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Jupiter—A Waiting Giant

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COVER: Jupiter, with its Great Red Spot (lower left), and its retinue of Galilean satellites—Io (center), Europa (far right), Ganymede (not pictured) and Callisto (bottom left)—were last visited by spacecraft from Earth in 1979, when* Voyagers 1 *and* 2 *flew through the system. They were to be shortly followed by* Galileo*, an ambitious orbiter and atmospheric probe mission once scheduled for launch in late 1981 or early 1982 from the space shuttle. Problems with the shuttle have repeatedly delayed* Galileo*'s launch, and it is now scheduled to be on its way in October of this year, to arrive at Jupiter in 1996.
Image: JPL/NASA

FROM THE EDITOR

As this issue reaches your hands, we are still celebrating the launch of the *Magellan* spacecraft to Venus. This is the first planetary mission launched by the United States in over a decade—since *Pioneer Venus* began its work in 1978—and this coming decade holds promise for would-be planetary explorers. *Galileo* is scheduled for launch in October of this year; the Soviets plan further Mars missions in 1994 and 1996 or 1998; the US may launch the Comet Rendezvous Asteroid Flyby mission in 1995, with the *Cassini* mission to the saturnian system following in 1996.

Magellan is the first planetary mission to be launched from a space shuttle (*Galileo* was to be the first, as you'll read in this issue), and it will reach its target after a 15-month journey. With a direct trajectory, the spacecraft could have reached Venus in only five months, but shuttle problems have pushed the mission back to a later launch and to the longer flight path. (The April 1989 issue of *Discover* carries a nice article about this mission.)

Magellan's launch is not the only news in planetary exploration. In this issue we also cover:

We hope you enjoy this issue of endings and beginnings—*Charlene M. Anderson*

Members' Dialogue

The Soviet *Phobos* mission, following the success of the *Venera* and *Vega* missions, was conceived as a major new step involving 13 countries, with US help in tracking and, for the first time, formal participation of 10 US scientists (including myself).

Even while the *Phobos* spacecraft were being readied for launch, still more ambitious US-USSR collaboration on a Mars '94 mission to explore the surface was being defined. Then disaster struck. Both *Phobos* spacecraft failed. *Phobos 2* did record valuable data [see pages 14-15], but the failure of both spacecraft is a blow to US-USSR space cooperation, suggesting unreliability of the Soviet hardware.

We must ask, "Can US-USSR space cooperation continue to grow in spite of this setback?" My answer is yes, but only if the groups that develop Soviet spacecraft begin to share decision making with international scientific users of the craft.

Before looking into the future, let's look backward to gain a perspective on the planetary program. The *Vega* and *Venera* missions were the last in a long series of flights that used a basic spacecraft design introduced almost two decades ago. Early versions did suffer some failures, but as the spacecraft were sent repeatedly to explore Venus through the 1970s, greater and greater successes were achieved, laying the engineering foundation for the daring triumphs of the 1980s.

However, the spacecraft developed for the *Phobos* mission belong to a new generation of space vehicles. "Teething" problems were to be expected. But Soviet industry seems to have taken a step backwards—they excluded the scientists from the system design. Furthermore, delays in project approval left no time for adequate system analysis and testing.

Soviet missions are organized very differently from NASA's. NASA Headquarters establishes science working groups to help define mission objectives with the engineers at NASA centers and in industry. All interested parties play a role in the design.

The Soviet system is different: Major engineering groups and industry are independently funded and managed separately from the Soviet Academy. There is no single boss accountable for the entire enterprise in the way that a NASA project manager has to answer both for the engineering requirements and the scientific designs. Instead, the engineering groups independently conceive and define the nature of spacecraft, and only later do they negotiate with the scientific groups regarding its use. Too much power is given to the industrial contractor, who is not accountable to any authority. The *Phobos* mission was planned and developed in the pre-*glasnost* environment. But its failures occurred in the new era of openness and of blossoming international cooperation. Can the Soviet space program change to meet the new realities?

The failure of the *Phobos* spacecraft clearly indicates that there are serious system design flaws. It lacks adequate on-board intelligence to recover from problems. These must be overcome before new missions are flown.

In response to the demise of *Phobos 2*, a commission was appointed under the jurisdiction of the engineering groups—with only minor representation from the Academy of Sciences. To their credit, on April 15 the commission publicly highlighted on-board computer problems that may have contributed to the second failure and outlined plans to improve the computer. This was a new and welcome sign of *glasnost*. However, there was no indication that the fundamentally inadequate design of the spacecraft—its inability to recover from minor faults—has been recognized. Furthermore, the engineering group's public report suggested that a natural cause, such as a meteorite impact, rather than a design problem, could have been the culprit. Independent analyses by the Space Research Institute and by an informal group at Caltech have shown that this was extremely unlikely. Invoking a *deus ex machina* was not constructive.

All of us—Americans, Soviets and Europeans—have suffered disappointments before in exploring space. It goes with the territory. But to build a broader collaboration, new openness in Soviet technical deliberations must now replace the cloistered and secret engineering world.

I believe that with the growing ties of space scientists and engineers on Earth, these space projects will recover and even benefit from this failure. Eventually these cooperative endeavors can pave the way for humankind's first footfall on Mars.
BRUCE C. MURRAY, *The Planetary Society, Pasadena*

A companion piece to this statement, by Academician Roald Z. Sagdeev, Scientific Director of the Phobos *mission, will appear in the next issue of* The Planetary Report.

NEWS BRIEFS

If left unchecked, orbital debris, or "space junk," could threaten the safe and reliable operation of robotic and piloted spacecraft in the next century, according to a six-month US government study. Co-chaired by NASA and the Department of Defense, the study cited the breakup of satellites and rocket bodies as the main source of the problem.
—from the Langley Research Center's *Researcher News*

Senators Robert C. Byrd and Jay Rockefeller of West Virginia have urged the National Science Foundation to quickly make plans to replace the 300-foot antenna that collapsed at Green Bank last November (see News Briefs in the January/ February 1989 *Planetary Report*).

"This type of telescope is important to scientific research," said the senators. "We think the telescope should be replaced as quickly as possible with state-of-the-art equipment and we want to see it replaced at Green Bank."

Radio astronomers also fear that without a "world-class" radio telescope at Green Bank, there may be attempts to chip away at the national radio-quiet zone that surrounds the observatory. Once that isolation is broken into, the US could lose a major national resource that might never again be available.
—from Ronald A. Schorn in *Sky and Telescope*

In Oracle, Arizona, marine biologist Abigail Alling recently ended five days of isolation in a 23-square-foot, greenhouse-like enclosure that cut her off from the rest of Earth's environment.

In the Biosphere experiments, according to Margaret Augustine, the project director, plants and organisms purify the air and water and replenish oxygen. Food is grown, harvested and prepared inside the biosphere and wastes are biologically treated and recycled as fertilizer.

Four men and four women are scheduled to enter a two-and-one-half acre biosphere in 1990 for two years to see if human beings can exist in a completely enclosed world, possibly as a precursor to space colonization.
—from the Pasadena *Star News*

THE SOLAR SYSTEM IN CHAOS

by Eugene F. Mallove

Hyperion, the small, irregularly shaped moon that orbits Saturn between Iapetus and the giant Titan, tumbles chaotically as it circles the planet. It's the first confirmed example of chaotic rotation among the known planets and moons. The icy object is roughly 400 by 250 by 200 kilometers in size.
Image: JPL/NASA

The clockwork solar system is dead, or at least sprung. To their considerable surprise, astronomers have discovered that not all the paths and spins of celestial bodies are predictable with infinite precision, even *in principle*—far from it. The mathematical notion of chaos has invaded the formerly serene world of celestial mechanics.

Some examples:

—Certain irregularly shaped moons may be tumbling wildly and unpredictably;

—The chaotic orbits of some asteroids may explain the influx of meteoroids to the inner solar system, and thus the presence of meteorites on Earth;

—The orbit of Pluto appears subject to erratic changes in its inclination (the tilt of its orbit relative to the ecliptic, the plane defined by Earth's orbit about the Sun) and in its eccentricity (the deviation of its orbit from a circle).

We may no longer be able to take even the overall stability of the solar system for granted.

The extreme regularity of the motions of celestial bodies has been for centuries a central assumption of science. This predictability in the heavens served as a model for the predictability of all other natural phenomena. The idea of universal "laws of nature" was invoked by Isaac Newton in the 17th century when he formulated his law of gravitation.

To find in the late 20th century that *unpredictability*—chaos—plays a significant role in the orderly celestial arena is not only a surprising development but a revolutionary one in the history of science. Efforts to evaluate the implications of chaos have brought forth conferences and books, including James Gleick's best-selling *Chaos: Making a New Science.*

The relatively young field of chaos suggests that *very* small changes in a mechanical system can lead to grossly irregular behavior. In the calculation of a moon's spin as it orbits around a planet, for example, a tiny gravitational influence may make long-range outcomes in its orientation impossible to predict. Another example of chaos, and more readily observed, is the erratic motion of a kinetic art pendulum, the kind found typically in glittery gift boutiques. Give it the slightest nudge, and the pendulum veers off onto completely unexpected gyrations. Celestial chaos, though rooted in gravitational influences, not contact forces, is much like that.

Chaotic behavior in the solar system means that the trajectories of objects that formed nearby each other can "diverge exponentially," as theoreticians say. That is, very small differences in initial conditions—seemingly insignificant changes in a planet's motion—projected ahead in time, lead to radically different positions and velocities. Chaotic trajectories are said to show "sensitive dependence on initial conditions."

Bringing Chaos Out of Order

Although mathematical physicist J. H. Poincaré hinted at chaotic behavior in celestial bodies as far back as the turn of the century, it was not possible to study these problems until the advent of digital computers of enormous power. The findings of chaos researchers have already touched fields from meteorology and fluid mechanics to chemistry and the population dynamics of ecosystems. As a result of studying chaotic behavior, atmospheric physicists now realize that detailed forecasting of weather patterns on Earth and other planets is literally impossible for more than a few weeks ahead. Chaos makes certain celestial predictions chancy too.

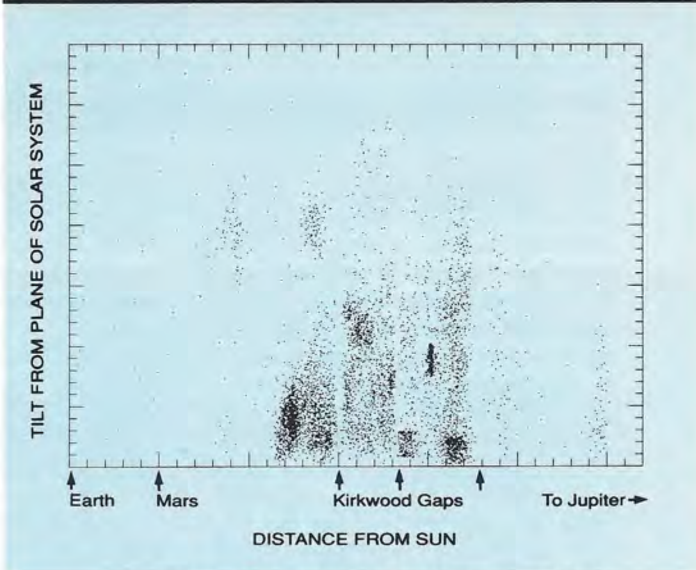
Studies of celestial and other forms of chaos trace their contemporary origin to the work of mathematician-turned-meteorologist Edward Lorenz of MIT. In 1961, while conducting a long-range projection of weather, Lorenz repeated a computer simulation of atmospheric circulation, beginning with numbers that were only slightly different from those in the first simulation. He was amazed to find disproportionate and dramatic variations between the outcomes of his two computer runs. This discovery of chaos at work in fluid mechanics sparked further investigations of chaos in other scientific fields. [See box on Jupiter's Great Red Spot.]

The discovery of celestial chaos, according to Jack Wisdom of MIT, a pioneer in the field, was delayed because the idea of a mathematically predictable, clockwork solar system had been firmly entrenched for centuries. Since the time of Isaac Newton, astronomers had believed that if initial conditions were known with sufficient precision, then the future or past courses of celestial bodies could be calculated to any desired accuracy. Thus, "the possibility that motion in the solar system was irregular really wasn't considered."

In the early 1980s, Wisdom, then at Caltech, discovered that asteroids and their fragments within a particular zone in the asteroid belt between Mars and Jupiter could be nudged by the planets' gravity into highly eccentric orbits. These unexpected orbits, crossing the paths of Mars and almost certainly Earth, would finally explain the origin of meteorite impacts on those planets.

For an asteroid to be thus removed, its initial orbit would have to have a period that was close, for example, to a 3:1 resonance with Jupiter's 11.9-year orbital period—the asteroid making three revolutions around the Sun to every one by Jupiter. Other "commensurable" resonances, such as 5:2, 7:3 and 2:1, produce similar effects.

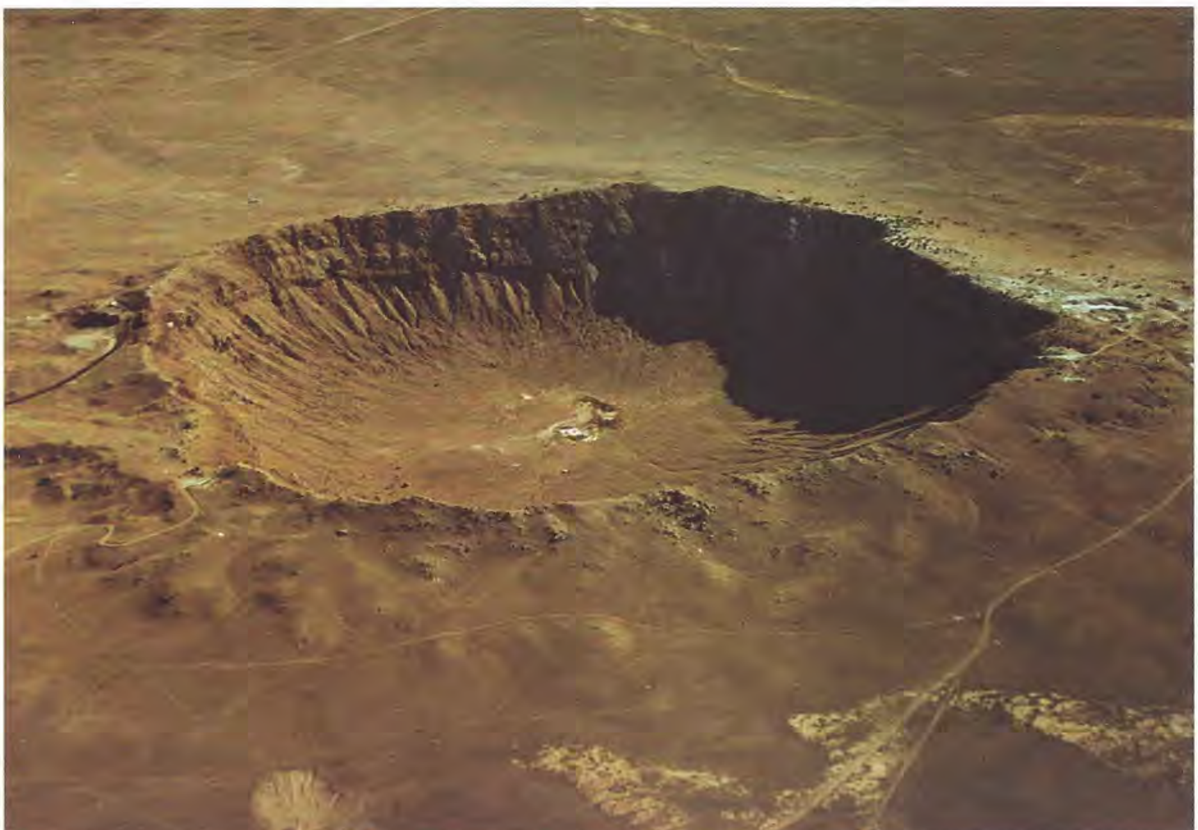
If such resonant orbits have indeed sent asteroids beyond their accustomed paths, then the mysterious voids in the asteroid belt called Kirkwood Gaps may at last be explained. Wisdom found that a resonant asteroid's orbit may remain relatively stable for hundreds of thousands of years; then its eccentricity may abruptly shoot up to more than three times its normal 10 percent variation.



The main belt of asteroids circling the Sun between the orbits of Mars and Jupiter exhibits several empty regions. This plot of 6,000 asteroids shows a cross-section of the belt, with the Kirkwood Gaps clearly visible. The new mathematics of chaos may help explain how gravitational interactions among the asteroids and Jupiter created these gaps. ***Chart: Mark Sykes, Steward Observatory***

Hyperion Tumbling

During *Voyager 2*'s 1981 encounter with Saturn, images of the moon Hyperion showed that it was not spherical, the moon's shortest axis of about 200 kilo-



Chaotic effects may divert asteroids from their usual orbits between Mars and Jupiter to paths that intersect Earth's orbit. When an asteroid strikes Earth, the results can be catastrophic: The dinosaurs may have been helped to extinction by a colliding asteroid. In a less deadly case, the impact may form a distinctive crater, such as Meteor Crater in northern Arizona (left). This scar is roughly 1.2 kilometers across and 200 meters deep.

Photograph: Meteor Crater Enterprises, Inc.

meters being only about half its longest measurement. Jack Wisdom, Stanton Peale and Francois Mignard later predicted that Hyperion would be found to be tumbling chaotically, based on a computer analysis of the interaction of its spin, orbital period and tides within its solid (yet elastic) body. By contrast, most other satellites in our solar system have evolved to rotate in some kind of synchronization with their orbit about a planet. One face of the Moon, for example, perpetually presents itself to Earth.

The researchers predicted that Hyperion's spin would oscillate chaotically between a state of zero and two rotations per orbit of Saturn. Recently MIT graduate student James Klavetter made measurements at the Cerro Tololo Observatory in Chile of variations in the light from Hyperion, in an effort to confirm the small moon's chaotic spin, and the results do seem to prove the point. Wisdom notes that "Hyperion's chaotic tumbling makes it the first confirmed example of chaotic rotation among the permanent members of the solar system."

In his Urey Prize lecture, delivered in Paris in 1986, Wisdom said, "For the most part, the world of our everyday lives is classical [Newtonian], but classical mechanics is not at all simple. Newton could not have dreamt of the beauty and complexity of the mechanics he brought forth. The final state of Hyperion is completely unpredictable."

Another of Wisdom's explorations by computer, done with graduate student William C. Tittemore, concerns possible chaotic conditions in the orbits of Uranus' moons. Their conclusion is that the uranian satellites have spent long intervals in chaotic orbits.

What about the overall stability of the solar system? This is a problem that for centuries has resisted analytical attacks by great mathematicians and physicists. Wisdom, MIT colleagues, and researchers at Caltech and Columbia University have in recent years devoted their energies to this question.

The Digital Orrery

Now chaos in the solar system can be examined on the largest scale with a new tool of computer science, the "Digital Orrery." (The original orrery, made for the Earl of Orrery, was a wind-up model using balls to show the relative sizes, positions and motions of planetary bodies.) With this digital computer, Gerald J. Sussman of MIT and Jack Wisdom determined that Pluto's orbit can exhibit chaotic motion over a remarkably short time scale—a mere 20 million years, barely a flash in our solar system's 4.6-billion-year history. This may be the first indication that the overall motion of the planets has manifested anything other than perfect stability for billions of years.

Sussman and Wisdom have combined advanced computer design with sophisticated programs to produce a numerical simulation of Pluto's orbit over an unprecedented 845 million years, surpassing a longstanding million-year calculation of outer-planet motion done by C. J. Cohen, E. C. Hubbard and C. Oesterwinter in 1973, as well as their own 200-million-year projection performed in 1986.

Their Digital Orrery is dedicated exclusively to the complex task of simulating the motion of the outer planets under their mutual gravitational influences. It is a marvel of electronic design and is only about a cubic foot in volume. Yet it manipulates numbers at one-third the rate of a Cray supercomputer applied to the same problem. Recalling the beautiful brass clockwork orreries of past centuries, Sussman says with a grin, "We used modern technology to make an ugly one."

The Digital Orrery computed the positions and velocities of the outer planets for times 32.7 days apart, an interval chosen to minimize the build-up of errors in the simulation. The computer simulates at the rate of seven million years per day and is extremely accurate. After 845 million years, for example, the error in Jupiter's orbital position—as measured by an imaginary observer at the Sun looking outward at the 360 degree panorama of planets—is said to be a mere five degrees.

Pluto: Chaos Comes to the Planets

Astronomers already knew, of course, that diminutive Pluto was something of a maverick: a small, inner-solar-system-sized world misplaced among the giant outer planets, Neptune, Uranus, Saturn and Jupiter. The last planet to be discovered (by Clyde Tombaugh in 1930), Pluto is a virtual double planet—a tiny world with a large moon, Charon. And

A classical orrery (top) is a clockwork model that shows the relative sizes, positions and motions of planets and moons. Aaron Willard, Jr. of Boston built this elegant one around 1828.

Photograph: National Museum of American History

A more modern version is the Digital Orrery (right), a powerful computer that has numerically simulated Pluto's chaotic orbit for a projected 845 million years. Jack Wisdom (left) and Gerald J. Sussman (right) appear with their dedicated calculator of planetary motion.

Photograph: Donna Coveney for MIT Photo though Pluto is nominally the outermost planet in our solar system, its eccentric orbit periodically brings it closer to the Sun than neighboring Neptune.

What is Pluto doing in its unusual and apparently chaotic orbit? Wisdom, for one, doesn't accept the theory that Pluto was originally a moon of Neptune. Rather, he believes that Pluto may have formed in place and survived from the early history of our solar system, when the planet's orbital characteristics were probably different. He says that Pluto's orbit is reminiscent of the resonant asteroid orbits that typically evolve to high eccentricity and orbital inclination.

However it originated, Pluto now displays many different and complex resonances with Neptune's orbit, which Wisdom and Sussman say are often associated with both enhanced stability and instability. Among other patterns, the simulation revealed 3.8-million-year and 34-million-year oscillations in the inclination of Pluto's orbit, as well as surprisingly long 150- and 600-million-year cycles. Pluto's closest approach to the Sun, or perihelion, displays cycles of 3.7, 27 and 137 million years.

The simulations do not take into account such effects as gravitational influence from the occasional close approach to our solar system of a nearby star, or the "evaporation" of the Sun's mass through emission of electromagnetic radiation and particles. The small effects from inner planets, general relativity, errors in the assumed masses of the planets, and uncertainties in initial conditions are also not included. But these effects are thought to be small enough not to alter the general conclusions.

The researchers believe that the exact value of Pluto's still-uncertain mass has negligible impact on their conclusions about its orbit. If this is so, they say, "Pluto's irregular motion will chaotically pump the motion of the other members of the solar system, and the chaotic behavior of Pluto would imply chaotic behavior of the rest of the solar system."

The new era of chaos research certainly flies in the face of 18th century notions of our solar system as immutable celestial clockwork with motions predictable, at least in principle, indefinitely far into the future. However, these results should not be of much concern for the near term—unless one counts the already well-known hazard of Earth-crossing asteroidal debris.

But with somewhat ominous import for our descendants in a presumably solar-system-wide civilization, Wisdom and Sussman have written, "Planetary systems which appear stable may in fact be slightly unstable. . . this slight instability can manifest itself in dramatic and relatively sudden changes in orbit. The stability of the solar system should thus not be taken for granted."

Eugene F. Mallove, an astronautical engineer, is Chief Science Writer at the MIT News Office. He is the author of The Quickening Universe: Cosmic Evolution and Human Destiny *and co-author of* The Starflight Handbook: A Pioneer's Guide to Interstellar Travel.

Chaos and Jupiter's Great Red Spot

Jupiter's Great Red Spot has delighted and mystified observers since Galileo first turned his telescope on it over 350 years ago. As seen in sequential *Voyager* images, the spot rolls like a ball between currents to its north and south that move in opposite directions. Yet the enormous rust-colored atmospheric eddy has endured for centuries and appears to be yet another instance of dynamical chaos, in this case involving fluid turbulence on a giant scale.

The arrow shows a vortex created in the laboratory but remarkably similar to Jupiter's Great Red Spot.

Photograph courtesy of Steven Meyers, University of Texas at Austin

The puzzle has been how such a large "object" —it extends 25,000 kilometers in longitude— could persist so long in the turbulent jovian atmosphere. This led inevitably to suggestions that the spot was a manifestation of some underlying non-uniformity deep within the planet. Smaller-scale features in Jupiter's atmosphere, by contrast, change within a few days.

Now, in the February 25, 1988, issue of *Nature*, two research groups have reported independent evidence that Jupiter's famed marking, indeed, may be understandable as a chaotic phenomenon.

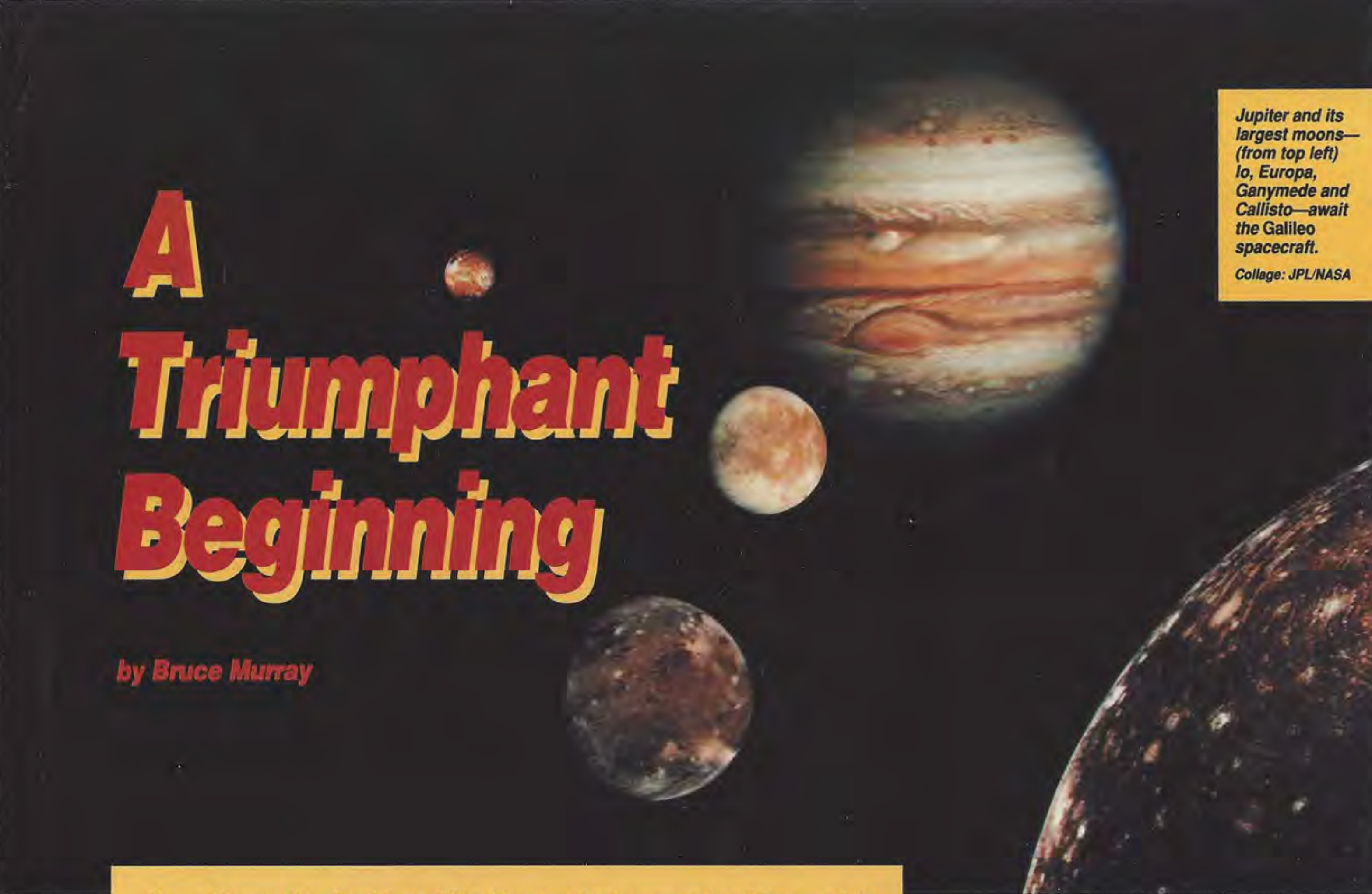
Philip S. Marcus of the University of California at Berkeley numerically solved the complex equations of fluid motion for a model of Jupiter's atmosphere. Marcus' calculations suggest that "Large spots of vorticity [whirlpools] form spontaneously" under certain conditions and remain stable, rolling like a pencil between your palms. In a computer-generated film, a single spot is seen to form even after a variety of initial fluid conditions.

The other evidence is experimental. Joël Sommeria, Steven D. Meyers and Harry L. Swinney at the University of Texas, conducting tests with fluids spun in a laboratory apparatus, found that "over a wide range of rotation and pumping rates the flow evolves until only one large vortex remains." The remaining vortex bears a remarkable similarity to the Great Red Spot.

Saturn's atmosphere also displays large, stable vortices, illustrating perhaps once again the omnipresence of chaotic phenomena of astronomical scope.—*EM*

A Triumphant Beginning

by Bruce Murray



Jupiter and its largest moons—(from top left) Io, Europa, Ganymede and Callisto—await the Galileo *spacecraft.*

Collage: JPL/NASA

Bruce Murray, Vice President of The Planetary Society, served as Director of the Jet Propulsion Laboratory from 1976 to 1982. During his tenure he enjoyed the triumphs of the *Viking* landings on Mars and the *Voyager* encounters with Jupiter and Saturn, and shepherded JPL through the attempts to cancel NASA's planetary program in the the early 1980s. Dr. Murray chronicles his involvement in planetary exploration in a newly published book, *Journey into Space: The First Three Decades of Space Exploration.*

We have adapted a chapter of that book, "A Triumphant Beginning," for readers of *The Planetary Report*. This chapter is part of a longer section telling the story of the *Galileo* project to explore Jupiter and its Galilean moons. The spacecraft was originally scheduled to launch from a space shuttle in late 1981 or early 1982. It is now scheduled for launch in October of this year. What happened? Dr. Murray begins the story as he takes over as Director of JPL. —*CMA*

My first year as a university professor turned laboratory director was crammed with new learning experiences.

The *Viking* search for life on Mars in the summer of 1976 attracted the greatest media coverage for a space endeavor since the *Apollo* landings on the Moon. This fusing of *Viking*, the bicentennial celebration and a presidential election year created an ideal environment for drumming up nationwide support for bold new American projects of planetary exploration.

Those purple times offered our best chance to start on a new mission to the planets, now long overdue. That logical step was an ambitious follow-up to the *Pioneer* and *Voyager* flybys, a Jupiter orbiter, just as the *Mariner 9* orbiter brilliantly followed the earlier *Mariner* flybys. But our proposal offered even more. It combined a powerful orbiter with an atmospheric entry probe (like *Venera 4* at Venus), which would be hurled directly into the swirling, colored atmosphere of the Sun's largest planet —thus its name, Jupiter Orbiter with Probe (JOP).

An ominous note was sounded in late 1975. NASA decreed that the Jupiter orbiter mission would be the first planetary mission to use the shuttle, in late 1981 or early 1982.

In August 1976, NASA Administrator James Fletcher submitted JOP as a "new start" for the congressional budget cycle of spring 1977. JOP was then endorsed by President Gerald Ford's Office of Management and Budget (OMB) in the months just before his Nixon-burdened presidential campaign lost to smiling Jimmy Carter's in November 1976. Carter's OMB quickly reapproved JOP, however, and the proposed project sailed through the House and Senate authorizing committees in the early spring of 1977.

By April 1977 I was feeling pretty good as I reflected on my first year as director of JPL. Popular support for planetary exploration had been highlighted by the *Viking* mission to Mars, and bipartisan political support seemed to flow from both the White House and Congress. JOP promised to be a high-yield mission for scientists and citizens alike. Perhaps approval of JOP would propel us toward more ambitious adventures—a rendezvous with Halley's

Comet, a radar portrait of Venus, or even a return to the surface of Mars.

Ambushed in Congress

But on Wednesday, May 4, 1977, the Jupiter Orbiter with Probe mission was suddenly ambushed in Congress. Without warning, all JOP funds were deleted by the House appropriations subcommittee that controlled NASA's funds. This subcommittee also oversaw other independent agencies like the National Science Foundation, the Environmental Protection Agency, the Veterans Administration, and the Department of Housing and Urban Development. Its chairman, the austere Edward P. Boland, hailed from Massachusetts, as did his closest confidant, Tip O'Neill, Speaker of the House. Boland also chaired the House Intelligence Committee. Therein lay a problem, for Boland was repeatedly assured by intelligence officials that the space shuttle was essential for national security. "I have no problem with the space shuttle program," he said. "That was the direction in which the Nixon administration indicated we ought to go, and the *Apollo* program was the direction in which the Kennedy administration felt we ought to go." Boland supported NASA's space shuttle program, even while terming it NASA's "sacred cow" and criticizing NASA's failure to allow for inflation in shuttle cost estimating.

Saving the Space Telescope

The flip side of Boland's staunch, if acerbic, support for the shuttle was his insistence that NASA prioritize its other missions, especially its space-astronomy program, into which he lumped all planetary exploration. In 1975 he had temporarily killed the *Pioneer* Venus mission. But when the Senate restored those funds, Boland backed off *Pioneer* Venus in the ensuing House-Senate conference committee. (The *Pioneer* Venus spacecraft were launched on two *Atlas-Centaur* rockets in 1978.) In 1976 Boland escalated his "prioritizing" campaign and came down hard on his real target—the proposed Space Telescope (ST). He correctly surmised that the Space Telescope, like the shuttle, would cost far more than NASA had advertised.

But Boland had not reckoned with the avalanche of national support that developed for the Space Telescope. The National Academy of Sciences had in fact given it its highest endorsement. NASA itself had a strong interest in the Space Telescope, the principal scientific use of the shuttle in the 1980s. Boland's 1976 assault, however, pushed the Space Telescope one year further back in NASA's queue of proposed new projects—to 1977. JOP also had to be approved in 1977, in order for it to be launched during the especially favorable opportunity in December 1981 and January 1982.

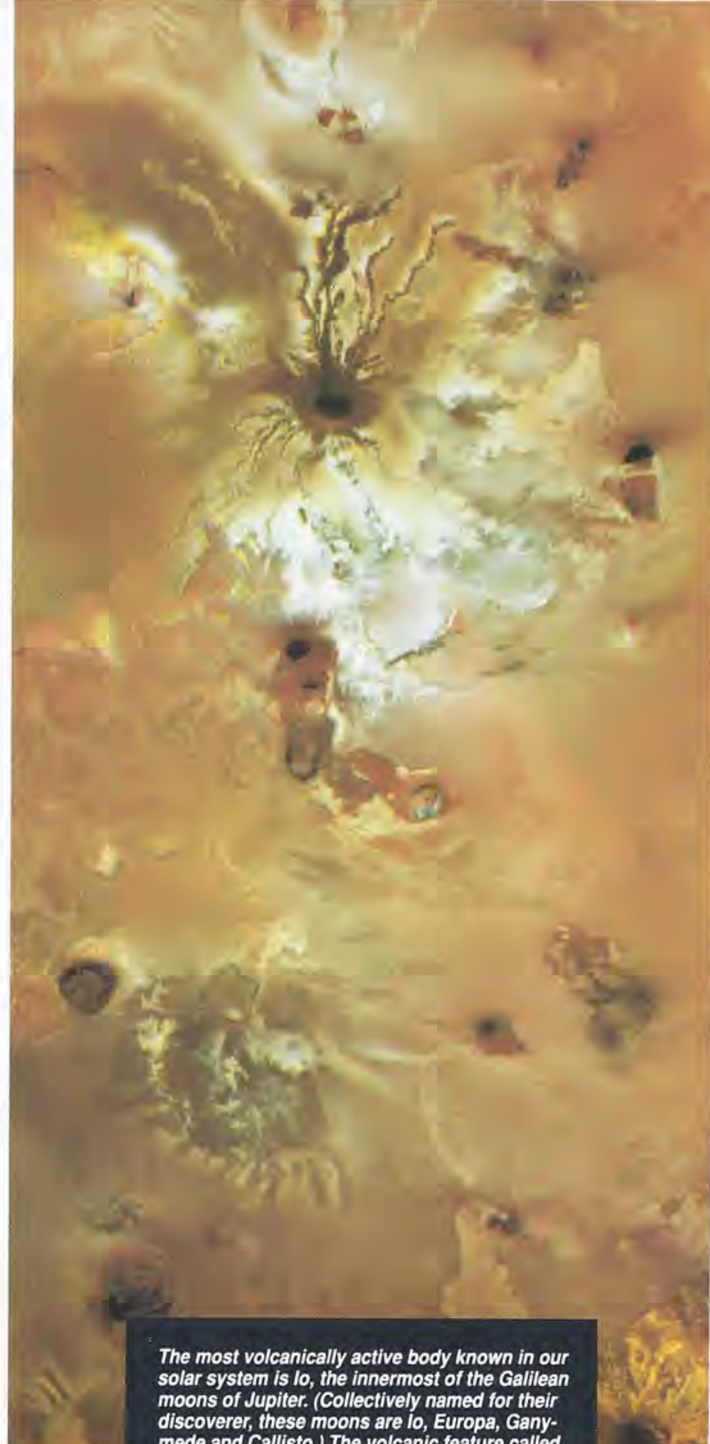
NASA couldn't focus on everything. In the spring of 1977 it worried about the fate of the Space Telescope, not about JOP, because a further challenge to the Space Telescope loomed in the form of Senator William Proxmire. Long the scourge of NASA, Proxmire now chaired the Senate subcommittee that voted on appropriations for NASA. His open skepticism created for NASA the nightmare of a Proxmire-Boland alliance to kill the Space Telescope.

"Jupiter Will Be There . . ."

But Boland, faced with a determined NASA and with strong National Academy of Sciences support for the Space Telescope, shrewdly shifted at the last minute and struck at JOP. He knew full well that NASA's overall top priority was the shuttle and that the primary commitment of NASA's Office of Space Science was to the Space Telescope. Thus, in chopping JOP, he could at most expect opposition from the third and fourth layers at NASA headquarters. Of the seven large NASA centers, only two, JPL and the Ames Research Center, were involved. JOP was an easy target. Boland announced:

"But not every project that the scientific community wants can have first priority, and that is why we made the budget priority choice —to provide the Space Telescope—but we denied the Jupiter Orbiter Probe.

"Jupiter will be there 5 or 10 or 15 years from now when this project can be reinstated. In all the 20 years that this Nation has been involved in a major effort—in all those years—the Congress has never, never made an attempt to deny funding for a major space mission. I think it's time that we did that."



The most volcanically active body known in our solar system is Io, the innermost of the Galilean moons of Jupiter. (Collectively named for their discoverer, these moons are Io, Europa, Ganymede and Callisto.) The volcanic feature called Ra Patera dominates this computer-processed image compiled from Voyager data. The Galileo spacecraft will swing by Io on its tour through the jovian system.

Image: Alfred McEwen, Tammy Rock and Larry Soderblom, United States Geological Survey

This was no delicate political minuet like the one in 1970 when the *Mariner* mission to Venus and Mercury was held hostage in Congress by another committee chairman, who forced NASA to kick in more money for his favorite NASA program. No, this was a bare-knuckled power clash. At stake was a symbolic $20 million out of NASA's $4 billion total budget. Over-

Jupiter's icy moon Europa has one of the smoothest faces yet seen in our solar system. Some process has resurfaced Europa, erasing most traces of meteorite and comet impacts. Some researchers have speculated that this fascinating body may have a liquid water ocean beneath its surface. Occasional eruptions of "ice volcanos" from this source may be the resurfacing agent. (The dark band extending from the top is an artifact of processing.) Image: United States Geological Survey

all, Boland's subcommittee controlled $70 billion. Boland did not want a compromise. He wanted complete victory —the demise of JOP and the demonstration of his committee's ability to shape "budget priorities."

Most of NASA, JPL quickly discovered, cared more about maintaining Boland's support for the shuttle and the Space Telescope than about risking an open confrontation with him over JOP.

Chairman Boland's Home Field

JOP and JPL suddenly seemed overmatched in a political struggle we did not expect or understand. Our only hope was to gain strong support from Senator William Proxmire's Senate appropriations subcommittee. "Imagine Proxmire as a white knight," I mused. Tuesday, June 15, 1977, was a dramatic day. The full House supported Boland and voted to delete JOP. But Proxmire's subcommittee included JOP in its appropriations bill. It had heard our plea for help.

Four weeks later, at 3:45 p.m. on Tuesday, July 12, Chairman Boland and his chosen House members sat down across the conference table to face Senator Proxmire and his Senate colleagues. Their task was to resolve JOP and 38 other individual differences in the appropriations bill between the House and the Senate.

Time passed slowly in Pasadena as we waited for word to leak out from behind those closed doors under the Capitol rotunda. We had asked our Senate allies to press for a compromise on the first-year funding—say, $10 million instead of $20 million for JOP—anything, in fact, as long as the mission was authorized.

It was late, even on the west coast, when we finally learned the result. The conference committee had resolved all but 2 of the 39 differences. An emotion-laden amendment to the House bill concerning veterans' payments, which had been added from the floor, could not be resolved by the conference committee —nor could the committee reach an agreement on JOP.

"What happens next?" I asked JPL's congressional liaison in Washington over the telephone.

"It goes back to the full House for a special vote."

"When?"

"That's up to Speaker O'Neill and Chairman Boland. It could be just a week."

"You mean we have to try to reach all 435 members of the House and persuade them to openly reject Eddie Boland's position in less than a week?"

"I'm afraid so."

Now we were playing on Eddie Boland's home field, and it was not at all level. In desperation, we tried every political circuit we could reach, along with pleas to the customary supporters of space science like the presidential science adviser Frank Press.

Mid-July Mayday

Governor Jerry Brown of California had discovered JPL—and its captive press corps—during the *Viking* mission in 1976. He also queried me frequently on another topic of mutual interest, solar energy. Now he responded vigorously to my mid-July Mayday by making personal phone calls to most of the California congressional delegation. His political support supplemented our scattered contacts in southern California and those that the Ames Research Center (on the south side of San Francisco Bay) could discover in the north.

Many scientists who belong to the Division for Planetary Sciences of the American Astronomical Society correctly perceived Boland's JOP actions as a threat to planetary science. A telephone and letter network spontaneously sprang to life, building its own momentum and reaching some congressmen from home-district constituents. Carl Sagan, James Van Allen and other prominent scientists spent days making personal visits to members of Congress.

Through good fortune, 5,000 "Trekkies" arrived in Philadelphia for their yearly "Star Trek" convention just three days after the conference committee's bombshell. Gene Roddenberry, the originator of the seemingly immortal TV series "Star Trek," was to be their principal speaker. Roddenberry sounded the clarion call, practically exhorting his followers to show their commitment to space exploration by bombarding their congressmen directly with telegrams and phone calls on behalf of JOP.

Howard Simons of the *Washington Post* had covered *Mariner 4*'s dramatic first look at Mars way back in 1965. Now he was managing editor and sympathetic to our predicament. On Monday, July 18, the *Post* led off its editorial page with "On to Jupiter," an incisive analysis of the political realities:

"What is involved here is the ability of a subcommittee chairman, who thinks this country is spending too much money on space programs, to veto a worthwhile, already-approved project simply because it is vulnerable. Jupiter Orbiter is a low-cost item, as space missions and most other government projects go. Its start-up costs, which are the ones in difficulty, are $20.8 million. Its established total cost is $280 million. Because it is small and because it lacks the drama of manned space missions, it has little political support. The big items in the $4 billion space budget, like the space shuttle, generate many jobs and much backing from members of Congress. Rep. Boland, who can't curtail the big projects because of that support, picked this one to slice out of next year's budget as a demonstration that the space crowd can't get everything it wants."

The editorial concluded with a crucial endorsement:

"This nation ought to use its space capability to gain more basic knowledge of the universe as well as to engage in practical—and exciting—applications of Earth-orbiting satellites. Congress accepted that view of our world some years ago, or so we had thought. If it now upholds one subcommittee's veto of this project, it will be turning its back on its own commitment to a space program that makes scientific sense."

To drive the point home to its readership, which included every staffer on the Hill and most members of Congress, the *Post* also ran a news article by its science reporter Tom O'Toole, a longtime admirer of JPL and space exploration. He detailed how the political goals of Boland were about to destroy a valuable and vulnerable American endeavor.

High Noon in the House

On Tuesday, July 19, 1977, the full House of Representatives took up the conference committee report. Boland quickly disposed of everything else and staked out his position on JOP. Member after member rose either to voice support for Boland and the deletion of JOP or to differ with him and urge support for JOP. Boland skillfully answered every objection and rejected all compromise.

Finally the Speaker pro tem announced that time for discussions had expired. A voice vote indicated a stronger "nay" than "aye" vote on the JOP deletion. Boland then called for a quorum. Absent House members rushed to the floor, and the electronic voting machine tallied up the results. Boland lost. JOP won by a vote of 280 to 131.

Nothing like this had ever happened before, nor has it since. To me, this demonstrated the breadth and depth of American political support for planetary exploration. The drought in new efforts to explore the planets must finally be coming to an end. Surely nothing could stop us now from returning to Jupiter.

After receiving congressional support, JOP was renamed *Galileo* on January 17, 1978. (This renaming, incidentally, helped remove political associations lingering from our bruising congressional battle.) *Galileo* was then officially scheduled for launch in January 1982, on the thirtieth planned shuttle flight.

"18 Months of Pad"

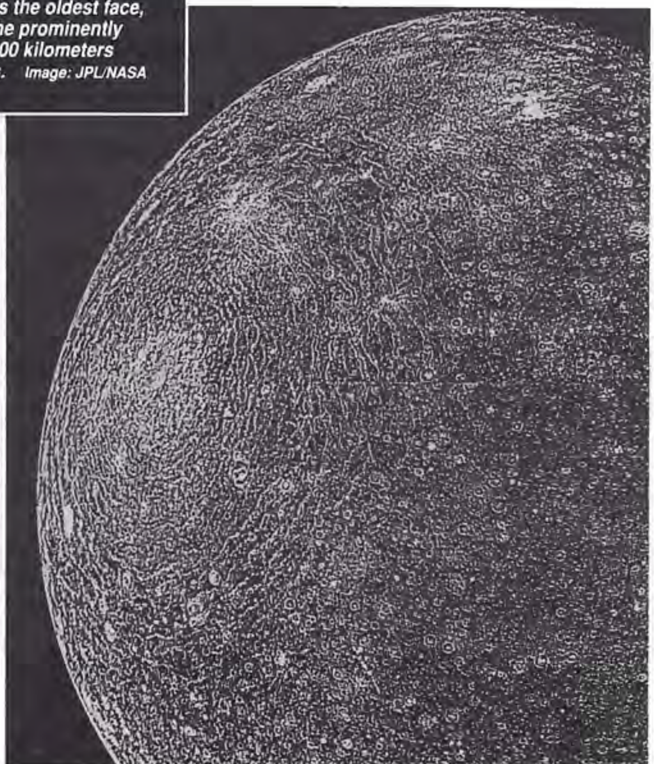
In boarding a late flight from Los Angeles to Washington, I had bumped into John Yardley, NASA's top man for the shuttle. Along with NASA's Deputy Administrator, Alan Lovelace, he was returning from a round of meetings with Rockwell International, the Los Angeles-based prime contractor for the whole space shuttle effort.

"How sure are you about the shuttle schedule, John?" I asked, polite but anxious. "*Galileo* has *got* to be launched in the Jupiter window of January 1982." Yardley jotted down a few key dates and smiled back at me tolerantly.

"Hell, Bruce," he said, "we have 18 months of pad." ➔

Ganymede (below left) is Jupiter's, and the solar system's, largest satellite and also displays the most varied terrain. Ancient, heavily cratered regions are crossed by younger, grooved terrain similar to the low mountain ranges of Pennsylvania. The rayed impact crater (about 150 kilometers in diameter) is a relatively young feature with the exposed water ice still shining brightly. Mosaic: JPL/NASA

Callisto (right) is the outermost of the Galilean satellites and retains the oldest face, with crater imposed upon crater until the surface was saturated. The prominently ringed feature is called Valhalla; its bright central region is about 600 kilometers across, and the concentric rings extend out about 1,500 kilometers. Image: JPL/NASA



Galileo was to be the first planetary probe launched from the space shuttle, sometime in late 1981 or early 1982. Delays in the shuttle program, and then the *Challenger* tragedy, have kept it on the ground for nearly a decade. *Galileo* is now scheduled for launch in October 1989. Photograph: NASA

It was April 1978, and the shuttle's first fight was only 18 months away by Yardley's schedule. Here was a perfect opportunity to air my growing unease over the shuttle's progress with NASA's shuttle boss. I could quietly remind Yardley of the devastating threat that any shuttle delay posed to America's *only* new planetary probe. The trusty *Atlas-Centaurs*, and their successors the *Titan-Centaurs*, had propelled America to world leadership in robotic exploration of the planets. Now they were museum pieces. NASA had decreed that all new planetary missions be launched with the shuttle and the new upper stages. America's future in space, robotic and otherwise, had been tied completely to human-piloted shuttle launches.

This fateful course had begun in January 1972, when NASA Administrator James Fletcher finally sold the shuttle to President Richard Nixon as America's key to the future in space.

On May 23, 1977, the newly elected President Jimmy Carter appointed Robert Frosch to replace James Fletcher as NASA Administrator. But John Yardley continued as NASA's shuttle chief, more powerful than ever under the new and less experienced NASA management. Indeed, Yardley continued to lead the shuttle program all the way into President Reagan's administration.

Back in the early 1970s, Fletcher, Yardley and Deputy Administrator George Low knew that the old hands of automated spacecraft, whether in science, commercial communications or defense, would never voluntarily relinquish *Atlas-Centaur* and other unmanned launch vehicles. These proven rockets were too reliable. NASA's claims that a *manned* shuttle could provide lower-cost and more-efficient launches for *unmanned* payloads were viewed very skeptically by those interested primarily in space achievements with automated spacecraft. So how could NASA create for the shuttle a monopoly on US access to space?

Pricing for a Shuttle Monopoly

Yardley's Office of Space Transportation controlled NASA's launch vehicle systems. The Office of Space Science in NASA headquarters controlled funds for all missions of space science and planetary exploration. Since it reported to NASA's boss, Fletcher, it was easy, beginning in the mid-1970s, for Fletcher simply to *require* that all new NASA missions of this sort be designed for launch by shuttle.

Private companies developing communications satellites were, however, not under NASA control. They could not be forced to choose the shuttle. So Fletcher and Yardley offered to commercial satellite builders and users a government subsidy in the form of guaranteed low prices for future shuttle launches. These prices were set low enough to discourage the birth and growth of an American private-sector industry for launching satellites with conventional unmanned rockets. Indeed, they were far lower than the likely cost to NASA for launching those commercial satellites on the shuttle. Thus, big commercial communications satellite companies like Hughes, Ford Aerospace and RCA, as well as satellite users like Comsat and Satellite Business Systems, had to be content with guaranteed and affordable NASA prices for future transportation into space by the shuttle.

Many fretted in private, but rarely in public, about NASA's ability to deliver that service reliably and on schedule.

Into this commercial void stepped Europe. France and the European Space Agency shrewdly developed the *Ariane* expendable-rocket system, specifically tailored for efficient commercial use, employing much of the conventional rocket technology that the United States was abandoning.

The Shuttle in USAF Blue

NASA still had to deal with the Defense Department, which had its own launching capability and requirements. The DoD was (and is) the largest single user of American launch vehicles. How could the generals and the civilian defense officials be persuaded to abandon their existing fleet of *Titans*, *Deltas* and *Atlas-Centaurs*? What would bring them to the shuttle as *the* American launching vehicle? How could they be enticed to let national-security payloads become wholly dependent on the shuttle? That sales task required even more massive NASA subsidies. All the billions of dollars to develop the shuttle would come from NASA. And NASA's rates to the DoD for future launches, like those for commercial communications satellites, were set far lower than the probable costs to NASA for providing those services. The Air Force merely had to promise to build a decade later the west coast base for the shuttle and use it.

Starting in 1977 and continuing through 1980, as scheduling problems worsened, the shuttle found its greatest friend in the Pentagon. This was Dr. Hans Mark, the key Defense Department official for space and for the shuttle. Mark became deputy secretary of the Air Force in 1977, with special space responsibilities, and the secretary in 1979. Mark, a shuttle and space station messiah, had earlier directed NASA's Ames Research Center.

I had known Mark for many years, even before serving as a fellow NASA center director with him in 1976 and 1977. When visiting him in 1977 in his Pentagon office, I could not ignore the detailed model of the shuttle that dominated his desk. The only difference between this model and those in the NASA offices was that Mark's was painted Air Force regulation *blue*. It was no secret that he advocated an Air-

Force-controlled shuttle system. He later recounted with pride how he intervened with President Carter to save NASA's shuttle program from the ravagings of its detractors. In his memoirs, he describes how on November 14, 1979, he represented the DoD and USAF at a critical shuttle meeting in the Cabinet Room of the White House. Carter, faced with strong and continuing support for the shuttle by Defense Secretary Harold Brown, as well as by Mark, agreed to continue without change the delay-plagued shuttle development. Carter's science advisor, Frank Press, was also present and approved, although he opposed additional new ventures like the space station.

A Mixed Fleet

However, Mark's memoirs indicate that a much more significant shuttle meeting had taken place two years earlier, on December 16, 1977, in the office of the OMB's director, James McIntyre. McIntyre and the OMB were pushing to downgrade the shuttle to an experimental program, with only three orbiters, operating exclusively from the Kennedy launch site. Such an approach would necessarily have kept expendable launch vehicles.

Events have demonstrated that this option would have been an inspired solution to the shuttle problem. Development of a mixed fleet—and acknowledgement that the shuttle was properly an R & D program—would have prevented the launch vehicle disaster that finally grounded America's efforts. Yet, according to Mark, Harold Brown, supported by Stansfield Turner, director of the CIA, deemed the OMB proposal unacceptable from the viewpoint of national security. Presumably, Brown and Turner were trying to protect the shuttle's promised capability to launch extra-large reconnaissance payloads from Vandenberg Air Force Base at Lompoc, California. (Brown did, however, insist on the procurement of long-lead-time parts for continuation of the *Titan 3* as backup. He thus provided launch vehicle insurance for the DoD for some years in the future.)

Mark's successor in the Reagan administration, Edward ("Pete") Aldridge, had a far less cluttered agenda concerning national security. In 1985, after a bitter battle with NASA, Aldridge gained presidential permission to ignore the decade-old "shuttle-only" national launch policy. He began to rebuild an independent launch capability for the Air Force. As a consequence of his foresight, industrial contractors were busy at work on an improved *Titan*-class launcher for the Air Force on January 28, 1986, when the *Challenger* accident blasted into oblivion the shuttle-only launch policy of the United States.

On March 5, 1979, *Voyager 1* brilliantly revealed to a "planet-struck" world the wondrous details of giant Jupiter and its extraordinary moons.

On July 5, 1979, *Voyager 2* repeated the spectacle and added intriguing new details.

On July 20, 1979, just 15 months after Yardley's patronizing response, "Hell, Bruce, we have 18 months of pad," we at JPL learned by telephone from our friends at NASA in Washington that the shuttle would not be ready to launch our Jupiter Orbiter with Probe during the critical January 1982 window.

Our victory over Eddie Boland seemed hollow now, gutted by NASA itself. □

When Galileo *is finally carried into space by the shuttle, it will be launched toward Jupiter by an Inertial Upper Stage (IUS) booster. Originally the spacecraft was to have used a more powerful* Centaur *upper stage that would have sent it directly to Jupiter. Safety concerns for astronauts put* Galileo *on the IUS, and it will have to swing by Venus once and Earth twice to build up enough velocity.*

Painting: Ken Hodges for JPL/NASA

THE *PHOBOS* ARGOSY—A

With the spacecraft about 320 kilometers above Phobos and some 6,000 kilometers above Mars, the wide-angle camera caught the small moon with Mars in the background. Details on the planet's surface are readily seen, unobscured by dust storms that usually occur later in the martian year.

This image of Phobos has been enhanced to make it four times brighter than it would normally appear, but even so it appears dark relative to Mars. With the bright planet in the background, the moon's irregular shape stands out.

The *Phobos 2* cameras used charge-coupled devices (CCDs) to generate these images, covering a much broader spectral range than previous spacecraft studying Mars. Before it was lost, *Phobos 2* returned about 40 images of the moon and Mars.

More than three years ago, Soviet scientists revealed to the world their plans for another step in humanity's exploration outward to Mars. As they had done for the *Vega* international mission that sent two spacecraft to Venus and Halley's comet in 1984-1986, members of the Space Research Institute, then headed by Society Advisor Roald Sagdeev, published their objectives and described the experiments and instruments for a bold new enterprise in deep space. This time the goal was to visit the martian moon Phobos. In addition to their primary objective, the two *Phobos* spacecraft were to make solar and interplanetary measurements during their trip to Mars, and once in orbit there they would make remote sensing measurements of the martian surface.

In contrast to *Vega,* which used a derivative of the reliable *Venera* spacecraft (in service since 1975), the *Phobos* expedition would use a new-generation spacecraft having many exciting capabilities, including hovering close to Phobos and dropping small landers on its surface. Early in 1988, exhibit models of this complicated and powerful six-ton craft were shown at international gatherings.

On July 7 and 12, 1988, the two spacecraft of the *Phobos* mission were launched. After mid-course maneuvers, the mission settled into routine. But in early September the first spacecraft failed to respond to commands. Analysis showed that a subtle combination of system design faults and operator errors had caused a turn-off of attitude control, with the result that the craft slowly tumbled, losing solar power and environmental control. After fruitless recovery attempts the *Phobos* team directed all its efforts toward the surviving spacecraft. Among the careful pre-encounter tests of *Phobos 2* were several that included NASA's Deep Space Network as part of a worldwide, cooperative radio-science experiment.

In late January 1989, its large propulsion system placed the spacecraft successfully in an initial, eccentric orbit about Mars, and in subsequent weeks the craft was maneuvered down into a circular orbit close to the orbit of its namesake moon. With the main rocket system jettisoned, the craft began an intricate series of maneuvers using its small jets. The cameras took pictures of Phobos, enabling specialists to refine their calculations of the moon's orbit and the spacecraft's orbit, so that the next maneuvers could be finely trimmed for the approach. After one such session, on March 27, the craft failed to return to its proper orientation, and

BRAVE AND BITTER TALE

ultimately its signals were lost. At this writing the cause is unknown.

So ended a splendid interplanetary voyage, literally within sight of its goal. It was a bitter moment for all who yearn to discover the secrets of Mars. But it is a brave emblem of the future, for the Soviets chose not to try to keep secrets on Earth. With the *Vega* and *Phobos* missions, the Soviets have signaled that their approach to deep-space exploration is now open and international. They are accepting not only the risks of technical failure but also the risks of adverse publicity. Before the eyes of the world, the triumphs and the failures of the *Phobos* mission were reported immediately.

In earlier times such disasters were hidden, but the truth eventually emerged. Ever since 1960 the USSR has attempted missions to Mars and Venus—more than 12 to Mars, more than 30 to Venus. New equipment often failed, but through persistent effort, success came to the Soviets. Can the Soviet deep-space team be as persistent in this new, public, international environment? Only time will tell. Meanwhile the new-generation spacecraft has come a long way toward proving itself.

The successful *Vega* and the so nearly successful *Phobos* missions have created enormous goodwill in the world toward the USSR as a country now willing to make large commitments to the peaceful, scientific goal of exploring the solar system—and willing to do so, win or lose, in the full view of humanity. As this new resolve must by now be well known at all levels in their government, we have good reason to hope that they will continue to aim for Mars.

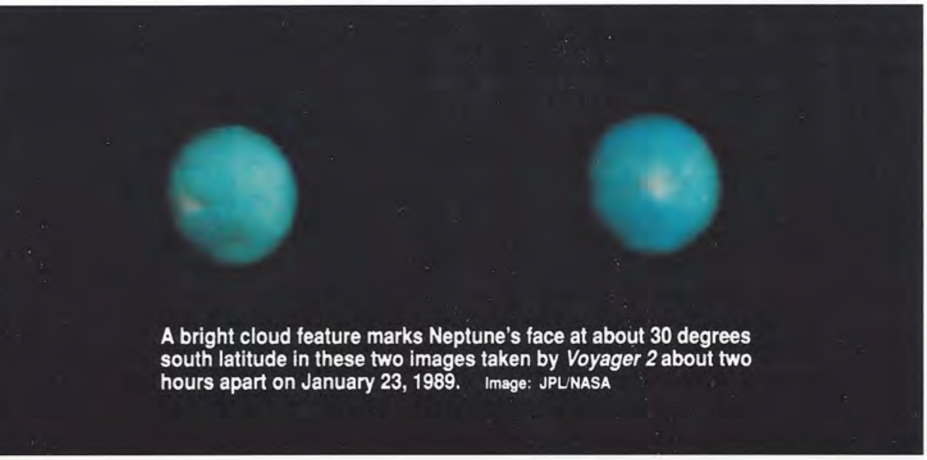
—James D. Burke, Technical Editor

PHOTOS: SPACE RESEARCH INSTITUTE, USSR

Mars' innermost moon, Phobos, is a small, dark, irregularly shaped object pockmarked by eons of impacts from debris moving through space. Phobos may be an errant asteroid captured into Mars orbit by the planet's gravity. This little moon's most distinctive feature is the crater Stickney, 11 kilometers across, seen here half in shadow in the lower right. The moon's surface appears saturated with craters. The bright patches surrounding the crater ramparts are probably pulverized debris from impacts.

This *Phobos 2* image is the most detailed ever taken of the region seen here. The spacecraft's narrow-angle camera took the image on February 21, 1989 from about 440 kilometers away. The view covers a section of the moon about 20 by 24 kilometers across, with the north pole at the top.

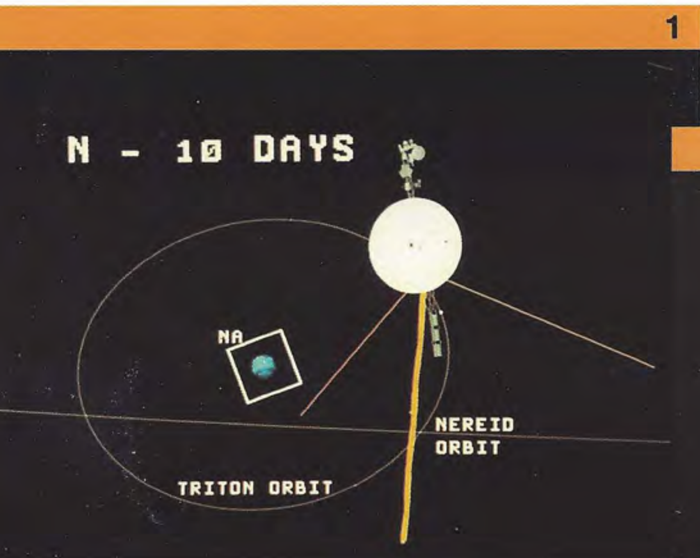
APPROACHING NEPTUNE

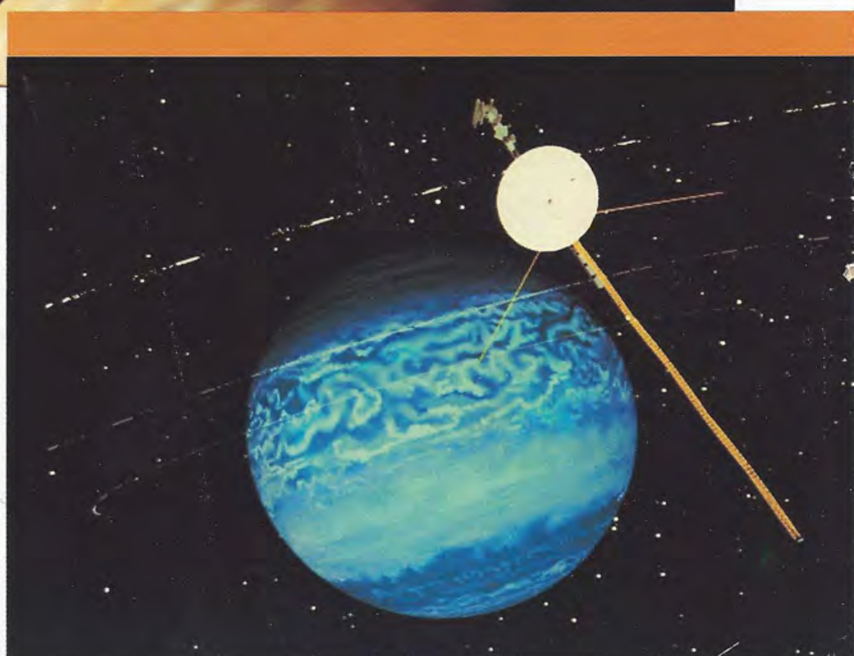


A bright cloud feature marks Neptune's face at about 30 degrees south latitude in these two images taken by *Voyager 2* about two hours apart on January 23, 1989. Image: JPL/NASA

Voyager 2 is now preparing for its final encounter—with Neptune on August 25. When it completes its planetary mission, this doughty spacecraft will have visited four planets and over 30 satellites, braved the planets' magnetic fields, crossed the planes of four ring systems and, with its sister craft, *Voyager 1*, enlarged our knowledge of the outer solar system immeasurably.

Since its launch in 1977, *Voyager 2* has explored Jupiter, Saturn, Uranus and the space between them. It's now traveling 18.9 kilometers per second (42,380 miles per hour) toward its next target—the neptunian system. *Voyager 2* will make its closest approach yet to a solar system body when it flies within 4,850 kilometers (3,000 miles) of Neptune's cloud tops. After swinging by the big blue planet,





1 ***Voyager 2*** **photographs Neptune from 14.7 million kilometers.**

2 **The computer portrays Neptune as it would be seen at a distance of 354,000 kilometers—from its large moon, Triton.**

3 ***Voyager 2*** **prepares to pass over the outermost ring arcs.**

Computer graphics: Charles E. Kohlhase and William J. Kosmann, JPL/NASA

Voyager 2 Prepares for an August Encounter

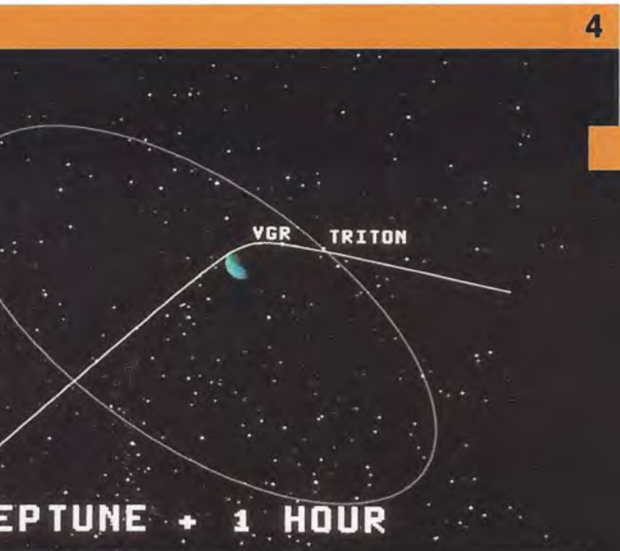
the spacecraft will intercept Triton and attempt to penetrate the large moon's atmosphere with its cameras and other instruments.

The encounter with Triton could be one of the most exciting moments of the *Voyager* mission. Like Saturn's moon Titan, Triton possesses a substantial atmosphere. With luck, this atmosphere may not be as hazy as Titan's, allowing *Voyager 2*'s cameras to see through to the surface. Oceans of nitrogen and methane may cover parts of Triton, which would make this a most unusual world.

Voyager 2 may answer the question of rings around Neptune. Some scientists observing from Earth have noticed stars "blinking out" just before or after Neptune passed in front of them. Such "occultations" may indicate the presence of encircling rings or discontinuous sections called ring arcs. But out of 110 observed occultations, only 8 have shown evidence of rings. *Voyager 2* should help scientists understand what is going on around Neptune.

In the years since the spacecraft's 1986 encounter with Uranus, the project team has been busily preparing for Neptune. Here is a sequence of computer graphics depicting events as they will occur in August.

Voyager 2 has already been observing the planet for several months. Although it's still millions of kilometers away, the spacecraft's cameras have picked out more detail in Neptune's atmosphere than it ever saw on the bland face of Uranus. Bright cloud features circle the planet, confirming scientists' hope that Neptune will be a fascinating place. —*CMA*



4 The computer takes the viewer within 585,000 kilometers of Neptune just after its closest approach to the planet.

5 After flying by the planet, *Voyager 2* gets ready to encounter Triton, now 217,000 kilometers away.

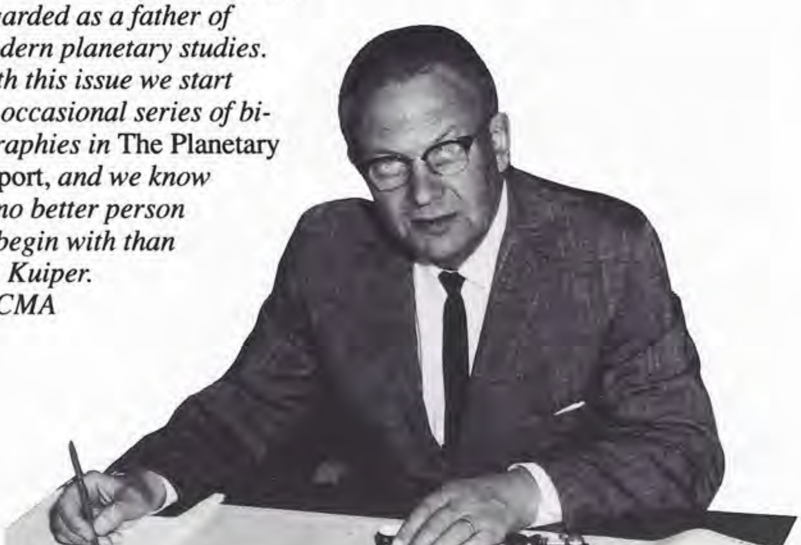
6 Having completed its planetary mission, *Voyager 2* says goodbye to Neptune, now 475,000 kilometers behind, and begins its journey out of the solar system.

A Pioneer of Planetary Science

by Bettyann Kevles

Modern planetary science is a field of study that only recently emerged from a period of relative obscurity. During the early part of this century, the furor over martian canals helped to discredit some planetary observers, and diminished the scientific prestige of the field in general. Meanwhile advances in telescopic technology placed the glamorous stars and galaxies within easy reach of ambitious young astronomers. Planetary science attracted few practitioners.

The coming space age would change all that, but in the decades before 1957 and Sputnik, *the planetary flame was kept alive by few scientists. One important practitioner was Gerard P. Kuiper, who is now regarded as a father of modern planetary studies. With this issue we start an occasional series of biographies in* The Planetary Report, *and we know of no better person to begin with than Dr. Kuiper.*
—CMA



As a graduate student at Leiden University in 1929, Gerard Peter Kuiper joined the Dutch solar eclipse expedition to Sumatra, where he immersed himself in the beauty of the island, learned Malay, took notes on local customs, painted beach scenes and still managed on the eve of the eclipse to correct an error of 90 degrees in the spectrograph slit of one of the cameras in time to ensure the expedition's success. At 23, Kuiper displayed the energy, imagination, attention to technological detail and fascination with objects in the solar system that would distinguish his career in planetary science.

Born in Harenkarspel, The Netherlands, in 1905, Kuiper had been an unusual schoolboy, spending one whole winter mapping even the faintest stars in the Pleiades with a small telescope that his father had given him. After high school in Haarlem, where he was steeped in Cartesian mathematics and natural history, he studied optical astronomy at Leiden University where he completed his doctorate in 1933. In retrospect he explained his choice of thesis topic—a statistical study of binary stars—by recalling that early in his career, he had been asked to review a book about the origin of the solar system and soon realized that "the state of astronomy did not permit its solution." He decided to find a closely related problem that with "finite effort would probably lend itself to a solution: the origin of double stars."

When he finished his doctorate, he packed all of his personal possessions and set sail for San Francisco, where he had been offered a year's fellowship at the Lick Observatory to continue the research in his thesis. A stickler for detail, both personal and scientific, Kuiper notified the staff at Lick that his ship was expected to arrive at Oakland, California, at 7:51 a.m. Assuming no delay, he predicted almost to the minute his arrival on Mount Hamilton—precisely at noon on the day his fellowship began.

Split Views of Double Stars

He immediately unpacked the gratings that he had designed for the telescope at Leiden and that he would continue to use in California. Each grating was an arrangement of thin, parallel, black rods, mounted so they could be slipped as a unit over the front surface of the telescope's lens. The lens then produced by diffraction a series of images, not simply a bright central picture but also the fainter images on either side. According to Donald Osterbrock's history of the Lick Observatory, "the grating allowed Kuiper to measure the magnitude difference between two stars of very different brightness, such as the two components of a double star, by comparing a secondary image of the brighter star with the primary image of the fainter one."

At Lick, Kuiper discovered that a high percentage of the most common stars are in fact double stars, which in turn led to the discovery that the mean distance between binary star components is roughly the same as the distance of Jupiter or Saturn from the Sun. The question would thus be raised in future studies of solar system origins: Were the planets a special case of binary star formation, or vice versa?

Meanwhile, Kuiper had impressed Robert Aitken, who, preparing to retire as the director of Lick Observatory, urged the University of California to appoint Kuiper as his replacement. The economics of the Depression interfered, but Kuiper won a temporary appointment at Harvard University. The next year, 1936, he married an American, Sara Fuller, and joined the faculty at the University of Chicago with a position at the Yerkes Observatory nearby in Wisconsin.

At Chicago Kuiper joined Otto Struve and G. Van Biesbroeck. His responsibilities included overseeing the construction of the McDonald Observatory in Texas, the first of a cluster of new observatories that would be built with telescopes that incorporated a constantly improving state of the art.

In 1937 Kuiper became a citizen of the United States and published a classic paper on stellar astronomy in which he presented a color-magnitude diagram for galactic clusters. The next year he refined his results, providing the basis for the stellar temperature scale still in use. In 1939 he celebrated the dedication of the McDonald Observatory with its high-quality spectrograph.

Outbreak of War

With the outbreak of war, Kuiper went to work for the Radio Research Laboratory at Harvard as well as for the civilian Office of Scientific Research and Development. During the winter of 1943-1944 he managed a leave of absence in Texas, during which he conducted a spectrographic study of the major planets. In rapid succession he explored Triton (Neptune's largest moon), the Galilean satellites of Jupiter, and four of Saturn's satellites, including Titan where he discovered several bands of methane—the first sign of an atmosphere on any satellite. His postdoctoral research had honed his expertise as a spectrographer, and from this winter on Kuiper concentrated his attention on objects within the solar system, using the tools of the newly invented specialty, planetary chemistry.

After the war, when many military inventions became public, Kuiper applied the new infrared detectors, which both the Allies and the Germans had developed, to observing the heavens. Kuiper collaborated with R. J. Cashman and W. Wilson to construct an infrared spectrometer to study stellar spectra, with which he discovered carbon dioxide on Mars. Another product of the war—rockets—raised the question of the Moon's military potential, so the Air Force decided that it had to be properly mapped. Under their aegis Kuiper pub-

In 1948, Gerard Kuiper discovered Miranda, one of Uranus' moons. Voyager 2 visited this little moon some 38 years later, and found it to be one of the strangest objects in the solar system with very diverse terrain. Some scientists speculate that Miranda has been broken apart—perhaps several times—by collisions with large, errant bodies. The gravitational attraction among the pieces eventually reformed them into a moon. Image: JPL/NASA

Titan is one of the most intriguing objects in our solar system, for its atmosphere contains the organic molecules that on Earth may have been the precursors of life. Gerard Kuiper's discovery of methane on Titan during the winter of 1943-1944 was the first evidence of an atmosphere on a moon.

Image: JPL/NASA

lished a lunar atlas.

In 1948 he organized a symposium on planetary atmospheres to celebrate the 50th anniversary of the Yerkes Observatory, the proceedings of which he edited as *Planetary Atmospheres and Their Origins*, published in 1950. His own paper in this volume suggested that the solar wind was responsible for the removal of hydrogen from the inner solar system during the Sun's early T Tauri stage (a period when some stars throw off huge amounts of gas and dust).

Kuiper spent the next 20 years studying planetary atmospheres and the origin of the solar system. His prewar study of double stars proved useful as he applied the same methodology to bodies within the solar system. Where he had once studied the angular momenta (spin) of double stars, he later studied the division of angular momentum between the Sun (a star) and its planets as a key to understanding their beginnings. He explained this intellectual development in his acceptance speech at a joint meeting of the American Association for the Advancement of Science and the Franklin Institute where he received the Kepler Gold Medal in 1971: "I felt that I had come to understand the problem of double-star origin, at least in outline, [from which] it followed that the solar system was no more than an 'unsuccessful' double star with the companion mass opened out radially into a disk that in time developed the planets."

The great lunar crater Copernicus, about 90 kilometers across, displays the classic features of a giant impact scar: central rebound peaks whose material seems to have come from deep in the lunar crust, a bumpy flat floor, steep walls with great slump terraces, a hummocky apron of ejecta, and long rays of thrown-out material spreading across the surrounding mare lavas.

Photograph:* Lunar Orbiter IV, *Frame 126M, NASA

Seen through a telescope, the surface of Mars is crossed by dark features that appear to grow and recede with the seasons. Working from analogy with Earth, some astronomers speculated that these regions were covered with vegetation. Examining Mars with spectrographic equipment, Kuiper recorded data that indicated no green plants but that were possibly consistent with lichens.

Composite photograph: Robert Leighton, California Institute of Technology

The Media Take Notice

Kuiper was a formal person, always European in dress, and stubborn in his opinions. But he was very American in his relations with the media. He caught their attention when he discovered carbon dioxide on Mars through spectrographic investigation in February 1948, and suggested that the apparently green areas on the Red Planet were covered with low-order plants that "act like sponges and soak up water vapor present in the air." Later that year he discovered Miranda, a fifth moon of Uranus, and Nereid, a second moon of Neptune. He delighted the public by suggesting that the frequency of planetary systems was at least one for every thousand stars, and thus there might be billions of planets like Earth in the universe.

Kuiper continued to observe in Texas where, in 1948, he attracted his first student in planetary astronomy, Daniel L. Harris III. In 1949, as director of Yerkes and McDonald observatories, he initiated an asteroid search that resulted in the 1958 publication of 1,200 photographic plates, co-authored by his second student, Tom Gehrels.

Kuiper shifted his attention to the inner planets: to Venus, charting its apparent rotation, and back to Mars, observing that the spectra he had recorded earlier did not represent chlorophyll but were possibly consistent with lichens. Looking toward the outermost planets, he determined a new, more accurate measurement of the diameter of Pluto, which he found wanting as a planet. He took the controversial position that Pluto ought to be recategorized as an escaped Neptunian moon. Kuiper directed both the Yerkes and McDonald observatories from 1947 to 1949, and again from 1957 to 1960. During this latter period his third graduate student, Carl Sagan, picked up the torch as a leader in planetary science.

Meanwhile, Kuiper continued to wrestle with the puzzle of the origin of the solar system. The vortex model of the solar system, postulated in an elementary way by Descartes and honed by C. F. von Weizsäcker to a sophisticated theory in the 1940s, convinced Kuiper that planets evolved in a dense universe filled with whirling vortices of matter that coalesce about spinning centers. Kuiper posited that planets formed out of protoplanets, massive concentrations in a huge disk of dust and gas.

The "Hot Moon" Controversy

Seemingly inexhaustible, Kuiper turned to the study of the Moon for evidence of planetary evolution. He believed that the lunar maria (the smooth, dark regions that Galileo thought were seas, hence their name) were products of volcanic activity and that the Moon had gone through enormous internal changes over time. This "hot moon" theory was rejected by his colleague, Harold Urey, who held that the scars on the Moon's surface were from impacts and that the Moon was an unadulterated mass left over from the primordial solar system. The two planetary scientists debated the Moon's nature for 15 years in the *Proceedings of the National Academy of Sciences* and elsewhere.

This was a debate for which there was going to be an answer. In 1957 Kuiper undertook a second photographic lunar atlas and, in 1960, he left Chicago to found the Lunar and Planetary Laboratory at the University of Arizona.

The race to the Moon had begun and Kuiper helped NASA select the landing sites for the *Apollo* astronauts. Now a public figure, he predicted to a nationwide television audience in 1964 that "if you walked on the Moon, it would be like crunchy snow." In preparation for the *Apollo* landing, Kuiper worked on NASA's robotic probes as principal investigator on the *Ranger* program. And when the astronauts took their first steps, the debate with Urey ended. The maria proved to be dark basaltic lava flows, and Kuiper's "hot moon" theory proved right.

Kuiper retired as director of the Arizona laboratory in the summer of 1973 but continued making site visits to expand the linkage of telescopes in the west. At the time of his death on Christmas Eve, 1973, he was on his second site selection trip to Mexico in one week, exuding the same energy and enthusiasm that had marked his Sumatran adventure 44 years earlier.

By the time of his death, he had been made a Knight Commander of the Dutch Order of Orange and Nassau and had received the Kepler and Rittenhouse medals. Posterity will recognize his name in the "Kuiper bands" (methane on Uranus and Neptune) and in the crater Kuiper (the first crater identified on the surface of Mercury). Perhaps the most fitting memorial is the Kuiper Airborne Observatory, a flying telescope that circles the globe.

Bettyann Kevles is a Pasadena writer whose latest book, Females of the Species, *was just released in paperback by Harvard University Press.*

NASA's Kuiper Airborne Observatory carries instruments and astronomers high above Earth's interfering atmosphere. Among the discoveries made from the observatory are the rings of Uranus and the atmosphere of Pluto. ***Photograph: NASA/Ames Research Center***

Who Cares About Planetary Exploration?

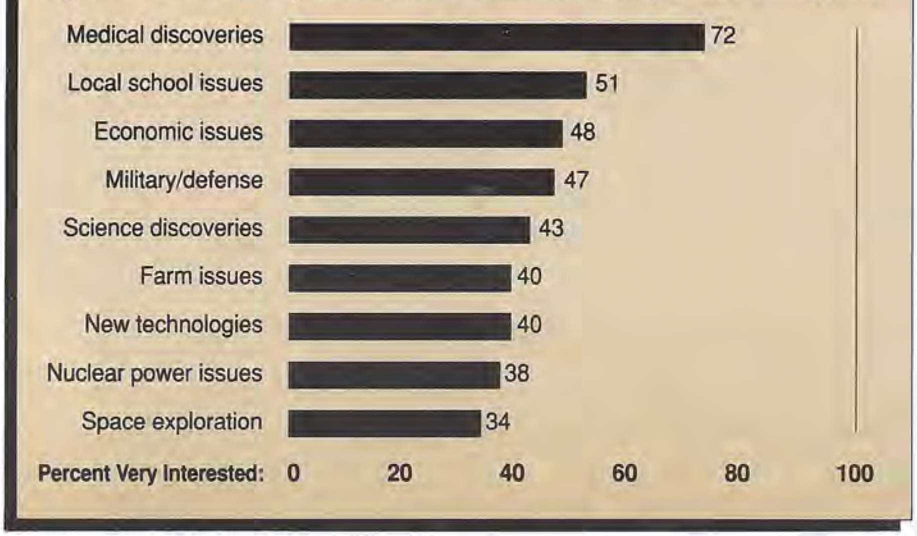
by Jon D. Miller

Our private and public worlds are very busy places. There are always new problems and new challenges at work. Meanwhile, at home, children want to play or need to be picked up from a lesson. Committees. Piles of great books and aging magazines to read. A new crisis in the Middle East. A zoning dispute in the neighborhood. The car needs to visit the shop. Last week's dry cleaning needs to be picked up. And there are one or two issues before the Congress that you would like to write a letter about. Where did all of the hours go?

The basic problem of the modern citizen is that our supply of time is finite and the demands for a share of that time have been growing steadily over recent decades. Try to think of anyone you know who is able to stay up to date on the full range of issues involving foreign policy, economic policy, agricultural policy, housing policy, transportation policy, science policy, civil rights and the space program . . . to say nothing about the important issues facing state governments, city governments, school boards and other groups involved in formulating public policy. We live in an age of political specialization. Only about half of the adults in our society bother to follow any of the major clusters of political issues, and those citizens who do try to participate in public affairs typically report that they are able to stay reasonably well informed about only two and three issue areas.

The space program is but one of several issue areas competing for each individual's time, and only about a third of adults in the US are very interested in space exploration, according to a July 1988 survey conducted by the Public Opinion Laboratory at Northern Illinois University (see Figure 1 above). However, over the decade of the 1980s, the percentage of adults with a high level of interest in space exploration has risen from 26 percent in 1981 to 34 percent in 1988.

Figure 1: Percent "Very Interested" in Selected Issues, United States, 1988



Can Congress Ignore Space?

What does this level of interest in space exploration mean for the political future of the space program? Can the Congress safely disregard the space program, focusing time and resources on more popular issue areas? The answer is no. In a highly specialized political system like the United States, public policy on specialized issues like the space program is largely negotiated between the political decision makers and a group of space and science policy leaders. When the policy leadership group is divided, or when it needs to exert more clout with political decision makers, the policy leaders turn to citizens who are interested in space exploration. These citizens—often called the attentive public for space policy—then respond to the call for support by writing or telephoning their representatives in Congress, collecting signatures on petitions and asking other politically active friends to do the same. Virtually all of the readers of *The Planetary Report* are attentive to space policy. There are 14 million space attentives in the United States, comprising about 8 percent of the adult population. (See Figure 2 on page 24.)

The attentive public may be thought of as the reserve army for the space program. When things are going all right, members of the attentive public follow the news concerning space activities, read magazines about space exploration, watch PBS shows about science and space, and talk with other people who share their interest. If an issue arises that concerns a space attentive, he or she will likely exert more influence in the political system than most citizens because members of the attentive public for space are more likely to vote, contribute to campaigns, and call a legislator or send a telegram to the White House.

Attitudes of Attentives and Other Citizens on Space Policy Issues, 1988

The American space program should build a space station large enough to house scientific and manufacturing experiments.

	AGREE	UNSURE	DISAGREE
Space attentives	84%	2%	15%
Other citizens	71	5	24

The American space program should try to land astronauts on Mars in the next 25 years.

	AGREE	UNSURE	DISAGREE
Space attentives	70%	2%	28%
Other citizens	50	6	43

The American space program should develop a scientific and mining colony on the Moon within 25 years.

	AGREE	UNSURE	DISAGREE
Space attentives	69%	4%	28%
Other citizens	48	5	47

Is the government spending too little, about the right amount or too much on exploring space?

	TOO LITTLE	ABOUT RIGHT	TOO MUCH
Space attentives	37%	47%	15%
Other citizens	16	37	45

Currently, the United States spends approximately twice as much on the military uses of space as on the civilian or scientific use of space. In your view, is this division of resources about right, or would you prefer greater emphasis on the military or greater emphasis on civilian and scientific uses?

	CURRENT DIST OK	EMPHASIZE MILITARY	EMPHASIZE CIVILIAN
Space attentives	13%	13%	69%
Other citizens	22	16	58

On balance, the space program has paid for itself through the creation of new technologies and scientific discoveries.

	AGREE	UNSURE	DISAGREE
Space attentives	76%	3%	21%
Other citizens	54	7	39

How likely is it that a war in space will occur within the next 25 years?

	VERY LIKELY	POSSIBLE, BUT NOT TOO LIKELY	NOT AT ALL LIKELY
Space attentives	6%	30%	64%
Other citizens	9	46	32

In general, would you say that you are in favor of or opposed to President Reagan's proposal that the United States build a new defensive space weapons system—sometimes called the Strategic Defense Initiative or "Star Wars"?

	FAVOR	UNSURE	OPPOSED
Space attentives	51%	11%	38%
Other citizens	41	21	38

Survey Note: The July 1988 survey results reported above are based on telephone interviews with a national probability sample of 2,040 adults, including 167 "space attentives." The interviews were conducted by the Public Opinion Laboratory at Northern Illinois University. The study was jointly supported by the National Science Foundation (NSF grant SRS-8807409), WGBH (Boston) and Geoff Haines-Stiles Productions. The margin of error on point estimates involving an approximately even distribution is plus or minus 2 percent. Percentages may not add to 100 due to rounding of figures and/or "no response" answers.

Space Attentives Agree

The attentive public for space holds very positive attitudes toward the space program. Nearly 70 percent of the attentive public favors increased federal spending for civilian and scientific purposes in space while only 13 percent would increase military spending in space. Some 76 percent of space attentives agree that the space program has paid for itself "through the creation of new technologies and scientific discoveries." Over 80 percent of space attentives favor the construction of a space station "large enough to house scientific and manufacturing experiments," and 70 percent believe that the space program should include an attempt to land an astronaut on Mars within the next 25 years. The same proportion would like to see a scientific and mining colony established on the Moon within the next 25 years. These results are similar to the results from questionnaires mailed to members of The Planetary Society, confirming the view that members of the Society are members of the attentive public for space policy.

Space attentives are divided over the Strategic Defense Initiative, or "Star Wars" program. Half of the attentives interviewed in July 1988 indicated that they favored building a defensive space-weapons system, while 38 percent opposed the idea. Another 11 percent were unsure about their position on the program. Only 6 percent of space attentives thought that a war in space was likely within the next 25 years.

Power of Unanimity

The political power of space attentives comes from the high level of policy agreement among its members and from the absence of an organized anti-space group. By way of contrast, the policy leaders and the attentive public for nuclear power issues are deeply divided about the safety and desirability of using nuclear power to generate electricity. This level of division often leads to political stalemate. In the area of space policy, the policy leaders and the attentive public are generally of one mind.

Citizens who are not attentive to a given issue area have little influence on the formulation of public policy in that area. For example, I personally have little interest in agricultural policy in the United States and even less knowledge about that area. I have no idea what kinds of issues will be dealt with in the congressional agriculture committees. And while it may seem impossible to those of us deeply involved with space exploration, the overwhelming majority of American citizens have no more interest in the space program than I have in agriculture. A majority of citizens who are not attentive to space will respond—when asked by an interviewer—that the government spends too much for space programs. However, they will not write a letter about it and are likely to have little information about the level of spending for space. These weakly held opinions will have little impact on the political system.

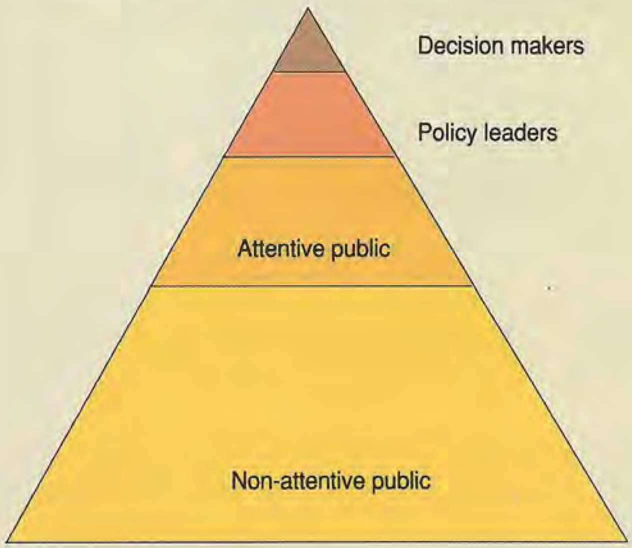
Being Effective in a Democracy

To return to my original question: Who cares about space exploration? The answer is four or five thousand space and science policy leaders and about 14 million citizens, who comprise an attentive public for space policy. The high level of agreement among space attentives and the absence of an organized anti-space movement give the combination of space and science policy leaders and the attentive public for space policy considerable influence in the political system. Through groups such as The Planetary Society, thousands—and sometimes tens of thousands—of space attentives let their elected representatives know about their support for the space program.

It is important that space attentives stay well informed about space activities and that they be willing to make their voices heard when they feel strongly about a question. Often we hear people say that they don't get involved in politics because they are only one vote in millions. Given the degree of political specialization, the relative influence of citizens who follow a set of issues and who stay informed about those issues magnifies several hundred fold over the influence of citizens who limit their participation to one vote every four years. The attentive citizen can have significant influence in the policy process if he or she is willing to focus his or her energies on a few issue areas, to become well informed about those issues, to work through organized groups when available and to make his or her views known clearly and persuasively to elected representatives.

It would be desirable for more Americans to have a high level of interest in space exploration and for a higher percentage to be members of the attentive public for space policy. But 14 million individuals who understand the system and work within it will be sufficient to sustain and advance our current programs of space exploration.

Figure 2: Stratified Model of Policy Formulation



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*Jon D. Miller is Director of the Public Opinion Laboratory and Professor of Political Science at Northern Illinois University. He has authored two books—*Citizenship in an Age of Science *(Pergamon, 1980) and* The American People and Science Policy *(Pergamon, 1983)—and is currently completing* Scientific Literacy, *which will be published by Plenum in early 1990.*

The Planetary Society Survey

Since early 1987, The Planetary Society has mailed hundreds of thousands of questionnaires to individuals interested in science and space. While the responses to these surveys are not a scientific sampling, they do provide valuable information about the attitudes of an informed sector of the public. More than 40,000 members of The Planetary Society have responded to one or another of our two surveys, which gives us a very good idea of how at least 30 percent of our members feel on important issues facing the US and international space programs.

Results from both surveys reflect approximately 90 percent support for increased US funding of its space program and for identification of a *focused* goal for the space program. International cooperation, with the USSR and other spacefaring nations, receives approval from 75 to 80 percent of Society members sending in questionnaires. More than 90 percent believe The Planetary Society should serve as an advocate for planetary exploration.

Particular missions also draw strong favorable ratings. In the most recent sampling (December 1988), a joint US/USSR effort to land astronauts on Mars enjoyed 70 percent support, as did development of a new heavy-lift launcher to carry larger payloads into orbit and to other planets. The radio astronomy Search for Extraterrestrial Intelligence received 65 percent support.

Asked to prioritize specific missions, respondents in the most recent survey gave the highest ranking to an Earth-orbiting space station, followed by a permanent Moon base and then human exploration of Mars. In the earlier version of the questionnaire (spring 1987), which did not include the space station as an option, the first and second priorities were the Moon base and human exploration of Mars, followed by exploration of the saturnian moon Titan. Other missions receiving about half as much support were robotic exploration of Venus and a mission to gather cometary matter for return to Earth.
—Tim Lynch, Director of Programs and Development

World Watch

by Louis D. Friedman

CAPE CANAVERAL—The United States launched its first spacecraft targeted beyond Earth orbit in more than ten years on May 4, 1989. *Magellan*, the Venus radar mapper, took flight on the seventh day of the launch period after correction of a fault in the fuel system.

MOSCOW—The *Phobos* mission came to an abrupt end March 27, 1989, after an unsuccessful maneuver left the spacecraft tumbling randomly.

The ambitious mission was a partial success. *Phobos 2* had reached Mars, gone into orbit and taken thousands of measurements and dozens of pictures of Mars and Phobos before the final rendezvous failed.

The loss is not expected to have a profound effect on Soviet space plans. However, Soviet space officials acknowledge that the accident will require major re-examination of spacecraft manufacturing. A special commission has been set up by Glavkosmos, the Soviet space agency responsible for the mission operations and spacecraft.

As we went to press, the commission had not yet reported on the cause of the failure or on recommendations for the future. An international meeting in Moscow was being planned for mid-May to review these subjects and to air preliminary science results.

In the face of Soviet economic and political reform issues, there has been considerable discussion in Moscow of weakened support for space exploration. The *Mir* orbital space station was left unoccupied in late April, a development that has been interpreted in some US press reports as a policy retreat. Soviet officials maintain that the shut-down is a temporary measure to effect repairs to the electrical system for use in future station operations.

Academician Valery L. Barsukov, a key figure in the Soviet planetary program, told reporters at the Kennedy Space Center that despite "new circumstances, we can assure the realization of our main tasks . . . the Mars '94 mission and the Mars '98 sample return." He and other Soviet officials reiterated that Mars '94 was still a first priority.

WASHINGTON—As we went to press, the following space policy officials in the Bush administration had been named.

•NASA Administrator: The resignation of James Fletcher has brought Deputy Administrator Dale Myers to the helm as Acting Administrator, pending confirmation of Admiral Richard Truly, President Bush's nominee. Truly's confirmation depends on passage of an act of Congress exempting him from the requirement (in the 1958 National Aeronautics and Space Act) that the Administrator not be a military officer.

•Executive Director, National Space Council: Mark Albrecht, former legislative assistant on defense matters to Senator Pete Wilson (R-CA), will report to Vice President Dan Quayle, who is chairman of the council, as specified by Congress in 1988.

•Science Advisor (Assistant to the President for Science and Technology): Allan Bromley, a distinguished nuclear physicist at Yale, served on the White House Science Council during the Reagan administration.

•Assistant Secretary for Oceans and International and Scientific Affairs, Department of State: Fred Bernthal, a Reagan appointee, will apparently continue in this post.

•Office of Management and Budget: Norine Noonan is the staff member responsible for matters related to space policy.

In the US Congress the key leaders for space policy are:

•Senate Committee on Commerce, Science and Transportation: Chairman Ernest Hollings (D-SC); Ranking Minority John Danforth (R-MO)

•Senate Subcommittee on Science, Technology and Space: Chairman Albert Gore, Jr. (D-TN); Ranking Minority Larry Pressler (R-SD)

•House Committee on Science, Space and Technology: Chairman Robert Roe (D-NJ); Ranking Minority Robert Walker (R-PA)

•House Subcommittee on Space Science and Applications: Chairman Bill Nelson (D-FL); Ranking Minority F. James Sensenbrenner (R-WI)

•Senate Appropriations Committee: Chairman Robert Byrd (D-WV); Ranking Minority Mark Hatfield (R-OR)

•Senate Subcommittee on HUD and Independent Agencies: Chairwoman Barbara Mikulski (D-MD); Ranking Minority Jake Garn (R-UT)

•House Appropriations Committee: Chairman Jamie Whitten (D-MS); Ranking Minority Silvio Conte (R-MA)

•House Subcommittee on HUD and Independent Agencies: Chairman Bob Traxler (D-MI); Ranking Minority Bill Green (R-NY)

•Senate Budget Committee: Chairman James Sasser (D-TN); Ranking Minority Pete Domenici (R-NM)

•House Budget Committee: Chairman Leon Panetta (D-CA); Ranking Minority Bill Frenzel (R-MN)

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

Background: Richard Truly

As head of NASA's Space Shuttle program since February 1986, Richard Truly has presided over the return of the Shuttle to flight after the *Challenger* accident.

Truly has twice flown Shuttle missions: in November 1981, when *Columbia* became the first "used" vehicle in space, and again in August-September 1983, when he commanded the first nighttime launch and landing.

A Navy flier since 1960, Truly joined the NASA astronaut team in 1969. He took part in the *Skylab* and *Apollo-Soyuz* missions. From 1983 to 1986 he headed the Navy Space Command.

News & Reviews

by Clark R. Chapman

The cosmos seems, because of vast distances, to unfold slowly and majestically. The drama of Supernova 1987A is an extraordinary exception. After its appearance two years ago in the Large Magellanic Cloud, the supernova evolved from day to day and week to week. Even two years later, with the supernova long since faded from naked-eye viewing, astronomers can still observe weekly changes. For instance, rings and arcs surrounding the supernova now extend to several times the apparent size of Jupiter, which implies an enormous true size, light-years across. Some arcs may be "light echoes" as the brilliant explosion is reflected toward us by dust clouds a couple of light-years away from the supernova.

Supernova 1987A provides insight to the vibrant aspect of the universe that we seldom witness. Although such explosions are a natural phase in the evolution of many stars, and provide the stuff of which planets, trees, and people are made, they rarely happen close enough to us to be measured. Even the Magellanic Clouds are far away. But the release of immense energy is so sudden in a supernova, and the effects so brilliant, that daily and monthly changes can be tracked from Earth with comparative ease.

Pulsar Mysteries

The academic journals in which scientists normally publish their results often take six or ten months to put an article in print. Some astronomical events, especially those dealing with the solar system, require more rapid communication. For this reason, the International Astronomical Union (IAU) has a telegram service. Astronomers whose needs are less urgent or who have less money can subscribe by mail; the 3 x 5 inch cards arrive at my office every few days. The telegrams are also available via electronic mail.

An especially exciting telegram is number 4735, dated February 8, 1989. Carlton Pennypacker, John Middleditch and their collaborators report in spare language that on January 18 they discovered a new pulsar at the site of Supernova 1987A. A pulsar is a star that varies in brightness very rapidly, nearly 2,000 times a second in this case, making it the fastest pulsar known. Shortly after the first pulsar was discovered two decades ago, astrophysicists concluded that pulsars must be rapidly spinning neutron stars, created in supernova explosions.

Pennypacker and his colleagues had been watching for a pulsar to emerge from the glow of Supernova 1987A, but the traits of the new pulsar proved astonishing. There has been no time for scientists to even begin debating these fresh results in the traditional journals with long lead times. But just two weeks after the initial telegram, several fast-publication magazines began to explore the ramifications of the new discovery.

Science reporter Ivars Peterson, writing in the February 18 *Science News,* offers the most basic and readable article, focusing on the pulsar's remarkable spin, which is so fast that one wonders why the neutron star doesn't fly apart. Peterson also writes about evidence that there is an object of Jupiter-like mass revolving about the pulsar; that would be especially remarkable because such an object would have been *inside* the outer envelopes of the star before it exploded. More likely it was created in the supernova explosion. Or perhaps it is just an illusion.

A short article by reporter Mitch Waldrop in the February 17 issue of *Science* describes how Pennypacker and his colleagues checked to be sure their results weren't spurious, but Waldrop leaves his readers with a healthy dose of skepticism, pending more data. Both Peterson and Waldrop note the failure of Pennypacker and colleagues to see the pulsar in late January, two weeks after the original discovery. As they report, perhaps the pulsar was temporarily obscured by the expanding supernova shell.

A lively but somewhat more technical article by David Lindley in the February 16 issue of the British science-news journal *Nature* is oblivious to the follow-up observations, although Lindley references the IAU telegram that mentions them. Lindley is more positive about the reality of the strange new pulsar. He also writes much about "instant science" speculations of other researchers. Whether these ideas will pan out—indeed, whether the original observations can be trusted at all—remains to be seen. But the traditional modes of scientific communication (publications in journals and talks at annual meetings) have been largely superseded by telephone, fax, and electronic mail. Fortunately, fast-publication magazines like *Science News, Science* and *Nature* can keep scientists and the public abreast of at least some of the largely unrecorded debates about rapidly evolving scientific research.

Future of the Space Program

A sober assessment of the future of NASA's planetary program is offered in a March 1989 *Scientific American* article by John Logsdon of The George Washington University (and a Planetary Society Advisor) and Ray Williamson of the Congressional Office of Technology Assessment. They conclude that while a viable space program requires access to space, "the development of a space transportation system should not be mistaken for a national space program."

NASA's planetary program office still hopes to implement missions developed several years ago by its Solar System Exploration Committee. In an attempt to communicate with a broader audience, that committee's reports have been rewritten for a general audience in the just-published, handsomely illustrated "Planetary Exploration Through Year 2000: Scientific Rationale," available for $7 from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

Clark R. Chapman's new general-audience book with David Morrison, Cosmic Catastrophes, *will be published by Plenum Publishing Company in April.*

SOCIETY *Notes*

SNAKE DESIGN TEAM

As the first private citizens' group to play a role in a planetary expedition, The Planetary Society is designing part of a vehicle that will explore the Red Planet during the Soviet Union's *Mars '94* mission. (You should have received a letter describing our work on this project.) The Society is responsible for the design of the guide-rope, or SNAKE, that will carry scientific instruments and stabilize the Mars balloon for flight at low altitudes (see September/October 1988 *Planetary Report).*

Bud Schurmeier, former project manager of *Voyager* and Associate Director at the Jet Propulsion Laboratory, has been selected by the Society's Board of Directors as manager for our SNAKE project. Working with him on the project team are James French, former chief engineer of the American Rocket Company; Titan Systems, Inc., of Los Angeles; and the Center for Aerospace Engineering at Utah State University. Other consultants and contractors will be brought onto the project team as needed.—*Louis D. Friedman, Executive Director*

FROM SRI LANKA

Remarkable testimony of worldwide support for planetary exploration appears in letters to the Society from countries such as Bangladesh, Iran and Sri Lanka, where issues of survival loom larger than issues of scientific advancement.

Yet "there is interest and enthusiasm among the younger generation [to know more about] space exploration and space technology," writes Nalaka Gunawardene, past president of the Young Astronomers' Association (YAA). He and Ray Jayawardhana of the Sri Lanka Astronomical Association (SLAA) put together a report of 1988 activities sponsored by local planetary enthusiasts, under the auspices of The Planetary Society's Mars Watch program.

The climax was a series of events in September for the perihelic opposition of Mars, including three nights when hundreds turned out to look through binoculars and telescopes at Mars at its most visible in 17 years.

The participation of developing nations in future planetary exploration seems assured if the dedication of Sri Lanka's amateur astronomers, even in the midst of a civil war, can flourish elsewhere too.—*LDF*

HELP THE PLANETARY SOCIETY BUY ITS HOME

We are in final negotiations to buy the wonderful old Designer-Craftsman house that The Planetary Society has called home for the past few years. There is still time to contribute to our Building Fund and—if you give $100 or more—to get your name inscribed on a plaque thanking those who have helped the Society make this purchase. The plaque will be prominently displayed to all who come visit our international headquarters.

Our members have generously contributed enough to guarantee a down payment, and we are moving ahead on the deal. But the larger the down payment, the lower our monthly mortgage payments will be, and the more money we will have to fund future projects. Every additional contribution frees us a bit more to continue the work of The Planetary Society—promoting planetary exploration and the search for extraterrestrial life.

As our longtime members know, the Society moved into this large and charming building in 1985, as our staff increased to serve our growing membership. The house was built in 1903 by the world-renowned architectural team of Charles and Henry Greene, who were leaders in the Arts and Crafts movement. This is one of the first homes that they built in the true Craftsman style, and we treasure it for its careful construction and elegant use of woods. Many of our members have come to visit us since we moved in, and they have all been enchanted with the Society's home.

Last year our landlord decided to sell the property and, because he shares our goals and admires our efforts, he offered it to us at a price substantially below market value. The Directors realized this was a chance to set up a permanent international headquarters, where our members could come and meet the staff, and planetary scientists and engineers could plan future exploration.

The Planetary Society will soon sign the papers to acquire its permanent headquarters. If you would like more information about how you can help, please write us here at 65 N. Catalina Avenue, Pasadena, CA 91106. And come visit us and see the home that you have made possible.
—*Tim Lynch, Director of Programs and Development*

VOYAGER WATCH

Interest in *Voyager* Watch is spreading rapidly as groups across North America make plans to celebrate the spacecraft's August encounter with Neptune.

Schools and astronomy groups organizing *Voyager* events may borrow the *Grand Tour* slide and audiocassette program, produced by the Society and narrated by Al Hibbs, the "Voice of Voyager." Videotapes from the *Voyager* missions are also available.

For a FREE information packet just write to *Voyager* Watch, c/o the Society. Educators, ask for the packet with lesson plans and activities for the classroom.—*Susan Lendroth, Manager of Events and Communications*

KEEP IN TOUCH

Our mailing address:
The Planetary Society
65 N. Catalina Avenue
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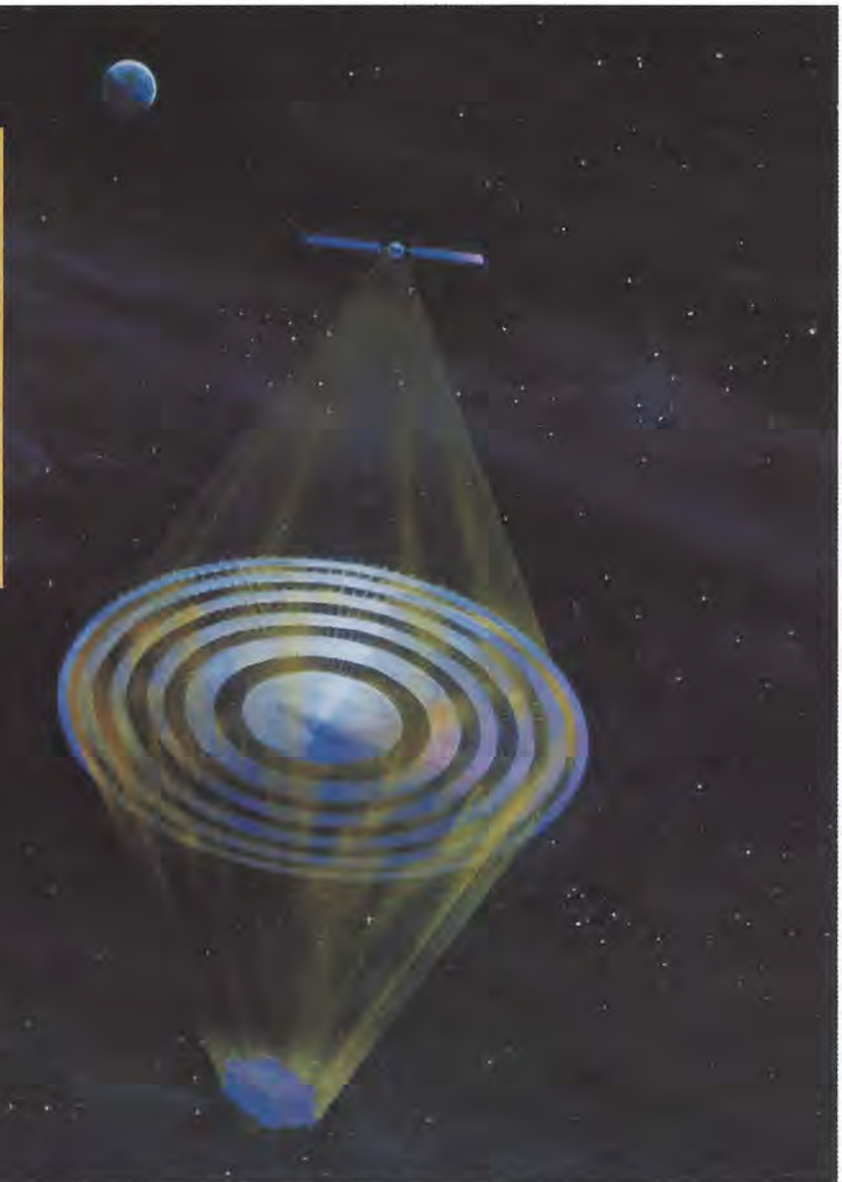
Questions & Answers

How feasible would it be to send maser (microwave) pushed probes to the various points of interest in our solar system? Are there any such projects currently being researched?
—Mike Porter, Dallas, Texas

I'm afraid it is not possible to send maser-pushed probes to the planets and moons in our solar system any time soon. It would require a large power station in space first. But once such a solar powered satellite were built, the microwave beam could be used for pushing space probes to the nearer planets when it was not needed for beaming power down to Earth. Also, by that time we will have developed the microfabrication technology to make the ultralight "Starwisp" wire mesh sensor/computer/transmitter probes.

Some people at Stanford University's Electronics Laboratory Radio Science Group have recently shown interest in research on building such a wire mesh probe. The probe would have a distributed computer consisting of millions of chips, with each chip placed at an intersection of the wire mesh and communicating with the others through the wires in the mesh. The chips would have chemical sensors as well as optical sensors, so the mesh could chemically analyze anything it landed on, after sending back pictures of what it saw just before it landed.



A hypothetical solar-powered satellite beams microwaves out to a collecting lens, which focuses the beams onto a wire-mesh probe. The radiation pressure of the microwaves pushes the probe at high acceleration toward its target planet or star.
Painting: Seichi Kiyohara, Hughes Aircraft Co.

Nearer term, many Department of Defense and NASA research centers are looking seriously again at beaming laser power over long distances to power distant spacecraft or planetary rovers. The laser could be in orbit or it could be on the ground and beam its power over long distances between Earth's surface, Low Earth Orbit, Geosynchronous Earth Orbit, the Moon and the planets, so laser beaming is likely to come first. [A laser amplifies light, a maser amplifies microwaves. Their operating principles are similar but the wavelength of their electromagnetic radiation differs greatly.] The laser power could be used directly to heat propellant for propulsion, or could be converted into electricity by solar cells that are specially designed for the laser light to achieve conversion efficiencies exceeding 50 percent. The electricity could be used in electric ion thrustors for propulsion, to power onboard electronics or to power motors on planetary rovers.
—ROBERT L. FORWARD, *Forward Unlimited*

Now and then someone asks a question for which the answer is very different from one scientist to the next. Here we present two answers to one question, a "mini debate."

Where does "deep space" begin?
—Cynde Fierro, West Covina, California

In the wondrous voyages of the mind, launched by science fiction writers before there was any possibility of human travel in space, concepts and words were carried over from the great ocean wanderings of our species here at home. Thus we have read of desperately tired crews, navigating with their last reserves of care and skill, coming finally to "planetfall" to meet only desolation.

Or, in other imaginings, to find worlds both rich and strange. A generation of youngsters, this generation that is now boldly striving outward despite both human and inanimate obstacles, grew up with those oceanic words: launch, the long beat to windward out of a gravity well, standing watches, navigating by the stars, dreaming away the long years as the ship runs down her easting through the galaxy. Deep, yes, space is very deep and it's dark as the ultramarine of the ocean a thousand miles from land. So it's no wonder that "deep" came to be the word for space beyond our neighborhood.

As soon as satellites were up, the pioneers saw the chance to move onward and claimed everything above Earth orbit as deep space. It was romantic, but it was also good public relations: Among the world's many tracking and data systems, the American and Soviet Deep Space Networks hold a special place. For a time, it seemed that the Moon would become another home for humans; hence the term "deep" would become inappropriate for lunar missions. After *Apollo*, humanity fell back. So today the Moon, as inaccessible as it was in 1959, remains an object of yearnings. Deep space begins there.

—JAMES D. BURKE, *Jet Propulsion Laboratory*

The use of the term "deep space" seems to have originated among amateur astronomers. The earliest use I am aware of is the long-running column headed "Deep Sky Wonders" in *Sky and Telescope* magazine. It was defined by L. S. Copeland when it first appeared as "marvels recommended for observation through amateur telescopes." In March 1946 he gave a more explicit definition, starting off that month's column with "Amateurs who look beyond the solar system are invited to hunt for the following. . . ."

"Beyond the solar system" is certainly the widely accepted use of the term. *The Dictionary of Astronomy and Astronautics* by Armand Spitz and Frank Gaynor (1959) defines deep space as a "colloquial term for space beyond the outermost boundaries of our solar system." As amateur telescopes have grown larger, "deep-sky" has become deeper. The general notion was always that these things were dim and required relatively large telescopes and/or magnification to show their structure. Anything visible to the naked eye was certainly ruled out, including nearby galaxies.

Here is a simple analogy: The nearest star is about a hundred million times farther away from Earth than the Moon. If we scale everything down by a factor of 100 *billion*, we can get the edge of the solar system (taken to be halfway to the nearest star) down to about five feet. Now the scaled-down distance from Earth to the Moon becomes about a tenth of the wavelength of visible light, which is about the thickness of the black spots that appear on a soap bubble just before it breaks.

There are perfectly good terms to describe the space within (cislunar) and beyond (translunar) the Moon's orbit, just as we have "interplanetary" and "interstellar" space and even "intergalactic" space. Anyone who doesn't like amateur astronomers' slang can use these well-defined terms without being misunderstood.

—ANDREW T. YOUNG, *California State University, San Diego*

References to "gravity-assist" or "gravity-boost" are common in descriptions of interplanetary spacecraft trajectories, implying that velocity can be gained by passing near an intermediate body. Since gravity is an attractive force only, wouldn't any velocity gained approaching the body be lost during departure?

—David A. Fann, Maitland, Florida

Because all velocity is relative, it must be measured in comparison to some reference point. Velocity is a measure of speed (its magnitude) and direction. So in answer to your question, yes, velocity gained during approach to a planet is lost during departure *relative* to the planet. But the spacecraft's velocity relative to the Sun can be increased or decreased.

When the planet's gravity pulls on the spacecraft as it flies by, the trajectory is bent and the velocity's direction is changed. The spacecraft's *speed* with respect to the planet is the same at the beginning and end of the flyby—only its *direction* is different. If the trajectory is bent the right way when the change in the spacecraft's direction is added to the planet's speed, the craft's velocity in relation to the Sun is greater after flyby. [Gravity-assist was explained in more detail in the March/April 1982 *Planetary Report*.]

—LOUIS D. FRIEDMAN, *The Planetary Society*

FACTINOS

Four scientists from NASA's Ames Research Center have reexamined *Voyager 1*'s infrared spectra and radio-occultation observations of Saturn's moon Titan and found that the satellite's atmosphere is so saturated with methane that it should condense and fall as rain. Stranger still, because of conditions in the atmosphere, it rains without clouds.

The group, headed by Owen B. Toon, simulated the moon's atmosphere using the optical properties of the constituents of Titan's air, then compared the results to what the spacecraft detected. The researchers confirmed earlier analyses that 0.2 to 0.6 percent of the atmosphere is hydrogen. The moon also has patchy "clouds" of methane lying about 10 to 30 kilometers above the surface. But they say that because the droplets are probably larger than 0.1 millimeter in diameter, "the methane clouds more closely resemble terrestrial rain than terrestrial clouds."

—from *Sky and Telescope*

◇

A geologic depression covering most of western Czechoslovakia may be a crater left by an immense object that smashed into Earth millions of years ago. Michael Papagiannis and Farouk El-Baz of Boston University studied satellite images of central Europe taken from 22,500 miles (37,350 kilometers) in space and concluded that the apparent crater is 200 miles (about 330 kilometers) in diameter.

"The object that would cause such an impact crater could have been 50 miles (about 80 kilometers) in diameter. It must have begun burning and possibly breaking up as it entered the Earth's atmosphere and plunged deeply into the ground," said El-Baz.

"The impact of such a large object would have been equivalent to an explosion a trillion times more powerful than the atom bomb at Hiroshima," Papagiannis said.

—from the *Los Angeles Times*

◇

Several researchers have said that Uranus' rings look young, less than a billion years old, compared to the rest of the solar system at 4.6 billion years. But Larry Esposito of the University of Colorado at Boulder suggests that the rings may not be young at all. Instead, he proposes, their chunks keep grinding against one another in a way that continually creates new particles. Without some such regenerative process to sustain them, he notes, Uranus' rings as *Voyager 2* saw them would be gone (due to atmospheric drag) in a billion years or less.

In the solar system's early days, according to Esposito, the material that later became the uranian ring system may have been nothing more than 10 to 12 moons, each about 200 kilometers across. Since then the rings have been in a continual state of evolution.

—from Jonathan Eberhart in *Science News*

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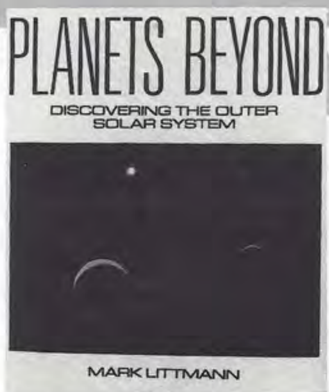

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In this painting Paul DiMare imagines what Pluto and its relatively large moon, Charon, might look like to a passing spacecraft. Pluto is smaller than our own Moon, and its density suggests that it is a mix of ice and rock; Charon is nearly half as large as Pluto.

Paul DiMare owns an art studio in Cleveland where he pursues his interest in space-related subjects. His work has appeared in Air & Space, Astronomy, Geo, National Geographic *and* Sky & Telescope.

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