mars: the Mars Geoscience-Climatology Observer.



ABOVE:* *A proposed version of the Mars Geoscience-Climatology Observer flies over Mars' north pole in this painting. This spacecraft will be the first of the Planetary Observers, a series of missions to the inner planets based on Earth-orbiting spacecraft.* *RIGHT:* Viking *Orbiter 2 imaged Mars' north pole in mid-summer, when the seasonal carbon dioxide polar cap had sublimated to reveal water ice and layered terrain beneath. The regularity of the layers suggests periodic changes in Mars' orbit. IMAGES: JPL/NASA

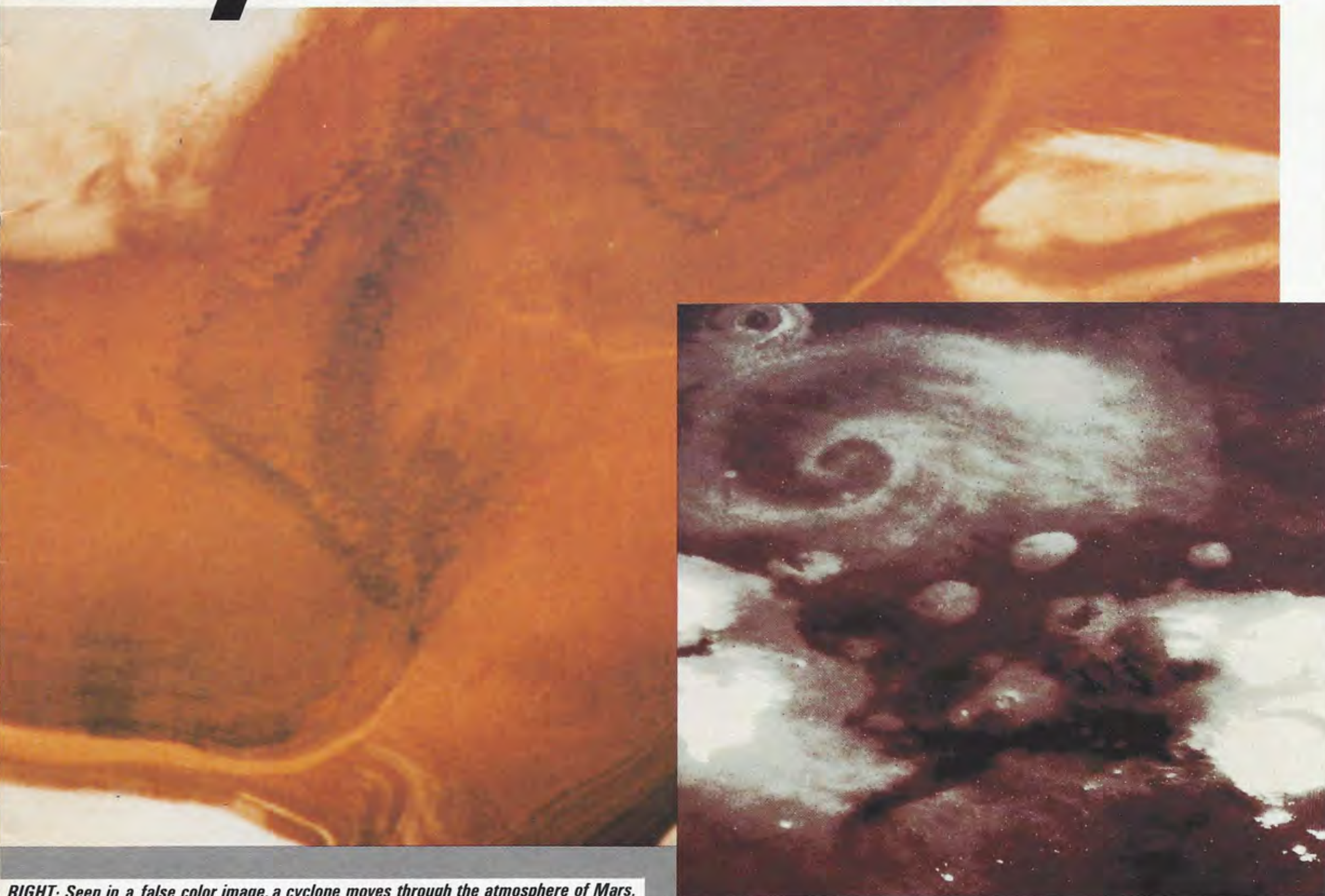
The Mars Geoscience-Climatology Observer (MGCO) is scheduled to study Mars between 1990 and 1993. It is intended to be the first of a new class of relatively simple, inner-solar-system missions using spacecraft already developed for use in Earth orbit. This concept, formulated by NASA's Solar System Exploration Committee (SSEC), represents a new approach to planetary science. Survival of planetary science was recently jeopardized by an almost complete dependence on expensive and complex missions, such as *Viking* and *Voyager,* that attempted to achieve a wide array of scientific goals. As fiscal constraints became more severe, it was more difficult to get Congress and the administration to approve such missions. The SSEC recommended instead a series of relatively modest, scientifically focused missions based on existing technology. These Planetary Observer spacecraft will study the inner solar system and MGCO will be a test of this new approach.

MGCO will build on the success of the *Mariners* and *Vikings.* Through these spacecraft we have chemically analyzed the Martian surface at two places, imaged the entire planet with resolution (ability to see detail) of 200 meters or better, and measured the thermal properties of most of the surface. We have taken meteorological measurements at the two *Viking* Lander sites and followed global changes in atmospheric temperature and water content for over two Martian years (over three and one-half Earth years). From these data we have been able to broadly outline the geologic history of the planet, identify the processes that shaped the surface, and generally describe the atmospheric circulation.

Despite these successes, large gaps remain in our knowledge. We know, for example, that Mars has a long and varied volcanic history, but we know little of the chemical composition of the lavas. Similarly, we have strong evidence that Mars has undergone major climatic changes, but we do not know how and why. Although we can fill some of these gaps

Step to Mars

by Michael H. Carr



RIGHT: Seen in a false color image, a cyclone moves through the atmosphere of Mars.

only with complex endeavors such as returning samples to Earth or establishing a global network of instrumented stations on Mars, we can fill other gaps with orbital observations. This is the aim of MGCO.

In the spirit of the SSEC recommendation, the MGCO is scientifically focused. Its objectives are:

1. To determine the chemical and mineralogical composition of the Martian surface and how it varies according to location,

2. To define more precisely the surface topography and gravitational field,

3. To determine where most of Mars' water and other *volatiles* (easily evaporated substances) are and how they participate in seasonal and longer-term climatic changes,

4. To determine more precisely the structure and circulation pattern of the atmosphere, and

5. To establish the nature of the planet's magnetic field.

We will use a commercially available spacecraft and are considering several candidates. The current plan is to launch in the summer of 1990 and arrive at Mars a year later. The spacecraft will be placed in a highly inclined, circular orbit with an altitude of 350 kilometers. The spacecraft will orbit the planet in just under two hours, completing a little more than twelve orbits each day. (The Martian day, called a "sol," is about 24 hours and 38 minutes long.) The planet will rotate under the orbiting spacecraft, so on each successive pass the planet will have "moved" 28 degrees in longitude. We expect MGCO to make observations for at least one Martian year (669 sols), mapping the entire surface and following atmospheric and surface changes through one complete seasonal cycle.

We have yet to choose the scientific instruments that will fly on MGCO. One major objective is to determine the chemical and mineralogical composition of the surface. This is vital to our understanding of the planet. It will tell us how the interior of the planet is chemically differentiated, what types of rocks are present, if and how volcanic processes have evolved with time, and it will provide clues to the composition and thermal state of the interior.

The *Viking* Landers chemically analyzed debris within their reach, but the analyses were all of weathered material, not coherent rock, and the Landers had no means of determining mineralogy. Both orbital and Earth-based telescopic observations indicate that not all the surface is covered with weathered debris. Bedrock is widely exposed and mineralogical and chemical differences exist. MGCO will probably carry two instruments for determining chemistry and mineralogy: a gamma ray spectrometer (GRS) and a mapping visual and infrared spectrometer (MVIRS).

Rocks at the Martian surface, like those on Earth, have a low level of radioactivity. Some of the activity is caused by long-lived, naturally radioactive elements such as potassium, uranium and thorium; other activity is induced by cosmic rays. The

Viking *Orbiter 1 looks obliquely across Argyre Planitia toward the horizon some 19,000 kilometers away. Clouds occasionally appear over this region, but on the day this image was made, the atmosphere was unusually clear. Haze, perhaps made of carbon dioxide crystals, appears in layers 25 to 40 kilometers above the horizon.*
IMAGE: JPL/NASA

radioactive elements emit gamma rays which can be detected from orbit; in 1974 *Mars 5* made the first such measurements of Mars. Because the energy of gamma rays is diagnostic of the nuclear reactions involved, we can determine the composition of the surface from the energy spectrum; this is the function of the GRS.

The MVIRS measures the reflectivity of the surface at many different wavelengths within the visible and near-infrared. In other words, it precisely measures the color of the surface. Because color is largely controlled by mineral combinations, the MVIRS will yield valuable clues about the mineralogy of the surface. The gamma ray and visual and infrared spectrometers complement each other and provide a powerful combination for determining chemistry and mineralogy. As bonuses, the two instruments will be able to detect ice that may lie near the surface and trace seasonal variations in ice on the surface.

Surface Topography

We would like to precisely determine the surface topography for a variety of reasons, but most important is to model surface gravity. The gravity on the surface of a solid planet varies with location because of differences in local topography and in the density of rocks below and around the measurement site. Our main interest is to determine how densities vary with depth, for this tells us much about how composition changes with depth and how thick the rigid crust is. But in order to derive densities, the gravity must be corrected for local topography, hence the need for accurate elevations.

Measurement of topography is also needed to model a variety of geologic processes such as stream flow, crater formation, volcano growth and bending of the crust under loads. Our current estimates of Martian elevations are based on an assortment of occultation measurements (the precise timing of when a spacecraft passes behind the planet as viewed from Earth), Earth-based radar measurements, photogrammetric determinations from *Viking* Orbiter imagery, and some measures of the scattering properties of the atmosphere. Their precision and accuracy vary greatly according to location, and in general are no better than one kilometer. MGCO may carry a radar altimeter similar to that flown on *Pioneer* Venus, capable of measuring elevation to within 20 meters so we expect a vast improvement in our knowledge of the topography.

Climatic History

The climatic history of Mars presents some of the planet's most intriguing problems. At present we think Mars undergoes small periodic changes in climate because of variations in its orbital and rotational motions. Its *inclination,* or tilt toward the Sun, varies between 15 and 35 degrees on a scale of about one million years. Such changes most strongly affect the polar regions where volatiles such as carbon dioxide and water are frozen out or adsorbed on the surface. An increase in inclination will tend to evaporate volatiles from the poles, thereby increasing the atmospheric pressure, which could in turn change the climate. Rhythmic layerings of sediments at the poles may be a direct result of such changes.

Probably the most dramatic indications of climatic change are the seemingly waterworn channels in the oldest terrains. It appears unlikely that variations in planetary motions could have induced climatic changes large enough to allow water to flow across the Martian surface. Much larger temperature and pressure changes would be required, but what could cause such changes remains a mystery.

MGCO will address the climatology problem in two ways, first by better determining where the volatiles come from and where they go, and second, by more clearly characterizing the present atmosphere so that we can extrapolate to past conditions. I've already mentioned the use of the GRS and MVIRS in detecting ice. In addition, a radar sounder could detect layering or discontinuities caused by ground ice, and could easily detect any liquid water that might lie near the surface. The most promising way to better understand past climates is through improved knowledge of the dynamics of the present atmosphere. If we can accurately model the present atmosphere, then we can reliably evaluate the effects of changing such factors as the latitudinal distribution of sunlight, the *albedo* (reflectivity) of the poles, or the amounts of dust in the atmosphere. MGCO will accordingly include an atmospheric sounder that will continually monitor the vertical distributions of temperature, water vapor, clouds, dust and so forth, over the entire planet for a full Martian year. Other possible instruments are an ultraviolet spectrometer and an ultraviolet photometer for measuring variations in the distribution of chemical species, such as ozone and hydrogen, within the atmosphere.

The Next Step

The MGCO mission is a logical next step in our exploration of Mars. It will provide us with abundant new information about the geology and climatology of the planet, and will greatly enhance the value of data gathered by previous missions. Merging the altimetry and compositional data with the *Viking* images could be particularly fruitful. By more completely characterizing the surface, the mission also paves the way for more ambitious missions, such as a Mars sample return or a surface rover. The MGCO mission thus demonstrates that solid and exciting planetary science can still be performed even under greatly reduced planetary science budgets. Our challenge now is to gain public and governmental approval for this and other missions in its class—missions very modest in comparison to the great enterprises of the recent past, but nevertheless offering real hope for our future in deep space.

Michael Carr, with the United States Geological Survey, is the Chairman of the Science Working Group for MGCO.

Questions & Answers

***While Jupiter is orange and Saturn is basically yellow, Uranus and Neptune are green. Why are they green?— Frank Weigert,* Wilmington, Delaware.**

THE TINY DISKS of Uranus and Neptune indeed appear slightly greenish, seen through our Earth-based telescopes. This difference in color from Jupiter and Saturn is not the result of colored clouds. It is caused by the strong absorption of the red component of sunlight by the large amounts of methane in the atmospheres of these two planets.

Methane, like water, appears colorless when light passes through small amounts of it. But just as water absorbs red light, making swimming pools blue, methane weakly absorbs red. If you look through a kilometer or so of methane (not likely to happen on Earth!) the red is lost and you are left with greenish light (methane and water can't absorb exactly the same way). The atmospheres of Jupiter and Saturn contain much less methane than Uranus and Neptune above the reflecting cloud decks, and so the "greening" does not appear.

In the infrared portion of the spectrum, just beyond visible wavelengths, the absorption of methane increases drastically, making Uranus and Neptune virtually black for a broad range of infrared "colors."

***Among the more interesting photos from the* Viking *mission are those of the "Pyramids of Elysium" and the "face" on Mars. What is the best guess as to what they are?— John D. Brinton,* Renton, Washington.**

Clockwise, from upper left: The "face" on Mars (upper center); the profile of the "Old Man of the Mountain" seen in New Hampshire; and the "Pyramids of Elysium" (lower center).
IMAGES: JPL/NASA AND THE STATE OF NEW HAMPSHIRE

PATTERN RECOGNITION is one of the almost-magic abilities of the human eye and brain. As computer scientists and their computers become more and more capable, it is becoming evident that recognizing faces involves much more than just the storage and recall of an array of data representing light and shadow. Somehow we (and most other animals with eyes) are able to extrapolate and synthesize at a higher level—a level far more subtle than just noting someone's big nose or ears.

This same ability, however, also enables us to see things that are not there—a subject of fun with the clouds of a summer sky and of serious inquiry with the aid of ink blots. Reasoning by analogy, we make patterns, just as the ancient astrologers made out shapes and attached legends to the starry constellations.

Now, when whole new worlds are opening to our eyes, opportunities for this sort of thing abound. Yes, one can make out faces and pyramids on Mars. In the accompanying pictures sent to Earth by the *Viking* Orbiters we see some examples. **Figure 1** shows an area about 50 kilometers square, near the boundary between the old cratered terrain of Mars and the great, low northern desert, Acidalia Planitia. In these boundary regions the land appears to have wasted away, perhaps by the disappearance of huge volumes of subsurface ice, leaving a fretted, jumbled area with outlying remnants of the ancient highlands giving the appearance of mesas and mounds. Under the particular sunlight angle of **Figure 1,** one of these features, northeast of the central doughnut-like image defect, looks vaguely like a face.

Figure 2 shows a 180-kilometer-square region on the other side of Mars and includes the "Pyramids of Elysium." Such flocks of little hills are widely scattered on Mars and often, as here, they are aligned with each other and are vaguely pyramidal in shape. Geologically, they are interesting because their origin may have involved several processes: erosion or slumping of weaker, perhaps icy, ground away from more coherent structures, and also possibly ablation due to wind.

Every planet has its own geological style and despite some basic similarities, it is clear that each will reward its explorers with many new insights and surprises. And among these will surely be more patterns such as the faces and pyramids on Mars. □

Order from Chaos: The Atmo

by Andrew P. Ingersoll

***B**eing Earth-dwellers, we are used to planets with rocky, watery surfaces, encased in thin, blue atmospheres of nitrogen and oxygen marked by watery white clouds. Moderate winds, driven by sunlight and the planet's rotation, push ocean-born storms eastward across continents. There they spend their energy in blizzards, thunderstorms, tornados and other short-lived outbursts. As they die, other storms are born and the cycle begins again.*

Things are very different on Jupiter and Saturn. Thick atmospheres of molecular hydrogen and helium enshroud spheres of liquid metallic hydrogen, formed where great pressures strip electrons from protons. At the planets' centers may lie cores of rock and ice— nuclei of these swirling, churning worlds containing most of the matter left after the formation of the Sun. Earth and the remaining planets are debris compared to Jupiter (318 times Earth's mass) and Saturn (95 times larger than Earth). The faces of these giant planets are also very different from Earth's. Colored cloud bands circle their globes, marked by waves, eddies and giant storms. Saturn is the color of butterscotch; its bands and markings are darker or lighter tones in a fairly evenly colored atmosphere. Winds near its equator reach 1800 kilometers (km) per hour, two-thirds the speed of sound there. The red and white bands of clouds circling Jupiter are blown by relatively slow winds peaking at 540 km per hour; these alternating bands are filled with long-lived cyclones, anticyclones and other patterns of turbulence. The Great Red Spot, a massive storm that could swallow three Earths, has been watched by astronomers for the past three centuries.

To describe the behavior of the atmospheres on these strange and imposing worlds, scientists can begin with the known equations of motion— Newton's laws of the conservation of mass, momentum and energy. Telescopic and spacecraft measurements provide a basic picture of what's going on at Jupiter and Saturn. But to explain why *these atmospheres behave as they do, what produces the bands, storms and other features, scientists must build "models" of the atmospheres. Their knowledge of the atmosphere is basically limited to the visible cloud tops; they must make assumptions about what they don't know, what's going on in the depths of the atmospheres. These assumptions, such as the extent of the atmospheres and their energy sources, differ among scientists and lead to differing models.*

In this article we examine some of the competing models of giant planet atmospheres and take a look at how scientists try to understand some of our planetary neighbors.

The bands, spots and other features we see in the colorful *Voyager* images of Jupiter and Saturn are basically weather patterns. The colors appear because cloud particles at some places on the planet are made of chemical compounds differing from those at other places. The clouds are

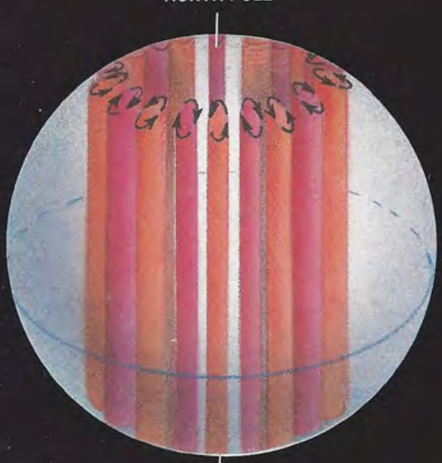


FIGURE 1

FIGURE 2

ABOVE: According to the model of F. H. Busse, the spots and ovals in giant, fluid atmospheres may be the visible ends of columnar convection cells spinning about axes parallel to the rotation axes of the planets (Figure 1). The zonal jets, which give the giant planets their characteristic bands, may be the surface expressions of rotating nested cylinders (Figure 2) driven by the planets' heat and rotation.
ILLUSTRATIONS: S. A. SMITH

spheres of Jupiter and Saturn

blown by winds, and the winds are organized into the banded features that give Jupiter and Saturn their characteristic appearances. These cloud patterns are different from those of Earth in many ways. On Earth there is only one cloud-forming substance — water. On the giant planets the elements carbon, hydrogen, nitrogen, oxygen, sulfur and phosphorus can react in sunlight to form a rich variety of colorful compounds, many of which can condense into clouds. The compositions and colors of these mixtures depend on temperature, pressure, amount of sunlight and rate of updraft within the clouds.

The dynamic features in the giant planet atmospheres and those of Earth's differ in their structures and the lifetimes of their storms and other features. On Jupiter and Saturn bands of clouds circle the planets along lines of constant latitude. Each band has its own east-west (zonal) wind that blows relative to the rotation of the planet. We measure the speeds of these winds, or *zonal jets*, by taking pictures at different times and noting the movement of the features within them.

We also see circulating oval spots that roll like ball bearings between the opposing jets. These spots are like huge cyclones and anticyclones in Earth's atmosphere, but they are larger, more colorful and often last for months, decades or even centuries. On Earth such features last for days or weeks at most.

The longevity and banded structure of the Jovian and Saturnian features do not come from interaction with an underlying solid surface. We know from the bulk densities of the giant planets, the preponderance of hydrogen and helium in their atmospheres, and the fact that they radiate stored internal energy (possibly left over from their formation), that these planets have warm, fluid interiors. Any solid continents or mountain ranges could exist only at the surfaces of the rocky cores postulated to lie three-fourths of the way to the centers of the planets. Thus, the longevity of the cloud features must come from processes within the fluid atmospheres themselves.

One of the surprises in the *Voyager* time-lapse imagery was the frenzied activity among the eddies, spots and waves in Jupiter's and Saturn's atmospheres. At scales less than 1000 km, all was chaos, or so it seemed during the first months after the *Voyager* encounters. We watched small spots form and decay every few days at many latitudes. Such spots are continuously pulled apart by the opposing zonal jets, or are swallowed by larger spots. Jupiter's Great Red Spot, which has lasted at least 300 years, is immersed in a band where small features become unrecognizable after 24 hours. The Great Red Spot is the largest storm on the planet, 10,000 km wide and 25,000 km long. How the larger spots and the bands in which they sit endure for hundreds of years was almost more of a mystery after *Voyager* than it was before.

We now better understand the differences between atmospheric dynamics on these giant planets and atmospheric dynamics on Earth. We've progressed by comparing *Voyager* images with theoretical models — sets of equations that describe the evolution of fluid motion at all locations. The equations themselves, based on Newton's Laws, are known exactly. But we don't know what is happening at scales

ABOVE: Jupiter's atmosphere changed in the four months between the encounters of Voyager 1 and Voyager 2. In images returned by Voyager 1 (left), scientists watched small atmospheric features approach the Great Red Spot and then swing around it. In Voyager 2 images, features approached the Great Red Spot and dissipated in the chaotic region to its east.

LEFT: The colors and atmospheric features on Saturn are much more subtle than those of brilliantly marked Jupiter. The colored bands produced by zonal jets are not as pronounced, and spots (mid-right) tend to be smaller.

IMAGES: JPL/NASA

smaller than we can see, nor do we know the boundary conditions — what is happening below the visible clouds. A complete model, including all the small-scale motions, of Earth's or any planet's atmosphere would not fit on the largest computer.

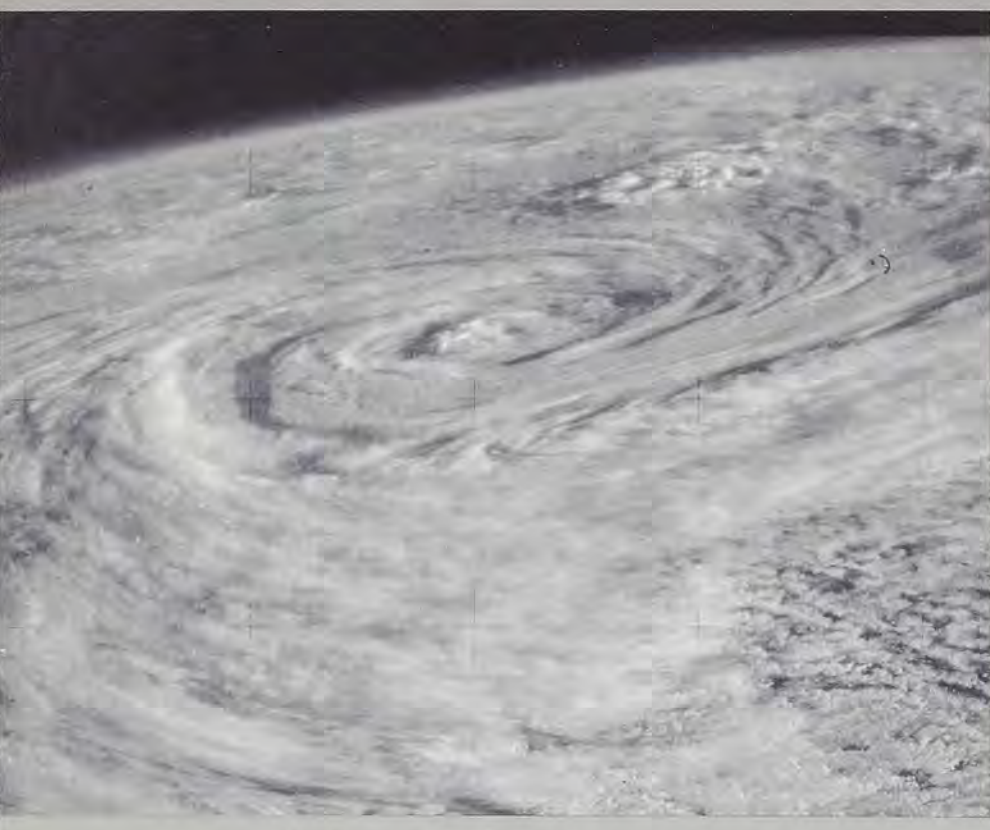
To make the models fit, we reduce the complex interactions of the small, rapidly varying eddies with the larger, longer-lived features to a simple mathematical relation containing one or two free parameters. Similarly, we isolate the visible cloud layers from the deep fluid interior, reducing the complex interaction to a simple boundary condition with free parameters. We can then compare the dynamic features in the models to the features actually seen on Jupiter and Saturn.

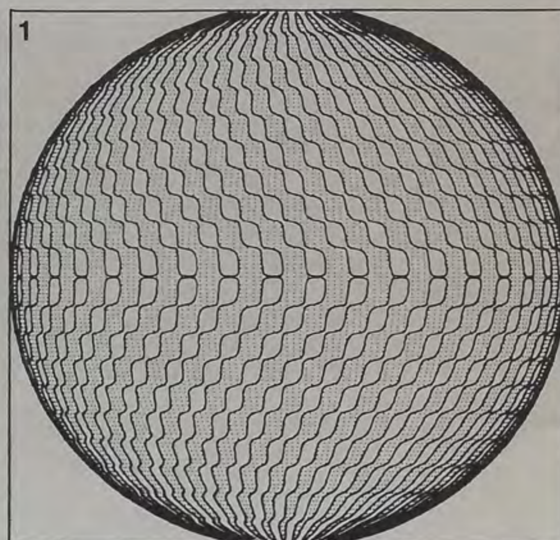
Two competing basic models are now being debated by scientists working on giant planet atmospheres. The models differ because their creators made different basic assumptions about the circulation within the fluid bodies of the planets. Gareth Williams of the Geophysical Fluid Dynamics Laboratory at Princeton University, who published his models before the *Voyager* encounters, assumed that the fluid atmospheres below the visible clouds could be rotating as solid bodies, much as Earth rotates beneath its atmosphere. In the models of F. H. Busse of the University of California at Los Angeles, the atmospheres behave much differently, as if they consist of deeply imbedded, concentric cylinders rotating around the central cores. Working from these very different assumptions, both researchers attempt to explain the zonal jets, eddies and other features of the giant atmospheres.

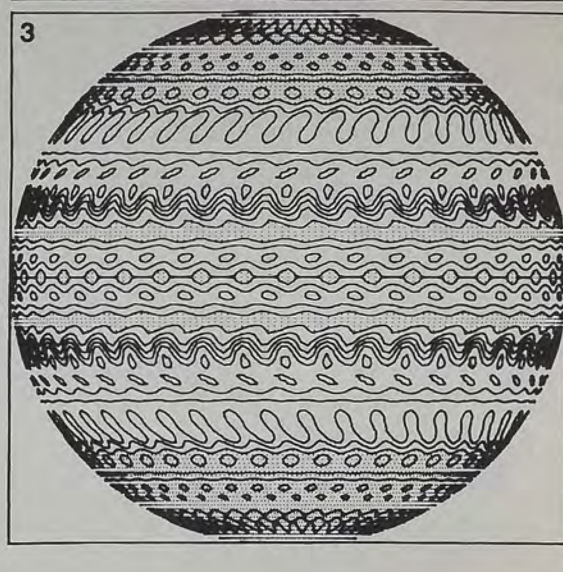
Williams' models indicate that turbulent eddies can feed energy into the zonal jets, helping to drive the colored bands. These eddies must have their own source of energy, and in Williams' models that source is sunlight, which heats the equatorial atmospheres of the giant planets much as it heats Earth's tropical atmosphere. The difference in temperature between the heated equatorial regions and the cooler poles generates energy that feeds the eddies. They are eventually pulled apart by the zonal jets, but rather than dissipating their energy into disorganized motion, they give it to the jets. This chaos-into-order transfer of energy is an example of what is called a *negative-viscosity phenomenon*. Such phenomena occur in Earth's atmosphere and oceans, which circulate over a solid body. They are also found in laboratory-generated flows where the fluid is strongly *sheared* (as the layers slide across each other). The difference between Jupiter, Saturn and Earth, according to Williams, is one of scale. The eddies and jets are the same sizes as on Earth, but on Jupiter and Saturn the jet pattern has ten times more room to repeat itself between equator and pole.

Voyager actually observed such a transfer of energy from eddies to jets in Jupiter's atmosphere. The eddies are tilted by the shear of the zonal jets. By measuring this tilt we determined the rate at which the eddies were feeding energy into the jets. This agreement between models and observation is encouraging, but it does not confirm every aspect of Williams' hypothesis. In particular, the eddies do not necessarily get their energy from sunlight, nor does the visible atmosphere necessarily behave as if it flowed over a deeper fluid layer that acted as if it were solid.

Busse has shown that the same transfer of energy from eddies to zonal jets occurs in dynamic models of the Sun's atmosphere, in which a deep fluid without a solid boundary is driven by an internal source of heat. His models are extensions







ABOVE: Storm systems on Earth are driven by solar heating and the planet's rotation. PHOTO: JOHNSON SPACE CENTER/NASA

RIGHT: In the models of Gareth P. Williams, the processes that drive the Earth's atmosphere are at work in the giant planet atmospheres. This computer-generated sequence shows the evolution through time of the eddies and zonal winds, driven by solar heating and the planets' rotation.
ILLUSTRATION: GARETH P. WILLIAMS

of work done in the early 1900's showing that relatively slow movements within a rotating fluid object (such as the Sun, Jupiter or Saturn) occur as columns parallel to the object's axis of rotation. [See Figure 1 on page 8.] The tops of these circulating fluid columns are *convection cells* (overturning motions within the fluid) that form the oval spots, or eddies, on the planets' surfaces. They draw their energy from heat stored within the planets during their formation. The swift rotation of the planets gives the convection cells their columnar alignment. The zonal jets, which get their energy from the convection cells, are the visible edges of nested cylinders rotating at slightly different rates about the planets' axes of rotation. [See Figure 2 on page 8.]

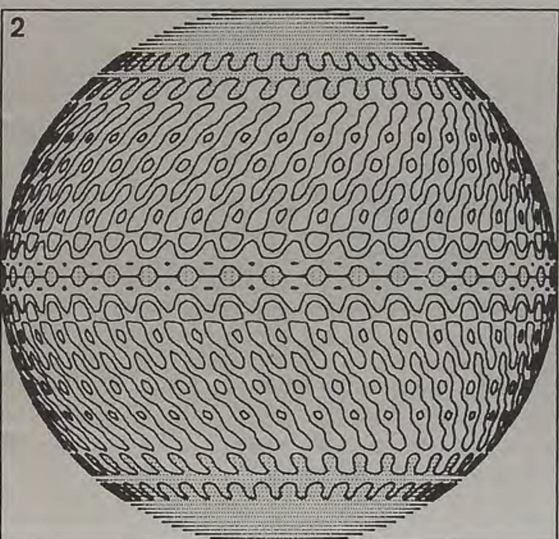
It is not easy to choose between Williams' and Busse's models with the data we have, but the task is by no means hopeless. One clue to the puzzle came after the *Voyager* encounters with Saturn. The spacecraft detected radio emissions from charged particles trapped in Saturn's magnetic field. These emissions rise and fall at an interval (their *period*) close to the time it takes the slowest moving spots to rotate once about the planet. We presume this interval matches the period of regions deep within the planet where the magnetic field is generated. The surprise is that most of the atmosphere is moving eastward at speeds up to 1800 km per hour faster than the internal rate of rotation. If the layers immediately underneath the visible clouds were rotating with the deep interior, enormous shears, or differences in wind speeds, would have to exist between the clouds and the lower layers. According to the laws of fluid motions, if these shears existed, there would have to be large differences in temperature between the equators and the poles. But the *Voyagers* did not record such temperature differences. The simplest explanation is that the difference in eastward velocity between the visible atmosphere and the interior is spread out over a deep layer; in other words, the observed zonal winds extend deep into the fluid interior, as in Busse's model.

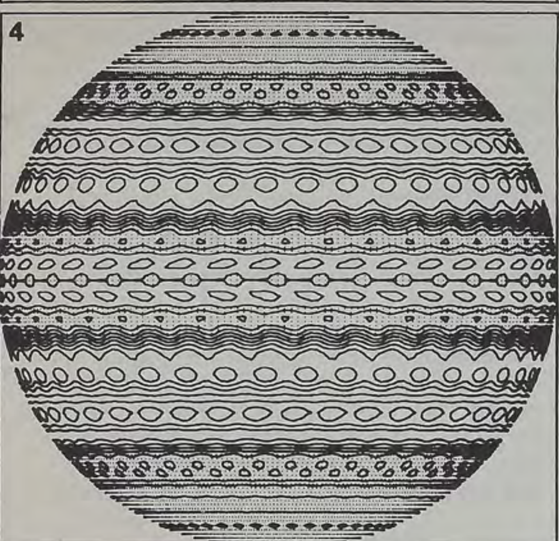
Another clue comes from attempts to model the behavior of long-lived oval spots as they roll like ball bearings between opposing zonal jets. Models published by P.-G. Cuong, David Pollard and myself indicate that this configuration is stable only if the zonal jets extend down to great depths. Jets that die out rapidly with depth and jets in a thin layer bounded by a solid lower boundary as in Williams' models are unstable, at least in models we used. The whole system of spots and jets tends to break up in a matter of days unless the jets are deep.

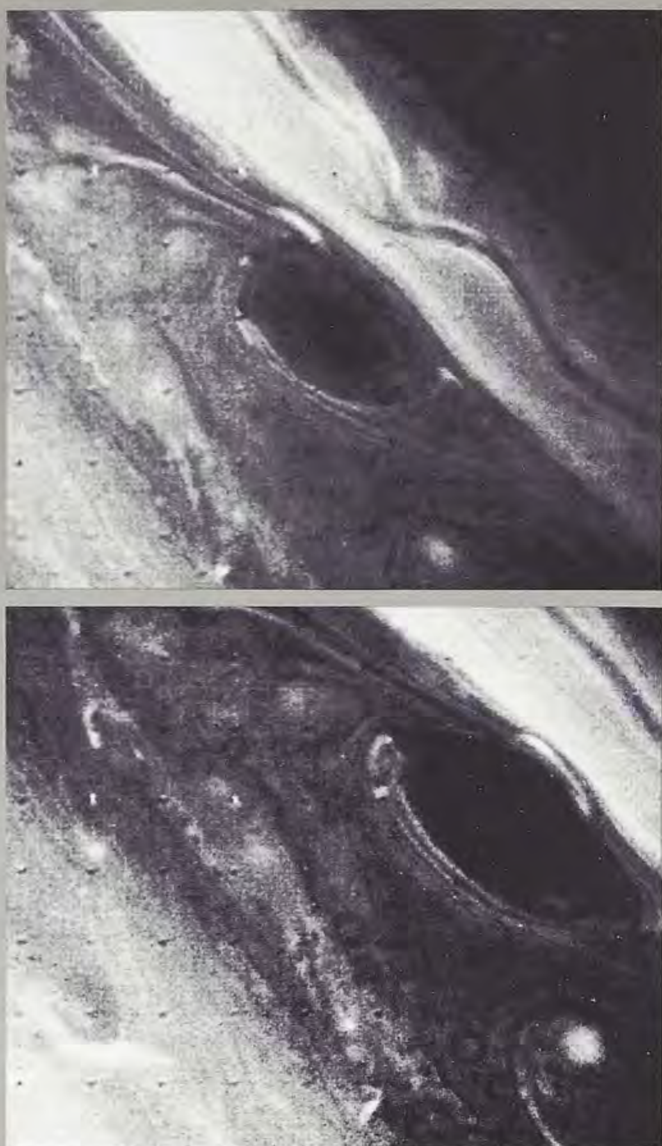
I call these observations and model results "clues" because they are not definitive. Scientists more clever than we may find ways to reconcile the observations cited here with thin-layer models like Williams'. However, the *Voyager* data set is vast, and other clues are hiding in the chaotic behavior of spots, jets and eddies.

In five years, the *Galileo* spacecraft will orbit Jupiter and send a probe into its tumultuous atmosphere. It will provide us with temperature and wind data from the cloud tops to below the base of the clouds. By comparing these data with models, we will eliminate many of the hypotheses; perhaps then we will understand why the atmospheric dynamics of Jupiter and Saturn are so different from those of Earth.

Andrew P. Ingersoll is a professor of planetary science at the California Institute of Technology, specializing in dynamic meteorology and climatology of Earth and other planets. As a member of the Voyager *Imaging Team, he analyzed observations of the atmospheres of Jupiter and Saturn.*







LEFT:
These high-contrast images, taken 10 hours apart by Voyager 2, show the motion of a large brown spot in Saturn's atmosphere.
IMAGES: JPL/NASA

by Clark R. Chapman

We live in an exceptional epoch of human history. During the last two decades, many of the planets and satellites of the solar system have been revealed to us as real worlds. Pictures returned by spacecraft flying past or orbiting around the planets have changed these bodies from blurry astronomical "objects" into true places that we can appreciate and relate to on the same terms with which we see our own planet. Fuzzy "spots" on Mars materialized into vast regions of cratered canyonlands, dry stream beds and fields of ice. The pictures permitted us to compare Mars with Earth, both on a personal emotional level and on the level of physical, chemical and geological processes.

Although the early *Mariner 4, 6* and *7* pictures of Mars showed small regions of the planet at moderately high resolution and demonstrated that Mars was heavily cratered in those places, the true mission of discovery was *Mariner 9.* When it encountered Mars in 1971 the planet was enshrouded in dust, but over the next few months the dust settled and ultimately revealed an amazing variety of landforms on Mars, including the remarkable signs of aqueous processes that still fascinate us today.

Revealing New Worlds

In a solar system of just nine planets, there cannot be many missions that reveal a new world for the first time. It is a rare privilege to be at the Jet Propulsion Laboratory during an historic encounter, and there won't be many more of them. To be sure, there will be excitement indeed for future generations as humans ultimately move out through the solar system and beyond. But after the completion of this phase of solar-system reconnaissance, never again will a generation witness the revelation of a new planet of the Sun. Therefore, the morning of Thursday, March 15 was a memorable one for the several hundred planetary scientists gathered in the Gilruth Center auditorium at Johnson Space Center. Beginning at 10:30 a.m., two scientists from the Soviet Union began to present, for the first time anywhere, a slide show of the radar images of Venus, recently acquired by the *Venera 15* and *16* orbiters.

There had been earlier pictures of Venus—images of the cloudy atmosphere from *Mariner 10* and *Pioneer* Venus, pictures of small patches of ground next to the earlier Soviet *Venera* landers, and increasingly interesting ground-based radar maps of parts of the surface of Venus. But the quantity and exquisite quality of the new data far exceeded these earlier accomplishments. As picture after picture appeared on the screen, I rapidly realized that the *Venera* radar orbiters constituted the *Mariner 9* mission for Venus!

The occasion for this extravagant picture show was the fifteenth annual Lunar and Planetary Science Conference. These meetings began in the heyday of *Apollo* when the first results from analyses of moonrocks were presented to the scientific community, and the conference has evolved into the premier annual meeting of the planetary geosciences. That the Soviet scientists chose the Houston meeting as the first forum for presenting their spectacular Venus results was a demonstration of mutual yearnings for international cooperation in space science.

Touring Venus

Professor V. L. Barsukov, Director of the Vernadsky Institute of Geochemistry in Moscow, was the first speaker. Talking through a translator, he led the expectant audience on a tour of the northern regions of Venus. His only words in English were "Next slide, please"; each such utterance ushered onto the two screens new landscapes never before witnessed. Murmurs of amazement swept through the audience. Venus was revealed as a planet extraordinarily active volcanically, manifesting a variety of landforms, including some that are familiar on Earth and Mars and others unique to Venus. Without a doubt, Venus has more mountain ridges than any other planet except Earth, but the underlying tectonic forces that shape the topography remain to be understood.

Following Barsukov, Dr. A. T. Basilevsky spoke in English about impact craters on Venus. Venus is such a geologically active planet that few of the numerous craters that must once have formed on its surface are still there to be seen—57 in the 18-million-square-kilometer region scanned by the *Veneras* during the first few months of radar mapping. But the form of the craters surprised and intrigued Basilevsky, and he shared his conjectures with the audience. Certainly there are some special characteristics of Venus' impact craters, and they may tell us about the influence of the planet's thick atmosphere on an incoming projectile, or about the effect of the very hot surface temperature on a hole in the ground. Basilevsky estimated the age of the surveyed part of Venus at about a billion years, applying the calibration of crater densities derived by some American scientists. Before he left Houston, Basilevsky was presented with a Texas "vanity" license plate bearing the word CRATER and signed by several dozen scientists.

Bittersweet Success

For the Soviet planetary program, the *Venera* radar results are a stunning success. For the American scientists in the audience who are interested in Venus, the occasion had its bittersweet aspects. For years, they had sweated and toiled to bring into being an American radar mapper, called VOIR (Venus Orbiting Imaging Radar), that never made it past the Office of Management and Budget. If VOIR existed now as it was originally conceived, it too would be in orbit at Venus, complementing the *Venera* data with coverage at higher resolution and mapping the entire planet, including the southern regions which the *Veneras* do not see. 1983 was the year, in the eight-year dynamical cycle of Venus' and Earth's orbits, to launch such missions, as both we and the Soviets have known since at least 1970. So it is disappointing that shortsighted leadership of the American space program has made that sensible mission a might-have-been.

On the other hand, last year Congress did finally approve a stripped-down and cheaper version of VOIR, the Venus Radar Mapper, and it is nice to know that Venus is truly a geological wonderland justifying continued work on that mission. But it is difficult not to yearn for the high-resolution mode of the original VOIR plan. Perhaps this Soviet accomplishment can improve our perspective in planning the American planetary program; to the extent that either effort stimulates the other and opens opportunities for cooperation, American and Soviet planetary scientists should wholeheartedly applaud each others' successes.

Clark Chapman is a planetary scientist interested in asteroids, comets and other small bodies in the solar system, as well as in the scars they leave on planets' surfaces.

World Watch

by Louis D. Friedman

In the last issue of *The Planetary Report* we reviewed the process by which Congress determines the budget for US space activities. There are three steps in their consideration: setting a budget, authorizing the program and appropriating the funds. At each of these steps, Congress passes a bill which becomes law, and is then reconciled with the government's budget as a whole. NASA and other agencies are then granted approval to conduct their programs.

In addition to these yearly activities, Congress also considers broader issues of policy. Two controversial space issues are now before Congress: Soviet-United States cooperation and the deployment of weapons in space. Seven resolutions on these subjects are now before Congress; six specifically deal with space weapons and one, related to arms control, deals more broadly with international cooperation.

Resolutions in Congress

Several resolutions favor space weapons:

(1) House Resolution 215, introduced by Representative G. William Whitehurst (R-VA), and Senate Resolution 100, introduced by Senators Malcolm Wallop (R-WY) and Paul Laxalt (R-NV), both urge the President to proceed more rapidly toward building a space-based ballistic missile defense system;

(2) House Resolution 259, introduced by Representative Charles E. Bennett (D-FL), also urges the more rapid building of a ballistic missile defense system, although it does not specify that such weapons must be in space;

(3) House Resolution 3073, introduced by Representative Kenneth B. Kramer (R-CO) and Senate Resolution 2021, introduced by Senator William L. Armstrong (R-CO), would establish a new agency to accelerate the development of directed energy technology, create a unified space command, transfer the Space Shuttle and other launch vehicles to the Department of Defense as necessary for national security activities, and initiate the development of a manned space station for national security purposes.

There are also three resolutions opposed to space weapons:

(1) House Joint Resolution 87, introduced by Representative Robert W. Kastenmeier (D-WI), calls for a verifiable treaty to ban space weapons;

(2) House Joint Resolution 120, introduced by Representative John J. Moakley (D-MA), calls for immediate negotiations toward a ban on weapons of any kind in space;

(3) Senate Joint Resolution 129, introduced by Senator Larry Pressler (R-SD), calls for a verifiable ban on weapons in space and on weapons designed to attack objects in space.

Cooperation in Space

In addition, there are two resolutions calling upon the President to renew our previous agreement with the Soviet Union for cooperation in space, and to initiate talks with the Soviet Union (and other interested governments) on cooperative ventures in space as an alternative to an arms race in space. They are Senate Joint Resolution 236 by Senator Spark Matsunaga (D-HI), and House Concurrent Resolution 140 by Representative Mel Levine (D-CA). All of these bills are in various stages of consideration by congressional committees and may be the subjects of hearings.

Senator Matsunaga's initiative is of special interest to members of The Planetary Society because it deals with two of our own objectives: increased opportunities for space science and exploration, and cooperation among all nations. The Matsunaga bill notes "the opportunities offered by space for prodigious achievements in virtually every field of human endeavor, leading ultimately to the colonization of space in the cause of advancing human civilization, would probably be lost irretrievably were space to be made into yet another East-West battleground." The bill goes on to say that "allowing space to become an arena of conflict without first exerting every effort to make it an arena of cooperation, would amount to an abrogation of governmental responsibility that would never be forgotten." It calls upon the President to renew the 1972 to 1977 agreement between the United States, the Soviet Union and other countries to explore opportunities for cooperative East-West ventures in space as an alternative to the arms race. Specific areas mentioned for such ventures include: planetary science, manned and unmanned space exploration, space biology, space medicine and space rescue.

ASAT Control

Two other relevant pieces of legislation passed last year during the 1984 budget process and have been reintroduced this year. The authorization and appropriations to the Department of Defense carried an amendment prohibiting anti-satellite (ASAT) tests and holding up ASAT funding until the President certifies to Congress that he is trying to negotiate an ASAT ban and reports on his policies regarding arms control in space. In response to the amendment, Mr. Reagan submitted a report to Congress in early April, asserting that ASAT controls are now unverifiable. "Until we have determined whether there are, in fact, practical solutions to these problems," he said, "I do not believe it would be productive to engage in formal international negotiations."

For more information about these subjects, you can contact these sources:

—Senator Matsunaga's office (US Senate, Washington, DC 20510) can provide a copy of the legislation and related materials.

—Your Congressman can provide you with the Library of Congress' Congressional Research Service issue brief on "Star Wars: Anti-satellites and Space-Based Ballistic Missile Defense," authored by Marcia Smith. Ask for CRS Issue Brief 1B81123.

Copies of the other legislative items cited above can be obtained from their authors in the US Congress.

Louis Friedman, Planetary Society Executive Director, spent one year as a Congressional Fellow with the Senate Committee on Commerce, Science and Transportation.

S O C I E T Y   N O T E S

■ FACT SHEETS FOR PRESS

The Planetary Society, as a service to working science reporters and writers, is providing fact sheets about important foreign space initiatives. These sheets contain basic information about everything from launch date, location and rocket to the science objectives, spacecraft instrumentation and a few items about telemetry. An artist's conception of the craft illustrates each fact sheet. We've already sent out our first fact sheet on the Soviet Union's *Venera 15* and *16* spacecraft, now in orbit around Venus and returning radar images of the surface.

Often, in the heat of the fray when important news is breaking about space, a science writer may suddenly be in dire need of a basic description of some foreign spacecraft, but has nowhere to get the information. The Planetary Society fact sheets provide just what is needed to write a few detailed paragraphs on these space vehicles, make it more interesting, and, at the same time, more accurate. We are now working on fact sheets for all the missions to Comet Halley: the two Soviet *Vegas,* the Japanese MS-T5 and *Planet-A* craft, and the European Space Agency's *Giotto* probe.

■ SOCIETY ON DISPLAY

Donna Davidge of Rockford, Michigan, is an example of an enthusiastic member who promotes The Planetary Society by setting up local displays. In cooperation with Society staff, she set up a display in the Roger B. Chaffey Planetarium in Grand Rapids. Visitors to the planetarium saw the posters that Ms. Davidge set up in the lobby and hallways. She also arranged to have our "Mars in 3-D" film shown after the regular planetarium show.

■ EXTRATERRESTRIAL SYMPOSIUM

The International Astronomical Union (IAU) is holding its first symposium on the search for extraterrestrial life in Boston, June 18–21. The IAU recently established a commission on the search for extraterrestrial life with funding from The Planetary Society. At this symposium, scientists from many different disciplines will discuss topics such as the search for other planetary systems, interplanetary and interstellar organic matter, and universal aspects of biological evolution. The principal focus will be on SETI, including the Society's Project Sentinel. The discussions will be scientific and attendance is limited to qualified persons. For further information, call or write: Michael D. Papagiannis, President, IAU Commission 51, Department of Astronomy, Boston University, Boston, MA 02215, (617) 353-2626.

■ SETI IN CONGRESSIONAL RECORD

Early this year, Representative Timothy E. Wirth (D-CO) read into the Congressional Record the international petition in favor of the Search for Extraterrestrial Intelligence (SETI), prepared by Carl Sagan and supported by The Planetary Society. [See *The Planetary Report,* March/April 1983.] In presenting the petition, Representative Wirth said, "Though there is a wide range of opinions concerning extraterrestrial intelligence, the following list of distinguished scientists are in unanimous agreement that an investment in planetary exploration—by all nations—could provide momentous insight into our view of the universe and ourselves." The petition is signed by 73 leading scientists from 14 nations, including 7 Nobel laureates and several senior Soviet scientists.

Sentinel's First Anniversary

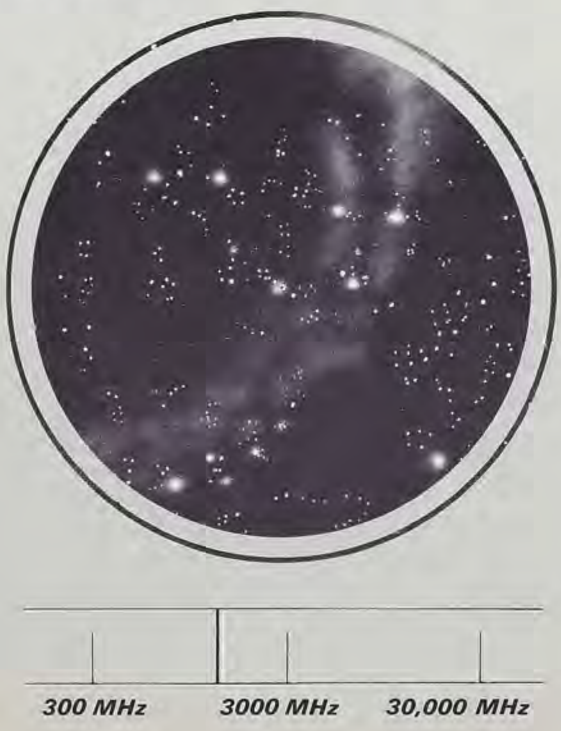
Project Sentinel, The Planetary Society's major project in the Search for Extraterrestrial Intelligence (SETI), is now one year old. On March 7, 1983, the project was turned on at Harvard University's Oak Ridge Observatory in the town of Harvard, Massachusetts.

Sentinel has completed its first survey of the part of the sky visible from Massachusetts. Using an 84-foot dish antenna, the project's originator, Harvard Professor Paul Horowitz, has been scanning the sky at frequencies near the 1420 megahertz band, where interstellar hydrogen atoms naturally emit radio waves. We are now exploring the possibility of establishing a similar SETI project in Australia to cover the part of southern sky not visible from the northern hemisphere.

Our membership-supported research is already the most advanced SETI project operating in the world. The Society has agreed to give Professor Horowitz financial support to expand the system from the present 131,000 radio channels to eight million. This expanded project, called META for Megachannel Extraterrestrial Assay, will vastly increase the scope of the search.

Professor Horowitz has now switched Sentinel to one of the bands of the hydroxyl radical (OH), near 1700 megahertz. When combined with hydrogen, hydroxyl forms water ($OH + H = H_2O$), and because of this connection with water—the essential ingredient of our kind of life—some scientists think an extraterrestrial civilization might broadcast near that frequency to announce its existence to other civilizations. In the words of the "Cyclops Report," "Nature has provided us with a rather narrow quiet band in this best part of the spectrum that seems especially marked for interstellar contact. It lies between the spectral lines of hydrogen (1420 megahertz) and the hydroxyl radical (1662 megahertz). Standing like the Om and the Um on either side of a gate, these two emissions of the dissociation products of water beckon all water-based life to search for its kind at the age-old meeting place of all species: the water hole."

— THOMAS R. McDONOUGH



The Solar System in Pictures and Books

● BOOKS	PRICE	QUAN.	TOTAL
Voyages to Saturn by David Morrison—Description of both Voyager Saturn encounters, with color photographs.	$14.00		
Voyage to Jupiter by David Morrison and Jane Samz—Description of both Voyager Jupiter encounters, with color photographs. 199 pages.	$11.00		
The Grand Tour: A Traveler's Guide to the Solar System by Ron Miller and William K. Hartmann—A beautifully illustrated guide to 25 worlds in our solar system. 192 pages.	$ 9.00		
The Surface of Mars by Michael H. Carr—A definitive summary of Viking mission results. Large format. 232 pages.	**Soft cover-$15.00**		
Planets of Rock and Ice by Clark R. Chapman—Guide to the small planets from Mercury to the moons of Saturn.	$12.50		
The New Solar System edited by J. Kelly Beatty, Brian O'Leary and Andrew Chaikin—Up-to-date information on our planetary neighborhood. 224 pages.	**Soft cover–2nd Ed.** $12.50		
The Moon by Patrick Moore—An atlas and guide to our satellite. 96 pages.	$13.00		
Murmurs of Earth by Carl Sagan, Frank Drake, Ann Druyan, Timothy Ferris, Jon Lomberg and Linda Salzman Sagan—Account of the development of the Voyager record, a message from humanity to possible extraterrestrial life forms. 273 pages.	$ 7.00		
The Planets edited by Bruce Murray—Collected articles from Scientific American, presenting the state-of-the-art in planetary science.	**Soft cover** $ 9.50 **Hard cover** $15.00		
A Meeting with the Universe edited by Bevan M. French and Stephen P. Maran—Everything from the origin of the Sun to the edge of the universe is covered in this well-illustrated volume. 221 pages.	$15.00		
Distant Encounters by Mark Washburn—The excitement of the Voyager encounters is captured for those who could not be part of the events. 272 pages.	$11.50		
Out of the Darkness by Clyde W. Tombaugh and Patrick Moore—The discovery of Pluto is chronicled by its discoverer and a noted science writer. 221 pages.	$13.00		
Mission to Mars by James E. Oberg—Plans and concepts for the first human mission to Mars are detailed in this up-to-date book. 221 pages.	$13.00		
Planetary Exploration Through Year 2000—This colorfully illustrated executive summary of the Solar System Exploration Committee details the proposed future of planetary exploration. 30 pages.	$ 5.50		
Earth Watch by Charles Sheffield—A magnificent view of the Earth from Landsat in full-color and large format. 160 pages.	$20.00		
Pioneer Venus by Richard O. Fimmel, Lawrence Colin and Eric Burgess—A readable account of the Pioneer mission to Venus, illustrated with color photos and paintings of the veiled planet. 253 pages.	$12.50		
Worlds Beyond by Ron Miller and Frederick C. Durant III—The work of Chesley Bonestell, the father of modern space art, is beautifully reproduced in this full-color volume. 133 pages.	$13.00		
Atlas of the Solar System by Patrick Moore and Garry Hunt—This Rand-McNally atlas covers everything from the Sun to the distant comets. 464 pages.	$30.00		

Back issues of THE PLANETARY REPORT are now available to Society members. Each volume contains six issues. (Volume I, Number 6; Volume II, Numbers 1, 5 and 6; and Volume III, Number 1 have been sold out.) Specify the issues you would like by volume and number. A donation of $1.50 per issue to cover printing and postage costs is appreciated.

Total quantity of back issues __________ Total price __________

Mars in 3-D—This 16mm film, produced by Elliott Levinthal, depicts the Martian landscape as seen by Viking. It may be purchased for $135.00 or rented for $25.00, with a deposit of $100.00. 3-D glasses are available for $.25 each. Write to The Planetary Society for a rental agreement or purchase information.

● COLOR PHOTO REPRODUCTIONS (8½" x 11")	PRICE	QUAN.	TOTAL
Jupiter—A montage of the planet and its Galilean Moons, the Great Red Spot and dynamic Io. (set of 3 prints)	$ 2.00		
Mars—Approaching the red planet, Martian sunrise and sunset, the rocky surface at both Viking landing sites (set of 4 prints)	$ 3.75		
The Best of Voyagers 1 & 2 at Saturn—The planet, its rings and satellites (set of 15 prints)	$10.00		
Voyager 2's Future Missions—Don Davis paintings of the encounters with Uranus and Neptune (set of 2 prints)	$ 2.00		

● LASER COLOR PRINT (16" x 20")	PRICE	QUAN.	TOTAL
Apollo Photograph of Earth (full disk)	$ 8.00		

● COLOR POSTERS	PRICE	QUAN.	TOTAL
Voyager 1 at Saturn (Five 23" x 35" posters)	$16.00		
You Are Here (23" x 29" poster)	$ 5.00		

● 35MM SLIDE SETS	PRICE	QUAN.	TOTAL
Voyager 1 Saturn Encounter (40 slides with sound cassette)	$15.00		
Voyager 2 Saturn Encounter (40 slides with sound cassette)	$15.00		
Viking 1 & 2 at Mars (40 slides with sound cassette)	$15.00		
Voyager 1 & 2 at Jupiter (40 slides with sound cassette)	$15.00		
The Solar System Close-Up, Part One (50 slides with booklet)	$36.00		
The Solar System Close-Up, Part Two (50 slides with booklet)	$36.00		

● SALE ITEMS	PRICE	QUAN.	TOTAL
The Planets: A Cosmic Pastoral by Diane Ackerman—A collection of poems about the planets. 159 pages.	$ 2.00		
Planetfest '81 Posters (Two 23" x 35") of Saturn and the F-ring	$ 6.00		

Mail order and payment to:

THE PLANETARY SOCIETY
P.O. Box 91327
Pasadena, CA 91109

All prices are in US dollars and include postage and handling. On foreign orders, convert price to equivalent value and add $3.00 for additional postage. California residents add 6% sales tax; Los Angeles County residents add an additional ½% transit tax.

NAME

ADDRESS

CITY

STATE ZIP

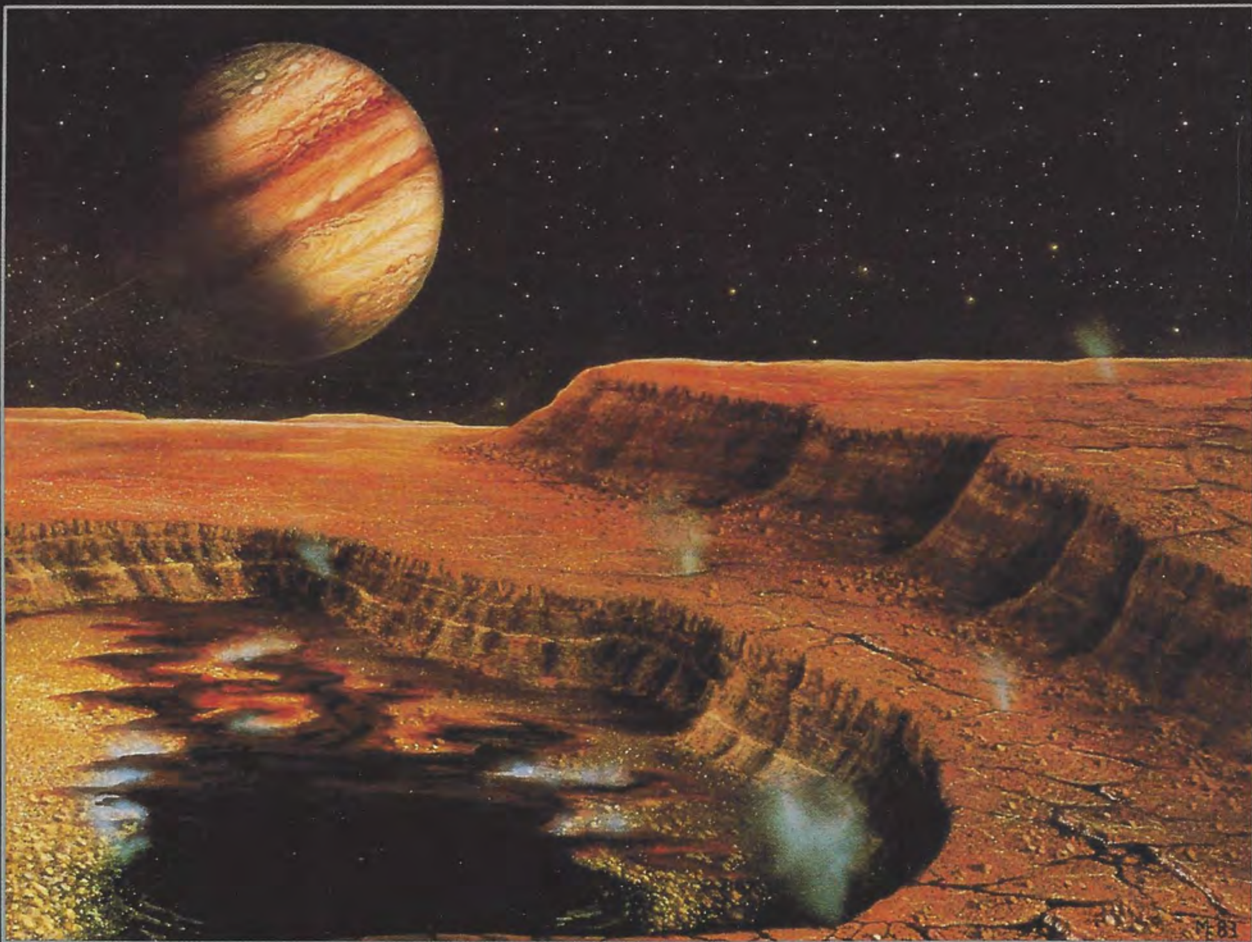
Total Enclosed $________ **Check one:** ☐ **VISA** ☐ **MasterCard**

ACCOUNT NUMBER EXPIRATION DATE

SIGNATURE

Please allow six weeks for delivery. Facsimiles of this form may be used for additional orders.

Officers of The Planetary Society do not receive any proceeds from sales of books of which they are authors and contributors.



FIRE PIT ON IO—A black lake of molten sulfur slowly cools on the surface of Io, while gases vent from cracks in the ruddy crust of Jupiter's volcanic moon. Io is the most volcanically active body known in our solar system; it is continually resurfaced with new layers of sulfurous lava, giving the moon its characteristic red appearance.

Maralyn Vicary is an astronomical artist whose work has appeared in many science magazines. She is now taking flying lessons so she will be able to do aerial comparisons of features on Earth with images of features on other planets.

THE PLANETARY SOCIETY
P.O. Box 91687
Pasadena, CA 91109

NONPROFIT ORG.
U.S. POSTAGE
PAID
LONG BEACH, CA
PERMIT NO. 786