# The PLANETARY REPORT

Volume XIX Number 3 May/June 1999

Martian Dunes

**On the Cover:**

*Mars Global Surveyor* has finally begun its mission to map the surface of Mars in unprecedented detail. Equipment problems delayed the mapping mission for many months, as the spacecraft settled into a near-circular orbit. But by March 1999 the spacecraft was returning spectacular images. Here we see a field of dark sand dunes in the Nili Patera region of Syrtis Major, a dark triangular area that has been observed from Earth for many decades. In this image, the spacecraft has resolved details as small as 3 meters across. The shapes of the dunes indicate that dark sand has been steadily blown from upper right to lower left by the Martian wind. The area shown is 2.1 kilometers (1.3 miles) across.

Image: MSSS/NASA

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## From The Editor

You can't blame the space program for the Internet. The enabling technologies for both grew out of military research and development during the Cold War. Regardless of its origins, the Internet, like the Space Age, has changed the way we live and do business.

In the publications business, we are riding a wave of transformation. The old craft of putting ink to paper is being superseded by the technology of arranging electrons on a mineral. How to change the way we bring information to Planetary Society members has become a constant theme among staff members.

We need a plan. And to do our job right, we need to know what our members want. So I'm using this editorial space to ask you a favor: let us know in what sorts of ways you would like us to communicate with you.

Do you regularly visit our World Wide Web site to supplement the information you receive in *The Planetary Report*? Would you like to receive regular updates via e-mail? Do you still find publications such as our special-interest newsletters useful? Or would you rather we devoted more energy and resources to electronic publishing?

We won't eliminate paper publications—at least not on my watch. But we do need to make the best use of the media available to us. Let us hear from you.

—*Charlene M. Anderson*

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# Members' **Dialogue**

### "Ices" Was Cool

"'Ices' Throughout the Solar System: A Tour of Condensable Species" [see March/April 1999] was a great article! I have always wondered what exactly scientists were talking about when they mentioned the different compositions that make up the "ices" on various planets and moons. I had no idea that Ganymede might have frozen oxygen, and Wendy Calvin's explanation for it was very educating indeed.

Especially helpful was the table showing what frozen compounds and elements are found on the different bodies in the solar system. It puts into perspective how diverse our solar system is. I really appreciate the articles that take the time to explain things that nonscientists might not know or understand.

—MICHAEL MATKIN,
*Mesa, Arizona*

### Humans to Mars

I am a young person who is determined to live and work on Mars. You may be familiar with these words by Konstantin Tsiolkovsky, which have been a focus in my inspiration to establish human colonization of other planets: "Earth is the cradle of the mind, but one cannot live in the cradle forever."

John F. Kennedy set a lofty goal for our country many years ago when he urged us to set a man on the Moon. This spurred America on to intense development of science and technology. But we need to keep moving. NASA is in the midst of its Discovery program, with the motto "faster, better, and cheaper." The program, including such missions as *Mars Pathfinder* and *Lunar Prospector*, relies on reusing already developed technology. I agree it makes sense to maximize our use of existing technology, but are we going to be content with this forever? The interest in the John Glenn mission has shown us that the American public is longing for new heroes.

Everyone's heard about how miserable United States students are in math and science compared to students in other industrialized nations. I think I speak for all children when I say we learn better when we're inspired with a chance for greatness rather than when we're taught down to and threatened with failure.

The goal of human colonization of Mars will give America something to dream of again. Lesser goals, like building space stations and robotic space missions, just don't fire the imagination and leave us burning with excitement. We need something outside of ourselves, bigger and better than all of us, to urge us to our limits. We need a shared dream—the human colonization of Mars.

—ANNIKA FITZPATRICK (age 10), *Lake Worth, Texas*

I must disagree with James Boshnack's letter in the January/February 1999 issue advocating returning humans to the Moon in force but putting off human expeditions to Mars until some distant date when technology has advanced far beyond our current capabilities.

I doubt that a human spaceflight program whose goal was solely to return to the Moon could gather enough support from the public and Congress to succeed. Human Mars missions, however, capture a level of excitement and imagination far beyond that. We should heed the enthusiasm generated by the *Mars Pathfinder* mission, whose Web sites registered an incredible 566 million hits during the mission's first month. My vote is for a human expedition to Mars early in the next century.

—GERALD BLACK,
*Cincinnati, Ohio*

### Get Real

I've been a member of the Planetary Society since the beginning and I love it. But one thing has me wondering: you "serious" scientists talk blithely about settlements and colonies on the Moon and Mars and about "controlled environments" needed for these settlements as though they already exist. But they don't.

When you had an opportunity to "rehearse" with a controlled environment [Biosphere II] a few years ago near Tucson, Arizona, very little interest was shown. It was well funded and well intentioned, but most of the people participating were amateurs, and it was a failure. Didn't that set off any warning bells in the scientific community? The things that went wrong were devastating, but on the Moon or Mars they would be fatal. And the relationships between the humans involved—pathetic, but typical.

It seems to me that biosphere living should be your number one priority. Has anyone *actually* extracted water and oxygen from rocks (especially on a grand scale), recycled urine into safe drinking water, and tried to keep people in a bubble for years without them murdering each other?

You talk as if these problems have been solved and we are ready to send people off to hostile planets tomorrow. The biosphere experiment should be taken seriously and repeated until it works.

—LYDIA KIMBERLY,
*Lake Park, Florida*

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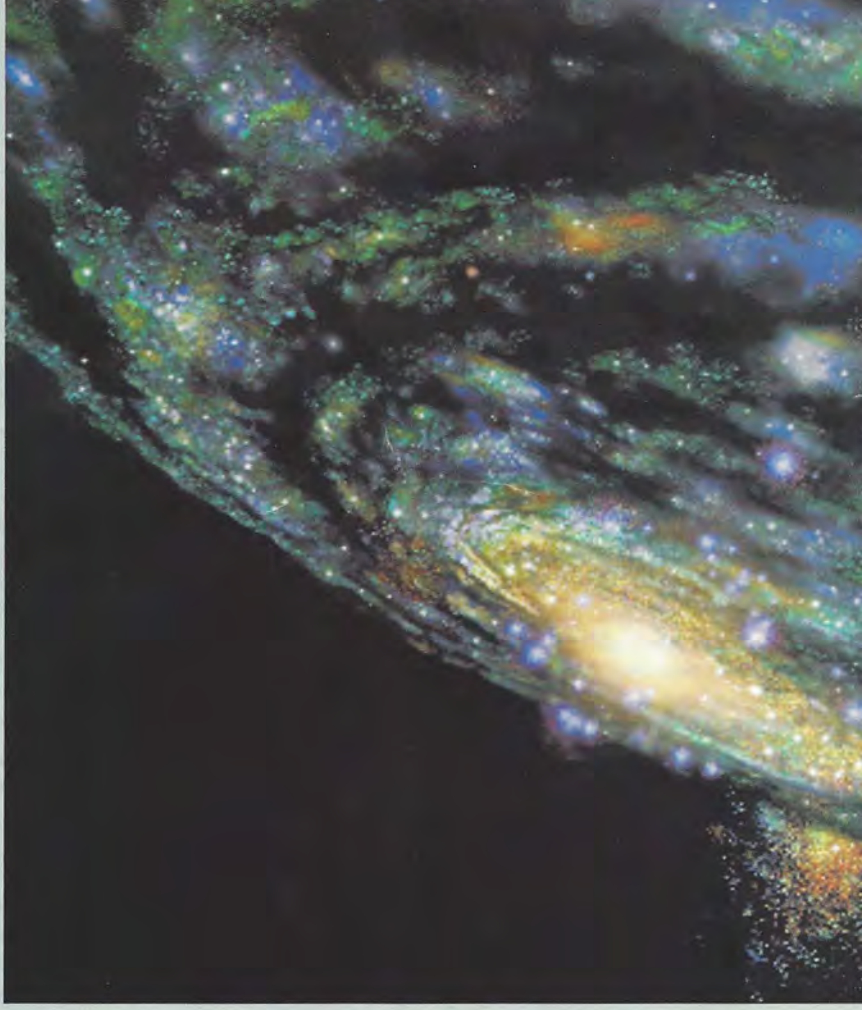
## OPINION:



*The scientific search for signs that we share the universe with other technical civilizations, usually known as SETI or Search for Extraterrestrial Intelligence, can be said to have begun in 1959, when Giuseppe Cocconi and Philip Morrison published in* Nature *a paper detailing how other technical civilizations might use radio waves to communicate across the galaxy.*

*Since that seminal paper, radio telescopes around the Earth have turned their receivers to the skies, listening for a sign that humanity is not alone in the universe. So far, no confirmed signals from another civilization have been detected.*

*SETI is a major program for the Planetary Society, and we support several efforts, including Project BETA at Harvard University and Project META II at the Argentine Institute of Radio Astronomy. With the SETI Institute, we cosponsor SERENDIP IV at the Arecibo Observatory and two new optical programs at Harvard University and the University of California at Berkeley. Our most recent undertaking is the innovative SETI@home screen saver project (see page 22 in the November/December 1998* Planetary Report*).*

*Since SETI@home has generated a lot of new interest in the search, we thought it was time to review some of the reasons we feel SETI is important. Here we print two short essays, the first by Phil Morrison, a "founding father" of SETI, and the second by Chris Chyba, one of the leading young researchers into questions of life on other worlds.* —Charlene M. Anderson, Associate Director

# Beginnings of Galactic Exploration

**by Philip Morrison**

The most challenging exploration in all the history of our species lies ahead, in the depths of galactic space. We stand at the point of entering upon that vast adventure in unprecedented ways.

Humans have walked over the land-linked continents for a long time. Our little hominid ancestors walked the Rift Valley a couple of million years ago; we have even found their tracks. Early *Homo sapiens* managed the trip to Australia 40,000 years ago, island-hopping from Asia by sea canoe. Full circumnavigation at sea had to wait for Magellan's caravel in 1520, and our astronauts set foot on the Moon 30 years ago.

But galactic space is grandly more generous than the whole solar system we now probe. The stars of Orion's Belt are about as far away as any star we can easily see with the unaided eye. A superior rocket might get to the Belt after 10 million years, more than double the time since the first protohumans appeared on Earth. Yet our galaxy has 10,000 stars that lie farther than the Belt for every star that lies closer!

There will be no travel to the stars in our day.

One big difference between our times and times past is the realization that, of all cargoes, no silk nor gold nor diamond is precious enough to justify an interstellar voyage. Only knowledge is worth that effort.

*Our current searches for signals from extraterrestrial civilizations concentrate on possible planetary systems within our own galaxy. Artist Don Dixon used radio maps of hydrogen clouds to create this view of the Milky Way as it might appear from a point 1,000 light-years from the galactic plane. The bright red star slightly above and right of center is Betelgeuse. Our Sun would be invisible at this distance.* Painting: Don Dixon

Philip Morrison wrote this essay on October 13, 1993, exactly one year after he helped inaugurate NASA's High Resolution Microwave Search (HRMS) at the Arecibo Observatory in Puerto Rico. He was deeply saddened by the US Congress' cancellation of all NASA SETI efforts. Dr. Morrison sent this essay to Tom Pierson, Executive Director of the SETI Institute, with the explicit instructions that it be used by the SETI Institute for its future SETI efforts.

Seeing the wisdom of preserving the equipment already built for the HRMS project, on that same day Dr. Morrison made a strong case to NASA Administrator Dan Goldin: "What I urge your office to do is to ascertain the facts: is there a way to reclaim value added in the past by completion of the large federal investment [in the HRMS project], so that it may find other uses, possibly with private support?"

Dr. Morrison's powerful statement about the importance of SETI was an extremely effective tool in helping to launch Project Phoenix, the SETI Institute's privately funded expansion of NASA's original HRMS project. After traveling to the Parkes Observatory in Australia and the National Radio Astronomy Observatory at Green Bank, West Virginia, the Phoenix system now resides at Arecibo, where it will complete a series of planned observations in mid-2002. ❍

## Searching by Radio

It now seems that microwave radio is best fitted to travel galactic distances at minimum power cost. (Maybe laser infrared will someday become a competitor?) We might send such a signal to—to where? To everywhere, for we do not know which star to choose. Sending a signal in every direction is expensive. Still worse, it could take a long time to see results. We might easily wait a millennium for the message to reach the nearest neighbor across the vast distances.

We need to recall that among us the whole history of radio is only a century old. Those out there may easily boast a history of technology that is twice as old as our own or even up to a thousandfold our species' depth in time, for Sun-like stars and the life that such a star kindles are enormously older than any newly evolved species. Since our knowledge of radio is so new, it is their possibly long head start that offers us the chance for listening success before many centuries pass. Their signals might be here now, started our way long ago.

Since 1960, radio astronomers have listened sporadically for the possible signals that some other astronomers might have sent from anywhere in our star-rich galaxy. A few thousand years, even a few million years, mean little to the natural processes of planets and suns but much to human history. Are we the very first to become conscious, questing creatures in this galaxy of half a billion Sun-like stars? How self-centered a question that is!

Our best chance for an answer is to listen patiently and to search wittily among all the directions and all the channels that physics allows. We seek that signal from unknown counterparts, if in fact they exist. That indeed is the Search for Extraterrestrial Intelligence, or SETI. Humankind is capable of SETI for the first time, using the full prowess of current data-handling technology in brand-new systems. We must continue our vigilance.

Even the most clever search is, of course, without warranty. But we have a strong and reasoned hope for success. We aim past mere oceans, far beyond the Moon or Mars, into remote interstellar space. As the years pass, we will ask, not by wishful speculation but by solid, reproducible investigation, the question of all questions: are ours the only thinking minds among the stars? The first surely detected signal will give the answer.

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*Philip Morrison, Institute Professor at the Massachusetts Institute of Technology, has been a Planetary Society Advisor since our founding in 1980.*

# Some Thoughts on SETI

**by Christopher Chyba**

What are the prospects for there being other intelligent technical civilizations in our galaxy? Discoveries in the past few years have certainly increased the likelihood of extraterrestrial *life*. In just the past few years we have learned that planetary systems are not uncommon, if not necessarily similar to our own. We have learned that liquid-water oceans, such as that likely to exist under the icy surface of Europa, may well exist on worlds heated from within—even if those worlds are otherwise too far from their stars for liquid water to be possible. Finally, it's becoming increasingly clear that Earth harbors a subsurface microbial biosphere, some of which may be capable of surviving independently of surface conditions. Earth's deep biosphere makes Mars and Europa seem more plausible as venues for life.

But what are the prospects for extraterrestrial *intelligence?* Here our ignorance remains profound. Before touching on new insights into this question, it is worth recalling some of the old arguments.

## The Fermi Paradox

The Fermi paradox is the suggestion that if extraterrestrial civilizations were widespread, one of them would have visited us by now. A more recent version is that were there many technological civilizations even slightly older than ours, one or another of them should by now have colonized the galaxy using self-replicating intelligent probes. Since that hasn't happened, the argument goes, they—extraterrestrial civilizations—don't exist. However, unless these probes' creators truly wished the entire galaxy—including their own resources—to be consumed, they would have built in some process to limit their machines' otherwise remorseless, exponential replication. In this case, resolving the Fermi paradox degenerates into interminable arguments over alien psychology: what limits would other civilizations place on the danger of exponential replication by robot probes?

Or would other limits inexorably evolve? Our world remains full of green plants, despite the presence of abundant, mobile, self-replicating "machines" (called insects) that feed on them. The insects are held in check by predators. The same could be true for the putative galaxy-eating robots: robot predators may have evolved for them as well. With these sorts of arguments, the entire discussion enters the realm of the ineffable; we simply cannot resolve it on the basis of anything we know.

## How Rare Is Intelligence?

A more interesting argument, I believe, has been posed by those biologists who view intelligence on Earth as an extraordinarily unlikely event, an event contingent on a list of very special and peculiar circumstances. If we could rewind the tape of life and start again from the beginning, they suggest, nothing like humans would ever evolve. Earth has seen multiple, independent evolutions of such highly selected capabilities as flight and sight, but intelligence, the argument runs, is not analogous to these. Intelligence has evolved only once among the very, very many species that have ever existed here.

Yet I find that this argument has a whiff of the tautological about it. Isn't it likely to be the case that the first intelligent species on the planet would look back over the history of life and ask why it, among all others, was first?

And what of the dolphins? Those dolphins with the largest brains in relation to their bodies are, by this measure, brainier than was *Homo habilis*—one of our tool-using ancestors. Are we really the only intelligence on Earth, or do we share this planet with intelligent, marine mammal species? If so, it is humbling to think that we have made so little progress in communicating with them. In any case, dolphin intelligence is not technical. Dolphins will never build radio transmitters or explore the planets.

But if multicellular life arose more than half a billion years ago, why has it taken this long, and the evolution of so many different species, for *technical* intelligence to arise just once? In this line of questioning, too, I am concerned about human myopia. Let's think about the total length of time over which multicellular life is likely to exist on Earth. The Sun is growing brighter, and in about 2 billion years our oceans will likely boil into a runaway greenhouse and Earth may become uninhabitable. Until that time, however, it seems likely—not certain—that multicellular life is here to stay. (It would be an impressive extinction indeed if every rat, every worm, every clam, every giant squid, and every cockroach were to disappear.) Multicellular life on Earth therefore seems likely to endure *in toto* for more than two-and-a-half billion years. From this perspective, technical intelligence arose on Earth *early* in the history of multicellular life—in the first 20 percent or so of its history. The observation that intelligence is a latecomer to the scene seems based in the human perspective.

## Extinction Cycles and SETI

There may be a kind of cosmic selection operating against planets that do not evolve technical intelligence. All that we now understand about planetary formation assures us that habitable worlds like our own will face ongoing collisions with objects similar to our comets and asteroids. On Earth, collisions big enough to cause a mass extinction—like that 65 million years ago at the end of the age of the dinosaurs—are statistically expected to occur every 100 million years or so. Any biosphere that does not evolve an intelligence capable of recognizing and responding to this impact hazard will therefore be catastrophically disrupted, on average, every 100 million years. If a mass extinction ensues, new niches and evolutionary paths open. Only biospheres in which technical intelligence evolves will have the chance to avoid this cycle of destruction and regeneration. Planetary biospheres with technical civilizations may, in this sense, be selected over those without them.

Each of these arguments is intriguing; I find none to be compelling. The seemingly interminable nature of these arguments reflects how little we know about intelligence. Therefore, I believe, the search for extraterrestrial intelligence is fundamentally an empirical problem. The best we can do is search.

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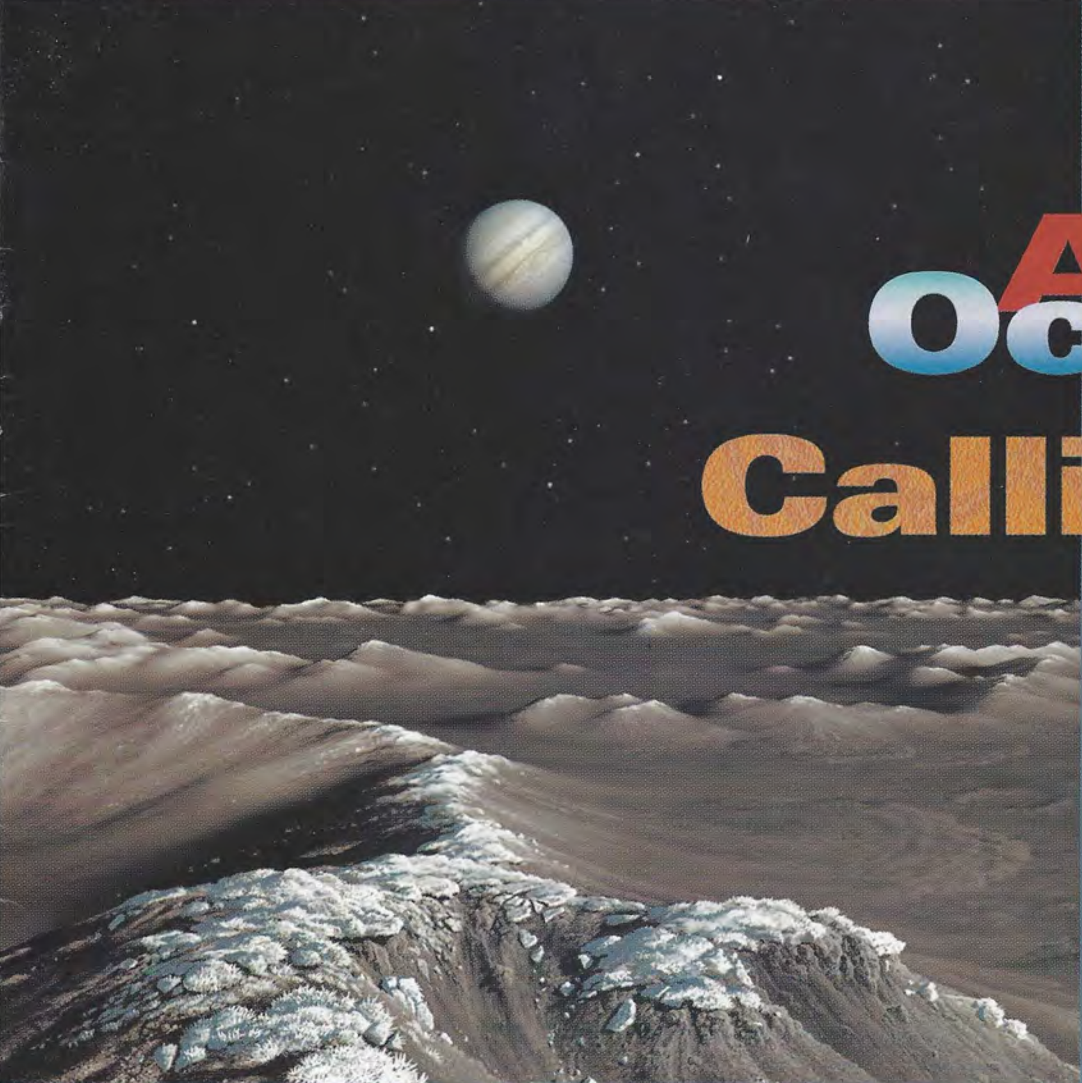
*Christopher Chyba is Carl Sagan Chair for the Study of Life in the Universe at the SETI Institute. He is also a Consulting Professor in the Department of Geological and Environmental Sciences at Stanford University and an affiliated faculty member at Stanford's Center for International Security and Cooperation.*

# An Ocean in Callisto?

**by David J. Stevenson**



*Left: Artist Don Davis strives for the utmost possible accuracy in his portrayals of planetary landscapes. Here we see Jupiter as it would look from the surface of Callisto. The planet appears in its true colors and at its correct angular size. The gray and icy surface of Callisto is as it would appear to the human eye.*

*Painting: Don Davis*

When the *Voyager* spacecraft arrived at the Jupiter system in 1979, they revealed the remarkable richness of the Galilean satellites: the volcanism on Io; the young, fractured, icy surface of Europa; and the diverse terrains of Ganymede. Callisto was the one Galilean satellite that did the dull, expected thing. It was covered with ancient impact structures and showed no sign of interesting internal processes. Callisto was the "ugly duckling" and received much less attention than its exciting siblings.

Since then, results from *Galileo* have forced us to rethink our ideas of Callisto—surely one of the biggest surprises of this highly successful mission. It seems that Callisto has an internal water ocean, and the moon's structure may be telling us something important about how the Galilean satellites formed.

## Callisto and Ganymede

Callisto belongs to a class of large, icy satellites, roughly 50 percent water ice and 50 percent Earth-like material by mass, with uncertain amounts of other constituents. Ganymede, its nearest neighbor, and Titan, the large atmosphere-enshrouded moon of Saturn, are also members of this class, though somewhat larger. With a radius of 2,400 kilometers (about 1,500 miles), Callisto is considerably larger than Earth's Moon and almost as large as the planet Mercury.

Callisto's surface is dirty but has unmistakable infrared features, detectable from Earth, that are due to water ice. However, it has none of the "grooved terrain" of Ganymede, attributed to internally driven tectonics during some past epoch (perhaps only one billion years ago). A major question debated by scientists in the post-*Voyager* era was: why are Callisto and Ganymede so different in appearance yet so similar in mass and radius? Although no consensus emerged, a favored explanation was that the ice and rock inside Callisto failed to separate; in short, Callisto was the solar system's largest "dirty snowball" (an intimate mixture of ice and rock).

Curiously, this view of Callisto reversed earlier (pre-*Voyager*) claims that all large satellites should have liquid water interiors, based on the assumption that radioactive heat from a large ice-and-rock satellite's rocky component would be more than enough to melt the ice. The non-melted state of Callisto was explained by the remarkable ability of ice to flow (as in terrestrial glaciers), which would allow the radioactive heat to be eliminated by the convection of solid ice, much as Earth eliminates its much larger internal heating through plate tectonics while its rocky component remains mostly solid.

Ganymede's differences from Callisto were thought to be due to its greater size, closer distance to Jupiter, or perhaps tidal heating. Renu Malhotra of the Lunar and Planetary Institute has shown that Ganymede, on its way to the present orbital configuration, may have passed through an exciting resonance with Europa and Io. Callisto, by contrast, does not have and has never had significant tidal heating, by virtue of its greater distance from Jupiter.

## The "Dirty Snowball" Sinks

It made a nice story—the model of Callisto as a primitive, unprocessed ball of ice and rock—but nice stories have a way of being undone by further observation, especially in the complex science of planetary and satellite evolution. *Galileo* observations of Callisto's gravity field and magnetic field have again changed our ideas about this most misunderstood moon. Spectroscopic and photo-geological observations are also yielding surprises.

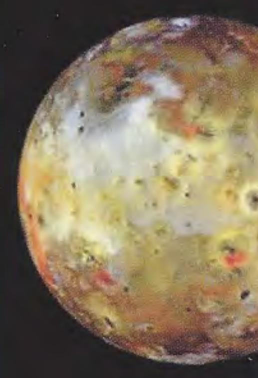
Gravity measurements show that Callisto is not a uniformly mixed sphere of ice and rock, but neither is it a differentiated body in which the rock has all settled to the center. Instead, Callisto is something in between. This intermediate structure is unprecedented in our study of planets and satellites but fits with the following picture: suppose that the deeper part of Callisto is indeed an intimate mixture of ice and rock but that its outermost 200 kilometers (about 125 miles) consist of nearly clean water ice or liquid water, with a veneer of dirt contributed by impacting bodies over the past 4 billion years.

This model explains Callisto's lower-than-expected moment of inertia (see page 10, sidebar on gravity measurements). Although other models could also be made to explain the observed moment of inertia, they don't fit with what we have recently learned about Callisto's magnetic field.

Measurements of Callisto's magnetic field show that the moon has an electrically conducting shell or outer layer. One way to explain this layer is to assume an ocean of salty water inside the satellite. At first sight, this hypothesis seems unreasonable compared with the well established expectation of a liquid-water ocean on Europa, which is tidally heated. For Callisto, there is nothing that requires the conducting layer to be liquid. Moreover, a salty ocean would make a rather poor conductor (more than a million times less conducting than copper, for example).

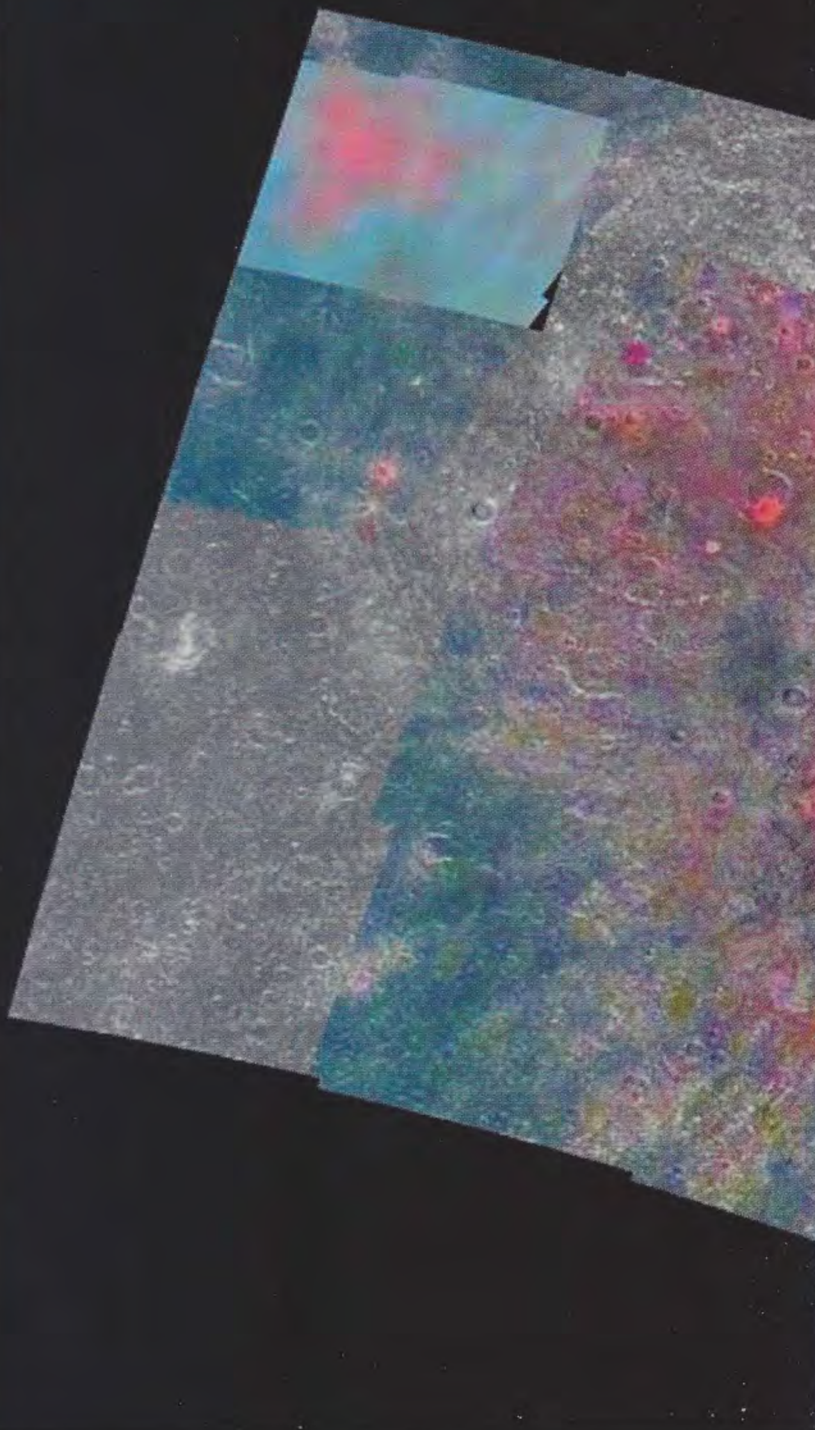
But the alternatives seem even less plausible. Callisto has no ionosphere sufficient to provide a conducting path (an ionosphere is an enveloping cloud of electrons and electrically charged atoms, called ions), and there is no plausible basis for assuming that Callisto has a global layer of graphite. A layer of frozen water or even frozen brine would be insufficiently conducting to account for the data from *Galileo*. Whatever it is, the conducting layer cannot be very deep within

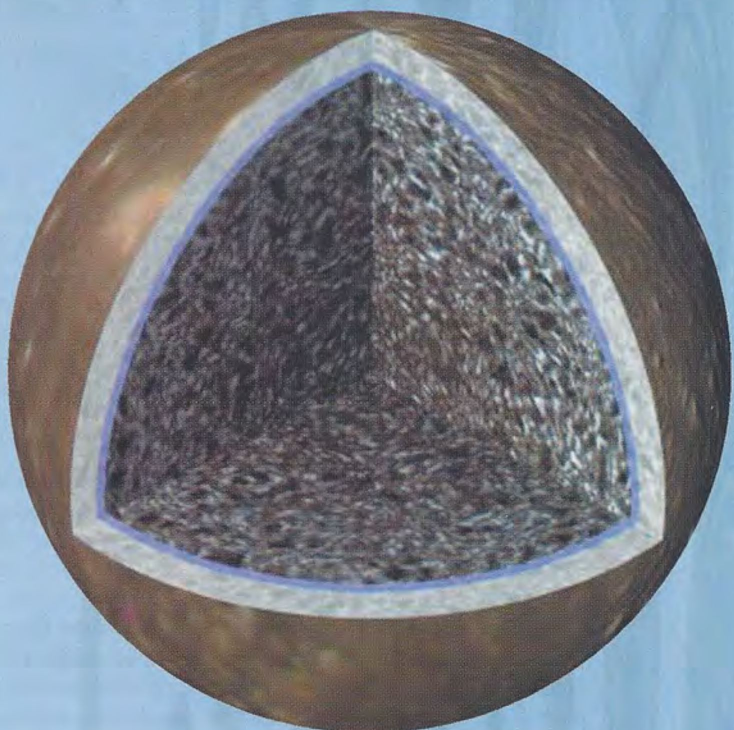
*(continued on page 10)*



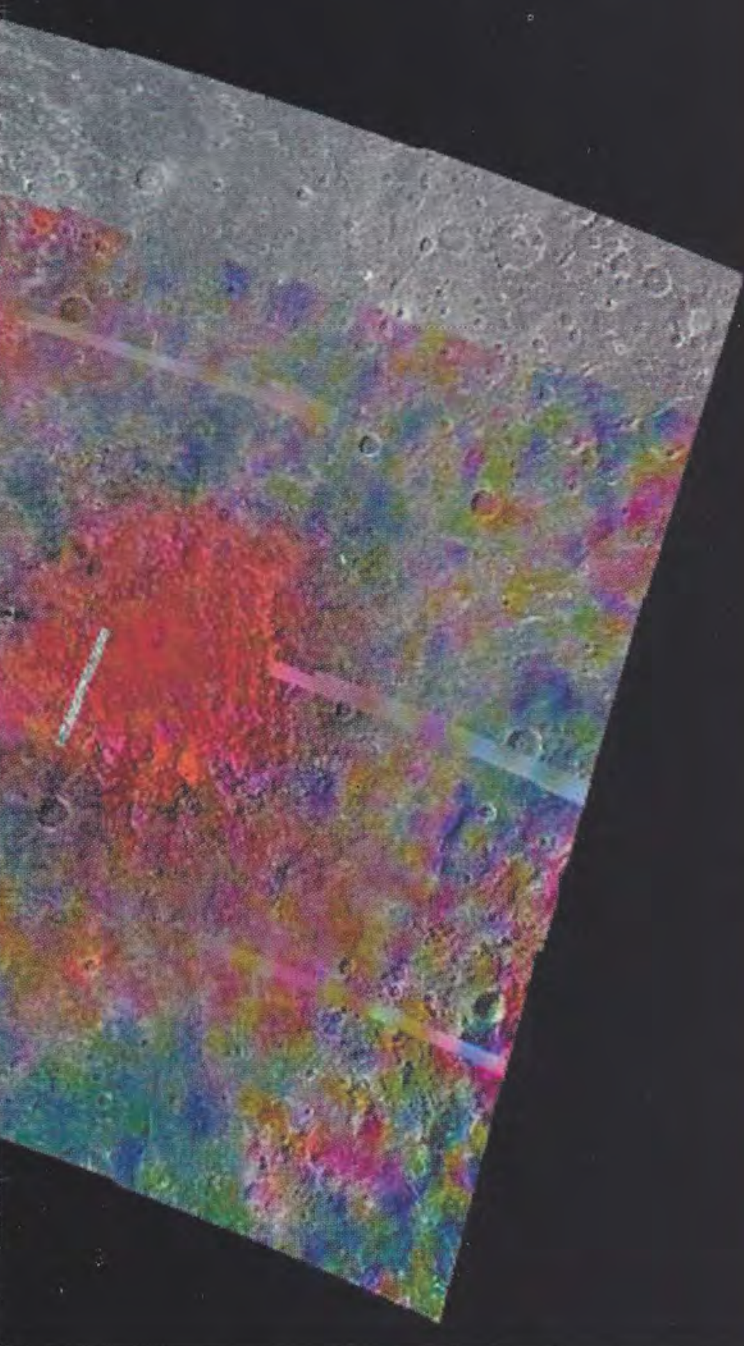
***Right: Here are the four sibling worlds that orbit Jupiter: from left to right, Io, Europa, Ganymede, and Callisto. Volcanic Io has erupted into space most of the water it once possessed. Orbiting a couple hundred thousand kilometers farther from Jupiter than Io, Europa has managed to keep more of its original water, and its active, icy surface attests to a liquid ocean beneath. Ganymede, the largest moon in our solar system (larger even than the planets Mercury and Pluto), has a strange wrinkled and pocked surface unlike any other known moon. And Callisto, once thought to be a dead sphere of rock and ice, is now revealed as a moon that may possess another hidden ocean.***

*Images: JPL/NASA*





*Above: Are there oceans hidden beneath the icy sheaths of two of Jupiter's moons? The case for a Europan ocean has grown stronger with each swing* Galileo *makes by that moon, and now the spacecraft's magnetometer has picked up evidence that Callisto may also possess an underground ocean. In this cutaway view, we see the darkish, cratered surface on top of an ice layer about 200 kilometers (125 miles) thick. Just beneath the ice is the thin, blue band of an ocean, perhaps more than 10 kilometers (6 miles) deep. Beneath that lies Callisto's rock and ice core.* Illustration: JPL/NASA



*Left: The* Galileo *spacecraft has many ways to "see" a world. This mosaic of a portion of Callisto's southern hemisphere includes data from the near-infrared mapping spectrometer (NIMS) and the solid-state imaging instrument (SSI). The overlay of NIMS data, shown in false colors, reveals compositional differences in the moon's surface materials—red areas have more ice, blue zones have less.*

*The pink splotch at upper left is the crater Buri, about 60 kilometers in diameter (roughly 40 miles). Against a blank background (no SSI data), Buri displays more water ice than the surrounding area. Near the center of the image, a large, unnamed impact crater shows a complex mix of ice and non-ice materials.* Image: JPL/NASA

## How Gravity Reveals Inner Structure

**Whenever *Galileo* flew close to Callisto, the spacecraft's velocity was changed by the gravitational influence of the satellite. This velocity change was precisely documented by Doppler radar, which we can use to learn something about the mass distribution inside the satellite. In particular, we can calculate the *moment of inertia*, which is a property of rotating bodies. As an example, a hollow spherical shell has a higher moment of inertia (that is, it takes more effort to set it rotating) than a solid sphere of the same mass and radius. And the uniformly solid sphere, in turn, has a higher moment of inertia than a sphere with a denser central core (but still the same total mass and radius).**

**From the work of John Anderson of the Jet Propulsion Laboratory (JPL) and his colleagues at JPL and the University of California, Los Angeles (UCLA), we know that Callisto has a moment of inertia significantly lower than that of a uniformly solid sphere (corresponding to the dirty snowball model) yet greater than that of an appropriately scaled model of Ganymede (which has been completely differentiated into an iron-rich core, an intermediate silicate layer, and a pure ice shell). The "in-between" inner structure implied by Callisto's moment of inertia is a first in planetary science. —*DJS***

***Right: This is the highest-resolution image ever taken of Callisto, and it shows details as small as 60 meters across. This region is in Valhalla, a large, ancient impact structure that is itself filled with small craters from more recent and less powerful impacts than the one that created the original feature.* Galileo *took this image on November 4, 1996 from a distance of 1,220 kilometers (760 miles). The area covered is about 11 kilometers (7 miles) across.*** *Image: JPL/NASA*

*(continued from page 8)*

the satellite; great depth would attenuate the signal. A conducting layer 150 kilometers or so below the surface (about 90 miles) would fit the facts we have observed.

### Weirdness of Water

To conclude that a liquid-water ocean is indeed the best explanation, we need another piece of information to fall into place. It has nothing to do with the observations but rather with a profoundly peculiar aspect of water, shared by no other elementary and highly abundant substance. Water ice is less dense than liquid water at low pressures (corresponding to depths less than about 150 kilometers in Callisto). Yet at greater depths, the reverse is true: water ice is then denser than liquid water. A bit of freshman physics, called the Clausius-Clapeyron equation, tells us that the melting point of ice decreases with increasing pressure, reaching a minimum of – 20 degrees Celsius (– 4 degrees Fahrenheit) at 150 kilometers' depth within Callisto. At still greater depths, the melting point rises. This remarkable property of water means that there is a "natural place" to put an ocean inside a big icy satellite. That place is a layer at the depth where ice is easiest to melt, allowing the ice above to float and the ice below to sink: an ice-water-ice sandwich.

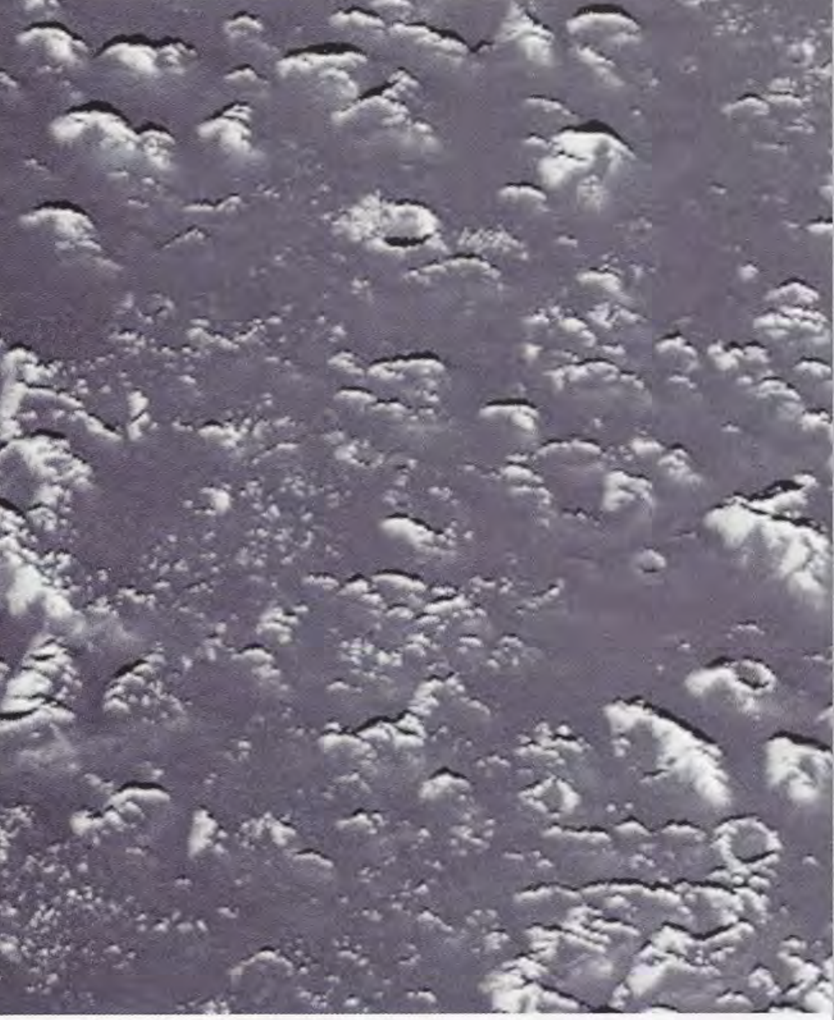
But that's not all. It is also the case that if you were to load up the outer ice with rock, the outer layer would be unstable and would not last long. The rock-bearing ice would be heavier than the water below, and the water would not be able to maintain large amounts of rock in suspension. So there is a natural cleansing mechanism for eliminating the rock from the outer layer, provided the system reached the melting point at some stage in its history. Thus, the model that explains Callisto's moment of inertia—dirty snowball inside, with 200 kilometers of liquid water/clean ice outside—also fits the magnetic-field data and makes sense in terms of thermodynamics and stability, if we posit a layer of water beneath the clean ice but above the dirty, denser ice.

There is much more to the story; indeed, it turns out that the greatest puzzle with Callisto is not that it could reach the structure we see but rather that it avoided melting still further and evolving to a state like Ganymede's. This topic of current research involves technical issues having to do with the fluid dynamics of convection and mixing in solid yet deformable materials.

### Jupiter: A Mini Solar System?

The post-*Voyager* model of Callisto as a primitive mixture of ice and rock was always somewhat troubling because it required that the moon formed in such a way that it did not exceed the melting point of water ice—no easy trick, since impactors falling onto the surface of the growing satellite would likely have hit at velocities around 2 kilometers per second (about 4,000 miles per hour). To explain how Callisto ended up in the state we see, it is necessary to suppose that it took quite a long time to form, perhaps a million years or more. If it had formed faster, it would have become too hot and would have differentiated to a greater degree.

This million-year period of formation, if correct, leads to



interesting insights on the Jovian system and on the often-heard speculation that Jupiter and its moons formed as a "miniature solar system." A million years—the blink of an eye in geologic time—is nevertheless quite a long stretch compared to the frequency of collisions that would be likely within a swarm of small bodies in Jupiter orbit. Probably, the miniature solar system picture is wrong. So Callisto, the ugly duckling, has come into its own and given us something that we could not get from the more spectacular Galilean satellites: a clue to how the Jovian satellites formed.

How remarkable is an ocean in Callisto? In retrospect, it is perhaps not so astonishing. If the ideas outlined here are correct, then all large, icy satellites (in particular, Ganymede and Titan) should likewise have such oceans. We don't know yet whether Ganymede has an ocean, because its magnetic field, like Earth's, is dominated by a dynamo in its liquid iron-rich core. The powerful dynamo makes it difficult (but maybe not impossible) to extract the subtle field disturbance that would be caused by an ocean. *Cassini* may soon tell us about an ocean in Titan.

The ocean in Callisto—because of its depth and the absence of volcanism—belongs in a different category than the one proposed for Europa. Callisto's ocean is not a likely location for life. But it is most certainly an intriguing piece of the planetary puzzle, suggesting how these satellites formed and evolved and offering a glimpse into the deep recesses of solar system history.

*David J. Stevenson is George van Osdol Professor of Planetary Science at the California Institute of Technology.*

## How a Magnetic Field Reveals an Ocean

**As Michael Faraday explained more than a century ago, a magnetic field that is varying in direction or amplitude will induce electrical currents in any nearby conductor. This process of electromagnetic induction is used to detect metal when you pass through the security checkpoint at an airport. It is also responsible for a well studied magneto-telluric phenomenon called "earth currents" (electrical currents that flow in Earth's oceans and in the water-saturated solid Earth, induced by daily variation in Earth's ionosphere).**

**Conversely, as the French scientist André-Marie Ampère explained, there is a magnetic field associated with any electrical current. Thus, a device capable of detecting and measuring a magnetic field can be used to measure the associated electrical current. *Galileo* has such an instrument, the magnetometer.**

**The magnetic variation that induces electrical currents in Galilean satellites comes from Jupiter's magnetosphere. Because Jupiter's magnetic field is inclined (like Earth's) relative to the planet's rotation axis, the field "seen" by any satellite varies in direction and amplitude on a timescale close to the rotational period of Jupiter (about 10 hours).**

**This varying field creates electrical currents within any conducting layer of the satellite. The magnetic field associated with those currents can then be detected by the spacecraft.**

**In the case of Europa, the magnetometer Principal Investigator Margaret Kivelson and her colleagues at UCLA and I collaborated in a study that showed that the disturbance of Jupiter's magnetic field near Europa was that expected for induction of electrical current in a salty water ocean of 10 kilometers' or greater thickness near the moon's surface.**

**The success of this study prompted a reexamination of magnetometer data from Callisto. We discovered to our astonishment that Callisto exhibited an even clearer, unmistakable, signal of an electrically conducting shell. —*DJS***

# Mars Global Surveyor: A Close Eye o

On the first day of mapping, the Mars Orbiter Camera (MOC) was greeted with this view of "Happy Face Crater" (center right) smiling from the east side of Argyre Planitia. This crater is officially known as Galle, and it is about 215 kilometers (134 miles) across. The picture was taken through red and blue filters. The bluish-white tone is caused by wintertime frost. The "happy face" was first noticed in observations by the *Viking 1* orbiter.

When a meteorite impacts a planetary surface, the resulting blast is very much like a bomb explosion. In this view of the Terra Meridiani region, two impact craters are distinguished by dark material that was blown out of the crater during the impact. The ejecta are darker because the crater-forming blasts broke through the surface and excavated a layer of darker material beneath, spraying out the radial patterns seen here. The fact that impact craters can reveal underlying material is very useful for geologists trying to determine the nature and composition of the subsurface. The larger crater has a diameter of about 89 meters; the smaller crater is about 36 meters across.

The MOC recently spied thi
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*Further information about the* Mars Global Surveyor *mission is available on the Internet at:* **http://mars.jpl.nasa.gov/mgs/**

*Latest Mars Orbiter Camera images are available at Malin Space Science Systems:* **http://www.msss.com/mars/global_surveyor/camera/images/index.htm**

The long-anticipated *Mars Global Surveyor (MGS)* mapping mission has finally begun. Earth stations are receiving a steady stream of new data from Mars, including high-resolution images since the successful deployment of the high-gain antenna on March 28, 1999. *MGS* conducted the first three weeks of mapping with the high-gain antenna in its stowed position, because of problems with a device that dampens the force of the deployment. By keeping the antenna stowed for the first three weeks of mapping, the team was able to meet the mission's minimum science objectives before risking the antenna deployment. While the antenna was in its safeguarded position, the spacecraft would aim all its instruments at Mars to collect data for nine orbits (about 18 hours); then for three orbits (about 6 hours) *MGS* would stop collecting data, turn itself around, and transmit data to Earth. After deployment of the steerable high-gain antenna, the rate of data transmission increased significantly. In the words of Joseph Beerer, *MGS* flight operations manager at NASA's Jet Propulsion Laboratory, "Having a deployed high-gain antenna is like switching from a garden hose to a fire hose."

# n Mars

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marking fault lines—
n to geologists as a
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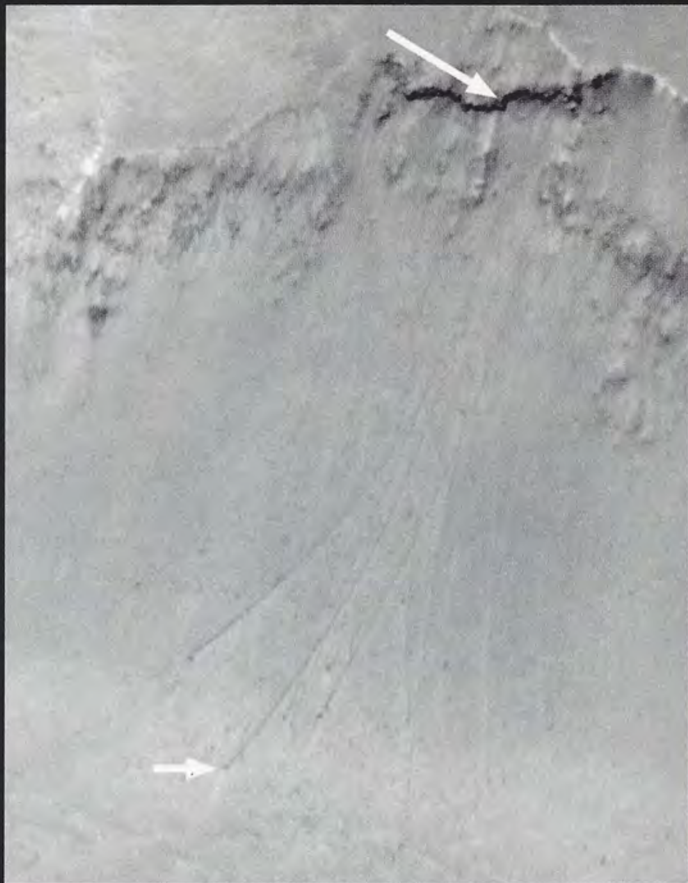

*MGS* was aerobraking (using atmospheric drag to slow down) when it acquired this image of a slope just inside the south rim of the Schiaparelli basin, located near the Martian equator. The large white arrow points to a steep cliff of dark-toned rock. The small white arrow points to one of several boulders (about 18 meters in diameter) that apparently broke off the steep, dark cliff and rolled down the slope to the basin floor. Each boulder left a trail on the relatively soft, dusty slope. In addition, some of the boulders exhibit bright wind-streaks (pointing toward the lower left and center), which indicates that these boulders have been sitting there long enough to influence distribution of sediment by the wind. These are the first boulder tracks seen on Mars.

During its March 1999 operations, the MOC captured this stunning wide-angle view of the western portions of Melas and Candor chasms in the Valles Marineris canyon system. This view covers an area about 80 kilometers wide and 220 kilometers long (50 by 137 miles). Melas Chasma is located at the bottom of the image, Candor at the top. Hints of layers in the canyon walls are evident in this image. Albedo (brightness) and color variations on the chasm floors indicate the relative distribution of dark sand and brighter sediments and rocks. The colors shown are not as they would appear to the human eye but have been adjusted to make differences more visible. Images: MSSS/NASA

Information from the science instruments is recorded 24 hours a day on solid-state recorders and transmitted to Earth once a day. Every third day, a second tracking pass is used to transmit "live" data directly to Earth. These data, including high-resolution images of the Martian surface, are transmitted at rates between 40,000 and 80,000 bits per second.

After two years of fine-tuning, the spacecraft's path around the Red Planet is now a nearly circular, Sun-synchronous orbit. This orbit was designed so that *MGS* passes over any given part of Mars at the same local time, allowing scientists to separate daily variations from longer-term trends. At about 2 p.m. local Mars time, the spacecraft crosses the equator flying northward on the daytime side, and at about 2 a.m. it crosses the equator flying southward on the nighttime side. Over the next two years, *MGS* will map the entire planet.

—*Jennifer Vaughn, Assistant Editor*

Background image: *MGS* view of Martian north polar cap, September 12, 1998

# WHATEVER HAPPENED TO PLANET X?

*Are there worlds beyond Pluto? Recent theoretical and observational discoveries indicate that there are many icy bodies in the Kuiper belt. But is there something larger—a Planet X? Data from the* Pioneer *and* Voyager *spacecraft, now searching our solar system's outer reaches, give no indication of such a world.*

*Painting: Michael Carroll*

**BY JOHN D. ANDERSON**

First of all, there is good reason to call a possible undiscovered planet beyond the orbit of Neptune "Planet X." In mathematics, the letter X designates an unknown. In Roman numerals, X is 10, and if such a planet exists, it would be the 10th planet in the solar system.

The search for suspected planets beyond the known planets has been a recurring theme in modern astronomy, going back to William Herschel's discovery of Uranus in 1781 and the discovery of Neptune in 1846 by Johann Gottfried Galle.

Because Urbain Jean-Joseph Leverrier and John Couch Adams had successfully predicted Neptune's position by computing its gravitational pull on Uranus, Percival Lowell turned to similar orbital calculations to predict, in 1914, the location of the solar system's ninth planet. In 1930 Clyde Tombaugh, while working at the Lowell Observatory near Flagstaff, Arizona, found Pluto at a location close to where Lowell said it would be.

At first, this discovery was hailed as another triumph for celestial mechanics, although Tombaugh himself was more cautious. Indeed, as it became clear that Pluto was far too small to induce observable effects on the orbits of Uranus or Neptune, astronomers agreed that the 1930 coincidence of Pluto's position with Lowell's prediction was a lucky accident.

## NEWS FROM BEYOND PLUTO

Eleven years ago I reviewed the status of the search for Planet X (*Planetary Report*, July/August 1988) and pointed out that a number of astronomers were using unexplained discrepancies in the positions of Uranus and Neptune to predict Planet X's general location in the sky. A lot has happened since then, the most important being confirmation that there is a belt of objects beyond the orbit of Neptune, as hypothesized by Gerard Kuiper in 1951 [see the January/February 1994 *Planetary Report* for more about the Kuiper belt]. Finding the Kuiper belt supports the view that during the formation of the solar system, while the known planets accreted from a relatively dense pre-planetary disk, it was impossible in the less dense regions beyond the orbit of Neptune for planets much larger than Pluto to accrete. Instead, tens of thousands of small objects formed. It seems highly unlikely that a planet of Earth's size or larger exists along with a belt of small bodies.

But there is more. In 1993, E. Myles Standish at the Jet Propulsion Laboratory (JPL) showed that the "discrepancies" in the positions of Uranus and Neptune, attributed to the influence of unknown planets, were not discrepancies at all. Standish found two explanations for the apparent disagreements. First, no one had attempted an adjustment of the orbit of Uranus after JPL's 1980 calculation of planetary orbits, distributed worldwide as Development Ephemeris DE200 and the basis of planetary positions in the *Astronomical Almanac*. Using data from both the 19th and 20th centuries, Standish found he could remove most of the error in Uranus' position by making small corrections in the calculation of its orbit.

To get rid of the small errors that remained, Standish adopted more recent values for planetary masses, determined between 1985 and 1990 from *Pioneer* and *Voyager* spacecraft flybys. Most significantly, the *Voyager 2* flyby of Neptune yielded a one-half-percent decrease from the mass assigned in DE200. Remaining errors in the position of Neptune could be explained by its long orbital period. Standish found no obvious discrepancies in prediscovery observations of Neptune by the astronomer Galileo in 1613 and by Joseph J. F. Lalande in 1795 (both assumed the planet was a star).

The fact that observations of Uranus and Neptune can be reconciled satisfactorily without a Planet X is definitely not proof that Planet X does not exist. In 1991, David W. Hogg, Gerald D. Quinlan, and Scott Tremaine at the University of Toronto concluded, among other things, that a more sophisticated analysis could yet produce strong evidence for Planet X. Nevertheless, all the work over the past decade suggests that Planet X will not be found by its effect on the orbits of Uranus or Neptune. If it exists, it will more likely be found at the telescope or by its infrared emission.

Despite all the telescopic searches to date, including Clyde Tombaugh's thorough search from 1929 to 1943, nothing has been found. Between 1977 and 1984, Charles T. Kowal performed a sky survey with the 48-inch Schmidt Telescope at Palomar Observatory, surveying a large region north and south of the ecliptic (the ecliptic is a geometric plane described by Earth's orbit; most planetary paths are within a few degrees of the ecliptic). Kowal's search included much fainter objects than Tombaugh's, but again the result was no new planet, although he did find 5 comets and 15 asteroids, including Chiron, which roams between the orbits of Saturn and Uranus. As for infrared emission, the Infrared Astronomical Satellite (IRAS) produced an extensive catalog of objects. None has been identified as Planet X.

If Planet X exists, our current technology is most likely insufficient to detect it. It might reside beyond the Kuiper belt with a long orbital period—say, 800 years or more—but new methodologies would probably be needed to find it. I suggest we put the Planet X hypothesis on hold until we have a new means of exploration at distances three or four times the distance to Pluto and Neptune. Even the new technology pioneered by Jane X. Luu of Harvard University and David C. Jewitt of the University of Hawaii, which succeeded in the search for Kuiper belt objects, is unlikely to succeed for a more slowly moving Planet X.

## AN UNEXPLAINED FORCE

In my 1988 article, I described attempts to use *Pioneer 10* and *11* to search for evidence of Planet X—the basic strategy being that if either spacecraft approached a planet with a mass four or five times greater than Earth's, there would be obvious deviations in the spacecraft's path. Although there is no evidence for a gravitational pull from Planet X, there is apparently a force acting on both *Pioneer 10* and *11* that is difficult to explain. Both spacecraft seem to be slowing at an unexpected rate as they escape from the solar system. When expressed as an acceleration (in physics, acceleration refers to a change of velocity, not necessarily an increase), this slowing is about 12 billion times smaller than the acceleration due to gravity at Earth's surface.

## NEPTUNE OBSERVED BEFORE IT WAS DISCOVERED

Neptune has an orbital period around the Sun of 164.79 years. Since its discovery in 1846, it has not completed even one orbital revolution and will not do so until July 2011. As seen from Earth, Neptune moves so slowly that it might easily be confused with a fixed star, and this possibility inspired researchers to look for observations of Neptune before its discovery as a planet.

Two researchers working independently—Sears Cook Walker in the US and Adolph Cornelius Peterson in Germany—found in 1847 that Joseph J. F. Lalande had unknowingly observed Neptune on May 10, 1795, as recorded in Lalande's *Histoire Céleste Français*. Going back to the manuscript for this book, Félix Victor Mauvais confirmed the May 10 observation and found another recorded on May 8, 1795. The angular separation between the two observations was as expected for Neptune's motion over two days.

Although there is general agreement that Lalande observed Neptune on two nights in 1795 and accurately noted its position in the sky, a third prediscovery observation identified in 1980 by Charles T. Kowal and Stillman Drake of the Hale Observatories is more controversial. Searching through Galileo's notebooks, they found that the first telescopic astronomer had plotted Neptune as a background star on January 28, 1613. There is little doubt that the object was Neptune; there is no star at or near the position recorded by Galileo. But Neptune was not where it was supposed to have been—a discrepancy that could be explained by disturbances to its orbit by Planet X. However, E. Myles Standish of JPL has made a reasonably good case that Galileo's drawing was not to scale, and he concludes that all three prediscovery Neptune observations are consistent with there being only nine planets in the solar system. *—JDA*

At the current distance of *Pioneer 10* from the Sun, the gravitational pull of the Sun is more than 1,500 times greater than the unexplained acceleration. As the Sun's pull weakens (with the inverse square of the distance), it will equal the unexplained acceleration when *Pioneer 10* is at a distance of 2,700 AU (one AU, or astronomical unit, equals the mean distance between Earth and the Sun). The unexplained acceleration shows no signs of weakening with distance but has remained remarkably constant since 1987.

What could it be? The direction of the unexplained force seems to line up on the Sun, but we cannot say that for sure. We have to consider that the slowing may be caused by forces originating from the spacecraft, in which case the apparent solar orientation might be an Earth orientation. As viewed from *Pioneer 10*, Earth and the Sun are not far apart. Both *Pioneers* are spinning, with their spin axes directed toward Earth. It is possible that forces generated by the spacecraft cancel out in all directions except along the spin axis.

The force is the same for both spacecraft. It does not vary with time or distance. The spacecraft are identical, so they might generate the same force. However, the size and constancy of the force are difficult to explain. Just to be sure, we monitored it for a decade before reporting results. As time went on, we recognized that we had possibly discovered something new. Consequently, in 1987 Eunice Lau and I at JPL made certain the *Pioneer* data were preserved for future analysis, and we began a more detailed analysis of the existing data. About three years ago, Philip A. Laing and Anthony S. Liu, using software at the Aerospace Corporation, began an independent analysis of the archived data. Within a few months, they verified our determination of the apparent force, and because they had used independent software, they concluded it was most likely not the result of a bug in the JPL computer code. Michael Martin Nieto at Los Alamos National Laboratory and Slava Turyshev at JPL also joined the collaboration to provide theoretical interpretation and to help with the data analysis. We published our preliminary results in the October 5, 1998 issue of *Physical Review Letters*.

Our basic conclusion was that the cause of the force is most likely some undiscovered systematic effect in the data or in spacecraft systems, but there is a small probability that we have discovered something new about how gravity behaves. If so, it is a strange behavior. Its effects are not observed in planetary orbits. As for smaller bodies, Robert H. Sanders of the Kapteyn Astronomical Institute has pointed out that if this Sun-directed acceleration were acting on the asteroid Icarus, we should expect to see an effect in the precession of the asteroid's perihelion (closest approach to the Sun). The predicted effect has not been observed.

So we are looking for a force that affects the *Pioneers* but not planets or asteroids—a tall order. The only things distinctive about the *Pioneers* are their small mass relative to solar-system bodies and the fact that they are on escape trajectories. No comet or other natural body has been observed on an escape trajectory from the solar system, so the *Pioneers* are showing us something new. If further analysis indicates that the force is not generated by the spacecraft and that it is not a result of systematic errors in the data, then there are some interesting possibilities for what the unexplained force might be.

***This diagram of the solar system shows the relative orbits of our familiar nine planets. If a tenth planet orbits somewhere in the boondocks of our planetary community, it's going to take technology that doesn't exist yet to find it.*** *Illustration: Alfred Kamajian*

There could be a cosmological connection. In 1929, Edwin Hubble discovered that galaxies in all directions were apparently moving away from us. He also established that the speed of a receding galaxy was proportional to its distance from Earth—distant galaxies appeared to be receding from us at ever-increasing speeds. Astronomers call this proportionality between a galaxy's speed and its distance the Hubble constant, and they interpret it as the rate at which the universe is expanding from the primordial Big Bang. If this interpretation is correct, the Hubble constant gives us an estimate of the age of the universe. From a knowledge of how fast the universe is expanding now, astronomers can calculate when the universe was just a single point at the beginning of time. Estimates vary, but the universe is probably about 16 billion years old. The connection with the *Pioneers* is that if we divide the unexplained *Pioneer* acceleration by the speed of light, we obtain a number in the same ballpark as the Hubble constant.

Moreover, the acceleration is approximately equal to a crossover point in the rotation of spiral galaxies, as studied by M. Milgrom of the Weismann Institute. Or the unexplained force could be a result of some as yet unknown "new physics," needed to describe the motion of spacecraft in the outer solar system.

Whatever the cause of the anomalous *Pioneer* force, we will continue to work on the problem, not only with the *Pioneers* but with other spacecraft as well. An upcoming Pluto/Kuiper belt mission will explore the outer regions of the solar system with instrumentation far superior to *Pioneer*'s 1969 technology. As a start, we have met with JPL engineers and scientists designing the mission to help ensure that it is as nearly free of spacecraft-generated forces as possible. Meanwhile, *Pioneer 10* continues its journey outward, extending our reach into the unknown.

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*John D. Anderson, a planetary scientist at the Jet Propulsion Laboratory, is a science team leader on the* Galileo *Europa mission, a member of the* Cassini *radio science team, and a Co-Investigator on the* Stardust *mission. He was a Principal Investigator on the* Pioneer 10 *and* 11 *mission.*

# News and Reviews

**by Clark R. Chapman**

The new millennium approaches with some positive signs concerning science and society. With high tech increasingly woven into the fabric of our lives, public interest in science is climbing again, and mass-media reporting of science is at an all-time high. Yet there are disturbing trends. In many scientific fields, national funding is stagnant or declining. Post-*Sputnik* optimism and competitiveness among the nation's brightest youth seeking scientific careers have been replaced by the demoralized outlook of researchers writing countless proposals rejected for lack of funds, so students turn to more lucrative pursuits.

The gap widens between public ignorance of science and the knowledge necessary to understand our world. Even as science reporting expands, pseudoscience and the occult win still broader coverage; the public becomes less capable of distinguishing between the two as news standards decline and "infotainment" ascends. Science and math education is in crisis, from preschool to postgraduate study. Last year, the University of Wyoming's physics and astronomy department graduated only one student with a bachelor's degree; now officials plan to shut down the department and close WIRO, the country's largest infrared telescope operated by a single university.

### Media Gatekeepers

Science journalism is at a fulcrum in this dilemma. Researchers able to explain their work to journalists can exploit the multiplying media outlets to inform and engage the public. Yet a cultural chasm separates scientists (who view journalists as sloppy, ignorant sensation-promoters) from journalists (who view scientists as inarticulate, arrogant intellectuals who can't give a simple, unqualified answer).

Jim Hartz and Rick Chappell analyze the schism and its societal context in a marvelous book, *Worlds Apart*, published in 1998 by the Freedom Forum's First Amendment Center (the book is available at no cost: phone 800-830-3733). The authors find hopeful common ground between scientists and journalists: both consider the universe their "beat," both are skeptical and competitive seekers of truth. Perhaps, together, the professions can address scientific illiteracy. For *Planetary Report* readers, this book is an engaging, easy read, illuminating what lies behind the science reports they see and hear about. Because of the authors' backgrounds (Hartz reported on *Apollo* for NBC-TV, and Chappell was a NASA scientist-astronaut), the space sciences often inform their anecdotes.

In *Worlds Apart,* we learn about media gatekeepers—the editors and producers, perhaps jaded by their personal experience of high-school physics, who must be "sold" a story . . . hence the narrow and trendy space discoveries and cancer cures "of the week" that trivialize the scientific process. We also learn about the cultural differences between scientists (who have months to draft a paper on a subject on which they are expert and to revise it in response to peer-review criticism before publication) and journalists (who have just hours or days to prepare a news report on a topic they may never have heard about before). It is easy to see why oftentimes scientists can't keep it simple and journalists can't get it right.

Despite its "we can fix it" tone, *Worlds Apart* unintentionally betrays the depth of this cultural conundrum. The book chastises journalists for muddling the number of subjects in a medical study (121,000, 121,700, or 122,000?), but I found more serious errors in articles Hartz and Chappell hold up as paragons of science reporting. One likens the Chicxulub impact energy to "several times" the world's collective nuclear arsenal; "thousands of times" would be accurate, a huge difference. Europa's still-hypothetical ocean is described with the barest of qualifications, and one scientist is quoted as "convinced" that "life exists" on Europa. Such distortions of what was known about Europa emanated from a problematical 1997 press conference and contingencies involving *Galileo* scientists (including me), NASA institutional factors, and the usual media hype.

### E & O Versus R & D

NASA chief Dan Goldin, quoted throughout *Worlds Apart*, is laudably encouraging NASA fundees to explain their research to the public. But he overreaches in asserting that any PhD must be "smart enough" to "speak plain English." No doubt, many scientists have such latent abilities and could do better, but others turned to science in part because they disliked English. People should develop their innate talents and not be forced to attempt what they do poorly. NASA's Education and Outreach (E & O) program risks demanding cookie-cutter approaches to public outreach, often subordinated to parochial dictates of the new E & O cottage industry with its official facilitators and promulgated checklist of E & O requirements.

The scientific *profession*, not every researcher, needs to reach out. As Hartz and Chappell recommend, professional societies might establish sites on the World Wide Web to provide intelligible help to journalists and teachers. And the scientific profession might encourage more scientists (but not all) to develop their latent talents for communicating the excitement of their research to the people, who are the ultimate source of funding.

*Worlds Apart* is a richly rewarding book, packed with insights, survey data, tips on how to write and talk, roundtable discussion, sidebar essays, anecdotes about stars and comets, and food for thought. Carl Sagan is quoted more than anyone else. No space scientist, journalist, or Planetary Society member should be without it. And remember: it's free!

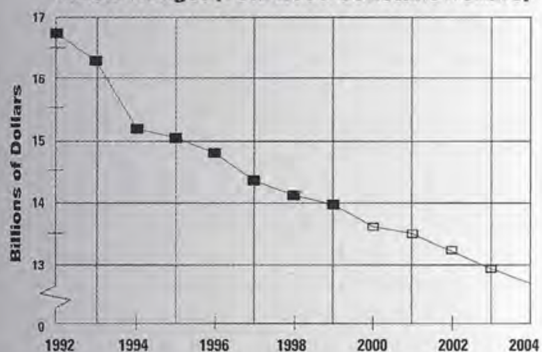
*Clark R. Chapman is Curator of the "IMPACT" exhibit, running through October at the University of Colorado Museum in Boulder.*

# World Watch

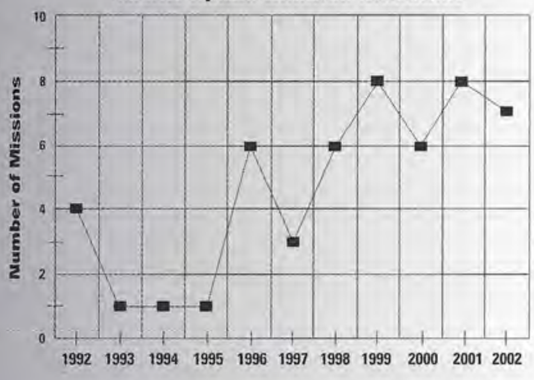
**by Louis D. Friedman**

**Washington, DC**—The two graphs below tell the story. The first shows the NASA budget over a period of seven years. The second shows the number of missions accomplished over that same time. That's just what the public wants: more accomplishments for less money.

**NASA Budget (Year 2000 Constant Dollars)**




**NASA Space Science Missions**




*Charts: B. S. Smith*

It should be obvious, however, that those graphs cannot extend forever. As a result of reduced budgets, NASA may be forced to cancel an approved mission.

Two recent developments have caused unexpected costs. First, the Advanced X-ray Astrophysics Facility (AXAF) has suffered major delays. Second, the gyroscopes on the Hubble Space Telescope (HST) are in urgent need of replacement. An additional shuttle mission has had to be scheduled—and paid for.

The extra mission to repair the HST is expected to cost $137 million alone. In previous years, NASA could have easily absorbed these costs. But today—after seven years of cutbacks, while funding demands of the International Space Station continue to increase—NASA no longer has the resources to deal with such expenses. Anticipated savings from privatization in space shuttle operations and the Deep Space Network have not materialized. The government made the mistake of budgeting these anticipated savings and allowing NASA's total budget to continue to fall.

To come up with the needed funds for AXAF and HST, NASA may have to make some terrible decisions. One—a direct result of the failure of privatized operations of the space shuttle to save money—is a cutback to the Deep Space Network, which would reduce tracking of spacecraft as well as radar observations of near-Earth asteroids. Other cuts are reducing some research funding for scientists to near-trivial levels. Even cancellation of a planetary mission is threatened. Solving the shortfall this way is ridiculous—the planetary missions are within budget and performing well. Their results have thrilled the public and brought scientists a treasure trove of new insights and discoveries. NASA's budget should not continue to go downward. The agency is reaching new heights of accomplishment, and its investments in new programs are paying enormous dividends—in science, in technology, and even in the general economy. A mere 1 percent increase in the NASA budget would overcome the difficulties this year and still result in a decrease compared to last year. We are urging Congress to add that 1 percent and direct NASA not to cancel any of the planetary exploration missions. We have mounted a campaign, by mail and on the Internet, asking all our members to sign a statement of support and send it to the House and Senate committees in charge of the NASA authorization.

As we go to press, consideration of the NASA budget is about to begin in Congress. You can find the latest news on the proceedings, and get details on any Planetary Society calls to action, by visiting our site on the World Wide Web: **http://planetary.org**.

**Paris**—Time is nearing for formal approval of the European Space Agency *Mars Express* mission. Our European members are urged to write the ministers of science in their governments expressing support for the mission. Scheduled to launch in 2003 with an orbiter and possibly a lander, *Mars Express* is an important part of the international effort to explore Mars. Not only does it contain a first-rate imaging system and other scientific instruments, but the spacecraft will be used as a relay in the international Mars Sample Return, tracking sample-return capsules that will be launched from the planet surface (see "Building Toward Mars" in the March/April 1999 *Planetary Report*). The exploration of Mars is an international endeavor, and we hope the European Space Agency will be part of it—in 2003 and throughout the 21st century.

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

# Questions and Answers

***When was it discovered that the atmosphere of Jupiter is very hot? Early science and science-fiction writers such as Willy Ley, Isaac Asimov, and Arthur C. Clarke assumed that the atmosphere would be extremely cold—even that large parts of the planet would be solid ice.***

***Do we know whether the atmospheres of the other gas giants are also hot? Or is Jupiter an exception?***

**—Richard McConnell,**
**Hessle, East Yorkshire, England**

It was in the early 1960s, when scientists began to make many observations of the giant planets at infrared and radio wavelengths, that we realized Jupiter is hot. Some of the first evidence for a deep atmosphere and a hot interior came from radio data indicating that the brightness of Jupiter increased with wavelength. Longer radio wavelengths penetrated deeper into the atmosphere.

At visible-light wavelengths, astronomers noticed dark spots in Jupiter's atmosphere, implying possible breaks in the planet's cloud layer. Infrared observations revealed that these spots were extremely bright at a wavelength of five microns, which reinforced the suspicion of higher temperatures beneath the clouds. In 1979, infrared measurements by *Voyager 1* indicated that Jupiter was emitting much more energy than it was receiving from the Sun, confirming that the interior of the planet was hot.

Much earlier, we had suspected from the orbits of its four largest moons that Jupiter's atmosphere was very deep. The orbits of the Galilean satellites gave a measure of Jupiter's total mass, which, when combined with its size, provided evidence of a low bulk-density for the planet. Although Jupiter is the largest planet in the solar system, it has a bulk density less than a quarter of Earth's! This low density, in turn, made it likely that Jupiter had a deep atmosphere, extending well into its interior, and that there might be no discernible surface underneath that atmosphere.

Similarly, Saturn and Neptune radiate excesses of heat from their interiors. Uranus showed little or no excess heat escaping from its interior during the 1986 flyby of *Voyager 2*. Nevertheless, those who model the interiors of the giant planets think it is likely that Uranus is also warm beneath its clouds.

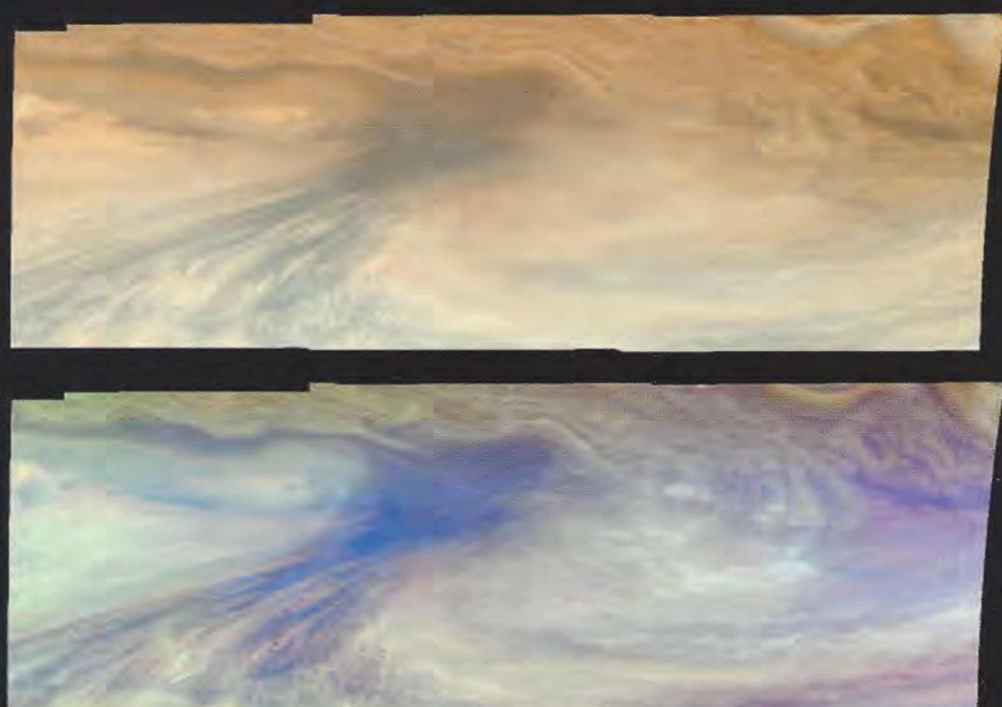
—ELLIS D. MINER,
*Jet Propulsion Laboratory*

***If comets condensed from the solar nebula at the same time as the planets, why is the Oort cloud so far from the Sun by comparison?***

**—Pedro Pereira da Silva,**
**Marinha Grande, Portugal**

Actually, the comets were formed ahead of the planets. Comets running into each other grew, or accreted, to form the cores of the giant planets. As the giant planets grew, they became massive enough to change the orbits of the remaining comets through gravitational interactions, much as they changed the orbits of the *Voyager* spacecraft and flung them outward to their encounters with Saturn, Uranus, and Neptune. This phase in the formation of the solar system, known as the "clearing

*Above: This large, brown spot on Jupiter and others like it tipped off scientists to possible breaks, or holes, in the giant planet's outermost clouds, indicating warmer layers below.* Voyager 1 *captured this image on March 2, 1979.*



*Right: These two images of Jupiter from* Galileo *reveal "hot spots" in the atmosphere. The top mosaic shows how Jupiter would look to human eyes; the bottom view uses the spacecraft's three near-infrared wavelengths (displayed in green, red, and blue) to show variations in cloud height and thickness. The dark-blue hot spot in the center is a hole in the deep cloud with a thin, overlying haze.* Galileo *is the first spacecraft to distinguish layers in Jupiter's clouds.*

*Images: JPL/NASA*

of the planetary zones," took several hundred million years. Eventually, all the comets between the giant planets either collided with one of those planets or were thrown out of the planetary system.

Most comets were hurled into outer space, where they became interstellar wanderers. A fraction of the comets, perhaps 10 to 20 percent, were flung into long-period orbits that took them as far as 100,000 astronomical units from the Sun (an astronomical unit is the mean distance between Earth and the Sun). At such distances, gravitational perturbations from passing stars can change a comet's orbit. In particular, stellar perturbation can increase the orbit's perihelion distance (closest approach to the Sun), so that on the next return the comet doesn't pass within the planetary system. Once isolated from the gravitational effects of the planets, comets' orbits are remarkably stable. They continue to orbit at great distances until a chance stellar perturbation throws them back into the planetary system. We then observe them as long-period comets.

This reservoir of distant comets is known as the Oort cloud, named for the Dutch astronomer Jan Oort, who first theorized its existence in 1950. A second comet reservoir, the Edgeworth-Kuiper belt, is located beyond the orbit of Neptune. Comets in the Edgeworth-Kuiper belt were never ejected because no giant planet grew in that region (Pluto is too small to exert that kind of effect on cometary orbits). The Edgeworth-Kuiper belt is believed to be the source of most Jupiter-family, short-period comets. [For more about the region beyond Neptune's orbit, see "Whatever Happened to Planet X?" on page 14.]
—PAUL R. WEISSMAN,
*Jet Propulsion Laboratory*

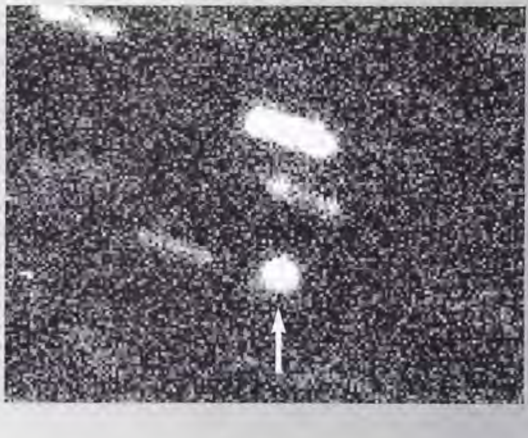
***How can the triple point of water be 32.02 degrees Fahrenheit and 0.006 atmospheres, as it says on page 9 of the March/April 1999 issue of* The Planetary Report*?***

***Atmospheric pressure is never that low on Earth's surface, and yet in some places water exists in all three forms—ice, liquid water, and vapor.***
**—Michelle Myers,**
**Raleigh, North Carolina**

The triple point for a substance is the temperature and pressure at which all three phases—solid, liquid, and gas—can coexist. The triple point for water is 0.01 degrees Celsius (32.02 degrees Fahrenheit) and 0.006 atmospheres. However, the definition of triple point assumes we are talking about a pure material in contact only with itself.

Because water is a minor phase in Earth's atmosphere, we have to consider the humidity factor—how much water vapor can our nitrogen/oxygen atmosphere hold at a given temperature? Let's say instead of Earth the planet is Europa, and we fictitiously assume that Europa has a thin atmosphere of pure water, as we might expect given the water ice on its surface, with pressure at 0.0061 atmospheres. If we suddenly brought Europa close enough to the Sun to warm it up to 0.01 degrees Celsius (32.02 Fahrenheit), then we would find the water ice would be stable in contact with new lakes at the surface and the thin atmosphere. That is, they could just sit there and not undergo any phase change.

Snow, water, and steam can exist together on Earth, but they will be undergoing a phase change. The snow first changes to liquid, then the liquid turns to steam. The other tricky part to remember is that water can exist as a liquid in the atmosphere. Clouds and fogs, for example, are usually liquid water droplets rather than "vapor."
—WENDY M. CALVIN,
*United States Geological Survey*



***This image of Kuiper belt object 1996 TO66 (arrow) was captured with the European Southern Observatory's 3.6-meter New Technology Telescope in La Silla, Chile. Scientists have discovered that this distant body rotates once every six hours, which may give insight into the processes by which our planetary system formed.***

*Image: European Southern Observatory*

# Factinos

Gravity measurements from the *Lunar Prospector* spacecraft have confirmed that the Moon has a small core. The discovery adds heft to the theory that most of our satellite was formed from material torn off the early Earth when a Mars-size object smashed into our planet.

Scientists presented these findings in March at the Lunar and Planetary Science Conference in Houston. Their data show that the lunar core probably contains less than 2 percent of the Moon's total mass, a small fraction in comparison with Earth's core, which makes up about 30 percent of our planet's mass. Researchers say that if the two worlds had simply formed from the same cloud of rocks and dust, the Moon would have a core similar in proportion to Earth's.
—from NASA Headquarters

Planetary dynamicists have recently discovered that Earth plays a stabilizing role in the inner solar system. Kimmo Innanen of York University in Canada and Seppo Mikkola from the University of Turku in Finland made this discovery as they tested long-term computer simulations of planetary motions. They found that removing the Earth-Moon system from their calculations caused Venus' and Mercury's orbits to gyrate wildly—with the likely outcome being Mercury's ejection from the solar system or a collision of the two planets.

The instability of the Earth-less solar system, they say, would come from a previously unrecognized resonance involving Venus and Jupiter. However, an object at Earth's heliocentric distance (even if only 10 percent of Earth's mass) damps out effects from the resonance.
—from *Sky & Telescope*

Clues to the era of planet formation may lie in the six-hour spin cycle of an iceball at the fringes of our solar system. The object, called 1996 TO66, is one of the biggest and brightest residents of the Kuiper belt [see image at left], although the faintest stars visible to the naked eye shine 1.5 million times brighter.

Scientists think that Kuiper belt objects (KBOs) have changed little since the formation of the solar system 4.5 billion years ago. If 1996 TO66's rotation truly hasn't changed since then, it reveals the "agitation of the stuff from which it formed," says Olivier R. Hainaut, a member of the international team of scientists who reported on the KBO rotation at a European Southern Observatory workshop held last fall in Garching, Germany. This rapid spin supports the idea that as the solar system formed, planets and comets grew larger by colliding with, and sticking to, similar-size bodies that increased their spin. Hainaut claims that the measured rotation rate of 1996 TO66 will help theorists model the early solar system.
—from *Science News*

# Society News

## The Planetary Society Invites You to Planetfest '99

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### Historic Projects Bring Students to Space

On May 6, astronaut and former US senator John Glenn announced at the National Air and Space Museum two unprecedented international projects rolling out at the Planetary Society. Red Rover Goes to Mars, an historic collaboration between the Planetary Society, the Jet Propulsion Laboratory, and NASA, will incorporate the ideas and efforts of young astronauts into the Mars Surveyor 2001 mission, which launches a Mars lander and orbiter in 2001.

In the first private-sector collaboration aboard a US science mission, LEGO and other sponsors will support Planetary Society participation in the mission's education and outreach program. We will help select a team of student astronauts who will work with mission engineers and scientists in devising and sending commands to the *Marie Curie* micro-rover and teleoperating the lander arm, which will collect soil and dust samples. The Society plans to reach students around the world through an essay contest. Updates will be regularly broadcast via the Internet throughout the mission.

The Planetary Society is also coordinating the Student NanoExperiment Challenge, another part of the Mars Surveyor 2001 lander mission. The contest will incorporate a student-designed experiment into the Mars Environmental Compatibility Assessment, which will test how the Mars environment affects patches of different materials, including spacesuit fabrics. To enter the contest, students must design and build a prototype for their experiment and submit it along with a 350-word summary. The Planetary Society will fund the building of the actual flight experiment, including materials, construction, and testing.

The NanoExperiment contest deadline is July 31, 1999. Entry forms and complete guidelines are available at Planetary Society headquarters and are posted on our Web site.

*—Linda Hyder, Manager of Program Development, and Jeffrey Oslick, Science and Technology Coordinator*

### UN Meetings to Help Shape International Space Agenda

The Planetary Society is taking part in two important United Nations (UN) meetings designed to establish international collaboration in space research and education during the next millennium. The eighth UN/European Space Agency Workshop on Basic Space Science and Scientific Exploration from Space, sponsored in part by the Planetary Society, took place in Jordan last March.

The workshop focused on recent scientific information about the heliosphere and the far reaches of the universe. Thirty-five countries were represented at the workshop, which included more than 60 astronomers, researchers, and space scientists as well as many students. Projects endorsed by the workshop will be included in discussions at UNISPACE III, which takes place July 19 through 30, 1999 in Vienna.

At UNISPACE III, Planetary Society Executive Director Louis Friedman will take part in the Space Generation Forum Advisory Council as well as participate in the forum, which is organized by younger members of the international space community. The Planetary Society is also conducting workshops on Mars exploration and near-Earth objects during the meeting. The outcome and recommendations of the forum will be included in the Vienna Declaration on Space and Human Development, an international policy framework to guide governments and industry in the first half of the 21st century.

*—Adriana Ocampo, Special Consultant*

### Keep Informed by E-mail

You can keep abreast of what's going on at the Planetary Society by leaving us your e-mail address in the Guest Book area of our Web site. Our list server will keep you updated with regular e-mail about Society projects, programs, political action, and other planetary news and information.

*—Cynthia Kumagawa, Manager of Electronic Publications*

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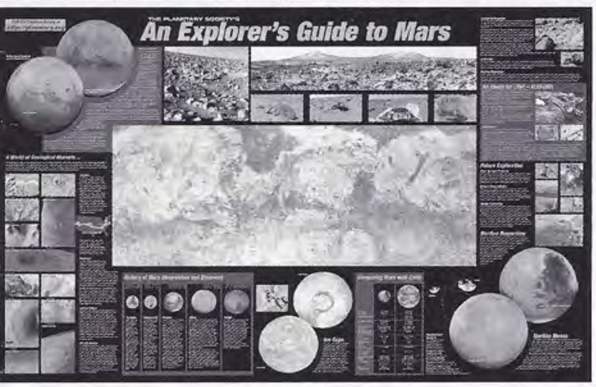


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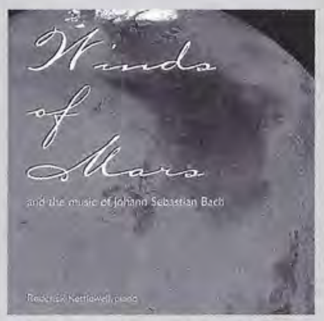


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Alfred Kamajian's first major space-art project was for Time-Life Books' Voyage Through the Universe series. He has since added *Scientific American* and *Discover* magazines, as well as NASA, to his list of clients. The artist lives and works in Crofton, Maryland.


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