# The PLANETARY REPORT

Volume XXI Number 6 November/December 2001

A New View

A PUBLICATION OF THE PLANETARY SOCIETY

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## From The Editor

This year has brought a series of extraordinary events into the life of The Planetary Society. Our *Cosmos 1* project has torqued everything as we work toward flying the world's first solar sail. The events of September 11 have changed the landscape in which nonprofit organizations exist, and we are still feeling our way along. And finally, we scored one of our biggest political victories ever when Congress, responding to our members' clamor for a mission to Pluto, provided the funds for NASA to continue efforts to reach the last unexplored planet in our solar system.

*Cosmos 1* is progressing a bit more slowly than we had hoped, and we are now aiming for a launch this spring. We've been pushing the envelope in several ways at once, and since our schedule is flexible, a small delay will not adversely affect the project.

And even as we celebrate the Pluto victory, we are planning our next moves in the campaign, for the mission is not yet safe. You'll see that we've reorganized our regular departments in this issue to bring you an expanded "World Watch" detailing developments in space exploration around the world.

This year was remarkably busy; next year will be just as full. We're glad to have you with us as we move into the future.

—*Charlene M. Anderson*

### On the Cover:

Two days after its closest approach to Jupiter, *Cassini* captured a stunning sight: a crystal-clear image of Io with Jupiter's swirling bands of atmosphere in the background. Although Io seems to be floating just above Jupiter's clouds, there is actually room for two and a half Jupiter-size planets between the gas giant and its innermost moon. *Cassini* collected its last images of the Jovian system in March 2001. The spacecraft is now on the final leg of its six-and-a-half-year journey, intending to keep its July 1, 2004 appointment with Saturn.

Image: NASA/JPL/University of Arizona

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# Members' **Dialogue**

### Science Didn't Fail

In the September/October 2001 issue of *The Planetary Report*, Glenn Cunningham misses the mark in his opinion piece, "Calibrating Success in Science: How Failure Fits In." While discussing the recent failures in the civilian exploration of space, he confuses failures of science and engineering. He argues that "Failure . . . is key to the scientific method."

The recent failures at Mars were clearly engineering and management failures, not scientific failures. They were failures in systems engineering, failure to include appropriate rigor in the development process, and, in the case of *Mars Polar Lander*, failure to communicate.

The scientific method is geared toward incremental discovery of the unknown. Engineering method and management techniques are geared toward the orderly development of a system to accomplish an objective. This distinction is important, as it is important to identify the proper root cause so that appropriate corrective action can be implemented.

Having said that, I do agree with Cunningham's recommendation to move ahead.
—DAVID DANNEMILLER,
*Friendswood, Texas*

### In Appreciation

My sister receives your magazine. I read it whenever she leaves it out but don't always make it a point to (regrettably).

However, I came across your September/October 2001 issue with Carl Sagan's essay on the cover and wanted to write with deep appreciation and gratitude. Of the millions of words and pictures conveyed since the attacks, beautiful and obscene, vital and redundant, few have moved me as much as your simple, powerful image and Sagan's touching, honest words.

In your humble and heartfelt reaffirmation of your awe-inspiring goals, and without t reading into mawkish self-importance, you perfectly summed up the blind futility of hatred and conquest. More important, in this battle between fanatics and murderous technology, you reminded us how science and humanity can walk together. Thank you very much.
—BRIAN O'NEILL,
*Park Ridge, Illinois*

### From South Africa

It's thrilling for your South African members to read something about astronomy in Africa in *The Planetary Report*! (See "Under African Skies" in the September/October 2001 issue.) Please keep popularizing space science on our continent. If any of you passes through Cape Town in 2002, feel free to look me up.
—KEITH GOTTSCHALK,
*Cape Town, South Africa*

### Clearing the Air

I'd like to answer the letter from Scott Pearson in the last issue (which contains some polemics regarding my letter in the May/June 2001 column).

Concerning the issue of funding, certainly the funds available to such membership-funded organizations as The Planetary Society are very limited, especially as compared with the needs of space exploration. Therefore, such organizations cannot undertake too broad a scope of activity if they are to be able to achieve any real results. Some priorities and scope limitations should be observed. Of the three general directions of Society activity (SETI, space advocacy, and space exploration), it seems to me that SETI is emphasized way too much compared with the real impact it can have on humankind's future in space.

I am thus reluctant to put the few funds I can spare toward an activity I consider of dubious value. If the organization's members could individually indicate which of the Society's directions they want to support (or if several, in specified proportions), everybody could fund his or her pet project(s) without qualms. I would advocate such a solution.

Concerning Pearson's "listening to the radio in a car" analogy, I can only answer that if our listening to the radio, while having no impact on our driving ability, would cost so much as to deplete our gas budget for the drive, then certainly we should stop listening to that radio.
—ZENON KULPA,
*Warsaw, Poland*

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# WORLD WATCH: SPECIAL EDITION

**Washington, D.C.**—The victory came as a surprise—our long campaign to save the mission to Pluto seemed to be drawing to a disappointing end, since the Bush administration's fiscal year 2002 budget had pointedly not included funding for the enterprise. But then, the US Congress added funds to the NASA budget and specifically directed the agency to continue development of the Pluto–Kuiper belt mission.

The Planetary Society had led the grassroots campaign to save the mission. Yet, after the administration opposed its consideration by Congress, we seriously doubted that Congress would reinstate it. Nonetheless, we pressed on, along with scientists and professional organizations involved with the mission, dedicated students, and, most of all, thousands of Planetary Society members who let Congress know they wanted NASA to explore the outermost planet of our solar system.

To be sure, there are still many hurdles to making the mission happen. The $30 million added by Congress is enough to fund only a year of preproject development. Unless the Bush administration includes the mission in its 2003 budget proposal, the fight in Congress will be repeated in what certainly will be a tougher budget year.

This year, Congress designated that Pluto be made part of NASA's Outer Planets Program, which already includes the development of a Europa orbiter mission. Some in the planetary science community fear that this sets up a divisive competition between the two missions—although a compromise seems possible by allowing the Europa mission an extra year or two of needed technology development and then launching it after the Pluto mission.

Indeed, a Europa mission could be launched any year, while the last Jupiter gravity assist to travel to Pluto for more than a decade will be in 2006. Currently, to arrive at the far reaches of the solar system, a spacecraft must use the gravity of a large planet to "slingshot" itself onto a faster trajectory, and the changing alignment of planets means the opportunity is available only during certain years. This dependence on planetary alignment could be mitigated by low-thrust propulsion systems similar to the ion drive successfully demonstrated on *Deep Space 1*.

Although the mission is not assured, Planetary Society members should feel gratified—they count! Congress heard us, even when preoccupied with a war and other budget priorities. The popularity of space exploration, as demonstrated by our members, overrode the opposition of the administration and NASA management toward the Pluto mission.

Thanks are due, too, to Senator Barbara Mikulski (D-Md.), who has again proved to be the leading champion of space science in Congress, as well as to the many other representatives and senators on Appropriations Committees who voted for this action. We also note the efforts of the American Astronomical Society's Division for Planetary Sciences, planetary scientists in academe interested in the mission, the engineering teams at Caltech's Jet Propulsion Laboratory and the Johns Hopkins University's Applied Physics Laboratory (APL) who produced lower-cost proposals for the Pluto mission (APL won the competition for final implementation), and ordinary citizens like (then) high school senior Ted Nichols, who led an Internet campaign in support of the mission.

In other budget action, Congress passed a final appropriations bill restoring full funding to the robotic Mars program—threatened by cuts in earlier Senate committee action. The Mars program has incurred escalating costs in the aftermath of 1999's mission failures as NASA attempts to increase spacecraft reliability.

NASA has planned two rover missions for 2003, with two more slated for 2007. But internal reviews have challenged whether these can be accomplished within budget, and the agency is considering delaying the landers from 2007 to 2009. As we go to press, we are also awaiting confirmation that the 2003 mission will include both rovers; one may be cut to meet schedule and budget constraints.

**Washington, D.C.**—Dan Goldin resigned as NASA administrator on November 17, 2001. Goldin's resignation was no surprise; he has piloted NASA for nearly a decade, longer than any previous administrator. Months ago, the Bush administration informed Goldin it was looking for a replacement. So, after steering the fiscal year 2002 budget through Congress, and with no mandate for future initiatives, perhaps Goldin felt that it was time to go.

Goldin's announcement came one week before the *Mars Odyssey* entered orbit around its target, so he was able to leave on a positive note—deservedly, since he promoted NASA's focus on a robust robotic Mars program. In his remarks after the successful *Mars Odyssey* orbit insertion, Goldin reaffirmed his vision of humans exploring Mars in the not-too-distant future.

Goldin's resignation, however, came just after that of Joseph Rothenberg, Associate Administrator for Human Spaceflight, and two weeks before the release of a critical report from the task force led by A. Thomas Young evaluating the costs and management of the International Space Station. The Young report criticized NASA management and deemed its budgeting for the space station not credible.

The Bush administration has placed little priority on NASA and space exploration. Its space policy is focused almost entirely on military-space issues. Indeed, the Bush administration has taken 10 months to name a replacement for Goldin (see page 5). And now, the administration has directed NASA to cover increased costs for the space sta-

BY LOUIS D. FRIEDMAN

***Pluto, the last unexplored planet in our solar system, is shown here with its moon Charon and a Kuiper belt object. From this vantage point, the distant Sun might produce a flare in the spacecraft's camera.*** *Painting: David A. Hardy*

tion from funding already approved—that is, to make cuts in existing programs. Principal reductions are to come from planned space station capabilities.

Thus, the space station—once seen as a fully equipped research facility for human exploration beyond Earth orbit—is being reduced to a three-member crew capable of conducting little science work and no long-duration flight research. For example, the centrifuge for use in life science research into artificial gravity and the TransHab module for developing capability for interplanetary flight have both been eliminated from the space station plan. Although the Young committee emphasized that long-duration flight research was the principal reason for the space station, it proceeded to endorse the limited-capability proposal.

**Washington, D.C.**—Following a prolonged search, President George Bush announced he will nominate Sean O'Keefe to succeed Daniel Goldin as NASA administrator. O'Keefe is currently deputy director of the Office of Management and Budget and is on leave from his position as the Louis A. Bantle Professor of Business and Government Policy at Syracuse University's Maxwell School of Citizenship and Public Affairs.

From July 1992 to January 1993, O'Keefe served as Secretary of the Navy under President George Bush Sr., and he was a longtime member of the Pentagon management team under then-Secretary of Defense Dick Cheney. Once officially nominated for his new post, O'Keefe will face confirmation hearings in the Senate.

Unlike his predecessor at NASA, O'Keefe has a background not in space exploration but in management. Planetary Society Director John Logsdon, who helms the Space Policy Institute at George Washington University, has pointed out that O'Keefe's background is comparable to that of James Webb, who led NASA in the 1960s at the height of the space race.

As deputy director of the Office of Management and Budget, O'Keefe has been highly critical of the cost overruns in NASA's human spaceflight program and the International Space Station in particular. In testimony before Congress on November 7, O'Keefe argued that the space station program was facing a "management and financial crisis" and that correcting the problem would require a profound change in NASA's management culture.

O'Keefe has a strong management background as well as recent experience with NASA's toughest challenge—making the space station serve the public interest. The future of human spaceflight will be determined by how he applies his management skills to the vision, achievement, and leadership the whole world expects from NASA. We wish him well.

*Louis D. Friedman is executive director of The Planetary Society.*

# THE SOCIETY'S NEW LEADER:
## *An Interview with Wesley T. Huntress Jr.*

***The Planetary Society's new president, Wesley T. Huntress (left), and vice president Neil deGrasse Tyson pose for a picture at a recent Society Board meeting. Huntress will serve a five-year term as president, while Tyson will serve three years as vice president.***
*Photo: Charles Nobles*

*As Bruce Murray assumes the chair of The Planetary Society Board, a new inspirational leader, Wesley T. (Wes) Huntress, takes the helm as Society president. Wes brings with him decades of experience, including 10 years as associate administrator for space science at NASA, as well as a longtime commitment to the goals of The Planetary Society. On his most recent visit to Society headquarters, Wes sat down for an interview with me and* Planetary Report *editor Charlene Anderson. We invite you to "listen in" on highlights of the interview—touching on his career, research interests, views on the US space program, and hopes for the future—for a chance to get to know Wes better.*
—Jennifer Vaughn, Managing Editor

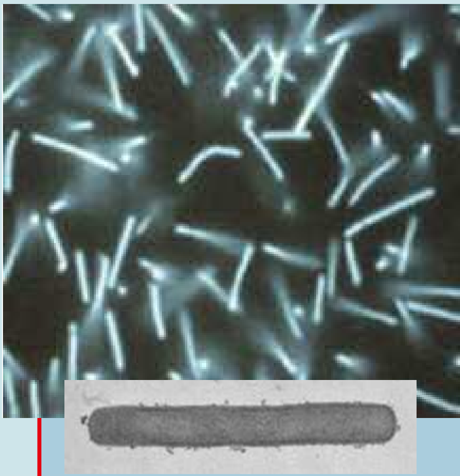
***The Planetary Report:*** *We'd like to welcome you as the new Planetary Society president. We are honored to have both you and Neil Tyson as our new leaders.*
**Wesley T. Huntress Jr.:** Well, thank you. I'd like to start by saying what a privilege it is to be the new president of The Planetary Society. I've been a member for a long time—in fact I was a founding member. I am particularly honored to follow people like Carl Sagan and Bruce Murray. And I'm delighted to have Neil Tyson on board as our new vice president.

I met Neil while serving on the Society's Board, and I recognized instantly how much fun it would be to work with him. He brings a great deal of knowledge to the whole enterprise—knowledge in terms of science, and skill in presenting that knowledge to an audience, which he does at the [Hayden] Planetarium. This mixture of expertise and the ability to communicate effectively with the public is something the Society has always promoted. That's what Carl [Sagan] was so great at, and he founded the Society so that others might follow his lead.

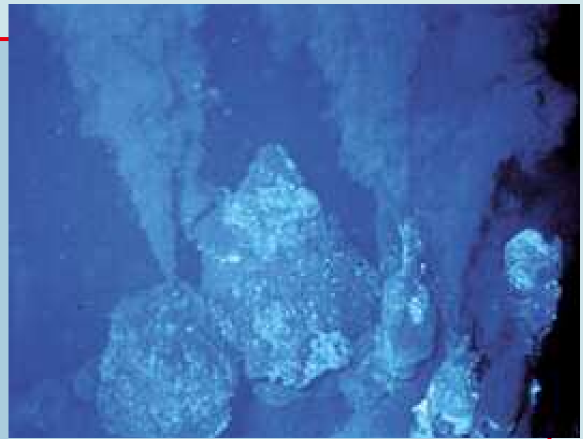
***TPR:*** *You mentioned in a speech you gave in 1998 [on the occasion of the second annual Carl Sagan Award, jointly sponsored by The Planetary Society and the American Astronautical Society] how Carl Sagan influenced your career—could you tell us more about that?*
**WTH:** I first saw Carl at a meeting at the Ames Research Center when I was a graduate student at Stanford University trying to decide what to do about my career. Carl gave a talk on life in the universe, and I was fascinated to see how he was able to engage more than just scientists in thinking about that. It was inspirational for me. It made me decide that rather than teaching chemistry at some research university, which was the track I was on, I wanted to participate in planetary exploration and the search for signs of life, beyond the Earth, in our solar system. As a result, I went to the Jet Propulsion Lab [JPL] and became an astrochemist. So, Carl was responsible for a big change in the direction of my life, and I'm a happier person for it.

***TPR:*** *What exactly is an astrochemist?*
**WTH:** The astrochemist tries to understand something Carl talked about. He said, "Isn't it marvelous how somehow the universe went from a collection of hydrogen atoms and radiation to human beings?" How did that happen? So, as an astrochemist, what I've been interested in is how you start with a collection of hydrogen atoms and radiation and produce complex, organic chemical compounds—on the surfaces of comets, in the interstellar medium, and on young planets—and how these compounds influence the potential formation of life on planetary bodies. That's what an astrochemist does: studies chemical evolution in the cosmos.

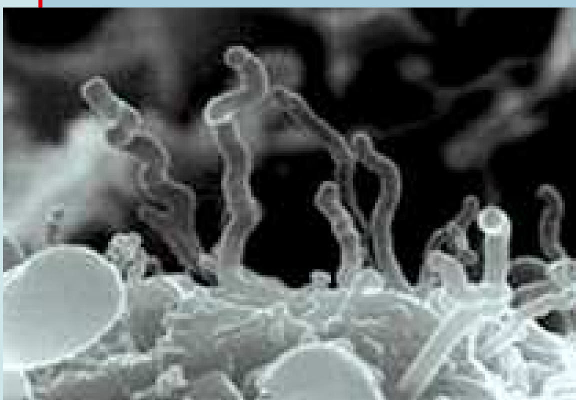
***TPR:*** *What are your current research projects?*
**WTH:** Two things. First, this new idea that life on Earth didn't necessarily evolve on the planet's surface—the way we've been studying it for the past 50 years—where electric discharges, ultraviolet light, and a reducing atmosphere created just the right chemical matrix for the rise of life. The new idea is that life originated at depth, under tremendous pressures at the bottom of the primordial ocean. There, volcanic activity was spewing all kinds of mineral and chemical resources into the ocean—which suggests that the chemistry preceding life happened beneath the surface. What's been driving the change is the discovery that hydrother-



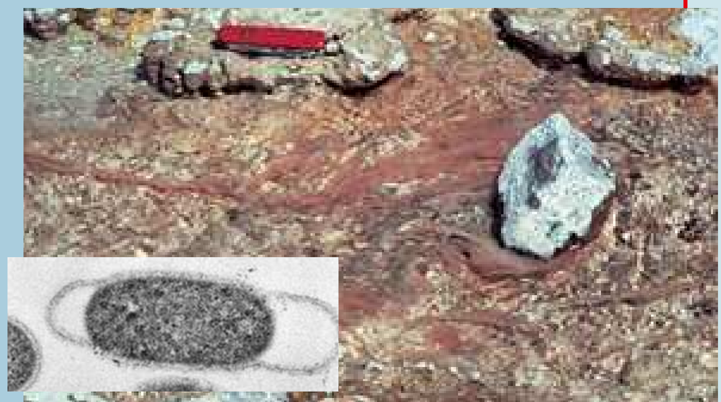
*Left: Many archaea live in extreme conditions, inspiring the name* extremophile. *Some extremophiles live in very hostile environments, such as salt lakes, hot springs, or midocean thermal vents, while others metabolize dangerous (or, at least, unpleasant) chemicals, creating methane as a by-product. One such methane-producing extremophile,* Methanopyrus *(two views shown here), lives deep below the ocean surface amid hydrothermal vents. Many experts think that if life is discovered elsewhere in the solar system, it will resemble members of the archaea kingdom.*
*Images: (c) University of Regensburg*



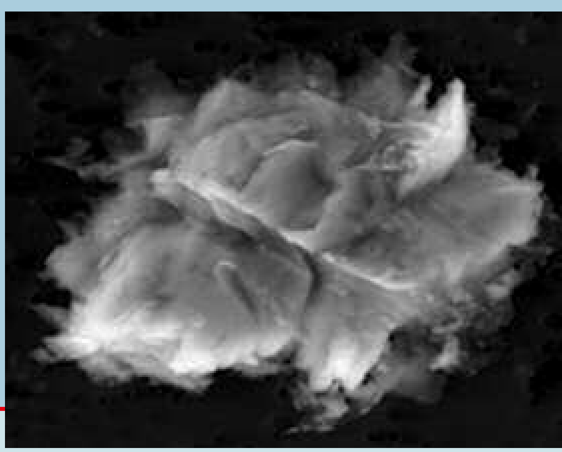
*Above: Thousands of feet below the ocean's surface on the midocean ridges, volcanic vents known as black smokers are constantly spewing hot water (up to 350 degrees Celsius [660 degrees Fahrenheit]). Still, the scalding temperatures, total darkness, and pressures equivalent to 30 atmospheres don't discourage some archaea from making these ocean vents their home.* *Image: Dr. Michael Perfit, University of Florida, and NOAA VENTS program*



*Above: Archaea have been found living inside rock more than 6.5 kilometers (4 miles) below the Earth's surface. The pressures at these depths are more than 14 tons per square centimeter (70 tons per square inch). The bacteria respire anaerobically, feeding off hydrogen gas emitted when water seeps through rock. The nanobacteria seen here (magnified 35,000 times) were found at extreme depths in the seabed sandstone off Western Australia. Perhaps such a habitat protects living organisms on Mars from the harmful radiation on the planet's surface.*
*Image: (c) 1999 The Centre for Microscopy and Microanalysis*



*Above: Yellowstone National Park is a hot spot for unusual research in microbiology. Discovered in hot springs heated by geothermal reactions deep in the Earth, the pink streamers of filamentous bacteria (center of photo) thrive at a toasty 85 degrees Celsius (185 degrees Fahrenheit). The bacteria,* Thermus aquaticus *(inset), also live in Yellowstone's scorching hot springs.* *Photo: David M. Ward; Inset image: (c) University of Regensburg*



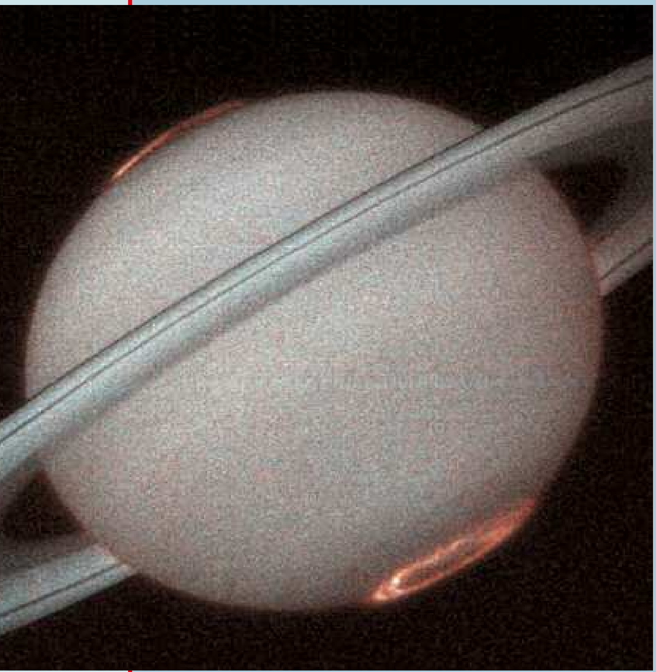
*Since most space environments are cold, researchers are particularly interested in microbes that can survive at low temperatures. In 1998, ice cores retrieved from depths of nearly 4,000 meters from Antarctica's Lake Vostok revealed cyanobacteria, bacteria, fungi, spores, pollen grains, diatoms, and yet-to-be-identified microbes (example at left, magnified 5,000 times). These organisms, thought to have been trapped in the ice for about 400,000 years, have been cut off from sunlight and are in a dormant state, though continuing to metabolize at a very low level. Such discoveries on Earth support the possibility of microbial life on Jupiter's ice-encrusted moon, Europa.* *Image: (c) Sally Hodges, 1999*

mal vents at seafloor spreading centers, though expected to be barren, are populated with life.

So, life on Earth turns out to be ubiquitous and robust. It's not at all marginal. On Earth, without exception, wherever there is the slightest bit of liquid water and some chemical source of energy, you will find life: in ice in Antarctica, in acidic hot springs in Yellowstone, in the most extreme environments you can imagine. What that says about the potential for life on other planets is enormous.

The second thing I'm studying is that if there is life out there, how would we go about detecting it? Especially if it is microbial life or microbial life that has long since died.

*Above: While serving as NASA's associate administrator for space science, Wes Huntress oversaw such projects as the Hubble Space Telescope and the planetary exploration program. For two decades, Hubble has delivered remarkable views of our solar system and beyond. Located 2.7 million light-years away, this image shows a vast nebula called NGC 604, which lies in the spiral galaxy M33. NGC 604 is an extraordinarily large nebula, nearly 1,500 light-years across. In it, more than 200 hot stars, much more massive than our Sun (at 15 to 60 solar masses) are beginning their lifetimes.*
*Image: Hui Yang (University of Illinois) and NASA*



*Left: In 1997, Hubble gave us a spectacular first image of Saturn's ultraviolet aurora. The auroral curtains of light that encircle Saturn's north and south poles rise more than a thousand miles above the cloud tops. Much like Earth's aurora seen occasionally in the nighttime sky, the Saturnian phenomenon is caused by an energetic wind from the Sun that sweeps over the planet. But unlike Earth's aurora, Saturn's can be viewed only in ultraviolet light invisible from the Earth's surface; therefore, the aurora can be observed only from space.*
*Image: J. T. Trauger (Jet Propulsion Laboratory) and NASA*

How can we detect its presence? That's pretty hard to do!

**TPR:** *Before ending up as director of the Carnegie Institution's Geophysical Laboratory, you had an illustrious career with NASA. Would you give us an overview?*
**WTH:** I'm a *Sputnik* kid. I was a sophomore in high school in October of 1957, and the launching of *Sputnik* both frightened and excited me. It frightened me because it meant there were people on the other side of the planet who, at any time they chose, could drop an atomic bomb on my head. That's one of the things *Sputnik* implied, and it was scary. The other thing *Sputnik* implied was that the same ability could take us to the planets. That's what inspired me. That's what got me started on my ultimate career path.

I went to Brown University to study to be a chemist, and then I went to Stanford to study physical chemistry. At Stanford, I was right next to the Ames Research Center. So, I did half my Ph.D. thesis on prebiotic chemistry and the other half on nuclear magnetic resonance, kind of hedging my bets on where I would end up after graduate school. Then, a JPL representative showed up my senior year, looking for someone to come to Pasadena and work on devising an instrument for studying processes involved in producing organic compounds in a planetary atmosphere. They didn't have to ask twice!

I flew down to Los Angeles, a young, impressionable student during the heyday of the *Apollo* program—the spring of 1968. I landed at the L.A. airport, where a helicopter was waiting. The helicopter flew me over the Rose Bowl to JPL. There, I landed on top of a building and was escorted to a control room. The folks at JPL meant to impress me—and they did—by stationing me where I could see controllers operating *Surveyor 7* on the surface of the Moon. I sat there fascinated while I watched these people at the console dig a trench on the Moon. It was fantastic! I just had to work there at JPL. Luckily, they offered me a job.

At JPL, I got to watch the planetary program mature—from the early *Mariner*s all the way through *Voyager* and *Galileo*. That was a privileged life. Where else in the world could you sit in the lunchroom and eat your sandwich while watching pictures being transmitted from another planet? It was a wonderful experience.

**TPR:** *How did you end up at NASA headquarters?*

## ANTICIPATING CASSINI

*Cassini* is one of the most thrilling planetary exploration missions we've ever done. It's going to one of the most visually stunning planets in the solar system. And it's going to one of the solar system's most intriguing moons, the only one with an atmosphere. There's organic chemistry happening right now in Titan's atmosphere—in this orange-reddish cloud below which we cannot see, hiding a surface that's got to be as unusual as anything we've yet witnessed in the solar system.

Actually, the Saturn system is full of exciting moons we'll get to see up close and personal. Saturn is kind of the junk yard of the solar system—the ring plane is filled with material. I anticipate a terrifically exciting mission.

The science we defined for it is extraordinarily comprehensive. *Cassini* is the last of the *Mariner* line. It's the culmination of JPL's large, comprehensive spacecraft. So, it has a huge complement of instruments aboard. That's appropriate, because it's hard to get to the Saturn system, so once you do, you want to be carrying a fair amount of good science.

*Cassini* is a mission of discovery. It's our first Saturn orbiter. We're going to find a host of things we were never expecting. So, I'm very much looking forward to it. My son graduates from college in June 2004, and the very next month, I'm going to be at JPL watching what happens when *Cassini* reaches Saturn on July 1. —*WTH*

*Launched from Cape Canaveral Air Force Station,* Cassini *began its 3.5-billion-kilometer (2.2-billion-mile) voyage to Saturn on October 15, 1997.* Cassini *is slated to reach Saturn on July 1, 2004 and begin its four-year tour of the Saturnian system. The spacecraft has already delivered stunning images of Jupiter and some of its moons, but the best is still to come: more than 300,000 color images of Saturn, its rings, Titan, and the planet's other moons, including 1,100 images taken by the* Huygens *probe.* Photo: JPL/NASA

**WTH:** At the time—this was 1988—I was the preproject US study scientist for *Cassini*, and we were trying to develop the mission concept and sell it to NASA. *Cassini* was then linked to another mission, the Comet Rendezvous Asteroid flyby, and I had been selected as the interdisciplinary scientist [IDS] for the coma, or the gaseous envelope around a comet. (I like to consider myself the "coma"tose IDS.)

I wanted to be involved in that mission in the worst way, and I also wanted to be the project scientist for *Cassini*—a terrific mission going to Saturn and Titan. All of a sudden, I got an offer to work at NASA headquarters under conditions likely to lead, ultimately, to a chance to play a major role in determining the nation's planetary exploration program.

Leaving JPL was a hard decision to make. It was a risk at the time, but it turns out, over the long run, to have been well worth it. In fact, I ended up as associate administrator at NASA, which I never expected. I had what I thought was the best job in Washington. I did that job for 10 years, and given how hard it is to perform such jobs in Washington, 10 years is long enough. So, in 1998 I left, content that I had accomplished some things, and went on to the Carnegie Institution of Washington as director of the Geophysical Lab, where I've been ever since.

***TPR:** We know of at least four people who turned down the chance to replace Dan Goldin as NASA administrator. Why the reluctance to accept this position?*

**WTH:** That's a hard question to answer, and I can only speculate, because the real answer has to come from the current administration. From what I can see, this administration, even more than the last, shows little interest in NASA or its programs. There's a tradition that the NASA administrator reports to the vice president, and it's been that way since the establishment of NASA in 1958. But the Clinton administration altered that tradition. Dan did not report to the vice president but to the president's science adviser, which is one rung down the ladder. In this administration, it seems NASA has even less visibility at the White House.

Someone running an agency like NASA needs the support and the ear of the administration. Otherwise, you can't accomplish anything. I think that might be one reason it's been difficult to find somebody.

***TPR:** Are you concerned about the near future of the space program?*

**WTH:** Yes, I am. And that concern has been heightened by the recent terrorist attacks. Dealing with the repercussions of those attacks is going to occupy much of the vice president's attention in this administration—as

**NEAR Shoemaker** *completed its mission to Eros on February 12, 2001, with an unprecedented landing on the asteroid.*

**Pathfinder** *landed on Mars on July 4, 1997. By the end of the mission,* **Pathfinder** *had collected more than 16,000 images of the Martian surface and nearly 8.5 million measurements of wind, pressure, and temperature.*

**Lunar Prospector** *orbited the Moon for one year before its July 31, 1999 controlled crash near the lunar south pole in search of water-ice.*

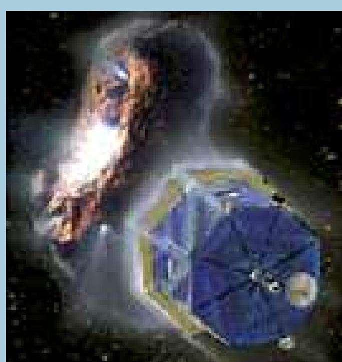
**Deep Impact**, *scheduled for 2005, will send an impactor to blast a crater into comet Tempel 1's nucleus to reveal the never-before-seen materials and structure of the interior of a comet.*

*When asked what he is most proud of during his years at NASA headquarters, Wes Huntress responded, "the Discovery program of low-cost planetary missions." The Discovery program opened up planetary exploration to more people, allowing the planetary science community to define its own missions. Currently consisting of eight missions (shown here clockwise from upper left)* **—NEAR Shoemaker, Pathfinder, Lunar Prospector, Stardust, Genesis, Contour, MESSENGER,** *and* **Deep Impact—** *the program strives to launch smaller missions every 12 to 24 months at a cost of less than $299 million per mission.*

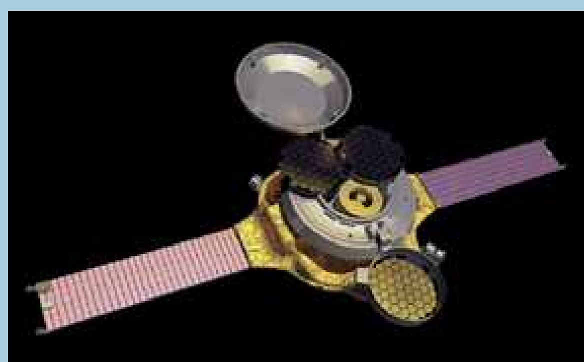
*Images: NASA*

**Stardust**, *launched on February 7, 1999, will encounter comet Wild 2 in January 2004, collect samples of interstellar dust, and return the samples to Earth in 2006.*

**MESSENGER**, *slated to launch in 2004, will complete two flybys of Mercury, mapping most of the planet and taking measurements of surface, atmosphere, and magnetosphere composition.*



**Contour**, *set to launch in August 2002, will visit at least two comets to study these mysterious building blocks of the solar system.*



**Genesis** *is now in orbit around Lagrange 1, or L1 (a place in space where the gravity between the Sun and Earth are perfectly balanced) and has just begun its two-year collection of solar wind. The samples will be returned to Earth in 2004.*

it probably should. However, this will further isolate the vice president from the civil space program. It will therefore be difficult to continue the same level of support the program has benefited from during its history. Congress has always been a friend of the space program. I'm hopeful that congressional support will still be there, and we currently also enjoy support at the civil service level in the Office of Management and Budget. My hope is that this combined support will help sustain the agency during a tough period in this nation's history.

***TPR:*** *How does the future of human exploration of space look to you?*

**WTH:** Since the end of the *Apollo* era, that enterprise has hung its hat on the space station. The space station is currently under construction, but like every endeavor involving human exploration, it's very expensive. It is unclear exactly what is going to happen. What happens in the near term depends a lot on the findings of the review committee, the Young committee, regarding space station funding and development difficulties.

The near term aside, I'm convinced that, in this century, humans will go to Mars. We'll go there because we will send robotic precursors. So, when humans get there, they will have all the support they need. In the meantime, getting there is not going to be easy. We have to resolve the space station issue. I wish I could tell you how I thought that could be done, but at the moment, I can't.

***TPR:*** *You mentioned the Young committee—what is that committee reviewing?*
**WTH:** The Young committee was commissioned by Dan Goldin in July 2001 when the $4 billion overrun to build the space station became an issue. Dan asked Tom Young, the former chairman of Lockheed Martin, to assemble a committee of engineers and scientists outside the agency to try and determine how to reorient the program in a way that would be acceptable—which to me means "stick to budget."

We're at a time, perhaps now more than ever, when sticking to cost guidelines is as important, if not more so, than the performance of the mission. In the old days, performance was the invariable parameter and cost the variable. What that meant was missions always cost more than expected. This continues to be a problem—we've had a number of cancellations in the planetary program—and the space station is in danger.

***TPR:*** *What do you see as the solution?*
**WTH:** Get the costs down. After the failure of the two Mars missions in 1998, the tendency has been to go overboard on mission assurance, and you can chew up a lot of money on mission assurance. There's an attitude now that failure is not an option—but it's always an option.

Of course, we need to design missions we expect will be successful, but I do think we've overreacted to the 1998 failures. We learned by experience in 1998 what the limits are to "faster, better, cheaper." In my view, instead of fixing what needed to be fixed based on what we learned, we backed off all the way to how we used to do missions; that is, performance is everything and cost isn't an issue. A Mars mission now, instead of approaching a cost of $300 million to $400 million, costs roughly $1 billion. That's too much to be sustainable.

It's a matter of balance. We're on a learning curve with "faster, better, cheaper," learning how to do these missions less expensively. We overextended ourselves, but now the pendulum has swung too far in the opposite direction.

***TPR:*** *Do you see new opportunities for international cooperation?*
**WTH:** Yes. One of the big disappointments in the late 20th century was the disappearance of the Russians from the scene of planetary exploration. They were great to compete with, though it is a shame we didn't join forces from the start—we would have accomplished far more than we can imagine today.

Now, Europe is becoming a strong player in planetary exploration, and Japan has sent a spacecraft to Mars, so the enterprise has become more inclusive. I think that's all to the good. The more countries that become involved, the better the hope for the future of humankind. After all, planetary exploration is a human enterprise, not just an American one—we simply happen to be leaders in the effort. And we need to continue to lead in order to draw the rest of the world into the enterprise.

***TPR:*** *What, in your wildest dreams, do you hope we might find out there in the universe?*
**WTH:** An independent origin of life, at least in our own solar system. I believe it's highly probable that there was an independent origin of life on Mars early in its history. That is, the same time that life originated on our planet, it originated on Mars. I also believe it's likely that this Mars life still exists somewhere on the planet, probably below the surface, under the ice caps, where the pressure of the ice melts a portion of the water underneath. I'm taking about microbial life, which is extraordinarily robust.

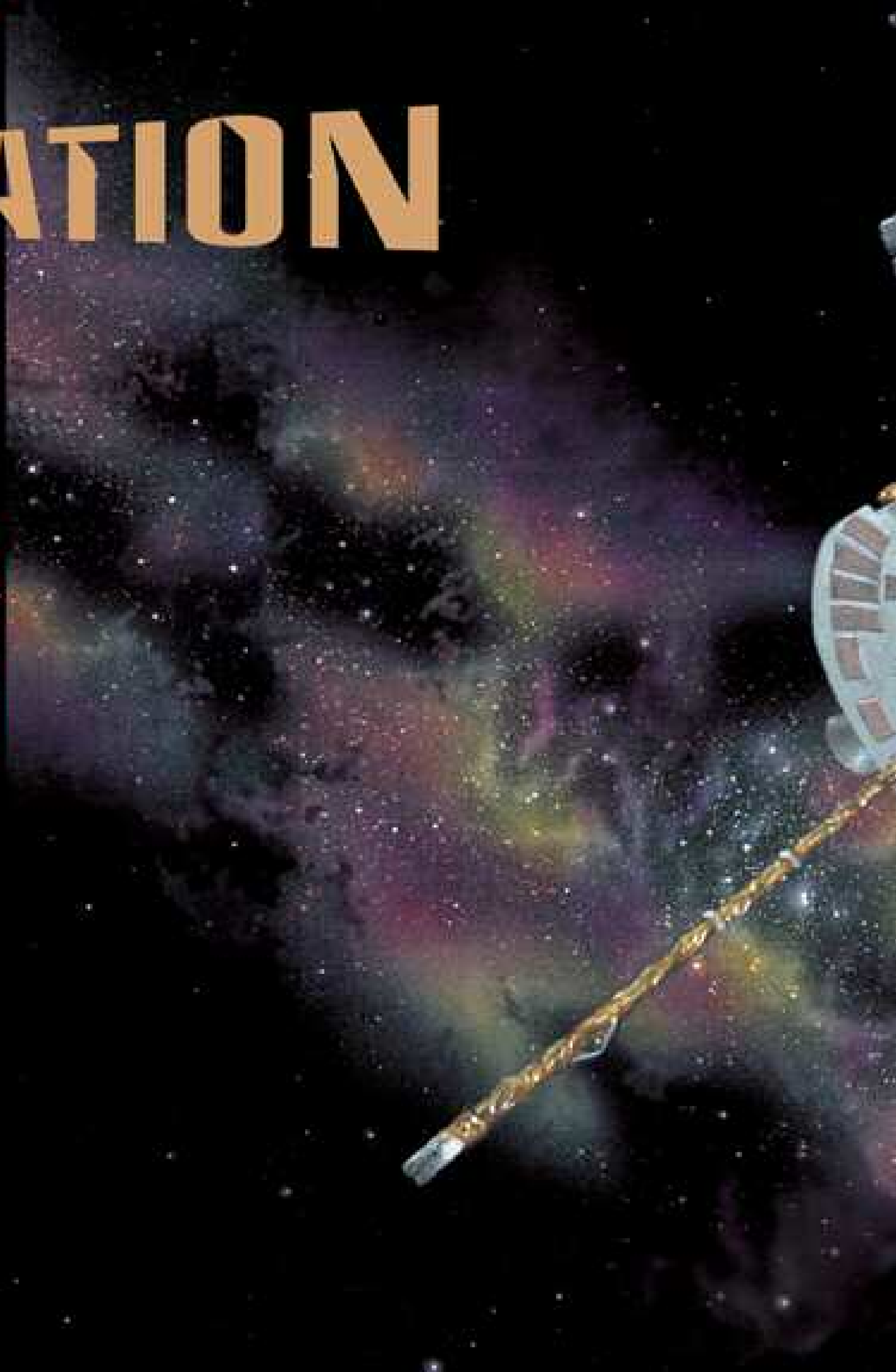
I think it's also probable, if we find an ocean under the ice on Europa, that we'll find microbes swimming there. The reason I say this is that a liquid ocean on Europa must be sustained by heat coming from the interior, otherwise it would freeze. This heat also produces volcanism and creates vents at the bottom of the ocean, which allow the inflow of nutrients on which life can thrive.

I fall in the optimist camp for life elsewhere, too. My bet is there is a law that the universe tends everywhere toward life.

***TPR:*** *How do you feel about living at a time when it's finally possible to make such assertions based on more than faith?*
**WTH:** It feels good. Really good. A host of evidence has been accumulating during the 1990s, through NASA's space science program and from biological research. I'm confident that as exploration and research continue, the chances get better and better of proving a theory of the prevalence of life.

**Read the full interview or listen to excerpts on planetary.org.**

# THE STRANGE ACCELERATION OF *PIONEER 10* AND *11*



Twenty-nine years after leaving Earth, and eighteen years after passing Pluto's orbit, *Pioneer 10* drifts through deep space. The Milky Way provides a backdrop for this vanguard explorer.

Painting: Michael Carroll

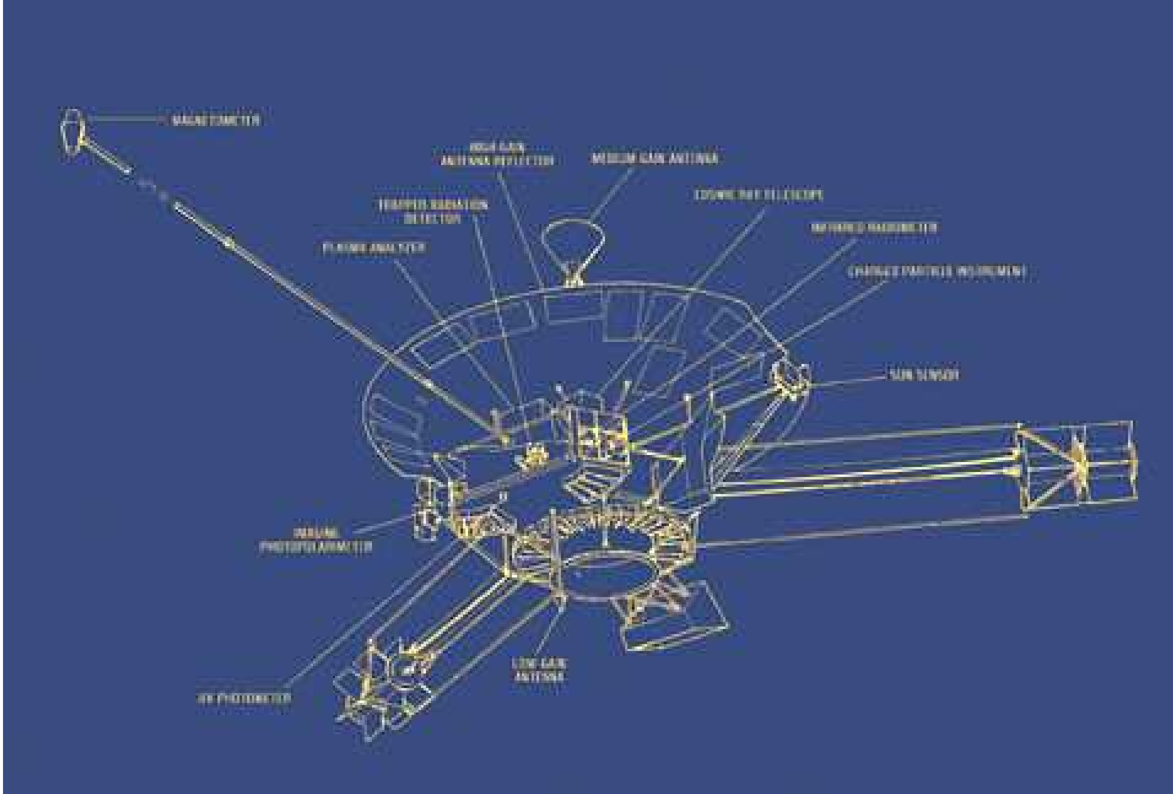
BY JOHN D. ANDERSON,
PHILIP A. LAING, EUNICE L. LAU,
MICHAEL MARTIN NIETO, AND
SLAVA G. TURYSHEV

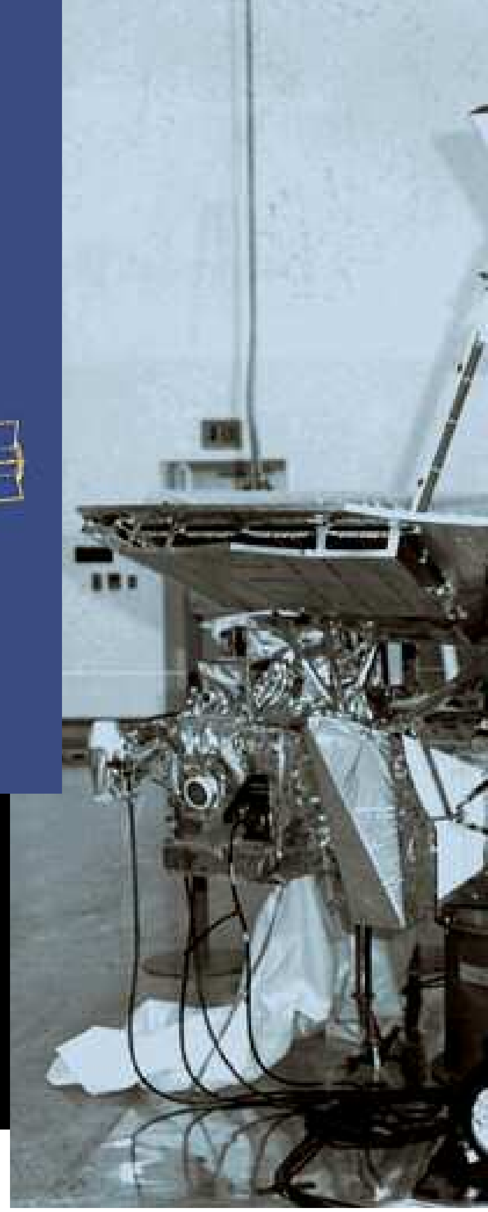
In the May/June 1999 issue of *The Planetary Report*, John D. Anderson published an article claiming that the *Pioneer 10* and *11* radio Doppler search for Planet X had come up empty. For this reason, among others, we were convinced the chance of discovering a 10th planet was slim. Although the discovery of numerous Kuiper belt objects (KBOs) proved there was plenty of material in orbit beyond Neptune, the presence of a single planet more massive than Earth seemed unlikely.

A number of 20th-century astronomers had suggested the existence of Planet X based largely on unexplained motions in the orbits of Uranus and Neptune. However, in 1993, E. Myles Standish Jr. of the Jet Propulsion Laboratory (JPL) showed that the orbits of these two outermost planets could be reconciled with all existing observations. There was no need for additional forces from Planet X or anything else.

Given these conclusions, one would think that further analysis of the *Pioneer 10* and *11* data would have been a waste of time—but not so. While searching for Planet X, we noticed that the Doppler data did not quite fit with the existing solar system model. Nor did the anomalous acceleration fitting the data match an expected Planet X force. A more precise verification of "anomalies" had been noted earlier but not followed up. When theoretical models do not fit experimental data, standard scientific practice is to find a reason for the mismatch. Therefore, we embarked on a program to study the anomalous acceleration.

We recently posted a report on the anomalous Doppler data at *http://arXiv.org/abs/gr-qc/0104064*. The report describes how, after all systematics are accounted for, there remains in the Doppler residuals a signal that can be interpreted as an anomalous acceleration directed *toward* the Sun. The result is of interest to fields as diverse as theoretical physics and precise deep-space navigation.





**Above: A schematic drawing of the *Pioneer* spacecraft.**

Illustration: Ames Research Center/NASA

**Right: The caption on this photo from NASA's archives reads: "The *Pioneer F* spacecraft during a checkout with the launch vehicle third stage at Cape Kennedy." *Pioneer F* would later be renamed *Pioneer 10*.** Photo: NASA

## THE SPACECRAFT

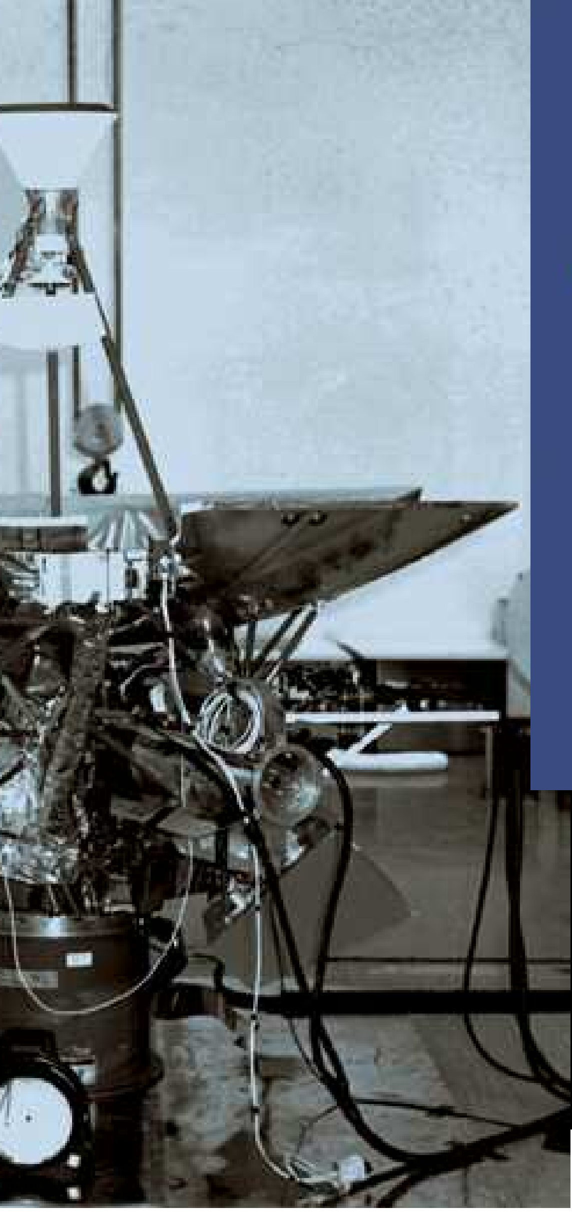
Some 29 years ago, on March 2, 1972, *Pioneer 10* was launched on an Atlas/Centaur rocket from Cape Canaveral. *Pioneer 10* was Earth's first space probe to an outer planet, encountering Jupiter on December 4, 1973. After Jupiter and (for *Pioneer 11*) Saturn encounters, the two spacecraft followed escape orbits near the plane of the ecliptic to opposite sides of the solar system. *Pioneer 10* was also the first mission to leave the solar system when, in June 1983, it passed beyond the orbit of the farthest known planet, Pluto.

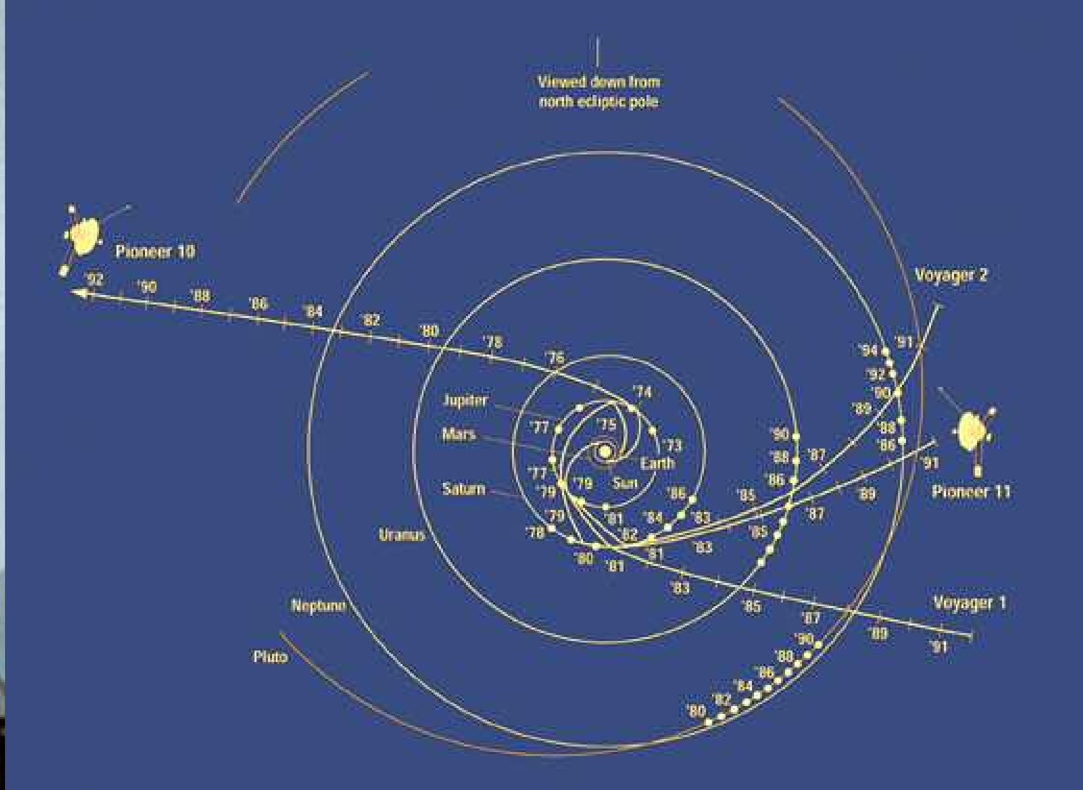
A switch failure in the *Pioneer 11* radio system on October 1, 1990 disabled the generation of coherent Doppler signals. So, after that date, when the spacecraft was approximately 30 astronomical units (AU) away from the Sun, no useful data were generated for the anomalous acceleration investigation. (One AU, the mean distance from the Sun to the Earth, is roughly 150 million kilometers, or 93 million miles.)

The *Pioneer 10* mission officially ended on March 31, 1997, when the spacecraft was at a distance of 67 AU from the Sun. However, the *Pioneer 10* radio system continues to operate, and the Deep Space Network (DSN) can still track the spacecraft and generate Doppler data for our investigation. DSN people do so because they want to test radio equipment and receivers with extremely weak signals from deep space. The SETI people, too, use the *Pioneer 10* signal to test their receivers, at the Arecibo radio telescope in Puerto Rico. (*Pioneer 10* certainly provides a weak signal. At the current distance of 79 AU, it is transmitting with a power of only 8 watts—less than is required by a small incandescent lightbulb.)

At a now nearly constant velocity relative to the Sun of 12.24 kilometers (7.6 miles) per second, *Pioneer 10* will continue its motion into interstellar space, heading generally for the red star Aldebaran, which forms the eye of the bull in the constellation Taurus. The round-trip light time to *Pioneer 10* is now approximately 24 hours.

In the future, we might be able to process the DSN Doppler data generated after the end of our current data set, July 1998. We would look for any changes in the anomalous acceleration and extend the distance over






**Above: The trajectories of *Pioneer 10* and *11*, as well as *Voyager 1* and *2*, are shown in this view from the ecliptic pole of the solar system. *Pioneer 11* is traveling close to the direction of the Sun's orbital motion around our galaxy's center. The Milky Way's core is located beyond the top of the illustration.**

**Illustration: Ames Research Center/NASA**

which it is known to affect spacecraft, from 70 AU in mid-1998 to at least 79 AU today.

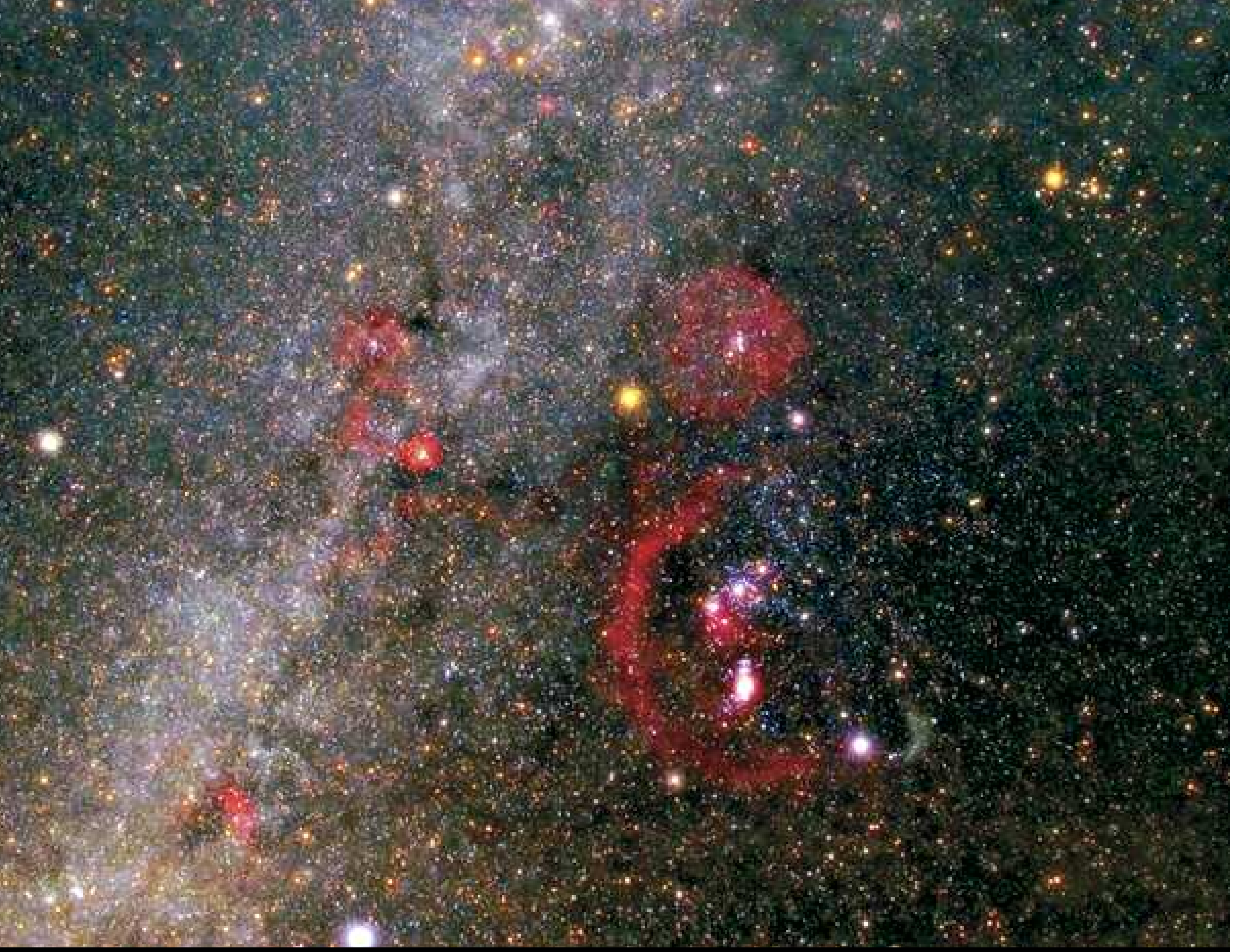
## THE DISCOVERY OF THE ANOMALY

Nongravitational forces acting on spacecraft are common. Unfortunately, they can cause problems for precision space navigation, as evidenced by the failure of the *Mars Climate Orbiter* (*MCO*). That spacecraft burned up in the Martian atmosphere because of an error interpreting the size of the measured small forces from the spacecraft's attitude control system. However, the *Pioneer* spacecraft are much simpler than *MCO* or, for that matter, any other spacecraft, including *Voyager*, *Galileo*, and *Cassini*. The two *Pioneer*s are simple spinners, with no continuous jetting of attitude control gas. Any nongravitational forces must come from solar radiation pressure (the same force that propels a solar sail) or from thermal or radio emissions generated by the spacecraft's power system—basically the Radioisotope Thermoelectric Generators (RTGs).

By 1980, when the spacecraft was at a distance of 20 AU from the Sun, the acceleration contribution from solar radiation pressure on *Pioneer 10*, away from the Sun, decreased to less than $5 \times 10^{-8}$ centimeters/second$^2$. This solar contribution fell off as the inverse square of the distance, as expected.

Hence, the *Pioneer* spacecraft were poor solar-sailing craft after they left the inner solar system. In fact, they were not designed for solar sailing even at one AU, although the effect could be seen easily in the Doppler data during the orbital transfer between Earth and Jupiter. But by 20 AU, it could barely be detected. At that point, we began to realize that another unexplained force was acting on the spacecraft, namely a predominant constant acceleration, $a_P$, directed *toward* the Sun.

After the discovery of the unexplained acceleration in 1980, two of us, John D. Anderson and Eunice L. Lau, decided to keep track of the anomaly. Yet, because we were reasonably sure the anomaly was some sort of navigation-modeling error, we did not give it high priority. We simply added a constant acceleration to our Doppler-fitting model so we could determine an accurate trajectory. We expected the anomaly would go away eventually. It did not.



This wide-range time exposure taken from the island of La Palma in the Canary Islands reveals an incredible view of stars, nebulae, the constellation Orion, and the Milky Way. Stretching across the image from the bottom left, faint stars compose the luminous band of the Milky Way. A group of yellowish stars at the upper right is dominated by the red giant Aldebaran, where *Pioneer 10* is headed. Image: A. Vannini, G. Li Causi, A. Ricciardi, and A. Garatti

In 1994, Michael Martin Nieto became involved. He was preparing a talk on tests of gravity for the 1994 Low-Energy AntiProton (LEAP) Workshop. He had contacted Anderson about how to tell if Newton's law holds on the interplanetary distance scale. To this day, he recalls the shock he felt when he received the e-mail from Anderson that said, "By the way, the biggest systematic in our acceleration residuals is a bias of $8 \times 10^{-13}$ kilometers/second$^2$ directed *toward* the Sun."

About this time, as it became clear a serious investigation into the systematics was in order, Slava G. Turyshev joined the team. Discussions with others in the physics and space navigation communities emphasized that before the claim could be taken seriously, an independent computer code would be needed to determine if the same result could be obtained. To this end, Philip A. Laing and the late Anthony S. Liu, a retiree under contract to The Aerospace Corporation, came on board. Phil and Tony, coworkers at JPL during the early *Pioneer* days, had later developed a navigation code, CHASMP, used for space navigation at The Aerospace Corporation.

With all collaborators now in place, the investigation of the anomaly shifted to a high-priority task. The Aerospace side of the collaboration was funded by NASA's Office of Space Science under a peer-reviewed grant from the Ultraviolet, Visible, and Gravitational Astrophysics Research and Analysis Program.

## THE STATUS OF THE ANOMALY

Using both JPL and Aerospace Corporation navigation software, we first analyzed in detail the data from January 1987 to July 1995. During that interval, the Deep Space Network had generated and delivered reduced radio Doppler data to Anderson and Lau, so it was readily available. After often contentious arguments on possible systematics, we concluded that there did indeed remain an unmodeled acceleration, $a_P$, toward the Sun of approximately 8 x $10^{-8}$ centimeters/second$^2$, for both *Pioneer 10* and *Pioneer 11.*

We published this result in *Physical Review Letters* in 1998, promising that a detailed investigation of the systematics would follow. During the course of that detailed study, and at our request, the DSN delivered more reduced Doppler data and extended the observing interval three more years, allowing us to complete our investigation.

Our conclusion, after all *known* systematics are accounted for, is that there remains an anomalous acceleration signal of $a_P = (8.74 \pm 1.25) \times 10^{-8}$ centimeters/second$^2$ directed toward the Sun. We emphasize *known* because we must admit that the most likely cause of the effect is some not-yet-understood systematic, probably generated by the spacecraft themselves. But neither we nor others with space science and spacecraft expertise have been able to find this effect. We conclude that the time has come to investigate the theoretical and experimental consequences such an effect, if real, would imply.

## WHERE DO WE GO FROM HERE?

Here are three possibilities, discussed one at a time. Many more have been suggested, at least some of which we take seriously.

- **Consideration of proposals that it is a new effect.**

Given that no satisfactory explanation has yet been found for the *Pioneer* results, a number of "new physics" suggestions have been made. These propose mechanisms that have their origins in cosmological, or large-scale, gravity/time effects. Does this mean the *Pioneer* effect is a short-range manifestation of cosmological phenomena? That is a stretch, but a possibility not to be discounted. Detailed phenomenological analyses are called for, and we plan to do them.

- **Consideration of proposals that Newtonian laws be modified**.

We have long been interested in the ideas of Mordehai Milgrom. These include a modification of our classical understanding of inertia and a Modified Newtonian Dynamics (MOND). MOND proposes that the normal gravitational force, which decreases with the square of the distance, is modified at very large distances. At such distances, the gravitational force would decrease as the inverse of the distance (not the square of the distance). As a result, the gravitational force would be relatively strong. The connection to the *Pioneer* spacecraft comes, first, because the *Pioneer* orbits are precisely analyzed hyperbolic orbits, and Milgrom considers a modified inertia in this situation. Second, although Newtonian dynamics rules out a tidal galactic force explanation, the force could in principle be large in the MOND case. We will investigate the possibility that these ideas are relevant.

- **Other experimental anomalies.**

If the effect remains unexplained, a look for related oddities is warranted. Unfortunately, the *Voyager* craft are not spin stabilized and are constantly jetting attitude control gas. An acceleration the size of the *Pioneer* anomaly is beyond detection with *Voyager* by about a factor of 10. The *Pioneer* craft are well tracked, small in mass, and on hyperbolic orbits. Thus, one possibility would be a statistical analysis of long-range asteroid and comet orbits. Perhaps better yet are Earth flybys used for gravity assists by the *Galileo*, *NEAR*, *Cassini*, and *Stardust* deep-space missions, also on hyperbolic orbits with respect to the Earth. The advantage of using Earth flybys is that the Earth's gravity field is well known from satellite and gravimeter data. However, after Earth gravity is taken into account, there do seem to be trajectory anomalies in at least the *Galileo*, *NEAR*, and *Cassini* data. The *Stardust* data, meanwhile, are corrupted by a constant gas jetting by the spacecraft's attitude control system, so they might not be useful. In any case, we plan to pursue a thorough investigation of the four available Earth flybys.

We owe it to any future space missions requiring accurate navigation or positioning that we gain an understanding of the *Pioneer* anomaly. The Space Interferometry Mission and a mission to Pluto and the Kuiper belt could be impacted. It is our hope either that the Pluto-Kuiper spacecraft in particular be designed so the on-board forces are well understood or that another dedicated craft be engineered specifically to repeat the *Pioneer* measurement beyond 20 AU. This is our hope independent of whether *Pioneer* revealed a manifestation of "new physics" or, alternatively, a systematic effect generated by spacecraft systems.

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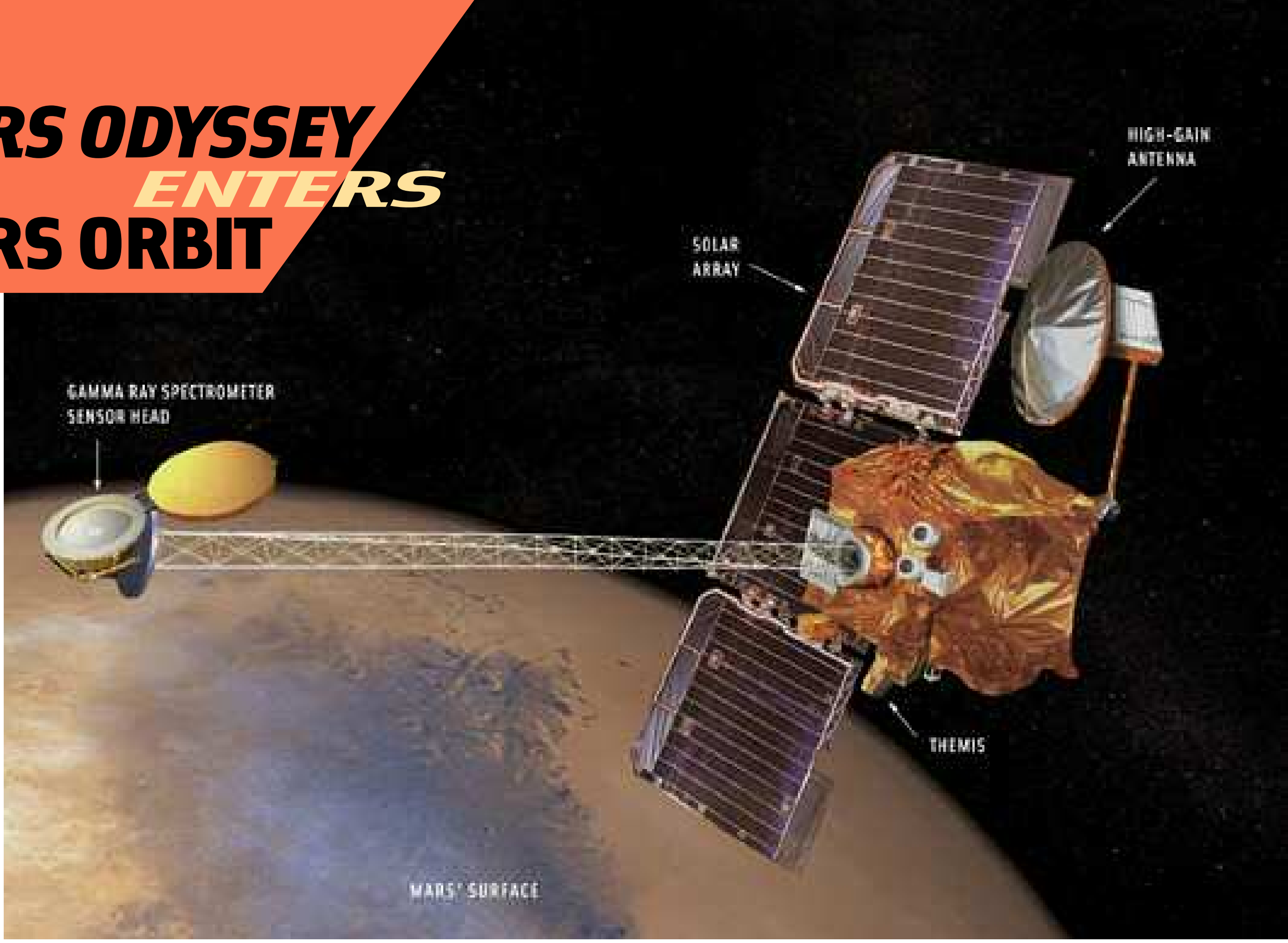
*John D. Anderson is an astronomer and senior research scientist, Eunice L. Lau is an applied mathematician and data analyst, and Slava G. Turyshev is a physicist and research scientist, all at the Jet Propulsion Laboratory. Michael Martin Nieto is a theoretical physicist at Los Alamos National Laboratory. Philip A. Laing is an engineering specialist in the Navigation and Geopositioning Systems Department at The Aerospace Corporation.*

# MARS ODYSSEY ENTERS MARS ORBIT




*This artist's rendering of* Mars Odyssey *in orbit showcases* Odyssey*'s science instruments that will be used to examine the Martian surface.*
*Image: JPL/NASA*

**by Bruce Betts**

After traveling 200 days and 460 million kilometers (about 285 million miles), the *Mars Odyssey* spacecraft successfully entered Mars orbit on October 24 (Universal Time; in the United States, it was the evening of October 23). The *Odyssey* mission will map the chemical and mineralogical makeup of the Martian surface and shallow subsurface, including looking into possible locations of liquid and frozen water, current as well as past. The spacecraft's successful orbital insertion is a morale boost for NASA after the two failures at Mars two years ago.

## Checking Baggage to Mars

*Mars Odyssey*, through no fault of its own, carries a lot of baggage—historical baggage, that is. NASA launched the *Mars Climate Orbiter* (*MCO*) and the *Mars Polar Lander* (*MPL*) in 1998. Both failed as they reached the planet. *MCO* failed during Mars Orbital Insertion (MOI), the same maneuver that *Odyssey* performed on October 24. Going further back in time, *Mars Observer* failed in 1992 as it prepared for MOI. Even the very successful *Mars Global Surveyor* (*MGS*), still operating in Mars orbit, had an aerobraking phase that took many months more than planned due to problems with a solar panel. Thus, things were a bit tense as MOI approached for *Mars Odyssey*.

After the failures two years ago, review committee after review committee evaluated *MPL*, *MCO*, JPL, and a series of other acronyms. Based on the resulting recommendations, NASA canceled the planned 2001 lander. Recommendations were also made to try to ensure the success of the *Odyssey* project. These included the addition of more staff and the transition of development personnel into operations.

NASA faced a real public relations problem if *Odyssey* failed—not to mention the loss of science. Mars is a tough place to go: only about one-third of all missions sent there have succeeded (this includes many Soviet/Russian attempts). Fundamentally, interplanetary spaceflight is hard. But, sadly, failures get much more publicity than successes, and NASA caught a lot of flak for the 1998 failures. Criticisms were raised that former NASA administrator Dan Goldin's mantra of "faster, better, cheaper" had been taken too far: too cheap and fast, and not better.

In addition to political baggage, *Odyssey* literally carries baggage from a past mission failure. The Gamma Ray Spectrometer (GRS) instrument on *Odyssey* is the last instrument lost in the *Mars Observer* failure to be reflown. All other *Mars Observer* instruments have reflown on *MGS* and *MCO*, although those on *MCO* have been unlucky twice now. Due to delays caused by the *Challenger* disaster, *Mars Observer* was postponed two years originally. So, the GRS instrument's history goes back 15 years, a long time to wait for a successful MOI.

## Success Where Others Failed

When all was said and done, *Odyssey* was tremendously successful with its MOI. Its orbit was almost exactly what was targeted—coming within one kilometer of the aim point, well within the hoped-for scenario.

Now, *Odyssey* is using a technique known as aerobraking to adjust its orbit. The spacecraft dips through the upper atmosphere of Mars to help it slow down. This saves greatly on the fuel the spacecraft must carry and therefore either frees up extra mass for science or allows the use of a smaller, cheaper launch vehicle. On the other hand, it adds risk and complexity.

## A Unique Situation

For the first time since the *Viking* orbiters in 1976, there are two working orbiters at Mars. And for the first time ever, there are two different but complementary orbiters.

The instruments on the two spacecraft are different and therefore not redundant, and the resulting data are nicely complementary. In addition, *MGS* is actively supporting *Odyssey* by providing critical atmospheric information that helps in planning *Odyssey*'s aerobraking. Included is information on the atmospheric density at various altitudes, the key to determining how much braking each aerobraking pass will provide.

## The Future

*Odyssey* itself is poised to aid future missions. *Odyssey* data, particularly from the THEMIS (Thermal Emission Imaging System) instrument, may help narrow down landing-site possibilities for the Mars Exploration Rovers that will be launched in 2003. In addition, *Odyssey*'s UHF antenna will provide a key communication link from the rovers to Earth. *Odyssey* and *MGS* are scheduled to be joined by another orbiter in 2005, the *Mars Reconnaissance Orbiter*, which will give us our highest-resolution look at the surface to date, down to tens of centimeters, as well as a new and different set of compositional data.

*Odyssey* will continue its aerobraking through January 2002. Once in near-polar-mapping orbit, it will commence the science-mapping phase of the mission, which will last more than a Martian year (Mars year = 687 Earth days). The THEMIS instrument is taking some data now, but data volume will increase tremendously when mapping starts.

*Mars Odyssey* is taking its place as one of the elite fleet of orbital spacecraft that is helping humankind complete the reconnaissance phase of Mars exploration. Its contributions will include the first elemental map, the best ability so far to track the existence of water in and near the surface, and the first-ever look at the hundred-meter-scale composition of the surface. All these observations are critically important to answering questions about Mars' past, present, and future.

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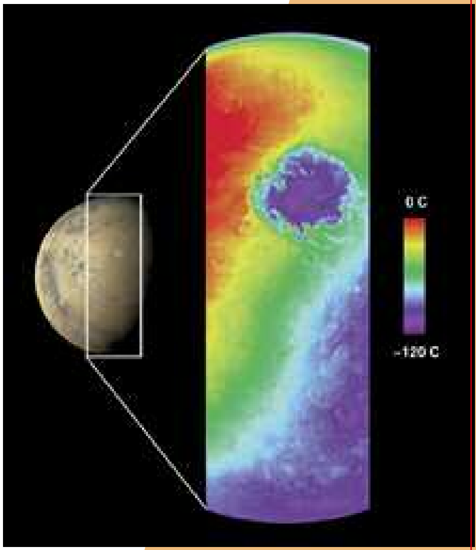
*Bruce Betts, director of projects for The Planetary Society, is a planetary scientist.*




***On October 30, 2001, as* Mars Odyssey *orbited Mars on its ninth revolution, the Thermal Emission Imaging System (THEMIS) acquired its first image. The image above, taken as part of the calibration and testing process of the camera system, shows the temperature of Mars in one of the 10 thermal-infrared filters. Registering about – 120 degrees Celsius (– 184 degrees Fahrenheit), the circular feature shown in blue is Mars' south-polar carbon dioxide ice cap. The cap, which currently is more than 900 kilometers (540 miles) in diameter, will shrink as summer progresses. Clouds of cooler air blowing off the cap can be seen in orange, extending across the image to the left of the cap. The cold region in the lower right portion of the image shows the nighttime temperatures of Mars, demonstrating the "night vision" capability of the camera system. The thin blue crescent along the upper limb of the planet is the Martian atmosphere.***

***Image: NASA/JPL/Arizona State University***

## *Odyssey* Science

*Odyssey* carries three dedicated science instruments: THEMIS, a thermal-infrared and visible imager; the GRS, a gamma ray spectrometer that also includes neutron spectrometers; and MARIE, a radiation detection experiment.

**THEMIS (Thermal Emission Imaging System)** will provide images of Mars in both the thermal-infrared (basically seeing temperature differences on the surface) and visible spectra. The thermal-infrared portion will also be able to map mineral composition by comparing different wavelengths observed. The presence or absence of certain minerals can provide clues as to the history of the Mars surface, including the possible identification of where liquid water may have been present in the past.

The **GRS (Gamma Ray Spectrometer)** and its associated neutron spectrometers are designed to determine the presence of 20 chemical elements on the surface of Mars, including hydrogen in the upper meter of the surface. The presence of hydrogen can be used to infer the distribution of water-ice. This is the first mapping of the elemental, as opposed to the mineralogical, composition of the planet.

**MARIE (Martian Radiation Environment Experiment)** is designed to measure the nature of the radiation environment on the way to Mars and in orbit at Mars, particularly with regard to safety issues for future astronauts. The MARIE instrument collected data during the first four months of the cruise to Mars but was turned off in August 2001 after failing to respond to a downlink request. Attempts will be made to revive the instrument after *Odyssey* enters a mapping orbit.

# Questions and Answers

***The September 7, 2001 issue of* Science *mentioned that the Moon is deficient in iron, while Earth's crust has more than expected. Might this be due to the conditions that created the Moon?***
**—Alfred C. Hexter,**
**Kensington, California**

When talking about the "iron content" of the Moon, you must keep several concepts distinct. The "bulk" Moon is depleted in iron, relative to the "bulk" Earth. That is because Earth has a huge iron core, while the Moon's core is tiny. Because iron is the most common high-density element in the solar system, we conclude that the bulk Moon has much less iron than does the bulk Earth.

However, my article in *Science* was discussing the iron content of the Moon's outer layer, or crust. The crust has even less iron content than does the bulk Moon because it's made up of anorthosite, a low-density, low-iron rock composed almost entirely of the aluminum-rich mineral plagioclase.

Both the *Clementine* and *Lunar Prospector* spacecraft have confirmed the great abundance of anorthosite in the Moon's crust. Because anorthosite forms only by removing crystallizing plagioclase from magma (molten rock), the thick, global layer of anorthosite on the Moon indicates that at least the outer part of the Moon was once molten. We call this stage the lunar "magma ocean." It resulted from the giant impact that created the Moon.

So, to answer your question directly, yes, the composition of the Moon does reflect the conditions of its formation. In fact, lunar composition provides important clues toward reconstructing the Moon's history and evolution.
—PAUL SPUDIS,
*Lunar and Planetary Institute, Houston*

## Factinos

***At a diameter of 24 kilometers (14 miles), Europa's largest known central peak impact crater, Pwyll (image above), contains a central peak roughly 5 kilometers (3 miles) in diameter and about 500 meters high. Recent calculations suggest that if there were warm, convecting ice beneath Pwyll's peak, the peak would have disappeared in less than a year.*** *Image: JPL/NASA*

Impact craters on Jupiter's moon Europa show that the satellite's brittle ice shell crust is more than 3 to 4 kilometers (1.8 to 2.4 miles) thick, report two University of Arizona (UA) scientists in the November 9, 2001 issue of *Science*.

Some researchers say Europa's crust must be only 1 or 2 kilometers (0.6 to 1.2 miles) thick, based on observations of ridges, cycloid cracks, and other geological features. Others contend that the crust must be 10 times thicker and that it includes a warm, convecting ice layer that shapes observed surface features.

Elizabeth P. Turtle and Elisabetta Pierazzo of the UA Lunar and Planetary Laboratory simulated impacts powerful enough to produce central peaks in impact crater images returned by *Galileo*. At least 6 of 28 impact craters observed by the *Galileo* and *Voyager* spacecraft have well-defined central peaks, Turtle said. They are found in craters larger than 5 kilometers (3 miles) in diameter.

"The morphologies [structures] of some craters indicate that these impacts didn't completely vaporize or melt through a cold, brittle ice layer on Europa. So, based on this observation, our impact simulations demonstrate that the ice crust must be more than 3 to 4 kilometers thick," Tuttle stated.

"What we're seeing here on Europa appear to be standard central peaks," she explained. "Since central peaks are deep material that's been uplifted, that means these impacts could not have penetrated through Europan ice to water. Water would not have been able to form and maintain a central peak."
—from the University of Arizona

The evolution of complex life on Earth may have been jump-started by a rise in oxygen in our planet's early atmosphere, say two teams of scientists from NASA's Ames Research Center. The groups reported their findings in the July 19, 2001

***Will* Mars Odyssey *photograph Phobos and/or Deimos while waiting out the current dust storm on the Red Planet (as* Mariner 9 *did in 1971)?***
**—J. Jason Wentworth, Fairbanks, Alaska**

*Mars Odyssey*'s camera, THEMIS (Thermal Emission Imaging System), will not be used for routine science operations until its aerobraking phase is completed next January. We do not know what the atmospheric conditions will be at that time, but it is quite likely the dust storm season will be over. During the science phase, the spacecraft's orbit will be only 400 kilometers (250 miles) above Mars' surface, which is too far from Phobos or Deimos to get any useful data.

Because *Mars Odyssey*'s flight team is focused on safe and successful aerobraking during the current aerobraking phase, science observations have been kept to a minimum. We considered observations of the moons at one point during the mission design, but we decided not to attempt them during aerobraking.
—JEFF PLAUT,
*Jet Propulsion Laboratory, Pasadena*

***The most recently discovered moons of Saturn have elongated orbits and are widely considered to be bodies captured into their orbits long after the planet formed. If these (and similar moons in the solar system) did not coalesce in orbit around their parent bodies, why do they deserve the distinction* moon *any more than planet-size bodies that did not coalesce in orbit around a parent star deserve the distinction* planet*?***
**—Bruce Bowman, Ann Arbor, Michigan**

This is really an issue of conventions in language use. In planetary science, everyone seems satisfied to say a moon is any body moving around a planet. At the same time, they say moons have formed by as many as three different mechanisms: co-formation (like miniature solar systems), capture, and planetary impact.

When it comes to the word *planet*, we have not yet agreed on the "conventional" meaning. To some, a planet is any body, which is not a star or brown dwarf, that is moving around a star; or it is any body smaller than a specified critical mass moving around a star. But to others, the word *planet* connotes that the body formed as did the planets in our own solar system. They make a distinction between "real" planets that formed like ours and other bodies of similar mass that might have had different histories.

This issue of semantics is becoming more important as we discover that many other planetary systems do not have circular, coplanar orbits like those of our own solar system.
—WILLIAM K. HARTMANN,
*Planetary Science Institute, Tucson*

issue of *Nature* and the August 3, 2001 issue of *Science*, respectively.

Tori Hoehler and his team reported in *Nature* that they'd measured gases released from modern microbial mats in Baja California, Mexico under conditions simulating our planet's early atmosphere. These mats are close cousins to those that once made up much of the young Earth's biosphere. The team found that the mats released large amounts of hydrogen at night. "If the Earth's early microbial mats acted similarly to the modern ones we studied, they may have pumped a thousand times more hydrogen into the atmosphere than did volcanoes and hydrothermal vents, the other main sources," Hoehler said.

In *Science*, David Catling and his team argue that oxygen increased in Earth's atmosphere more than 2 billion years ago because hydrogen atoms from water hitched a one-way ride into space inside methane gas produced by primitive microbes. This irreversible loss of hydrogen, they say, left behind an excess of oxygen, which gradually filled Earth's crust and then flooded its atmosphere.

According to Catling, his theory of high levels of hydrogen-containing methane gas, which acquired its hydrogen indirectly from water, also would account for why early Earth didn't freeze.

"Three billion years ago, the Sun was only four-fifths as bright as it is now. The Earth should have frozen over," he said. "But methane, a powerful greenhouse gas, would have kept the Earth warm."
—from NASA Ames Research Center

Eight new extrasolar planets have been discovered by an international team of scientists. While the majority of extrasolar planets found so far have elongated or "eccentric" orbits, at least two of the newly detected worlds have orbits that are roughly circular.

"As our search continues, we're finding planets in larger and larger orbits," said Steve Vogt of the University of California at Santa Cruz' Lick Observatory. "Most of the planetary systems we've found have looked like very distant relatives of the solar system—no family likeness at all. Now we're starting to see something like second cousins. In a few years' time, we could be finding brothers and sisters."

The recently detected planets range in mass from 0.8 to 10 times that of Jupiter. They orbit their parent stars at distances ranging from 0.07 to 3 astronomical units (AU). (One AU is about 150 million kilometers [93 million miles], or the mean distance from Earth to the Sun.)

For most of their discoveries, the researchers used the Keck 10-meter telescope on Mauna Kea, Hawaii; the Lick 3-meter telescope in Santa Cruz, California; and the 3.9-meter Anglo-Australian telescope in New South Wales, Australia.
—from NASA and the National Science Foundation

# Society News

## What Do You Think NASA Should Be Doing?

At NASA's request, the National Research Council is conducting a community assessment of the scientific priorities of the US planetary science programs for the next 10 years. The Planetary Society has been asked to assist this "decadal survey" by seeking input from the general public on planetary exploration via an online opinion survey. Please visit *planetary.org* and make your thoughts known.

*—Bruce Betts, Project Manager*

## Society Dues Increase—Renew Today and Save

After 10 years without a dues increase, The Planetary Society will raise annual membership dues by $5, beginning January 31, 2002. This means US members will pay $30, Canadian members $40, and international members $45. The $5 increase will help ensure the continuation of our groundbreaking projects. Your yearly membership dues truly do "make it happen."

Now for the good news: all current members are welcome to renew at the old rate for as many years as desired. Renew before January 31, 2002 for one, two, ten years, or more and pay the old membership rate. Even if you've already renewed for this year, you can still sign up for additional years of membership. So, call us at (626) 793-5100 before the January 31 deadline.

*—Stephanie Lam, Data Processing Manager*

## The Planetary Society Scholarship Program

The Planetary Society is offering university scholarships for space-related studies at either the undergraduate or graduate level. We will award two $1,000 scholarships annually for five years, beginning with the 2002–03 academic year. Members or persons nominated by members (one nomination per member) must submit their applications to The Planetary Society by April 30, 2002 for next year's awards. For an application, call Linda Wong at (626) 793-5100, e-mail her at *tps@planetary.org*, or write to: Planetary Society Scholarships, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

The Society is offering a full-tuition scholarship to the International Space University (ISU) Summer Session Program in Pomona, California for the June 29–August 31, 2002 session. Students accepted to the program who have not received other financial aid are eligible. (The scholarship will be awarded from among a pool of candidates determined by ISU to meet these criteria.)

*—Linda Wong, Program Development Administrative Assistant*

## Telescope Discounts Extend to 2002!

TPS members wisely took advantage of substantial savings on telescopes at Discovery Channel Stores for their holiday shopping. Now The Discovery Channel Store agreement with The Planetary Society, offering members a 10 percent discount on any telescope purchased at Discovery Channel Stores or *discoverystore.com*, has been extended into 2002! To benefit from this tremendous opportunity, simply show your Planetary Society membership card at any Discovery Channel Store or use the coupon code "PLANET" for online purchases.

*—Charles Nobles, Chief Operating Officer*

## Planetarium Discounts: The List Grows

To offer our members even more, we're continuing to negotiate discounts with planetariums worldwide. We're up to 43 participating planetariums—and counting! Planetariums in Austria; Alberta, Canada; Arizona; British Columbia, Canada; California; Connecticut; Florida; Georgia; Idaho; Illinois; Kentucky; Louisiana; Massachusetts; Michigan, Minnesota; North Carolina; New Jersey; New Mexico; New York; Nevada; Ohio; Oklahoma; Pennsylvania; Tennessee; Texas; Virginia; and Wyoming are offering discounts ranging from 15 to 100 percent off admission prices. For a complete list and more specific information, visit *planetary.org* or call Linda Wong at (626) 793-5100.

*—Linda Kelly, Program Development Manager*

## Special Thanks

We thank these companies for their support through matching-gift programs: A G Communications Systems; Adobe Systems Inc.; AES Duck Creek; Allegro Microsystems Inc.; Alyeska Pipeline; Ameritech Foundation; American Express Foundation; The Bank of America Foundation; Benjamin Moore & Co.; BP Amoco Foundation; The Chase Manhattan Foundation; Chubb; Cisco Foundation; Compaq; Computer Associates International Inc.; Datascope; Elser Enterprises Inc.; Enron Foundation; Equistar; Exxonmobil; Fannie Mae Foundation; Gannett Foundation; Honeywell; Investors Bank and Trust; J P Morgan; John Hancock; Kirkland & Ellis Foundation; Levi Strauss Foundation; Microsoft Matching Gifts Program; Monsanto Fund; N Y Marine & General Insurance Co.; Nokia; Norton Company Foundation; The David and Lucille Packard Foundation; The Prudential Foundation; Reader's Digest Foundation; Real Networks Foundation; SAFECO Insurance Company; The St. Paul Companies Foundation; Sun Microsystems Foundation; Tenet Healthcare Foundation; Times Mirror Foundation; United Technologies Corporation; The UPS Foundation Inc.; US Borax Inc.; US West Foundation; The Williams Companies; Veritas; Verizon.

*—Lu Coffing, Financial Manager*

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The Planetary Society's *Cosmos 1*, the first-ever solar sail, will take off into orbit early next year. This commemorative T-shirt is a Society exclusive. Long-sleeved, with glow-in-the-dark ink, it's perfect for dark nights of solar sail watching.
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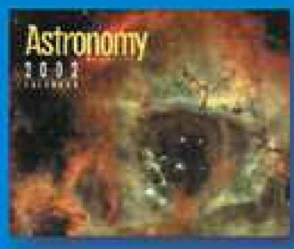


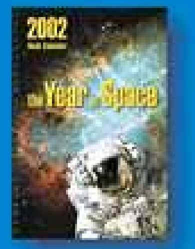


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*The Millennium Planet* depicts the huge, bluish gas giant (eight times the mass of Jupiter) in orbit around the star Tau Boo, some 50 light-years from Earth. Glowing aurorae and a close, tidally disrupted moon are David Hardy's own additions. This planet got its nickname because its discovery was widely reported near the end of 1999.

David A. Hardy illustrated his first book (*Suns, Myths, and Men* by Patrick Moore) in 1954 at the age of 18. His work has appeared in hundreds of books and magazines, and he has produced art for television, cinema, computer games, and packaging. He lives in Birmingham, England.

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