The PLANETARY REPORT

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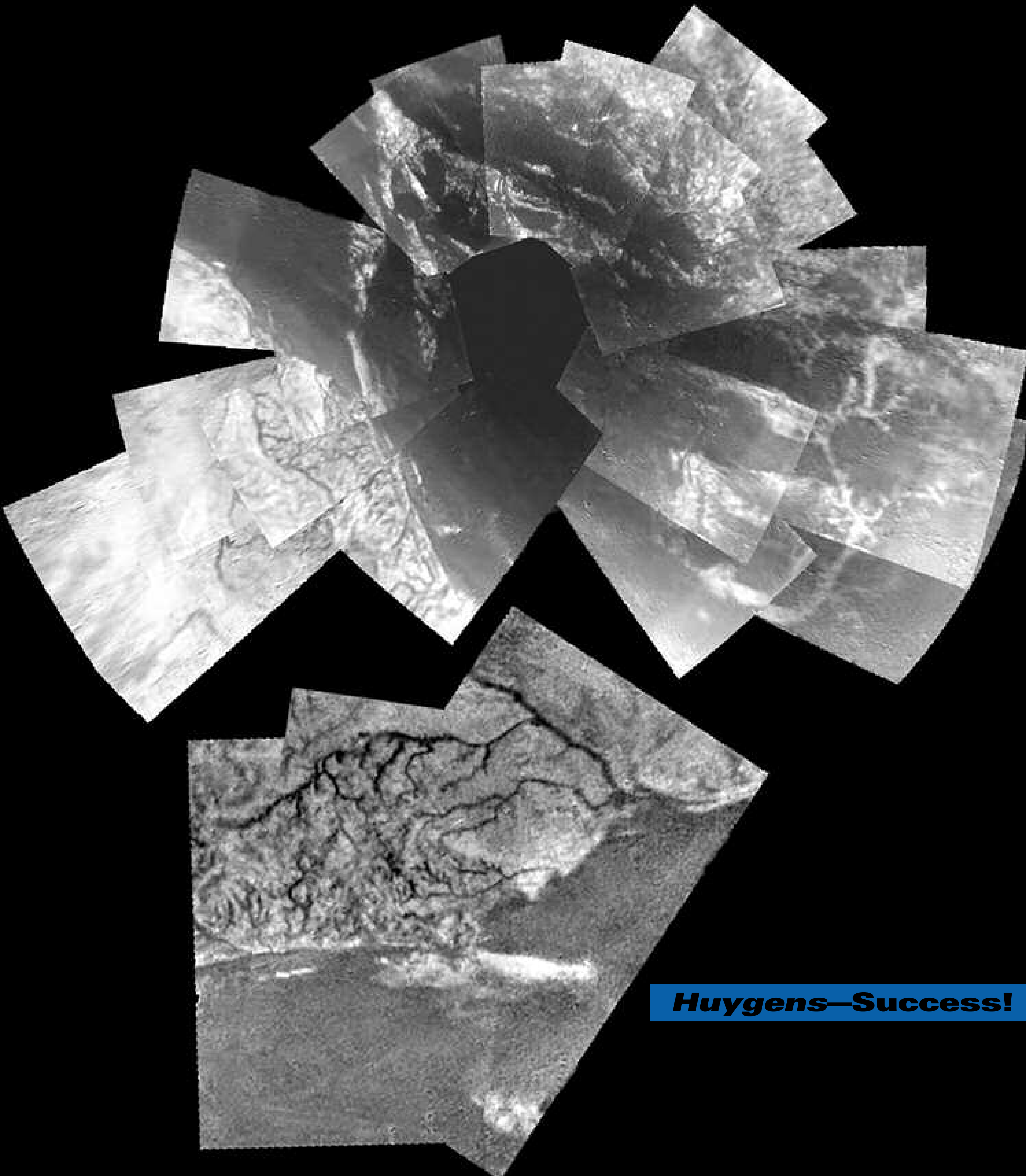

Huygens—Success!

A PUBLICATION OF THE PLANETARY SOCIETY

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2004 was an incredible year—with three spacecraft arriving at Mars and *Cassini* orbiting Saturn—and Society members were part of it all. For our members, we have put together a short report on our activities and an overview of the Society's financial status.

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From The Editor

We are waiting. We've been waiting 4 years. We are impatient. But this is something truly worth waiting for.

What has us all standing around, champing at the bit, on tenterhooks, and all those other clichés, is the launch of *Cosmos 1*, the first solar-sail spacecraft, on its mission to orbit Earth and demonstrate the feasibility of a technology that could one day take us to the stars.

The only thing that makes the delays bearable is knowing that we are doing what is necessary to ensure the success of our mission. It's a commonplace saying that a project can be done more quickly, less expensively, or better—but you can't have all three at the same time. The "faster, cheaper, better" mantra of NASA, to our regret, did not prove doable. We faced precisely this situation with our solar sail.

We are operating on a fixed budget, provided by Cosmos Studios, Peter Lewis, and the members of The Planetary Society. We have allowed improvements to our spacecraft to creep in, knowing that each redundancy and upgrade increases our chances of success. The element we have let slide is schedule.

So we will not meet our published launch date. But all that stands in our way now are final tests of the assembled craft and scheduling the launch with the Russian navy, which will send *Cosmos 1* into orbit with a converted submarine-launched ballistic missile. We're within weeks of reaching our goal. Fingers crossed! Good luck to us all!

—Charlene M. Anderson

On the Cover:

Top: As *Huygens* floated down through Titan's atmosphere, it captured these 30 images from altitudes of 13 to 8 kilometers (9 to 5 miles). Details are visible down to about 20 meters across, and the images cover an area 30 kilometers (about 19 miles) wide.

Bottom: A mountainous coastline marks the landscape near *Huygens*' landing site, as seen in this mosaic. Dark channels drain into a major river below. To terrestrial eyes, this looks like an aerial photo of a scenic lakeshore, but on Titan, water behaves like rock and hydrocarbons flow like water. Images: ESA/NASA/University of Arizona

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Members' Dialogue

Titan on the Web

We're glad you liked our web coverage of Huygens' *landing on Titan from the European Space Agency's European Space Operations Center in Darmstadt, Germany. Here are a few of the comments we received through* planetary.org.

Congratulations to all the many thousands of dedicated people who have made this age of wonder and excitement a reality. More to the point, thank YOU!

I was ten years old when *Sputnik* was the wonder of the world. That I have lived to see images of so many of my neighbors in the solar system knocks me out!

Thanks again to all those around the world who made this possible. I'm proud to be a member of The Planetary Society and, when we show this side of our nature, of the human race.

—THOMAS JORDAN,
Englewood, New Jersey

Emily Lakdawalla's reporting from Germany is simply wonderful! Her firsthand reports from the press conferences have given us all an insight into what goes on behind the scenes. She is a marvelous writer and a charming personality.

Thanks to Emily for her brilliant reporting and thanks for all the fascinating images and sounds from Titan. Thank you, Planetary Society, for all that you do.

—GORDON FIKES,
Gilmer, Texas

Please accept my hearty congratulations for your web log reporting of *Huygens*' landing on Titan. Your Society's science and technology coordinator, Emily Lakdawalla, has provided exciting "up-to-the-minute" coverage of this historic event that is unmatched by anything I have seen and read on the Web to date.

—RON LOCKWOOD,
Cape Town, South Africa

Interstellar Flight Technology

In "*Cosmos 1*: The Journey Begins" (see the November/December 2004 issue of *The Planetary Report*), the authors state that the solar sail is the only technology that may take us to the stars.

Back in the 1970s or 1980s, there was a feasibility study called "Project Daedalus," which determined that a fusion-powered ship (robotic) was capable of exploring Sirius. Travel time was about 12 years. The ship used pulsed microfusion explosions as a propellant.

No doubt, solar sails are far more financially probable than ships of the type described by Daedalus. However, that technology was investigated several decades ago and determined to be possible—just very expensive.

—FABIAN STRETTON,
Melbourne, Australia

Thanks for your note. Our statement about the only known technology for interstellar flight is based on several studies that all reached the same conclusion—two were done by NASA, and one was part of a technical conference on interstellar flight.

Nuclear fusion and other approaches are theoretically interesting but require bringing along large amounts of fuel. When the engineers got deeply into these studies, they were unable to find any practical mission possibility.

Of course, for interstellar sailing, we are probably a century or more away from being able to develop the kind of laser power that will be required for practical flight.

—Louis D. Friedman,
Executive Director

Proper Credit

How could I not agree with your reader James S. Veldman (see the January/February 2005 issue) regarding human spaceflight—especially when he says: "there is a window of opportunity for going into space, and that window will not remain open indefinitely."

However, for the sake of accuracy, may I point out that it was not Sir Patrick Moore who wrote the words in our foreword (from which this was paraphrased) but myself. Mr Veldman refers to "his [Moore's] recent book *FUTURES*," but the full title is: *FUTURES: 50 Years in Space* by David A. Hardy and Patrick Moore. The book celebrates the 50 years since Patrick and I first collaborated.

Speaking of anniversaries, may I offer my congratulations on The Planetary Society's silver anniversary. May the Society go from strength to strength, and accomplish its aims.

—DAVID A. HARDY,
Birmingham, England

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We Make It **Happen!**

by Bruce Betts

We are approaching the launch of The Planetary Society's largest and most challenging project ever: *Cosmos 1*, the first solar sail. *Cosmos 1* is a bold endeavor for an independent nonprofit organization such as The Planetary Society to undertake, but with our members and our primary sponsor, Cosmos Studios, we are making it happen.

Last November, we announced that *Cosmos 1* would launch in March. Now we know we will need to wait a little longer before the spacecraft takes off on its journey. Here, Louis Friedman, The Planetary Society's executive director and project director for *Cosmos 1*, updates us on the spacecraft's status. A more complete update as well as future updates can be found at *planetary.org/solarsail.*

Solar Sail Update

In mid-January, our lead consultants, Harris M. (Bud) Schurmeier and James Cantrell, went with me to Moscow to review the final stages of testing Cosmos 1 *and to judge when our solar sail spacecraft would be ready to fly.*

Flight components have all been delivered and thoroughly tested, and a full mission sequence has been simulated with the onboard computer. Our announced launch period of March 1 to April 5, 2005 has slipped approximately 6 weeks because we're taking more time for extra testing. The testing on the spacecraft has gone well, but some corrections and fixes have been required. To enhance reliability, extra precautions have been implemented in both the hardware and software of the spacecraft. We do not rule out other small slips if we take a few extra days here or there in flight preparations, testing, or last-minute checks.

The flight unit is almost fully assembled. To minimize the time that the sails are packed, they will be folded only in the last month before Cosmos 1 *is sent to the launch site. The last thing the engineers will attach to the spacecraft will be a CD carrying the names of Planetary Society members and selected documents from the history of solar sailing. The final test that* Cosmos 1 *will undergo will be*

What's **Up?**

In the Sky

Jupiter is at opposition (opposite the Sun from the Earth) on April 3. Rising around sunset and setting around sunrise, it is the brightest starlike object in the sky right now. Saturn is in the southwest after sunset, south in mid-evening. It looks yellowish, with its rings very open, great for viewing in a small telescope. Mars is low in the southeast at dawn, looking yellowish-red. The Moon is near Jupiter on March 26 and April 21 and 22, near Mars on April 3 and 4, and near Saturn on April 15.

There is a hybrid solar eclipse (total eclipse along part of its path and annular eclipse on the rest) on April 8, with the path stretching from New Zealand to South America. A partial eclipse is visible from portions of North and South America. See *http://sunearth.gsfc.nasa.gov/eclipse/solar.html* for details.

Random Space Fact

Twenty-one percent of Earth's atmosphere is oxygen. Almost all of it was produced by life (plants)!

Trivia Contest

Our November/December contest winner is John Anderson of Northern Ireland, UK. Congratulations!

The Question was: What is the gap between Saturn's A and B rings called?

The Answer: The Cassini division.

Try to win a free year's Planetary Society membership and a Planetary Radio T-shirt by answering this question: ***Hydrogen makes up most of the giant planets (Jupiter, Saturn, Uranus, and Neptune). What gas is the second most common material in the atmospheres of all the giant planets?***

E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 65 North Catalina Avenue, Pasadena, CA 91106. Make sure you include the answer and your name, mailing address, and e-mail address (if you have one).

Submissions must be received by June 1, 2005. The winner will be chosen by a random drawing from among all the correct entries received.

For a weekly dose of "What's Up?" complete with humor, a weekly trivia contest, and a range of significant space and science fiction guests, listen to Planetary Radio at *planetary.org/radio.*

a simulation of as much of the flight sequence as is possible while on the ground. A final internal review of procedures will follow, and then the spacecraft will be packed for shipment to the launch area.

Because this will be the first flight ever of a solar sail spacecraft, various space agencies around the world are showing considerable interest in our project. In the United States, NASA and The National Oceanic and Atmospheric Administration have asked to use flight data for their research programs, and they both have agreed to help in mission operations. —LDF

Free Online Astronomy Class

I am teaching an Introduction to Astronomy and Planetary Science class this semester in a partnership between the California State University Dominguez Hills Young Scholar program and The Planetary Society. The entire course is archived on the Internet, so don't worry if you haven't been tuning in—you can catch up right now. New classes air on Southern California television and are webcast live on Mondays and Wednesdays from 3 to 4 p.m. Pacific time. Find more information on the class, including a syllabus and how to tune in, at *planetary.org/bettsclass.*

Heads Up for a Deep Impact

The Planetary Society plans to hold an event in the Pasadena area on Sunday, July 3, 2005 to celebrate and watch the live high-speed impact into Comet Tempel 1 by NASA's *Deep Impact* mission. Save the date and watch for more information on *planetary.org* and in *The Planetary Report*.

Bruce Betts is director of projects at The Planetary Society.

BASIC SOLAR SAILING

BY BILL NYE

Standing outside on a nice day, you might feel the pressure of wind on your face and the warmth of sunlight on your skin. Both of these forms of energy come to you in pieces—actually, in particles. Here on Earth, we build kites, turbines, and sailing ships to harness energy in the moving molecules of the wind. For outer space, we have built a new kind of sailing ship to harness the energy of beaming starlight. Instead of air molecules bouncing off large sturdy sheets of cloth, packets of light energy called *photons* [FOE-tahnz] are bouncing off huge, delicate sheets of mirror-like plastic. It sounds wild, but at The Planetary Society, we've worked on this idea for a long time. We finally have the chance to try it out.

The Planetary Society, with the support of Cosmos Studios and Society donors and members, has helped build humankind's first solar sail spacecraft, *Cosmos 1*. When it opens up in space, it's about ten stories high. But unlike ten-story buildings, *Cosmos 1* is made of some of the lightest-weight plastic and rocket materials around.

Here's the idea. Once an object like a sailing ship is moving, it has what we call *momentum*. In sports, when a team gets going in the right direction, we say it's got the big "mo"—momentum. In science, momentum is all about getting going in one direction, but we use the word *momentum* in a special way—a mathematical way. Momentum is the mass of something multiplied by how fast it's going. Here's a real rocket science equation; it has just three letters:

$$p = mv$$

In the equation, *m* stands for mass, *v* is for velocity, and *p* is the traditional letter for momentum; it might be from the "p" in an older word for momentum, *impetus*, meaning "to push forth."

The faster something is moving and the more mass it has, the more momentum it has. The faster the wind blows, the more momentum air molecules can give to a ship when they curve around its sails. Air molecules have mass. Weigh an empty basketball and then a full one. The full one weighs more. If air molecules were weightless and had a mass of zero, then the equation would be zero times *v*—which is zero, every time. No momentum.

Light is pretty strange. Photons don't weigh anything, but they are energy, and they have momentum. This surprising feature of light comes from quantum physics. In nature, energy comes in tiny packets, photons being one type. It's connected to what might be the most famous equation of them all:

$$E = mc^2$$

If we divide both sides by the constant *c*, we get a math expression that looks like momentum, with a "*c*" instead of a "*v*." The letter "*c*" stands for the most constant thing we know of, the speed of light. This rearranged equation can be used to estimate the momentum that a solar sail can get—from pure sunlight.

Since we want the spacecraft's velocity change to be as big as possible, we try to make the spacecraft mass as small as possible. That is why we make our sails so thin—lightweight for small mass, big for catching as many photons as possible.

If we knew what *E* was, we'd know how much momentum we have in a beam of light and how much force is exerted on the sail. Well, we do know. Using solar cells and other instruments, people have measured the energy coming from the Sun. Around here (near the Earth, above the atmosphere), it's about 1,370 watts per square meter. Imagine the world covered with squares, each the size of a desk, with a dozen bright reading lights over every one of them. You don't have to imagine too hard; just go outside on a sunny day.

It's a lot of energy, a lot of heat and light. But we're still talking about photons, and you need a lot of them. So we make the sail big to create enough force to push our solar sail spacecraft around. We have eight long blades, 15 meters each. Added together, we have 600 square meters of very reflective sails. We made them very reflective because the more light bounces, the more momentum we can get from the photons.

We measure force in Newtons, named after Sir Isaac himself. The Newton is a smaller unit of force than a pound; an apple weighs about 1 Newton. In sunlight, we get about five millionths of a Newton on every square meter every second. Millionths of anything doesn't sound

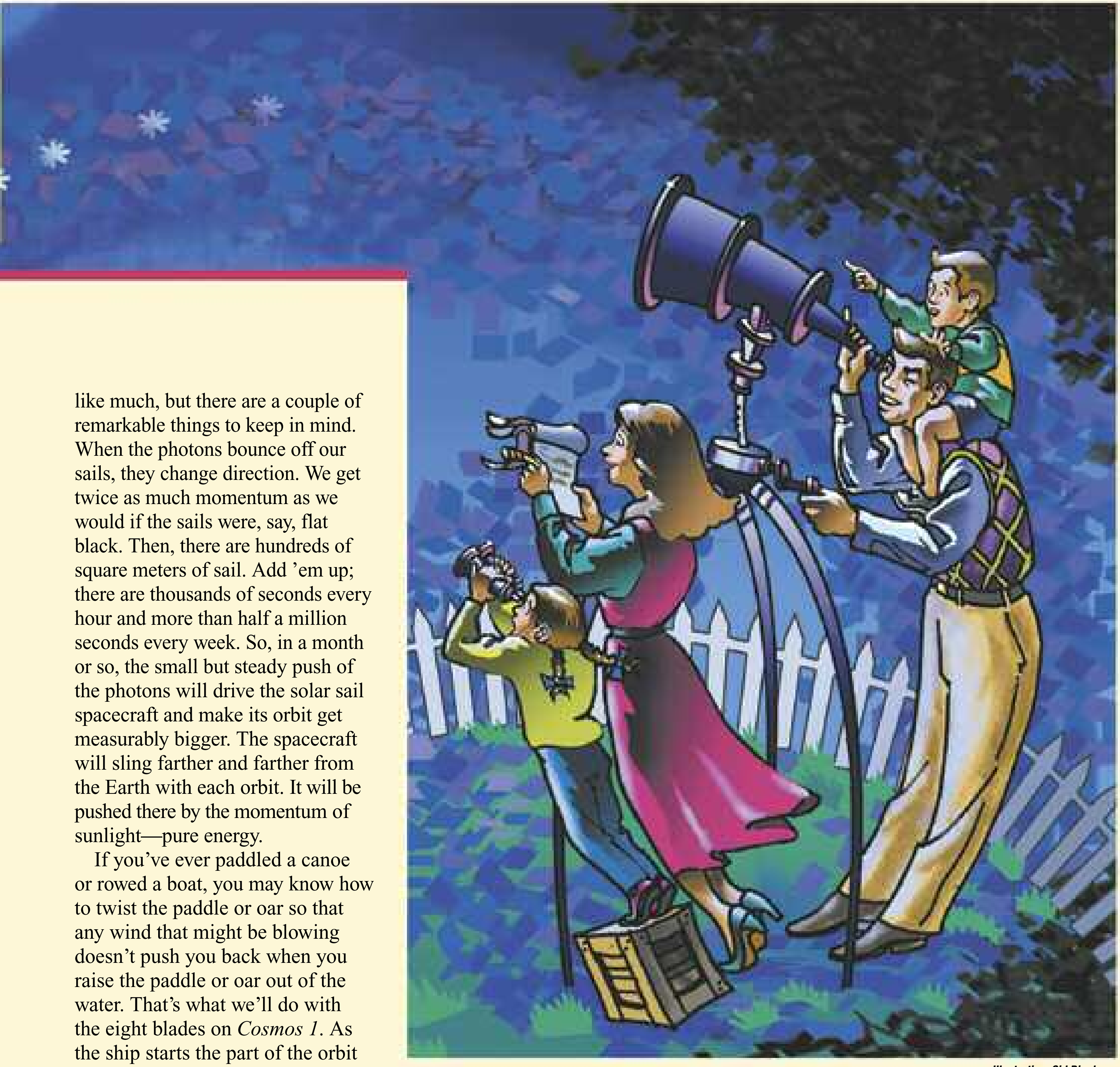


Illustration: Sid Bingham

like much, but there are a couple of remarkable things to keep in mind. When the photons bounce off our sails, they change direction. We get twice as much momentum as we would if the sails were, say, flat black. Then, there are hundreds of square meters of sail. Add 'em up; there are thousands of seconds every hour and more than half a million seconds every week. So, in a month or so, the small but steady push of the photons will drive the solar sail spacecraft and make its orbit get measurably bigger. The spacecraft will sling farther and farther from the Earth with each orbit. It will be pushed there by the momentum of sunlight—pure energy.

If you've ever paddled a canoe or rowed a boat, you may know how to twist the paddle or oar so that any wind that might be blowing doesn't push you back when you raise the paddle or oar out of the water. That's what we'll do with the eight blades on *Cosmos 1*. As the ship starts the part of the orbit carrying it away from the Sun, the blades will be turned to pick up the Sun's energy, just like a paddle held in a stream. When *Cosmos 1* comes around the Earth and back toward the Sun, we'll twist the blades so that most of the photons go flying right past, and our ship won't get slowed. The energy for the twisting comes from small electric motors powered by small solar panels. This is called *feathering* your solar sail blades (or your paddle). If you've ever held the shaft of a feather in your fingers, you know how easy it is to twist. Birds twist their feathers (they feather their feathers) all the time to control their flight. By feathering the blades, we can make use of the sunbeams' momentum as we're going away from the Sun or just let the photons slip past as we go toward the Sun.

You may have heard of the *solar wind*. That's what we call the constant spray of particles from the Sun: not light, but molecules that have mass. The pressure from the solar wind particles is only about a thousandth of the already tiny momentum of the sunlight itself. Our *Cosmos 1* sail is driven by light alone.

With *Cosmos 1*, we're witnessing the first time humans have ever tried sailing by starlight. It's very much like sailing the sea nudged along by the air, but this relies on much more subtle science. Sailing by starlight is the space travel idea of the future. So, let's sail on.

Bill Nye is vice president of The Planetary Society.

EAVESDROPPING on *Huygens*

by Sami W. Asmar

Standing atop the football field-size dish of the Green Bank Telescope (GBT) are (left to right) Kees van't Klooster, the team's liaison from the European Space Agency; author Sami Asmar; and GBT host and technical liaison Frank Ghigo.

Left: A looming snowstorm darkens the sky behind the 100-meter dish of West Virginia's GBT. The world's largest steerable radio telescope, the GBT played a major role in saving the Doppler Wind Experiment on the **Huygens** ***probe.***

Photos: Courtesy of Sami Asmar

On January 14, 2005, the European Space Agency's **Huygens** ***probe, carried to the Saturn system for 8 years by the*** **Cassini** ***spacecraft, descended to the surface of Saturn's moon Titan. The probe sent data and images back to the*** **Cassini** ***orbiter, which relayed the data to Earth a few hours later.***

One of the experiments on the probe was designed to measure the wind speed and direction in the atmosphere of Titan. Called the Doppler Wind Experiment, it translated the probe's motion during the descent into a shift in the frequency of the radio signal that was continuously transmitted to **Cassini.**

When the probe's mission ended, the **Huygens** ***team discovered that one of the two radio links had not functioned properly—which meant they'd lost the Doppler Wind Experiment data. However, a team from the Jet Propulsion Laboratory (JPL) had used radio telescopes on Earth to record the radio signal directly and, without knowing it at the time, saved the lost experiment. This is the story of this event, part of the exciting history of planetary exploration.***

Pocahontas County, West Virginia, home of the world's largest steerable radio telescope (called the Green Bank Telescope or GBT), is more than a 4-hour drive from the Washington-Dulles airport via mountainous roads. On the day that Sue Finley and I were to arrive from JPL, the forecast was for snow and high winds, not good for the quality of the faint radio signals arriving from nearly a billion miles away, and not good for driving either.

Sue and I arrived on different flights. I was overdressed and overpacked, carrying two laptop computers and additional hardware for the task. As we drove the narrow highway to Green Bank, I was glad that although the weather was very cold, it was not snowing yet. Our JPL colleague Bob Preston was wise to advise us to travel a few days before the event, in case of weather-related delays. Bob obsessively kept checking the forecast and inquired during every teleconference if it had started snowing in Pocahontas yet.

Meeting Colleagues and Testing Equipment

We spent the first 2 days testing the NASA equipment. The primary instrument, called the Radio Science Receiver (RSR), was borrowed from the Deep Space Network (DSN) complex in California. It was to be used for the real-time detection and post-event data processing for the European Space Agency's *Huygens* probe. Our efforts would have been easier at the Deep Space Network, our home turf, but the *Huygens* signal was outside the DSN's frequency range, and the modifications would have been expensive.

The backup receiver was a laptop computer with a digitizer. It was assembled by Garth Franklin and Jacob Gorelik, who took similar computers to radio telescopes at Kitt Peak, Arizona, and Mauna Kea, Hawaii, respectively. This PC did not provide any real-time feedback about the signal; it only recorded a wide bandwidth taken from the Very Long Baseline Interferometry (VLBI) instrumentation.

Colleagues from the Joint Institute for VLBI in Europe (JIVE) also came to the GBT. They required shifting the antenna every 2 minutes, from pointing at Titan (the probe) to pointing at a quasar, and back to Titan, then back to a quasar, and so on. The quasar, a natural radio source, was used as a reference for calibration. This technique would help us determine the probe's landing location.

This went against my intuition as a radio scientist: once you find a weak spacecraft signal, it would seem, you don't intentionally point away, but I came to appreciate the VLBI experiment. I also befriended the European Space Agency's liaison to our team, Kees van't Klooster. We had exchanged many e-mails in the planning phase, and he had numerous detailed technical questions. This led me to worry that it might be challenging to work with him, but when we met at the GBT, we quickly became friends and made the ceremonial exchange of souvenirs: he gave me an official *Huygens* mission polo shirt, and I gave him a NASA hat.

Our principal investigator (PI), Bill Folkner, had made an agreement with the VLBI PI, Leonid Gurvits, to allow two of our smaller stations to go through the pointing, "nodding" back and forth. These were Pie Town (New Mexico) and Owens Valley (California), which were staffed by Bill Folkner and Steve Lowe, respectively.

The third person on the project is the PI of the *Huygens* Doppler Wind Experiment (DWE), Michael Bird, from Bonn, Germany. Mike and I had worked together in the past on applying radio science techniques to study the Sun, the Io plasma torus, and the ionosphere of Titan. He had invited me to be a co-investigator on *Huygens*, and this was my opportunity to contribute to the experiment with additional data that would enhance our understanding of the winds.

Andre Jongeling, the Radio Science Receiver designer, had made a software modification specifically to handle the unique input from the GBT (lower versus upper sideband). Sue Finley was able to report that it worked well. That was one of two elements we could have gotten wrong, the other being the polarization, since these tend to be defined by convention and are subject to misinterpretation. We had decided to record both right-hand and left-hand circular polarizations to prevent a mistake and also to record multiple bandwidths in case the prediction of the signal dynamics was not very accurate, especially the timing of the events such as parachute deployment and surface impact.

The GBT staff was hospitable and supportive. They appeared excited about the historical event in planetary exploration in which their facility was about to participate. Our primary host and technical liaison, Frank Ghigo, offered to take us on a tour up the telescope, an impressive structure on the scale of the Eiffel Tower without the long lines and souvenir shops. I jumped at the opportunity and grabbed my camera as Frank drove us from the control building in an old converted Checker cab, painted blue and designated for the roughly 1-mile drive.

INDEX OF ABBREVIATIONS

DSN: Deep Space Network

DWE: Doppler Wind Experiment

GBT: Green Bank Telescope

JIVE: Joint Institute for Very Long Baseline Interferometry in Europe

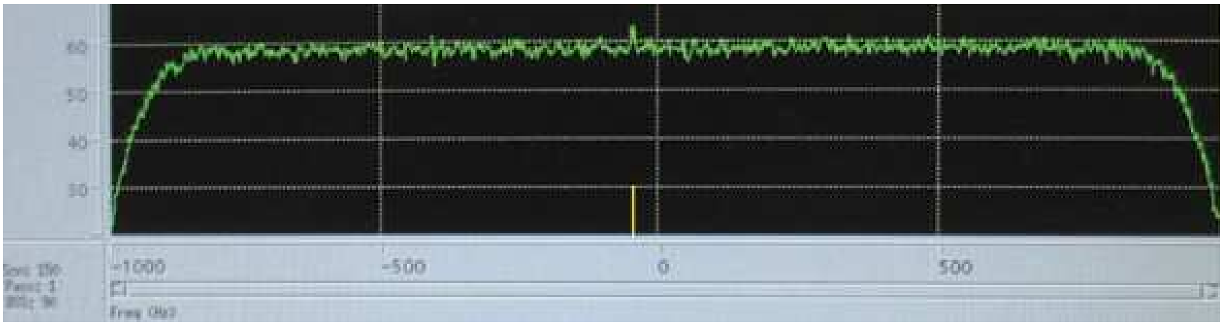
PI: principal investigator

RSR: Radio Science Receiver

UTC: Universal Time, also known as Greenwich Mean Time

VLBI: Very Long Baseline Interferometry

Various size feeds on top of the GBT's dish receive signals at different wavelengths. The author was relieved to see that each feed had its own snowblower.
Photo: Sami Asmar



This photo of the author's computer screen shows the tiny blip that was the first* Huygens *signal to be received on Earth—a faint but most welcome sign that the spacecraft was alive and working at Titan. Photo: Sami Asmar

The Telescope

As we climbed the telescope structure, we felt the wind blow harder. A technician who operated the elevator looked visibly worried about taking us all the way up; the ride was a bit rough. The telescope was stowed for maintenance because the wind had exceeded the threshold for safe operation (various people quoted wind speeds of 30–35 miles per hour as the threshold). Wind speed had exceeded 30 mph that day. When I expressed my concern to Frank about supporting the experiment, he pointed out that the GBT chief engineer would personally be present, because he was the only person allowed to grant an exemption to carry out observations through the wind. Frank smiled as if to say we wouldn't let a little breeze stand in our way.

On the top was a fantastic view of the 100-meter telescope dish. The various size feeds received different wavelength signals. It was good to see that a snowblower was attached to each feed. I had once climbed the 70-meter Deep Space Network dish at Goldstone and did not remember seeing snowblowers. I then remembered that I was in the mountains of West Virginia, not the California desert.

Listening to *Huygens*

In the early hours of the morning of January 14, the time had come to hear *Huygens* talk to us: well, it was not talking to us; it was addressing the *Cassini* orbiter, and we were eavesdropping. Nature decided to participate in the eavesdropping conspiracy. The wind subsided suddenly, and the snowstorm was delayed. (It later snowed as we were packing to leave.) I quickly reported that to Bob Preston.

As we set up the receiver, I recalled all the discussions that had come up at every meeting, seemingly hundreds of times, about selecting the optimum "coherent and incoherent integration times" of the Fast Fourier Transform display (which looks something like a heart monitor in a hospital). Although I already had a plan, I eventually relied on my intuition just as Bill Folkner had recommended; I could not disappoint Bill.

It was good that I did not know at the time about the anomaly with the link on the spacecraft and the added importance of the GBT data; I did not need the additional pressure. We continued to operate under the assumption that we were confirming that the probe was alive, 6 hours in advance of the project team receiving the data relayed to the DSN by the *Cassini* spacecraft. We found out only after we completed our work that the link from the probe to the orbiter that was referenced to the atomic clock had failed, causing the loss of the original configuration of the Doppler Wind Experiment. We then realized that we *were* the Doppler Wind Experiment!

Traveling at the speed of light, the radio signals took 1 hour and 7 minutes to reach Earth. At about 10:19 UTC Earth Received Time, the time of the first signal, the control room got very quiet as Sue and I tensely stared at our screens. At the expected time and expected frequency, a tiny blip appeared on the display (see picture), an actual signal from *Huygens* and the first indication the probe was alive and most likely performing as planned. Many of the GBT staff and European visitors huddled around our console. Others in the room, including those on the open phone line with JPL, the European Space Operations Centre, and fellow team members at the other stations, remained silent. They were waiting for me to announce what I saw.

Sue's body language told me that she interpreted the display the same way I did. I held back the temptation to announce the detection. In the field of radio science, detecting a very weak spacecraft signal from amid a lot of noise is common but never easy. I did not want to

ELEMENTS OF A LINK BUDGET

At a frequency of 2 GHz (or wavelength of approximately 15 centimeters), if a spacecraft transmits a radio signal at 10 watts, from a distance of nearly 1 billion miles from Earth, by the time it reaches Earth it would have diminished by almost a factor of 0.000000000000000000000000000001 (10 to the power –30). This is due to the "space loss," which is proportional to the inverse squared of the distance. Some of this is made up by collecting surfaces of the transmitting and receiving antennas. The bigger the antenna the more power is gained. —SWA announce a false detection and preferred to confirm what I saw after at least three refreshes of my screen, when I could find a pattern. The fact that we saw the blip when and where it was expected made me more worried than relieved because these things usually are a bit off compared with our prediction. It could be a spur or interference that we had struggled with eliminating in the test phase.

About 30 seconds later, I spoke on the phone line to two dozen people worldwide. "I see the probe signal, okay now, it has refreshed, I see three cycles, is this real, I'm now more confident"—something to that effect. When I said that, my own body tension dropped. I could sense the same in everybody around me, and then people started smiling and cheering. A few minutes later, after a short discussion with Bill Folkner, who was at the station in Pie Town to go over some numbers, I spoke directly to the European Space Agency's operations center in Darmstadt, Germany. I spoke first to Leonid Gurvits and then project scientist Jean-Pierre Lebreton. He was excited and relieved, as well as thankful for the good news. It wasn't until that conversation that I felt that this was real; it had happened, and we were now part of history.

Retrieving the Rest of the Data

We were not done. After this initial signal, there were three more critical events to watch out for: the stabilization parachute deployment, the landing, and the end of transmission, with the last two occurring during the observation period at the Parkes telescope in Australia, where JPL's Doug Johnston and Jim Border had traveled to operate the JPL equipment. I became distracted by my own happiness and did not hear Aseel Anabtawi, who staffed the radio science workstation back at JPL for the director and others to monitor our progress, calling me on the telecon line to say she lost the displays we were sending her over the Internet. I had been prepared for a different scenario, one of hard work searching for the missing signal, wrong polarization, or even another debate about those integration times.

At about 12:10 UTC, GBT started losing the signal, as expected. As the Earth rotates, the antenna pointing direction is adjusted until it reaches the horizon. By then, the effect of releasing a stabilization parachute had been captured in our data with a Doppler signature. The GBT had a horizon mask down to 5 degrees of elevation except toward the west, where a mountain range raised it to 7 degrees. We were by then pointed straight west and, as a result, lost a few minutes of data. I joked that at that time we were studying the winds in the mountains of West Virginia, not Titan.

The Parkes telescope team in Australia would not pick up the signal until 20 minutes after Saturn set over the western horizon at Green Bank. Once they did, they continued to receive it longer than we expected. We thought the batteries on *Huygens* would die, but they just kept going. It got to the point where Parkes had to set over the horizon while still receiving a signal. The telecon line got busy as people scrambled to get another station to continue receiving the signal after Parkes.

Before the day was over, we had heard about the problem with the original DWE. Within hours, Doug Johnston carried out the preliminary processing of the GBT and Parkes data in order to e-mail plots to Mike Bird and assure him that we had captured the data. Within days, after we all returned to JPL, our team had generated a profile of the winds on Titan. Somebody gave us the nickname Channel C (Channels A and B were the original links from *Huygens* to *Cassini*). Everybody wanted to see that profile, but we knew that it would be published in a scientific journal, and journals do not want to have results released prior to publication. We and the Europeans worked out the careful wording for a press release: winds on Titan are found to be flowing in the direction of Titan's rotation from west to east at nearly all altitudes. The maximum speed of roughly 430 kilometers (270 miles) per hour was measured about 10 minutes after the start of the descent, at an altitude of about 120 kilometers (75 miles). The winds are weak near the surface and increase slowly with altitude up to about 60 kilometers (40 miles). This pattern does not continue at altitudes above 60 kilometers, where large variations in the Doppler measurements are observed. We believed that these variations might arise from significant vertical wind shear.

We had witnessed a rough ride for the little probe but a happy ending.

Sami W. Asmar is a physicist and manager of the Radio Science Systems Group at NASA's Jet Propulsion Laboratory, California Institute of Technology, and a co-investigator on the Huygens *Doppler Wind Experiment.*

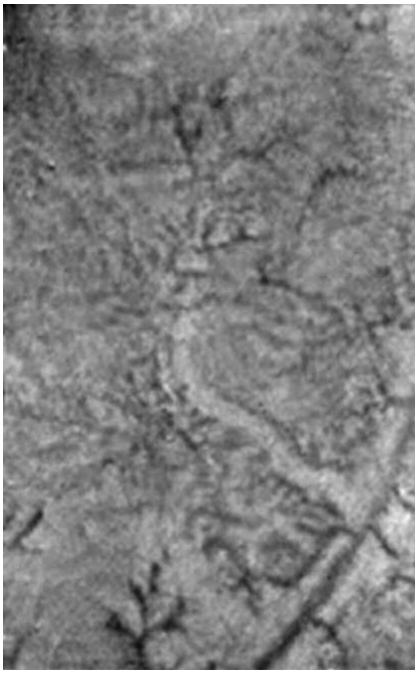
The snowstorm that threatened the reception of* Huygens' *first signal graciously waited until the mission was completed to engulf the GBT. Photo: Sami Asmar

A WORLD REVEALED: Hu

On January 14, 2005, humankind made another great leap of exploration when the European Space Agency's **Huygens** *probe landed on the surface of Titan, Saturn's smog-enshrouded moon, and sent home images of this never-before-seen land. The world* **Huygens** *found is a puzzle built of pieces that seem familiar but are assembled in very strange ways. Smog particles blanket the plains and channels in a sooty darkness. Steep hills, strings of "islands," and fist-size boulders, which on Earth would be made of rock, are here rock-hard water. Although the wet, sandy soil beneath Titan's crust contains granulated water ice, it's an arid place—until a periodic rainstorm of smelly liquid methane pours down, rinsing smog off the hills and flowing into rivers, streams, lakes, and pools. When the rain is gone, only the impressions of this liquid remain, cut into the frozen surface.*

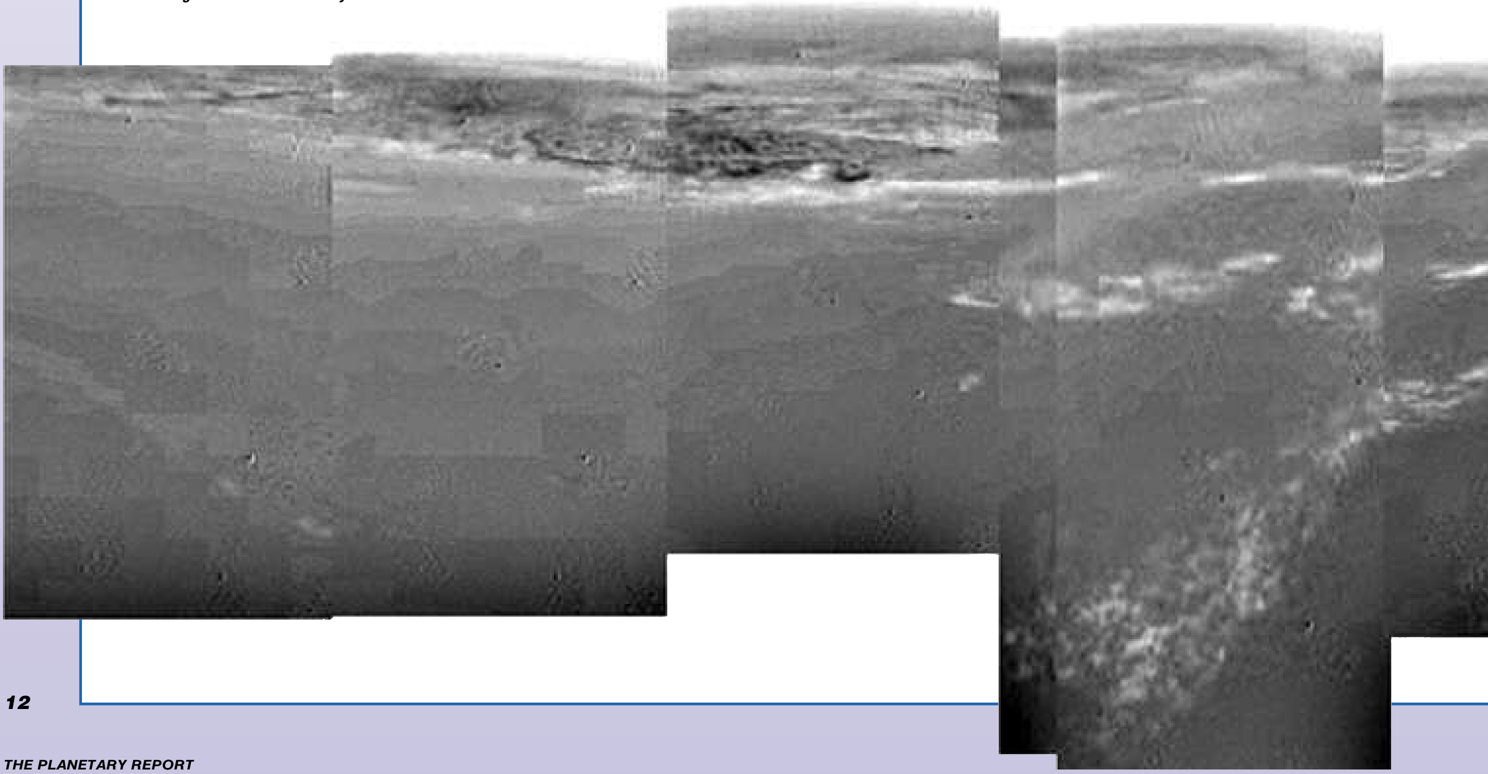
On January 21, **Huygens** *team members reported on their first scientific assessments of the data from ESA headquarters in Paris. "We now have the key to understanding what shapes Titan's landscape," said Martin Tomasko, principal investigator for the Descent Imager-Spectral Radiometer (DISR) on board the probe. "Geological evidence for precipitation, erosion, mechanical abrasion, and other fluvial activity says that the physical processes shaping Titan are much the same as those shaping Earth."*

Scientists have sifted through only a fraction of the data returned by **Huygens***. This Titanian treasure trove will keep them busy for months, or even years, to come. These images, all taken by the DISR, are a sampling of what* **Huygens** *saw.* **—Donna Escandon Stevens**

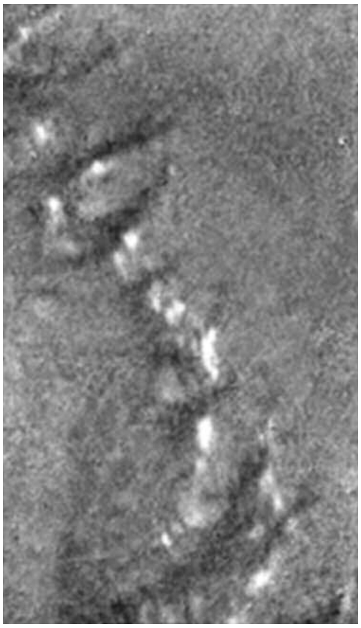


The detection of atmospheric argon 40 suggests that "lava" of water ice and ammonia may erupt periodically on Titan. The bright linear feature here looks like an area where this mixture may have extruded onto the surface. In a different moon-sculpting process, the short dark channels appear to have been formed by springs of liquid methane rather than by a persistent methane rain.

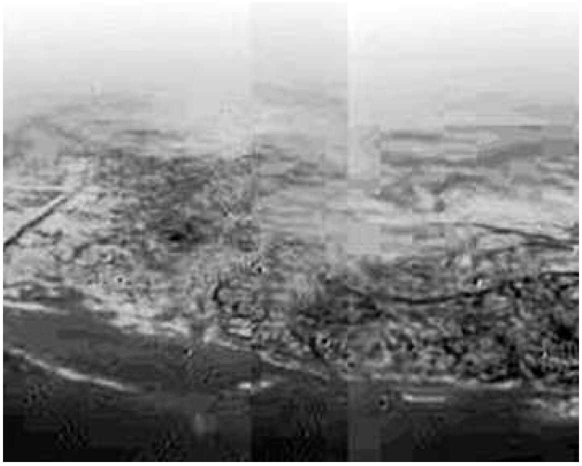
Below: This composite of images gives a 360-degree view as seen by Huygens *as it drifted to the surface of Titan. The left side reveals a boundary between dark and light areas. The white streaks near this boundary could be methane fog. As the probe descended, it drifted over a plateau (at center) and headed for a spot toward the dark area at right.* Huygens *took these pictures from roughly 8 kilometers (5 miles) up, showing surface details about 20 meters across. Based on the drift of the probe, scientists estimated the speed of Titan's winds to be 6 to 7 kilometers (about 4 miles) per hour at this altitude.*
Images: ESA/NASA/University of Arizona



uygens' Images of Titan

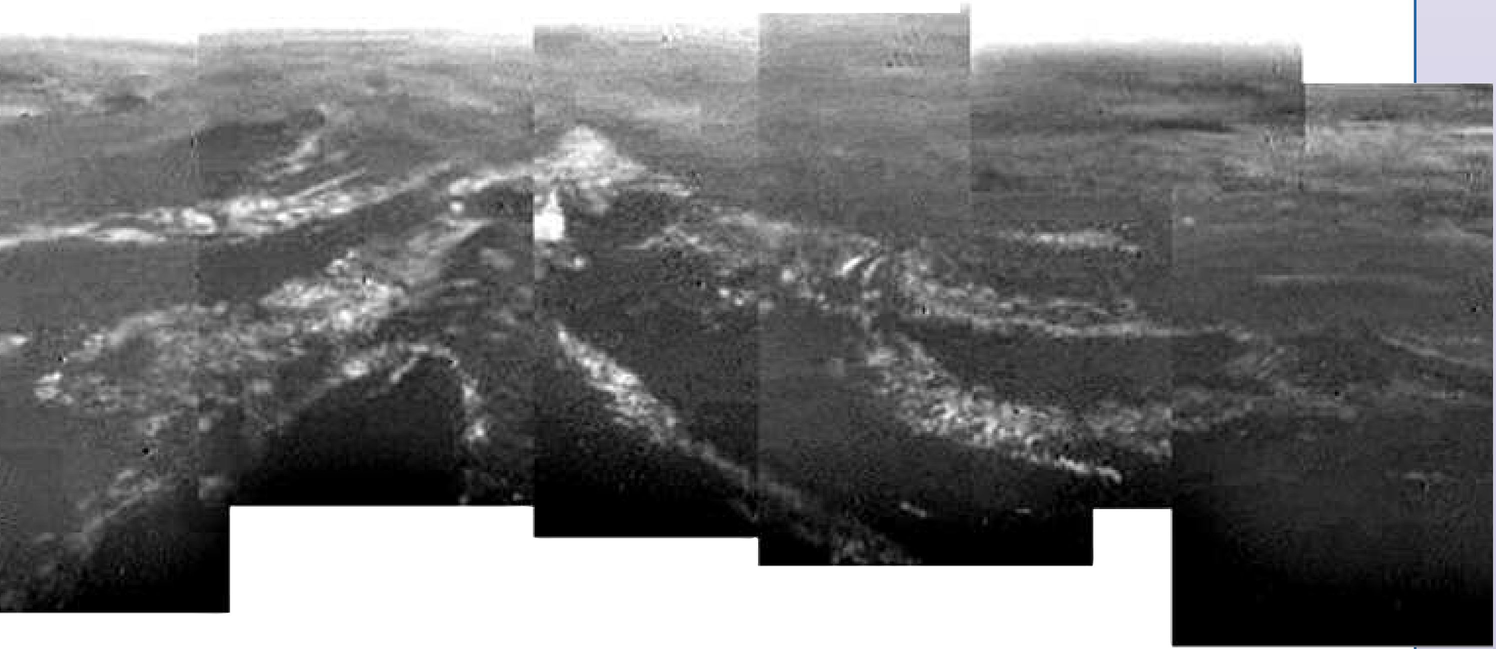


Rising above a dark plain, these bright highlands probably once were islands in a liquid methane sea. This noxious (to earthly noses) fluid once flowed around these islands, carving the dark channels we see now.



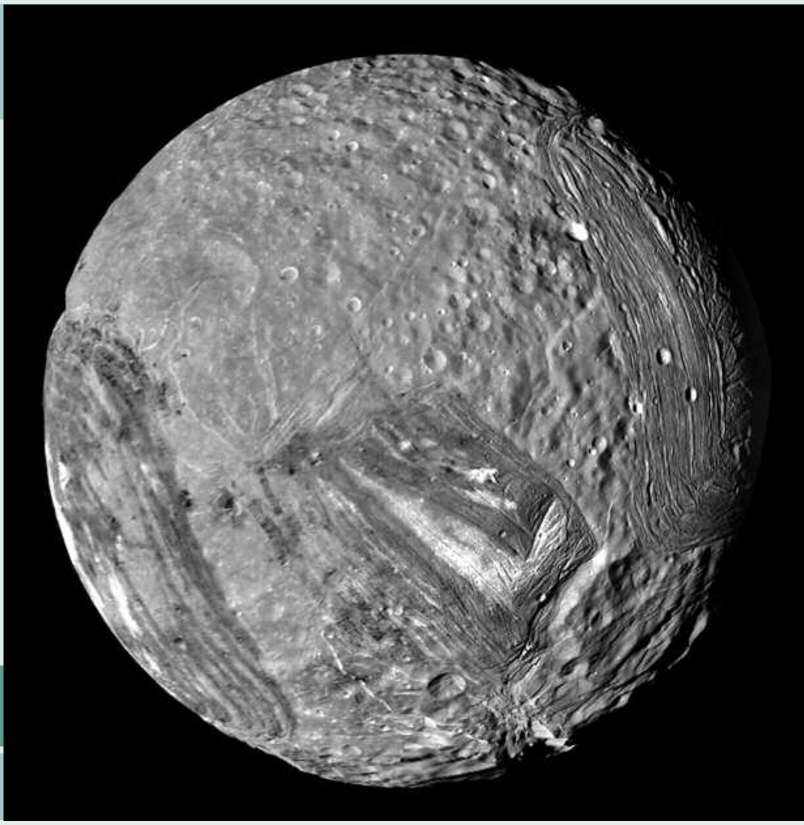
"It's impossible to resist the speculation that we are seeing drainage channels or some part of a shoreline," said Martin Tomasko about this image. "We don't know if there is still some liquid [in the channels or lake] or if it's drained away into the surface. Maybe this was 'wet' not so long ago and the liquid hasn't penetrated too far into the surface." The word "liquid," in this case, refers not to water (H_2O) but to methane (CH_4) or ethane (C_2H_6).

Researchers added reflection spectral data to imaging data to give us a better idea of the actual color of the surface. The "rocks" littering the ground are most likely grapefruit-size chunks of water ice. There are hints of erosion at the bases of these objects, indicating that something liquid, probably methane, once flowed around them.



Miranda: SHATTERING an Image

by Robert T. Pappalardo



Miranda, the smallest and innermost of Uranus' five major moons, at first looks like something squashed together using pieces scavenged from the scrap heap of planetary formation. What processes formed the surface features on this weird little world? All three of Miranda's bizarre coronae are visible in this global view centered on the satellite's south pole—a sizable portion of Arden shows at left, straight-edged Inverness is in the lower middle, and the southern side of Elsinore is visible at right.
Image: JPL/NASA, reprocessed by Paul Schenk, Lunar & Planetary Institute

Miranda has been called the most bizarre of the solar system's moons. It is the smallest in size and closest to its parent planet of the five "classical" moons of Uranus (Miranda, Ariel, Umbriel, Titania, and Oberon). But despite its size, only 472 kilometers (293 miles) across, Miranda shows signs of activity as intense as that of any of its solar system brethren.

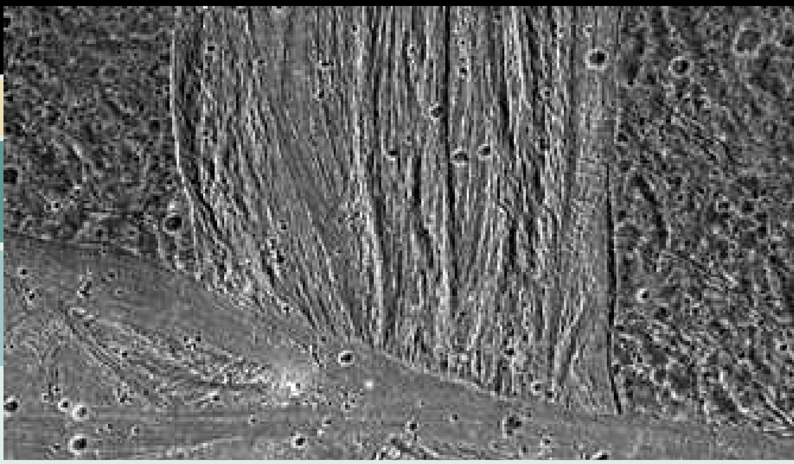
Uranus orbits the Sun tilted practically on its side, with seasons each lasting 21 years. In the mid-1980s, Uranus was oriented with its south pole facing toward the Earth and Sun, so its retinue of moons appeared to Earth observers to circle Uranus as if around a bull's-eye. In late January 1986, the *Voyager 2* spacecraft soared through the Uranian system and got a close-up look at Miranda, snapping some of the most detailed photos of its four-planet grand tour.

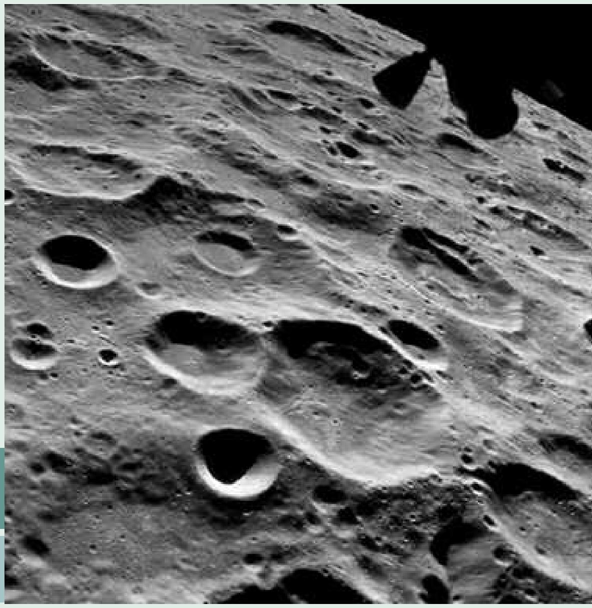
Miranda's tortured face seems to combine terrains of planets and moons found across the solar system. Its rolling, cratered terrains resemble the ancient highlands of our Moon. Its coronae are namesakes to round fractured zones on Venus. Ridges and grooves within the coronae resemble striated lanes on Jupiter's moon Ganymede and Saturn's moon Enceladus.

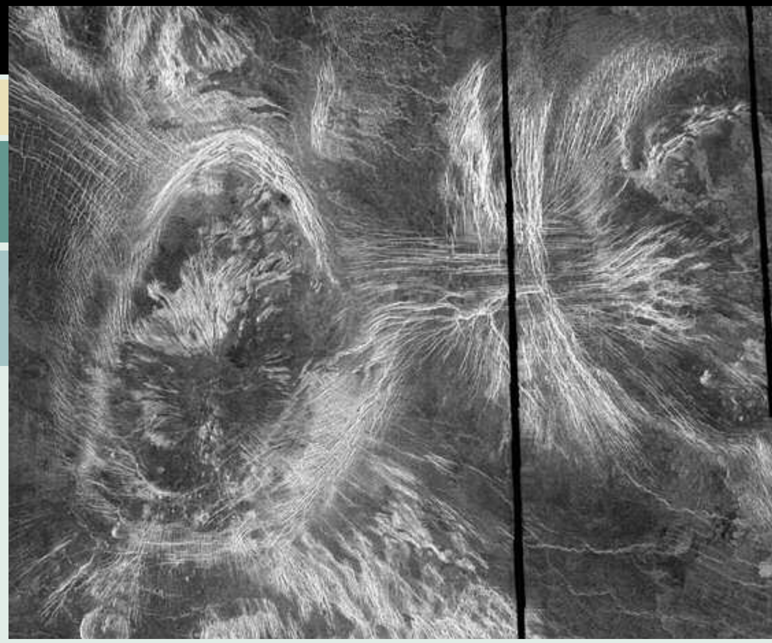
The three coronae of Miranda are flat-sided with rounded corners, each resembling an oval racetrack about 200–300 kilometers (125–190 miles) from end to end. Their lined outer zones surround inner, less organized regions. The coronae have been named Arden, Inverness, and Elsinore, following a scheme of places in Shakespearean plays. Only one of the three, Inverness, was fully illuminated and visible during *Voyager 2*'s encounter.

Arden's outer band is painted with dark and bright stripes surrounding an inner zone of bright and dark patches. Straight-sided Inverness Corona, located near the south pole, includes a chevron-shaped patch, mysterious and bright against a darker background. One side of Inverness continues toward the north, where steep-sided cliffs form the canyon of Verona Rupes, 10 kilometers (6 miles) deep. Elsinore Corona shows an outer band lined with prominent ridges and more subtle grooves wrapping around an inner zone of criss-crossing features.

The coronae are seemingly haphazardly plunked into a bright rolling plain. The bright regions between







As these three examples show, the features on Miranda's crazy-quilt surface resemble the terrains of a variety of solar system bodies. Clockwise from lower left: 1) Miranda's rolling, cratered terrain—older than the coronae themselves—resembles the ancient, cratered highlands of Earth's Moon. Image: NASA *2) The Erech Sulcus region of Jupiter's moon Ganymede resembles the striated lanes inside Miranda's coronae.* Image: JPL/NASA *3) The fractured ovals* Magellan *imaged on Venus also are called* coronae, *like Miranda's rounded features. Bahet Corona, the structure at left, is about 230 kilometers (140 miles) long and 150 kilometers (90 miles) across. A part of Onatah Corona, more than 350 kilometers (210 miles) in diameter, is visible at the right.* Image: JPL/NASA

coronae are named Dunsinane, Mantua, and Sicilia. These bright regions show bigger and more densely packed craters than the coronae, so must be older.

A Tortured Past

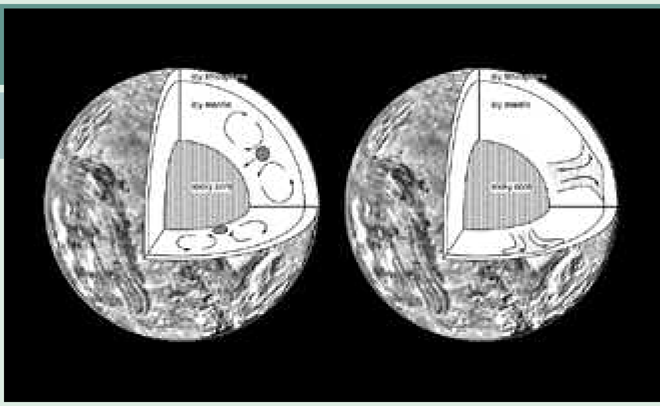
How can a moon as small as Miranda appear so haggard and torn, indicating a tortured history? How did its mishmash surface come to be? An enduring hypothesis was suggested by the late Eugene Shoemaker, father of planetary geology and pioneer in the study of impact cratering. Shoemaker understood that the innermost moons of any planetary system are subjected to the most ferocious impacts. The gravity of the parent planet accelerates incoming projectiles, so they hit inner moons most violently. Calculations have shown that early in its history, a moon Miranda's size and distance from Uranus should have been completely smashed apart by impacts not just once but many times over. The Miranda we see today, therefore, is probably not the original resident of this part of Uranian space; it is perhaps the seventh incarnation of the moon. Each previous version was smashed to bits by large debris that crossed its orbital path and then was reassembled as additional collisions and increasing self-gravity reunited lingering planetesimals.

Could this celestial reincarnation somehow explain Miranda's bizarre geology? When a moon assembles within the debris cloud surrounding its parent planet, the energy from collisions and from radioactive decay of rocky elements will heat the forming world. This self-heating can allow denser rock and metal to sink downward to form a core, while lighter ice would float upward to form a crust. A forming moon's interior can be layered like a Tootsie Pop.

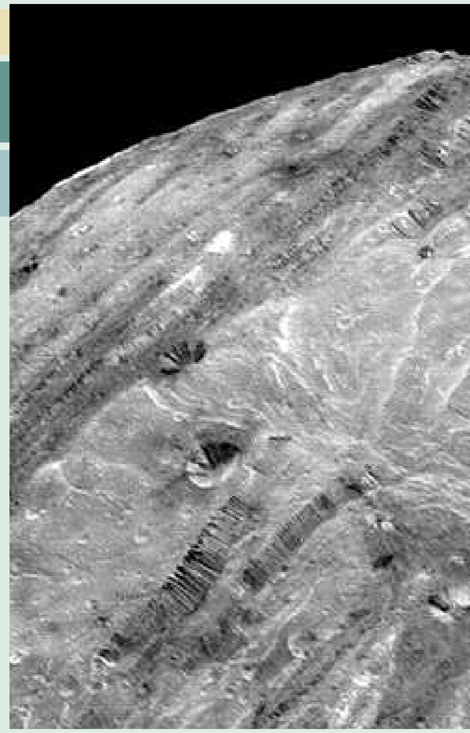
Shoemaker reasoned that a moon-smashing impact could break a layered moon into some pieces that were more rock-rich (the core of the former moon) and some that were more ice-rich (the former crust). It seemed that reassembly of such rocky and icy pieces might somehow explain the hodgepodge surface of Miranda.

Sinkers vs. Risers

In popular accounts, Shoemaker's ideas were portrayed as meaning that Miranda's surface was reassembled by gentle collisions between these chunks, with the dark coronae formed from rockier chunks and the brighter cratered plains from icier chunks. But a careful look at



Sinkers and risers, two alternative models for creating Miranda's coronae, are illustrated in this diagram. At left, a chunk of rocky surface material sinks down through the mantle toward the body's core, pulling and crumpling the surface downward over that area. At right, blobs of warm icy material rise through the young moon's icy mantle to the crust, stretching and faulting the surface above and erupting in some places to form a corona. Diagram: Robert Pappalardo



The sawtooth-shaped edges of Arden Corona seen along Miranda's limb are probably faults created by rising icy material stretching and breaking apart the crust. Image: JPL/NASA, reprocessed by Robert Pappalardo

Miranda's geology tells us that such a simple story cannot be the case. The transition from a corona to the bright cratered plain is sometimes gradual rather than abrupt, with ridges and grooves interlaced with cratered terrain.

Researchers Buck Janes and Jay Melosh picked up on Shoemaker's ideas. They developed the sinker model, in which rocky chunks of a reassembled moon sank slowly down through the icy interior of Miranda toward its forming core. As they sank, these chunks stirred downwelling currents in the ice, dragging the surface above downward and inward. Resulting stresses would crumple the surface into a corona. Janes and Melosh's calculations predicted a concentric zone of folds surrounding a zone of disorganized structures, similar to the organization of features in each corona.

But scientists Larry Soderblom and Bill McKinnon championed an alternative idea: instead of sinking chunks pulling the surface downward, rising blobs in Miranda's interior could have pushed the surface upward. In contrast to the sinker model, which predicts a compressed surface, this riser model predicts that the outer concentric and central disorganized corona features were formed when the surface was stretched and faulted above a riser.

In the following years, detailed geologic analyses lent increased support to the riser model. The edge of Arden Corona provides the most dramatic evidence that faulting pulled apart Miranda's surface to create the coronae. One *Voyager* photo shows Arden's edge in profile, revealing sawtooth-shaped ridges and valleys up to 2 kilometers (1.2 miles) in height. The triangular ridge shapes resemble toppled-over dominoes, characteristic of faults that have stretched and broken the crust.

The slopes that face outward from Arden are dark and corrugated. These striations could have been formed when Miranda's meager gravity (0.8 percent that of Earth's) caused small landslides, working to erode steep slopes. The striations also may have formed when opposing faulted blocks scraped against one another as they moved, gouging each other as if with giant fingernails. Either way, these striations seem to be characteristic of fault blocks that are found across the outer bands of Arden and Inverness Coronae.

Faults have exposed a dark layer that has trickled downslope, blackening most fault faces. Perhaps this dark stuff is buried elsewhere on Miranda, exposed only where tectonic forces have torn the surface. Similar dark material blackens other moons of Uranus, especially its small inner moons and charcoal-dark Umbriel. The origin of this dark stuff is uncertain. It might be primordial carbon-rich material, probably plentiful in the cold outer regions of the solar nebula when the planets formed. Alternatively, the moons of Uranus may contain carbon-rich ices like carbon dioxide or methane, which are known to darken with long-term exposure to radiation and ultraviolet light, forming sooty molecules of carbon.

Stretching of the crust above rising blobs to form the coronae jibes with the presence of bright and dark patches in Arden and Inverness Coronae, which could indicate that ices once oozed from Miranda's interior. Such icy volcanism is facilitated if fractures are yanked open by risers, allowing warmed ices to flow onto the surface.

The story of Elsinore Corona is complex. Its strange ridges do not closely resemble fault blocks; instead, they might have been formed by icy volcanism that warped the surface or erupted along fractures to form ridges. If so, the ices that built these 100- to 200-meter-tall ridges in Elsinore must have been stiff rather than runny. A

Elsinore Corona has a history more complicated than one caused by faulting alone. Elsinore's 100- to 200-meter-tall ridges may have been shaped by icy volcanism that warped the surface or erupted along fractures to form ridges.
Image: JPL/NASA

candidate icy lava is a mixture of ammonia and water ices, which would be stiff enough to pile up into ridges at Miranda's surface temperature of 70 Kelvin (–200 degrees Celsius, –330 degrees Fahrenheit).

Reading Miranda's Surface

Because Miranda's coronae apparently were shaped by extensional faulting and icy volcanism, the riser scenario is the best match to the moon's geology. How would these risers form, and what can they tell us about the interior and history of Miranda?

Risers within Miranda may be the manifestation of its separation, or differentiation, into a rocky core and an icy crust. As Miranda's interior heated at some time in the past, rock sank and ice rose within the moon, with each corona forming above a rising plume. Because Miranda's surface also shows ancient cratered portions, this differentiation may not have gone to completion before the interior cooled and froze.

Risers could help explain why the coronae, especially Arden and Elsinore, are not circular but instead have flat sides and rounded corners. Rising blobs would have been so large compared with the small size of this tiny world that they pushed against one another as they rose.

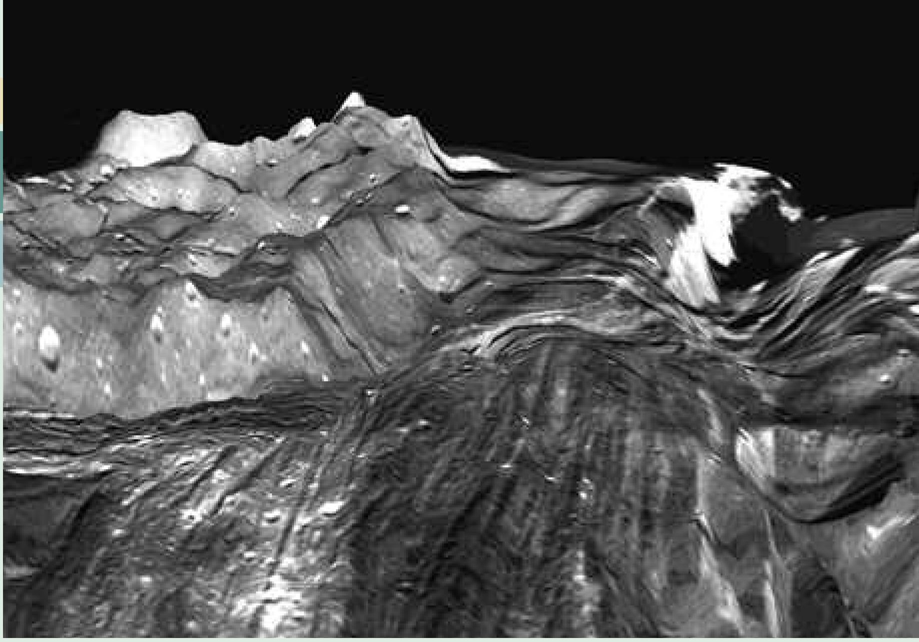
Among the many odd characteristics of Miranda, Arden Corona is centered near the leading point and Elsinore Corona near the trailing point of Miranda's orbital motion, and Inverness is near the south pole. This probably is not a coincidence; it may tell us something else about the coronae and Miranda's tumultuous history. If Miranda is only partially differentiated, then beneath the coronae are low-density icy blobs that rose toward the surface to create the coronae and then froze in place. The most stable orbital configuration for any moon is one in which denser areas face toward and away from the parent planet, while less dense regions face toward the leading and trailing points of orbital motion and are on the poles. The pattern of placement of coronae on the satellite is consistent with this orbital configuration, so is another argument that low-density risers lurk beneath the coronae.

It would be too much of a coincidence that the coronae formed in these preferred locations on Miranda. Instead, the moon probably reoriented itself when the coronae formed, turning to put Arden and Elsinore near the leading and trailing points of its orbital motion. Miranda's distribution of bright plains craters suggests that just such an event took place, telling that Miranda's orientation today is different from what it was in the distant past.

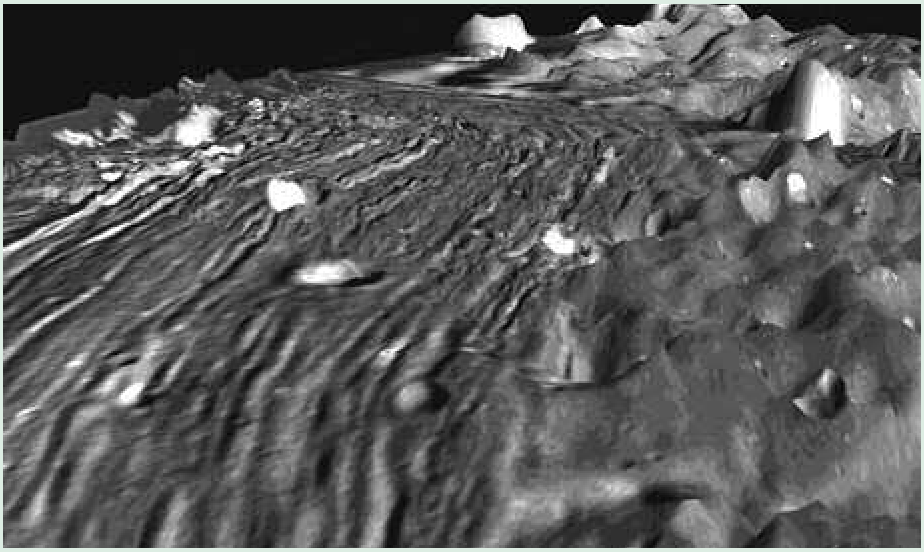
When this shift in orientation occurred, the part of Miranda that ended up facing toward Uranus should have been stretched open by the planet's distorting gravitational pull. This is probably what tore open Verona Rupes, the giant ice cliffs that face toward Uranus.

What might have created the mysterious bright chevron of Inverness Corona? The chevron's two arms seem to trace the branches of a Y, with Verona Rupes forming the base, so their origins could be related. On Earth, doming of the surface by upwelling from beneath can create a Y-shaped junction of rifts. It is possible that the two arms of the chevron were sites of icy volcanism and rifting, possibly including some spreading apart of the icy crust, while Verona Rupes was relatively inactive.

Miranda has been very geologically active, despite a size so small that internal heat should have been almost insignificant and lost long ago. Although it is possible that primordial heat caused Miranda's geologic activity, another plausible cause for heating of a moon so small is



Inverness is the corona with the distinctive, bright chevron shape at its center. This synthetic view is created from stereo images, as if we are looking across the bright chevron toward the steep cliffs of the canyon Verona Rupes.
Image: Paul Schenk, Lunar & Planetary Institute



This synthetic view generated from stereo images looks down the length of Elsinore Corona's ridges and grooves along its boundary with the surrounding cratered terrain. Lavas of ammonia and water could have formed ices stiff enough to pile up into the ridges that ring this racetrack-shaped feature.
Image: Paul Schenk, Lunar & Planetary Institute

tidal squeezing. Heating from tidal squeezing requires an elliptical orbit, and Miranda's orbit is too circular for such tidal heating to be important today. But there may have been a time when Miranda's orbit was perturbed temporarily by the moon Umbriel, which tugged Miranda into a chaotically elliptical orbit. An episode of tidal heating may have allowed Miranda to partially differentiate, creating the coronae and reorienting the moon. Then, as the orbital eccentricity settled down, Miranda's brief fling would have ended.

From the number of superimposed craters on the moon's coronae, Kevin Zahnle and his colleagues recently have determined that Miranda's heating event may have occurred less than 1 billion years ago. This suggests that this tumultuous time may have come surprisingly late in solar system history, favoring a tidal heating scenario rather than the effects of primordial heat.

Miranda is perhaps our solar system's best example of the universe being stranger than we can imagine. The riser model for the moon's geology does not rely upon shattering and reassembly but instead indicates that Miranda may have been caught in the act of differentiating and then froze solid. This may mean that Miranda awakened briefly from a long geologic slumber when Umbriel roused it into an episode of tidal heating.

In the solar system's earliest epoch, several proto-Mirandas probably were smashed apart and reassembled from debris in the vicinity of Uranus. The Miranda that we know was the last survivor in a succession but may not show any evidence of its shattered past. Instead, Miranda's own history of tidal heating, partial differentiation, risers, faulting, icy volcanism, and reorientation was set in motion.

Just once did I have the pleasure to meet Gene Shoemaker. In the few minutes that we had to talk, I asked him about Miranda and his idea that its geology is linked to early disruption and reassembly. To my surprise, he said that his original sinker idea had been misunderstood. Indeed, he envisioned sinkers, but these sinkers would have triggered neighboring risers over which the coronae formed, causing faulting and icy volcanism. Shoemaker had the right idea all along.

Robert Pappalardo is a professor of planetary science at the University of Colorado at Boulder. His research centers on the geology of icy moons and implications for their interior evolution.

World Watch

by Louis D. Friedman

Darmstadt, Germany—Congratulations to the European Space Agency on the success of its *Huygens* mission to the surface of Titan. ESA is now four for four in planetary exploration—*Giotto* to Halley's comet, *Mars Express*, *SMART-1* to the Moon, and now *Huygens*. The *Huygens* probe was carried to its success by NASA's *Cassini* orbiter, making this mission a landmark in international cooperation.

Washington, DC—In early February, the Bush administration sent its proposed NASA budget to the US Congress. Unlike most civilian agencies, NASA received a budget increase, although less than was planned. The policy recommendations accompanying the budget focused on redirecting human spaceflight beyond Earth orbit, as proposed in the Vision for Space Exploration that President Bush announced last year.

Dominating budget politics are the costs and risks of returning the space shuttle to flight, the future of the International Space Station, and the fate of the Hubble Space Telescope (HST). Safety dominates the return-to-flight issue, with servicing of the HST another consideration. The HST will need servicing soon, most likely within the next 3 years. The National Academy of Sciences concluded that a human servicing mission was more reliable and less costly than a robotic mission. But NASA concluded that a human mission couldn't be conducted safely within the guidelines of the Columbia Accident Investigation Board, leaving, they say, the HST without a way of being serviced.

Many news commentaries have linked the HST issue to the Vision for Space Exploration, saying that Moon and Mars exploration is sucking money away from the HST. This is not correct. Servicing the HST became an issue after the *Columbia* accident, when the safety of future shuttle missions began to be debated. Although cost is an issue, it would be whether or not the vision had been proposed.

How much is servicing the HST worth, now that it has surpassed its planned lifetime and a new space telescope is in the works? Congress will debate the issue in the current session. The Planetary Society position is that the decision to cancel a servicing mission and de-orbit the HST is not necessary or warranted yet, and that nothing should be done now that precludes servicing the telescope.

In space science, the big budget news was the postponement of the Jupiter Icy Moons Orbiter (JIMO), which was to be the first mission to use nuclear power from the Prometheus program. This cancellation leaves us without any plans to explore Europa, despite its high scientific priority and great public interest in the possibility of life there.

The Society supports the development of nuclear-electric power and propulsion in the Prometheus program but emphasizes that it will take many years to produce a workable system. The Europa mission is a high scientific and public priority, independent of the nuclear propulsion objective.

The positive news was the strong support for Mars exploration and other planetary missions. The *Lunar Reconnaissance Orbiter* for 2008, the first mission in the new exploration vision, also was supported. But there were cuts: the Discovery program of low-cost missions lost $12 million, and the New Frontiers Program, whose first mission is New Horizons to Pluto, was down $52 million.

Montreal, Canada—In January, leaders of the space agencies involved in the International Space Station (ISS) met to agree on plans for ISS development after the space shuttle returns to flight. The United States has committed to completing construction of the ISS by 2010. This means getting the European and Japanese modules delivered to orbit, a job that only the space shuttle now can do. The United States has not committed to operations, servicing, and use beyond that.

The new space exploration vision directs that US space station activities be focused on preparing humans for Mars missions. What the US will do with the space station is a critical question. Retiring the shuttle, for financial and programmatic reasons, by 2010 is key to the new vision. That would leave space station transportation in the hands of Russia until the new US Crew Exploration Vehicle is built. But current CEV plans have no capability for space station docking! We will continue to watch for the resolution of this conundrum.

Washington, DC—NASA announced selection of an infrared spectrometer to fly on the *Chandrayaan-1*, the Indian lunar orbiter scheduled for 2008. This is a so-called mission of opportunity in the Discovery program. Raising eyebrows in the planetary science community was the fact that NASA selected no new Discovery mission, contrary to plans and expectations for the program.

Louis D. Friedman is executive director of The Planetary Society

Annual Report to Our Members

Dear Planetary Society Members, Donors and Friends,

Carl Sagan, Bruce Murray, and Lou Friedman founded The Planetary Society 25 years ago to inspire the world's people to explore other worlds and seek other life.

Today, you and I—members and supporters of The Planetary Society in more than 125 countries around the world—are advancing the frontier of cosmic discovery. I am pleased to be your new Chair of the Board of Directors, knowing that my own life's trajectory greatly resonates with the dreams of The Planetary Society. With this letter, I offer a review of accomplishments over the past year and a 5-year overview of our financial status. A look back at the Society's actions and activities in 2004 shows clearly that with you, we are at the heart of space exploration.

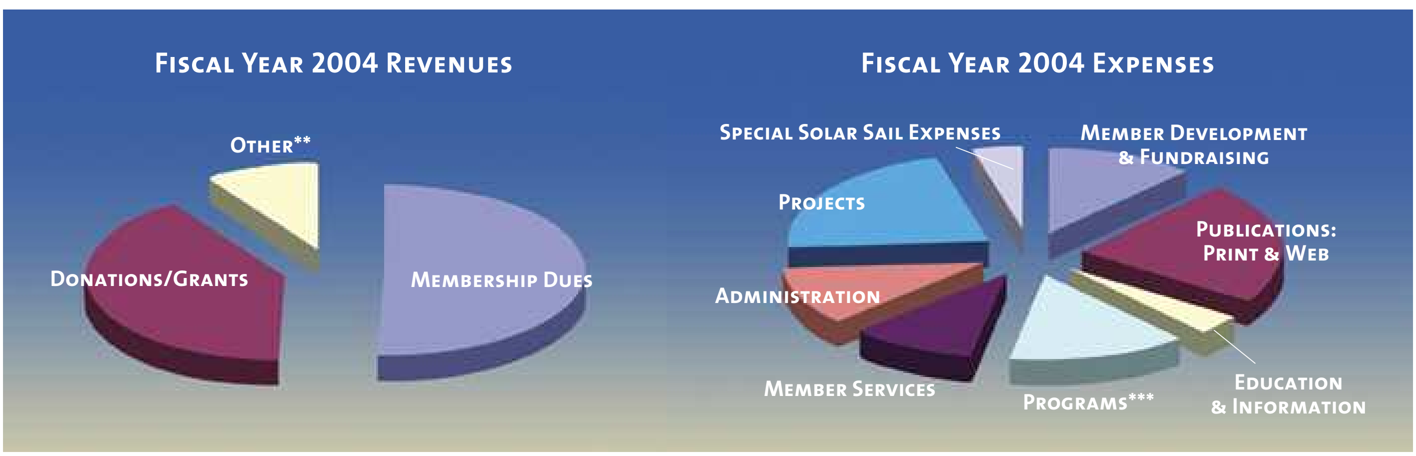
The year brought us two triumphant landings on Mars, offering direct evidence that water once drenched the Martian surface; spectacular images from *Cassini* on its tour of Saturn and its moons; and a new NASA vision, embraced by other spacefaring nations, for human and robotic exploration of the Moon, Mars, and beyond. The Planetary Society, your Society, took part in it all.

- In January, thousands gathered in Pasadena—and hundreds of thousands of others via the Web—at our Wild About Mars celebration of the *Spirit* rover's landing on Mars. An early image back from the Red Planet showed the MarsDial, a camera calibration target provided by the rover imaging team, The Planetary Society, and others.
- Our international corps of student "astronauts" participated in Red Rover Goes to Mars, our joint venture with LEGO on NASA's Mars Exploration Rovers (MERs), and spent months analyzing images of the MarsDial.
- Our Internet-accessible Mars Stations around the world, including the Carl Sagan Memorial Mars Station at our Pasadena, California headquarters, engaged people in exploring an unknown world through the eyes of a robotic rover.
- We continued the momentum with the launch of our Aim for Mars campaign to champion robotic and human exploration of Mars. We welcomed the new U.S. space initiative, which lays out a multidecade exploration agenda for the Moon, Mars, and the rest of the solar system, to include NASA and international partners.
- In July, Planetary Radio became available to U.S. public radio stations. Listeners around the world also tune in weekly via our website to hear from a scientist, engineer, project manager, advocate, or writer with a unique perspective on the quest for knowledge about our solar system and beyond. This year, as a measure of our show's popularity, XM Satellite Radio will regularly air Planetary Radio.
- The Society's 3-day SETI workshop at Harvard University in August brought together experts in the Search for Extraterrestrial Intelligence to consider new ways to advance that quest. The event included representatives from each of the SETI projects we fund.
- Our search for planets outside the solar system continued, which is crucial in our ongoing quest to understand our place in the universe. We look forward in 2005 to expanding the search with a "catalog of exoplanets" that we will host on our website.
- The Gene Shoemaker NEO Grant Fund is our tool for discovering, tracking, and characterizing potentially dangerous asteroids and comets. In recognition of the advances made in the area of detection, the 2004 call for proposals sought projects by amateurs for follow-up observations that refine the orbits of professionally discovered near-Earth objects (NEOs).
- Local events in communities around the world partnered the Society with museums, planetariums, science centers, and astronomy clubs from Pasadena, California to Darmstadt, Germany to Buenos Aires, Argentina to the People's Republic of China, and more—all run mainly by the dedicated volunteers of The Planetary Society.

Looking Ahead

With your help, and in partnership with Cosmos Studios, we are on the verge of launching *Cosmos 1*, the first space mission to be conducted by a private membership organization—as well as the first solar sail–propelled spacecraft to leave Earth.

From Mars to Pluto, from comets to near-Earth asteroids,



and from Europa to Titan, we look forward to a year of exploration and discovery—one filled with worldwide public excitement for space exploration, and one in which Planetary Society Members will once again help shape public discourse and the public policy that flows from it.

Your support, as Members and Donors, remains key to the health and growth of your Society, The Planetary Society. You have maintained our financial strength, even in difficult economic times. Major individual gifts and bequests have enabled us to undertake ambitious projects and advocate for exploration. You have helped us reach out to more people in more locations, involving them as Members at the heart of space exploration. You keep alive and vibrant the vision with which The Planetary Society was founded 25 years ago, shaping the future of space exploration as Members, Donors, and Friends of The Planetary Society, the largest independent space advocacy group in the world.

Sincerely yours,

Neil D. Tyson

Neil deGrasse Tyson
Chair, Board of Directors

Balance Sheet

For the Fiscal Years Ended September 30, 2000, 2001, 2002, 2003, and 2004 in thousands of dollars.

	Total All Funds:				
Assets	**FY2004**	FY2003	FY2002	FY2001	FY2000
Current Assets					
Cash and Cash Equivalents and Investments	1,572	1,959	2,274	1,104	1,695
Membership Dues and Misc. Receivables	209	114	5	113	427
Inventories	53	47	49	45	43
Prepaid Expenses	51	21	20	42	16
Total Current Assets	**1,885**	**2,141**	**2,348**	**1,304**	**2,181**
Land, Building, and Equipment	**638**	**658**	**698**	**760**	**818**
Total Assets	**2,523**	**2,799**	**3,046**	**2,064**	**2,999**
Liabilities	FY2004	FY2003	FY2002	FY2001	FY2000
Liabilities					
Accounts Payable and Accrued Expenses	129	101	170	164	312
Deferred Dues and Grant Revenue*	1,247	1,420	1,864	1,614	2,020
Total Liabilities	**1,376**	**1,521**	**2,034**	**1,778**	**2,332**
Net Assets (Deficits)	FY2004	FY2003	FY2002	FY2001	FY2000
Unrestricted	(96)	60	28	(254)	(36)
Temporarily Unrestricted	1,241	1,217	983	540	703
Permanently Restricted	2	1	1	0	0
Total Net Assets	**1,147**	**1,278**	**1,012**	**286**	**667**
Total Liabilities and Net Assets (Fund Balances)	**2,523**	**2,799**	**3,046**	**2,064**	**2,999**
Revenues	FY2004	FY2003	FY2002	FY2001	FY2000
Membership Dues	1,538	1,636	1,703	1,780	1,994
Donations/Grants	1,230	1,495	1,285	1,797	1,885
Bequests	0	10	631	59	0
Other **	282	258	288	335	291
Solar Sail Grant	0	0	677	2,226	126
Total	**3,050**	**3,399**	**4,584**	**6,197**	**4,296**
Expenses	FY2004	FY2003	FY2002	FY2001	FY2000
Member Development & Fundraising	380	342	339	518	689
Publications: Print & Web	721	629	749	711	589
Education and Information	121	102	129	310	487
Programs ***	455	551	430	324	736
Member Services	331	312	394	379	360
Administration	338	408	394	753	317
Projects	703	561	1,097	841	587
Special Solar Sail Expenses	132	228	326	2,369	126
Total	**3,181**	**3,133**	**3,858**	**6,205**	**3,891**

* Income received but not yet recognized
** Admissions, events, interest, net sales, royalties, etc.
*** Events, lectures, tours, expeditions

Society News

Planetary Society in Washington, DC

The Society was active in Washington during the second week of February. On February 8, NASA invited the Society to its Mars Roadmap Committee to present the results of our Aim for Mars studies, which we conducted last year. Louis Friedman co-led the presentation with former astronaut Owen Garriott. Garriott co-chaired the Society study "Extending Human Presence into the Solar System," which he presented to the committee. Friedman described other Society-funded studies: a Russian Moon-Mars scenario and a proposal for an international lunar waystation. The latter is to be a developmental step toward Mars Outposts—a goal for both the human and robotic programs.

On February 10, the Society organized a special presentation for members of Congress titled "Mars: A New World for Humankind," led by Mars Exploration Rover lead scientist Steve Squyres and Society Vice President Bill Nye. The purposes of the presentation were to excite Washington space policy leaders about the exploration of Mars and to remind them of the public interest in it.

Attendance at the meeting was terrific, with more than 40 staff from many congressional offices attending, along with national news media. Squyres gave a beautiful exposition of Mars Exploration Rover discoveries, and Nye wowed the audience with the passion, beauty, and joy of space exploration, explained in his inimitable style. After the presentation, Representative Sherwood Boehlert, chair of the House Science Committee, invited Squyres, Nye, and Friedman to his office for a private 45-minute meeting.

—Susan Lendroth, Manager of Events and Communications

Volunteers with Energy and Enthusiasm!

The Society volunteers have been busy lately getting the public excited about *Huygens'* descent into Titan's atmosphere. Two Titan events—one in Portugal, the second in Libya—were particularly noteworthy.

Francisco Miguel de Sousa Goncalves, volunteer coordinator in Portugal, planned an afternoon-into-evening event at The Centro Multimeios de Espinho, a theater and planetarium in Espinho, Portugal. More than 500 members of the general public and high school children attended the free event, which included presentations on Saturn, Titan, and the *Cassini-Huygens* missions; commentary on the sounds from Titan; observations of Saturn through a telescope; and teleconferences with Adriana Ocampo and Rosaly Lopez from NASA's Jet Propulsion Laboratory.

Miguel was the catalyst for this successful event, connecting the partners at Centro Multimeios, Publiproject (for media contacts), and The Planetary Society as well as inviting scientists from NASA and the European Space Agency to participate as speakers. Congratulations for all your efforts and hard work, Miguel!

The Planetary Society volunteer coordinator in the United Kingdom, Andrew Lound, was invited by the British Council to travel to Tripoli, Libya to give two presentations about Saturn as part of the British Council's touring exhibit "Exploring the Solar System." Andy's dramatic lecture, "Saturn—Lord of the Rings!" began with the history of the observation of Saturn and its moons, then reviewed the development of the *Cassini-Huygens* mission and showed the latest images and sounds coming back from the mission. Both presentations—one before a group of professionals at the Libyan Center for Remote Sensing and Space Science in Tripoli, Libya, and the second to a group of high school oil management students in the Janzour area of Tripoli—were well received. Kudos to you, Andy! With our volunteers beside us, we really do make it happen!

—Vilia Zmuidzinas,
Volunteer & Events Coordinator

Marketplace

Sail to Space with The Planetary Society!

Cosmos 1 is nearly ready to launch. Commemorate this historic project with these Planetary Society–exclusive products:

Cosmos 1 Crystal Cube
Commemorate *Cosmos 1*'s historic first flight with this stunning laser-etched crystal cube. Our elegant eight-bladed spacecraft floats inside double-beveled leaded crystal with the title "*Cosmos 1*, The First Solar Sail." Each 2-inch cube comes in a satin-lined gift box.
2 lb. **#577 $49.00**

Cosmos 1 Thermal Mug
This stainless steel, 16-ounce thermal mug filled with your favorite hot beverage will help keep you warm on chilly nights of solar sail watching. A limited-edition Planetary Society exclusive.
2 lb. **#575 $18.00**

Cosmos 1 Mission Patch
This 3-inch embroidered patch is the official mission patch for *Cosmos 1*. 1 lb. **#578 $3.50**

Cosmos 1 Mission Pin
Our official mission pin is 1 inch in diameter. It is polished silverplate with a vibrant, dark blue enamel background.
1 lb. **#579 $5.00**

Set Sail for the Stars! Poster
Cosmos 1 sets sail, leaving its home planet behind. In the distance, the Milky Way beckons. This stunning illustration created by Rick Sternbach captures both the elegance and the promise of solar sailing, the only known technology that may one day take us to the stars. 22" x 34"
1 lb. **#571 $13.50**

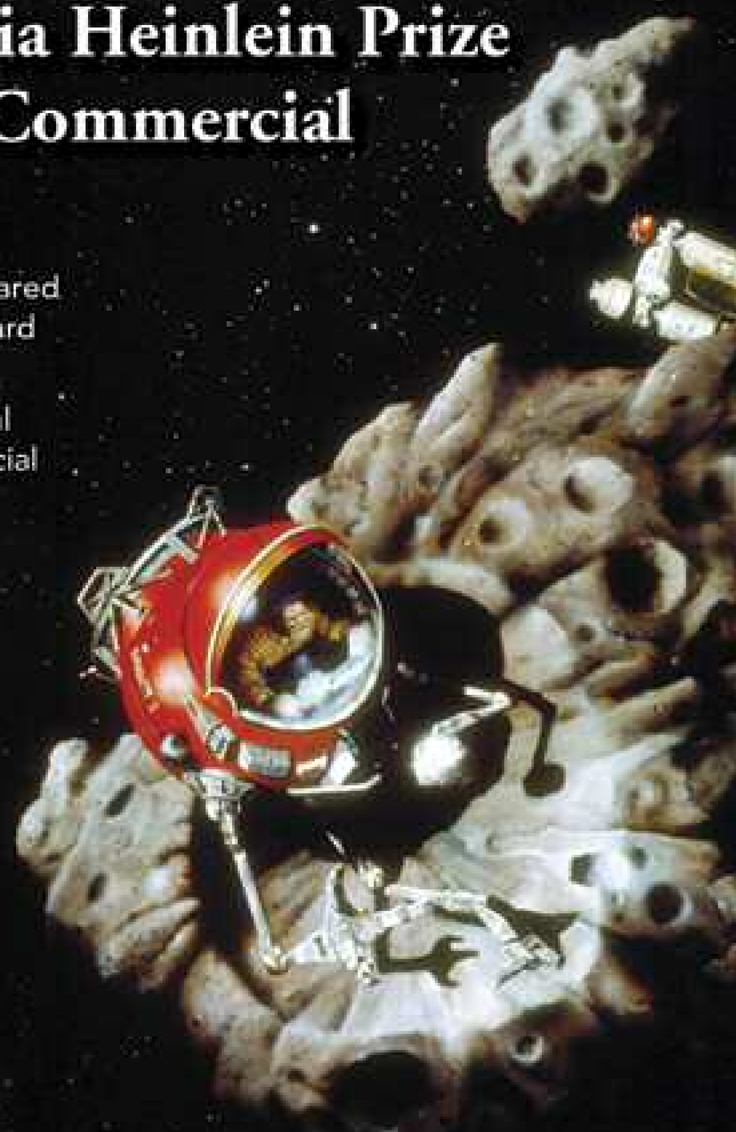
Cosmos 1 T-Shirt
The Planetary Society's *Cosmos 1*, the first-ever solar sail, will take off into orbit this year. This commemorative T-shirt is a Society exclusive. Long-sleeved, with glow-in-the-dark ink, it's perfect for dark nights of solar sail watching. Adult sizes: S, M, L, XL, XXL
1 lb. **#570 $25.00**

Cosmos 1 Team Jacket
Planetary Society Members are an essential part of the *Cosmos 1* team! Get your official team jacket only through The Planetary Society. These water-resistant jackets are cobalt blue with "*Cosmos 1* Team" embroidered on the front and logos for The Planetary Society, Cosmos Studios, and Russian space agencies printed on the back. Special order only (allow 6–8 weeks for delivery). Adult sizes: M, L, XL
1 lb. **#573 $60.00**

ORDER TODAY!

Phone: 1-626-793-1675
Fax: 1-800-966-7827 (US and Canada)
or 1-626-793-5528 (International)
Shop online at The Planetary Store! *http://planetary.org*

Attention teachers—submit your order on your school letterhead and receive a 20% discount.



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