The PLANETARY REPORT

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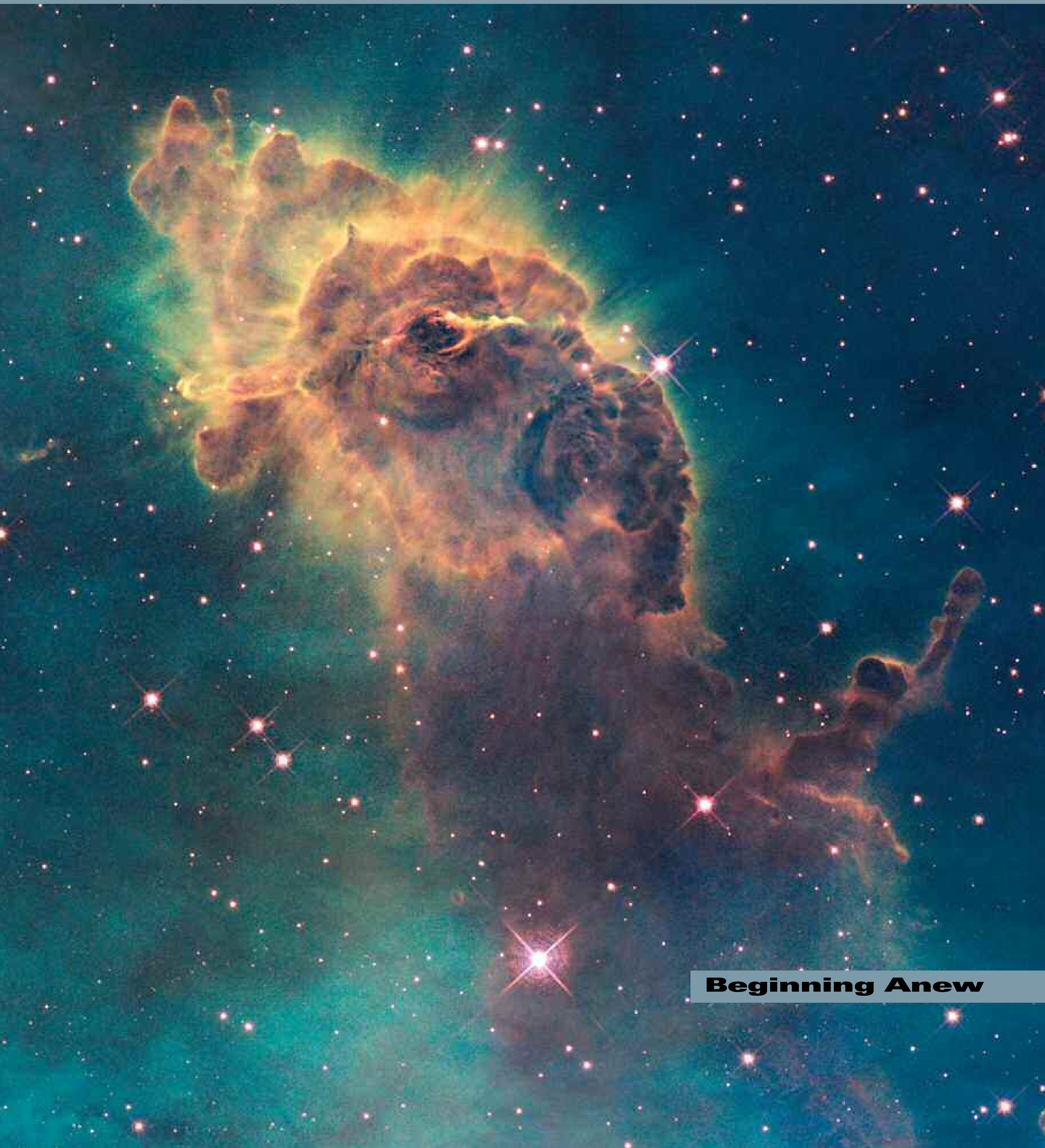

Beginning Anew

From The Editor

The solar sail is back! We're aiming to launch before the end of next year. We are truly excited, and not just because it's cool technology—although it undoubtedly is beyond cool—but also because of the great things solar sails can make possible. We have always talked of interstellar voyages, and, with our new *LightSail* project, we're also addressing the eminently practical.

For example, consider your own electronically connected world. What would happen if the power grid went down, not just for hours but for days or even weeks? It might happen. Coronal mass ejections from the Sun could trigger massive geomagnetic storms capable of crippling electricity-dependent nations.

This is not the overwritten plot of a Hollywood movie. The National Research Council of the U.S. National Academies recently warned that severe space weather could affect—in very nasty ways—our lives on Earth.

How can solar sailing address this? It could be the ideal technology to place solar weather stations between Earth and the Sun to give us enough warning to shut down transformers and save the grids.

But can solar sails do it? To test them out, our *LightSail-3* will travel toward Lagrangian point 1, between our planet and its star, where a solar sail could someday keep a weather station in position and provide the needed warning time.

How's that for a practical use of Planetary Society Members' donations?

Still, although practicality is good, we all need a little romance in our lives, and solar sailing provides that as well. Want to see what life is like around Alpha Centauri? There's only one way to get there . . . and our *LightSail* project is taking the crucial first step.

—Charlene M. Anderson

On the Cover:

Within the southern constellation Carina, located 7,500 light-years away, is a tempestuous stellar nursery called the Carina nebula. There looms this three-light-year-long pillar cloud of dense material, which is shaped by its interaction with radiation from stars both in and outside it. Radiation from exterior stars is disrupting the outer parts of the cloud, producing filamentary green and blue colors. The radiation is also compressing the cloud, inducing star birth. This image was taken in visible light by the Hubble Space Telescope's new Wide Field Camera (WFC3). For an infrared view of the same object, see page 12. Image NASA/ESA/Hubble SM4 ERO Team

Background:

This highly oblique image, shot over the northwestern part of the African continent, shows the thin blue line of Earth's atmosphere. Next year, *LightSail-1* will carry out its mission above Earth and the drag-effects of its atmosphere. This picture was taken on September 4, 1997 by an astronaut on board the space shuttle. Image: NASA/JPL/UCSD/JSC

Contact Us

Mailing Address: The Planetary Society,
65 North Catalina Avenue, Pasadena, CA 91106-2301

General Calls: 626-793-5100
Sales Calls Only: 626-793-1675
E-mail: *tps@planetary.org*
World Wide Web: *http://planetary.org*

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A PUBLICATION OF THE PLANETARY SOCIETY

LIGHTSAIL:

A New Way and a New Chance to FLY ON LIGHT

by Louis D. Friedman

Once again, The Planetary Society is preparing to set sail on the light of the Sun. **LightSail-1**, *our new solar sail, is the first of a three-part program that will unfold over several years. Here,* **LightSail-1**, *slated to launch at the end of 2010, floats 800 kilometers (500 miles) above the surface of Earth. At this altitude, sunlight alone will power the sail, increasing its orbital energy.* Illustration: David Imbaratto, Stellar Exploration

> *Let us create vessels and sails adjusted to the heavenly ether, and there will be plenty of people unafraid of the empty wastes.*
> —Johannes Kepler, in a letter to Galileo

Sailing on light is the only known method that can take us to the stars. The technology isn't ready—not now, not in a few years, and probably not in less than a century. But the journey begins now. The Planetary Society is, right now, creating this technology to fly a solar sail.

A sail powered by sunlight alone will not be able to reach the stars. Such a trip will require large solar-powered lasers that will beam concentrated light over interstellar distances. But solar sailing—flying on sunlight—will allow us to get around the solar system without fuel and to hover at important places in space, countering the effect of the Sun's gravity. It will enable us to monitor the Sun and protect Earth, and then to open up the solar

LightSail Team Members


Louis D. Friedman
Program Director

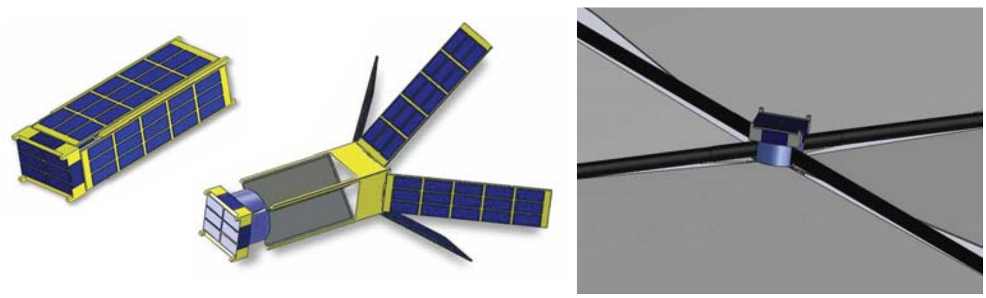

Jim Cantrell
Project Manager


Tomas Svitek
Spacecraft Manager


Bruce Betts
Payload Manager


Beth Wahl
Systems Engineer


Ann Druyan
Science Adviser



Near right: This image shows LightSail-1 *as it will look in its launch configuration, prior to opening its solar panels and deploying its sails. The blue rectangles are solar cells. Before opening, this unit will measure only 10 x 30 centimeters (about 4 x 12 inches).*

Middle: Once the solar panels have opened, the spacecraft housing will appear like this. The sail, electronics, and other internal components are not shown.

Far right: This view shows the center of the sail after deployment, looking at the "bottom," or the side that points away from the Sun. The gray fields represent the sail material, with solar cells in blue and the booms in black. *Illustrations: The Planetary Society*

system and the way to other solar systems after that. These practical applications will happen much sooner than interstellar travel.

In 2005, with the support of our sponsoring partner, Cosmos Studios, The Planetary Society built the first solar sail spacecraft and attempted the first solar sail flight, only to be thwarted by the Earth-bound rocket that was supposed to deliver us to space. The Volna rocket carrying our spacecraft was lost in the Arctic sea. We have not lost our vision or our determination to make it happen. Technology has advanced, and a new class of "nanosat" spacecraft makes solar sailing even more practical, with smaller sails giving higher accelerations and greater performance for flight (see "What's a Nanosat?" on page 6).

These ultralight spacecraft point the way to the future. A spacecraft designed for interstellar flight will have to be "atosat" in size, weighing perhaps only a few grams. For now, we will take the step of reducing mass by a factor of 25 while flying farther and faster. We have dubbed our project *LightSail*.

The concept of a nanosat sail was pioneered by NASA, but it was not designed for solar sail flight. NASA's nanosail application was an atmospheric drag device to help de-orbit satellites. NASA's solar sail development program was terminated several years ago. The Planetary Society is applying the nanosail concept to develop a new class of *LightSail* spacecraft that will take us step by step first into the solar system and then, someday, to the stars.

Thanks to a major new donation and the continued support of our members, we are now embarking on the first *LightSail*. Our first mission, *LightSail-1*, will demonstrate solar sail flight. *LightSail-2* will use the solar sail to increase the orbit energy and move us away from Earth, and *LightSail-3* will take us on a mission for which a solar sail spacecraft is uniquely suited: creating a solar weather monitor to provide early warning of solar storms that can affect Earth.

LightSail-1

LightSail-1 will be made up of three cubesat spacecraft. One cubesat will form the central electronics and control module, and two additional cubesats will house the solar sail module. Cubesats were developed about a decade ago, primarily for student spacecraft projects at universities, notably Stanford University. Since then, they have been used much more widely by industry, the military, and NASA for Earth-orbit missions.

We will adapt the cubesats to make a customized spacecraft for the *LightSail* missions. The central electronics and control module will house a camera to image the sail, a radio system to send and receive data, a computer to control the spacecraft and the sail, an accelerometer to measure the force of sunlight, and a Global Positioning System (GPS) to provide navigation information about the effect of the light force on the spacecraft's position and velocity. Taken together, these instruments make possible a controlled solar sail flight.

The sail module, housed in the other two cubesats, will deploy a sail approximately 5.5 meters on a side made of aluminized Mylar 4.6 micrometers (microns) thick. The spacecraft's mass will be less than 4.5 kilograms, and thus the mass-to-area ratio will be 140 grams per square meter. This will provide a characteristic acceleration (the acceleration from sunlight at the distance of Earth) of 6.5 micro-*g* (6.5 times one millionth the force of gravity), or 5.7×10^{-5} meters per second squared. This is better than *Cosmos 1*, which had a mass-to-area ratio of 160 grams per square meter.

The Planetary Society sail will fly in an orbit greater than 800 kilometers (500 miles) above Earth's atmosphere, where the only nongravitational force is that of sunlight pressure. The actual orbit will be determined by the launch vehicle on which we piggyback (fly as a secondary payload). Fortunately, our spacecraft is light and small, and there should be little trouble finding a ride into space.

What's a Nanosat?

Microsat, nanosat, picosat—this nomenclature concerning the size of spacecraft is now being used extensively in the aerospace industry. These terms are not precise, but they do provide general categorization:

- MICROSAT: Spacecraft that weighs 10–100 kg
- NANOSAT: Spacecraft that weighs 1–10 kg
- PICOSAT: Spacecraft that weighs less than 1 kg

The list doesn't make proper use of the prefixes, but the terms are now accepted in the spacecraft arena. For this article, I made up the term "atosat" to mean a spacecraft that might weigh as little as 1–10 grams and be used for future interstellar flight. —*LDF*

In fact, we have a Space Act Agreement with NASA Ames Research Center to cooperate on nanosat development, and this should help us find even more opportunities for flight. In any case, we will fly high enough to be out of the atmosphere even during times of solar maximum, when the atmosphere expands due to heating from solar wind activity.

The mission will fly long enough to enable us to detect the increase in orbit energy caused by the effects of sunlight reflecting off the sails. We will do this by integrating the spacecraft's acceleration measurements, observing the position and velocity changes with the GPS, and tracking the spacecraft from the ground. The onboard camera will verify the sail's deployment and dynamic behavior, and we will also arrange for Earth-based imaging to take pictures of the sail in flight.

LightSail-1 will be built over the course of 18 months and be ready for flight by the end of 2010. The launch vehicle possibilities include both U.S. rockets—the Minotaur, the Atlas V, and the Falcon—and Russian rockets—the Cosmos 3M and the Soyuz-Fregat. All of these have had recent successful experience launching multiple satellites.

LightSailing into the Future

LightSail-2 and *LightSail-3* will advance solar sailing, with trips increasing from days of light to months, and add spacecraft payload to permit more scientific information to be obtained.

The goal of *LightSail-3* is to fly instruments to monitor the solar output of protons and electrons before they hit Earth's ionosphere. Large solar magnetic storms create coronal mass ejections that can disrupt communications and power grids when the particles reach the ionosphere, as well as damage spacecraft in Earth orbit.

Currently, spacecraft to monitor the Sun and provide advance warning can be placed only at L1, a Lagrangian gravitational stable point between Earth and the Sun located approximately 1.5 million kilometers (900 thousand miles) from Earth. A solar sail will allow monitoring much closer to the Sun, making for better observations and longer warning times to help us protect our planet's electrical grid. *LightSail-3* will have its own propulsion unit, enabling the solar sail to be placed on a deep-space trajectory and to provide more flexibility in choosing the launch vehicle for the fight.

Together, We're Making It Happen

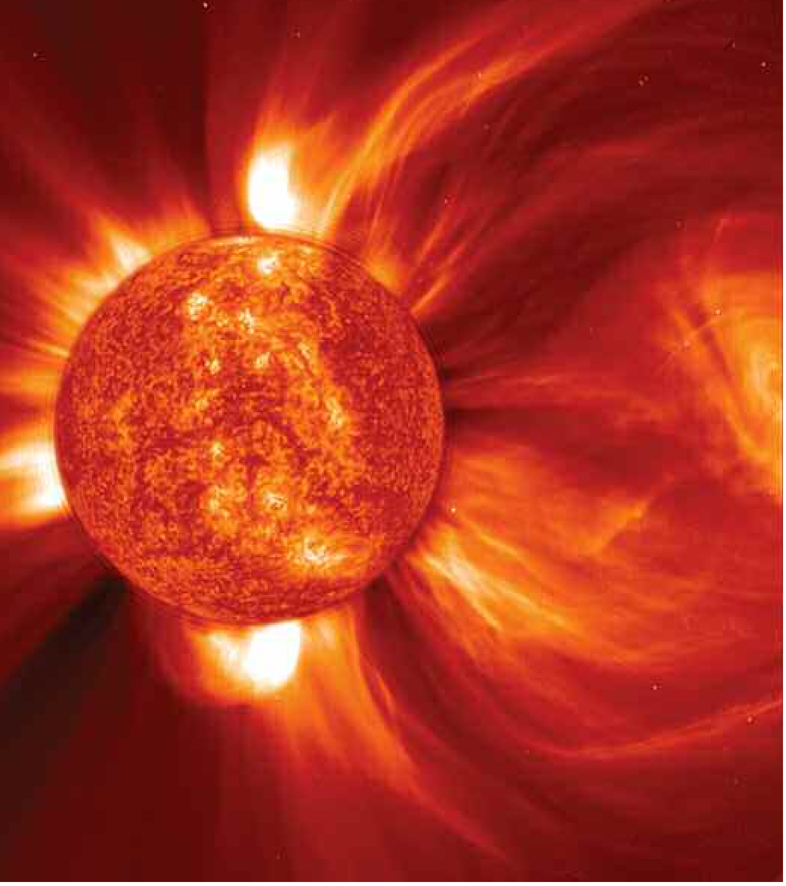
Sail forth—steer for the deep water only,
Reckless O soul, exploring,
I with thee, and thou with me,
For we are bound where mariner has
not yet dared to go,
And we will risk the ship, ourselves, and all.
—Walt Whitman

Can The Planetary Society do this? Is this a job for a public membership organization that accepts no government funding and that instead relies on private contributions from people who share its vision of exploring new worlds?

Having been in the space business for 40 years, I cannot deny that the program is audacious. The funding I had for our *study* of solar sailing in the 1970s was more than the budget for either our *Cosmos 1* mission or this new *LightSail-1* mission. NASA's cost estimate to do a mission to meet our first flight goals was nearly $100 million (in a proposal it developed three years ago). Nonetheless, we accept the challenge, and we will meet it.

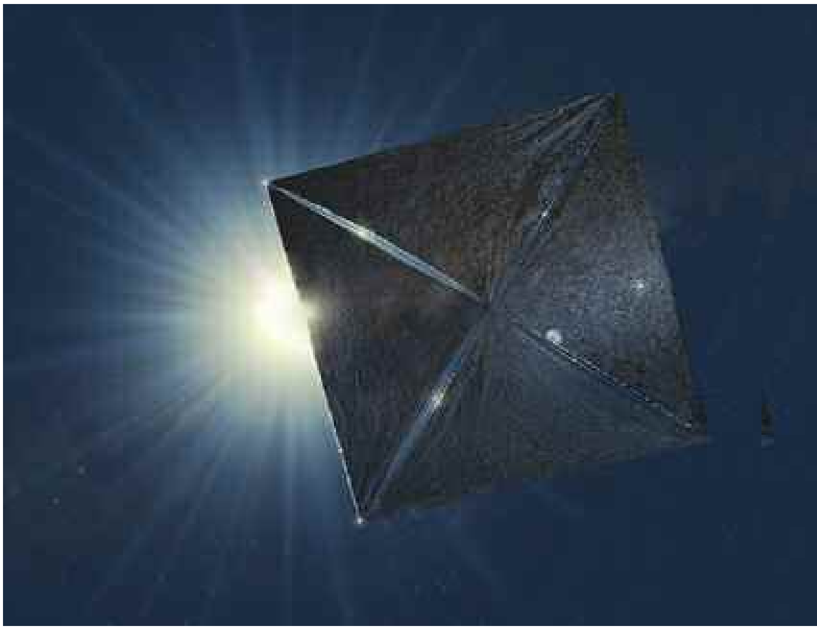
The Planetary Society, in partnership with our Russian colleagues and Cosmos Studios, built and launched Cosmos 1*, the first solar sail spacecraft. Although it failed to reach orbit, what we've learned from this project has helped us to bounce back, better than ever, with our three-part* LightSail *mission.*
Illustration: NPO Lavochkin, The Planetary Society

We don't aspire to be an aerospace industry contractor or miniature space agency. Instead, we seek to seed and prod governments and industry with creativity and innovation to further space exploration. Taking the first step to the stars by demonstrating an innovative new technology fits that role perfectly. Using small, excel-



Left: A coronal mass ejection (CME) is a violent and swift eruption of matter from the Sun's corona, so powerful that it disrupts the solar wind. These CMEs can interfere with spacecraft and their communications with Earth. When their effects reach our world, they can cause powerful geomagnetic storms, wreaking havoc with electrical transmissions and communications.

On January 8, 2002, the Large Angle and Spectrometric Coronagraph Experiment (LASCO) instrument on the international Solar and Heliospheric Observatory *(*SOHO*) imaged this CME as it blasted more than a billion tons of matter into space at millions of kilometers per hour. The image of the Sun was taken on a different day and superimposed over the occulting disk for added effect.* *Image: NASA/ESA*



Right: An early-warning spacecraft positioned at Lagrangian point 1 (between Earth and the Sun) could afford us precious minutes in which to shut down electrical transformers and other sensitive systems at risk for damage. LightSail-3 *will test the feasibility of using a solar sail to keep a solar weather station. Here, Earth and the Moon are reflected off the anti-solar, or "bottom," side of* LightSail-3 *as it sets off on its mission.* *Illustration: Rick Sternbach for The Planetary Society*

lent teams focused on a single purpose of flight is now a proven way to open up space to innovators and private entrepreneurs. It's called *new space*, and we are adopting the approach.

Our team brings together experienced professionals and youth, including students. Our project manager, Jim Cantrell, has worked with almost all the major aerospace companies as an engineer, manager, and consultant for both military and civilian space projects. He first worked with The Planetary Society on Mars balloon development (and even was assigned to the French space agency to help it adopt the technology advances we made on that project). He is now the CEO of Strategic Space Development.

Although this spacecraft will be different from *Cosmos 1* and built in the United States, we deeply respect our Russian colleagues who built that spacecraft, and we value their experience. After all, *Cosmos 1* is the only flight-ready solar sail spacecraft ever built. The Russians will continue to work with us on both the sail module and the spacecraft, and we keep open the option for flying on a Russian launch vehicle (although not the Volna). When we step up to *LightSail-2* and *LightSail-3*, we will likely need their expertise and experience.

Creating something new requires a fortuitous combination of circumstances. The greatest solar sail design is useless if we can't find an affordable launch to space. As I am fond of saying, there is no such thing as a free launch. *Cosmos 1* was enabled not just by a neat spacecraft design and a clever team but also by funding from an Internet venture start-up and continued support by a visionary—Carl Sagan's widow and collaborator, Ann Druyan, and her Cosmos Studios company. Planetary Society members are the other key component. Your support has been sensational and unique, making it possible to continue this quest for flight on light. *LightSail* is made possible by one anonymous member who provided us with a $1 million grant and challenged us to commit to flight. We accept.

That said, we have rigorously put together a detailed budget and plan and have engaged an outstanding team of space veterans to review our project and question our realism and technical approach. Included on this review team are Glenn Cunningham, former *Mars Global Surveyor* project manager; Bud Schurmeier, former *Voyager* and *Galileo* project manager; Donna Shirley, former head of JPL's Mars Program; and Viktor Kerzhanovich, a veteran of nearly every Soviet planetary mission as well as several U.S. planetary mission developments.

Imagining Interstellar Flight

Overhead and in the far distance are the lights in the sky that are stars. The stars they tell us we can never reach because they are too far away. They lie; we'll get there. If rockets won't take us, something will.
—Frederic Brown

Sailing on light without carrying fuel, with very low mass spacecraft and very large sails, is the only known method for practical interstellar flight. My imagined interstellar craft has a sail made purely of silver or aluminum ions. The sail is manufactured by depositing those ions on some kind of plastic substrate that evaporates after the ions take hold. The spacecraft avionics and electronics are all embedded in the sail, as are the power cells supplying instrument and computing power. Cameras and the magnetic bubble memories are also embedded. The sail also serves as the communications antenna, so that the weight of the vehicle outside the sail is nearly zero.

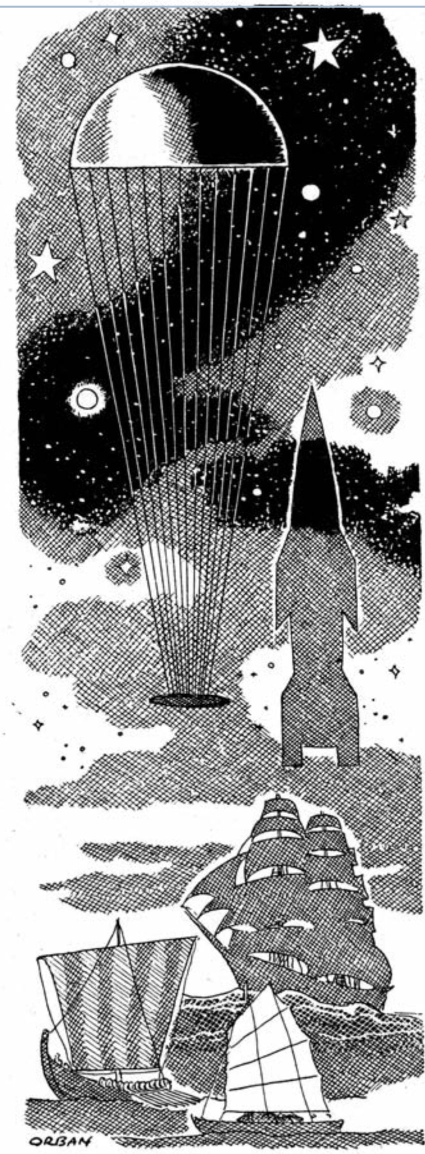
Ultra-thin, ultra-strong halyards will be required for control (steering) and also to detach and deploy a very clever inner sail to decelerate the vehicle when it reaches its destination star. This system was invented by Robert Forward, who wrote about it in both a technical paper and a science fiction story.

When you get near the star, the inner sail deploys. Being lighter than the outer sail, it speeds up relative to the main craft. The bigger outer sail is then turned 180 degrees, so that its reflection side faces the smaller sail. The light from the smaller sail then hits the bigger outer sail and provides a retro force to slow it down.

The source of power cannot, of course, be sunlight. It is a powerful laser beam focused over interstellar distances. The laser will reside in our solar system, probably on a large space platform orbiting somewhere between Earth and Venus. Ideally, it would be powered by enormous solar power, although an engineering trade-off with nuclear-powered laser platforms needs to be done.

Developing these technical elements is a big task, and we are not ready to start today. Creating the means to build the laser in space, the power system, the deposition of ions, and all the other things I mentioned will take, I would guess, at least 100 years—perhaps even 200. But they are all "known" technology.

Space is big, and interstellar flight is a long way off, but various advanced studies and technical literature (not science fiction stories) support the conclusion that light sailing is the best and, for now, the only technology we know of that can take us to the stars. *—LDF*



This illustration accompanied the first English-language scientific paper published on solar sailing. Titled "The Clipper Ships of Space," it appeared in the May 1951 issue of Astounding Science Fiction. *The author, aeronautical engineer Carl Wiley, used the pseudonym Russell Saunders out of concern for his professional reputation. The voyage of* LightSail-1 *will begin a new, nonfiction chapter in humanity's attempts to sail on light.*

Illustration: Paul Orban for Astounding Science Fiction

International Interest in Solar Sailing

So throw off the bowlines.
Sail away from the safe harbor.
Catch the trade winds in your sails.
Explore. Dream. Discover.
—Mark Twain

This era of solar sailing resembles the early days of ballooning and of aircraft, with technology expanding rapidly and little certainty about what kinds of approach will work and what kinds will fail. It's an exciting time to push the technology that will someday take us to the stars.

When we started our solar sailing effort in 2000, both NASA and ESA (the European Space Agency) had solar sail development programs. ESA was scheduling an Earth orbit flight before 2005, and NASA was building a much larger sail for a technology development mission. In addition, two other private organizations (one in the United States and one in Europe) also were trying to develop missions. Within a couple of years, all those projects ceased. Both space agencies had their technology development budgets slashed, and the cutbacks that followed affected much more than the solar sail program.

Around the same time, the Japanese Space Explo-

Solar Sail Deployment Tests

YEAR	COUNTRY	FLIGHT	RESULT
1993	Russia	*Znamiye*—Deployment of "shade" outside *Mir*	Success
1999	Russia	*Znamiye-2*—Deployment test from *Progress*	Collided with spacecraft antenna during deployment
2002	The Planetary Society	Suborbital deployment test	Rocket's third stage failed to separate
2004	Japan	Suborbital deployment tests	Success
2005	The Planetary Society	Fully controlled in Earth orbit	Rocket failed during first stage
2006	Japan	Deployment test in Earth orbit on *Astro-F* mission	Did not fully deploy
2008	United States	*Nanosail-D*—Deployment of a solar sail in the atmosphere as a drag brake	Rocket failed to deliver to orbit

ration Agency (JAXA) started a different kind of program—development of a hybrid propulsion system for an eventual Jupiter orbiter. The hybrid included both a solar sail and an ion drive electric propulsion engine. In this innovative design, solar power for the electric engine comes from solar cells embedded in the sail. The Japanese performed a successful suborbit sail deployment test in 2004.

Now they have built a technology development spacecraft with their sail and solar cells, and they will fly it next year as a piggyback on their *Venus Climate Orbiter* (currently known as *Planet-C*) mission. They will deploy the sail as the spacecraft departs from Earth, and if all goes well, they will try to fly it as a solar sailer. They have invited The Planetary Society to collaborate with them to disseminate public information about the mission and to share technical results. We will do that.

Back in 1993, the Russian Space Agency conducted a deployment test of what could be called a solar sail in Earth orbit. It was at low altitude, observed from the *Mir* space station, and was meant not for solar sailing but for the development of large reflective mirrors for a possible application to light up permanently dark regions of the Siberian north at night.

Seven tests of solar sail deployment have been conducted, and only one attempt (ours) at flight. The attempts are listed in the table above.

The Elegance of Sailing

> ***'Twas all so pretty a sail it seemed***
> ***As if it could not be,***
> ***And some folks thought***
> ***'twas a dream they'd dreamed***
> ***Of sailing that beautiful sea.***
> —Eugene Field

Two unique characteristics lured me into solar sailing. The first is that solar sails are beautiful. Spaceships tend to look like functional engineering boxes. Oops—that is exactly what they are. Solar sails look romantic.

The second unique characteristic is that they require no fuel; hence, they alone (from what we know) can make the trip to the stars. Even for them, it will be difficult (see page 8).

Although I have long argued other benefits—round-trip interplanetary ferries, robotic sample-return missions, and missions to Lagrangian points (gravitational equilibrium points) such as L1, for example—they are not quite as interesting because other spacecraft also can accomplish these missions. My colleague and friend Slava Linkin added a conjecture that solar sails are antigravity machines: they permit exactly countering the Sun's gravity anywhere in interplanetary space.

That makes hovering at nonequilibrium points possible—for example, at two or three times the distance toward the Sun of L1, where we could get two or three times the warning time of an impending solar storm. This is special—no other spacecraft can do this—and I am now much more hopeful of seeing a near-term application of solar sailing for this purpose.

It's special, and it's also rather elegant: we balance the force of the Sun's gravity with the force of the Sun's electromagnetic radiation (light). That jibes perfectly with our physical intuition—gravity may be the most pervasive force in the universe, but it is also the weakest. The strongest force is electromagnetic radiation. If we harness this fundamental property of physics to achieve a practical and important space application such as a solar weather station, then it will feel like just the right cosmic thing to do.

> ***We have lingered for too long***
> ***on the shores of the cosmic ocean;***
> ***it's time to set sail for the stars.***
> —Carl Sagan

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

2009 The Year in Pictures

The year 2009 saw a lull in launches to other planets, with both the American and Russian planned launches to Mars slipping two years to 2011. Momentous events occurred nearer to Earth, however: March saw the launch of the *Kepler* planet-hunting spacecraft (now trailing Earth in its orbit), and in May, astronauts rocketed up to rendezvous with the Hubble Space Telescope, performing repairs and installing new instruments that should give it at least another five productive years. Several more space shuttle missions have nearly completed the construction of the International Space Station, and in June, the simultaneous launch of *Lunar Reconnaissance Orbiter* and the *Lunar Crater Observation and Sensing Satellite (LCROSS)* marked the United States' return to the Moon (literally, in the case of *LCROSS*, which deliberately crashed into the Moon on October 9, following *Kaguya,* which deliberately crashed on June 11).

Meanwhile, plenty of spacecraft are actively exploring the planets. Mars continued to enjoy the attention of three orbiters and two rovers. *Cassini* witnessed a once-in-15-years event at Saturn, the equinox, when the Sun passed through Saturn's ring plane, illuminating bizarre ring structures through the long shadows that they cast. *MESSENGER* completed its third and final flyby of Mercury before entering orbit, while *Stardust, Deep Impact*, and *Rosetta* passed by Earth on their way to comets. Finally, *Dawn* and *New Horizons* patiently cruised onward in their long journeys to Vesta and Pluto.

We have these pictures and more from 2009 on our website at *planetary.org/yip*.

Emily Stewart Lakdawalla is science and technology coordinator for The Planetary Society and writes for the Society's blog at planetary.org/blog.

Massive Meteorite Makes Martian Mile Marker

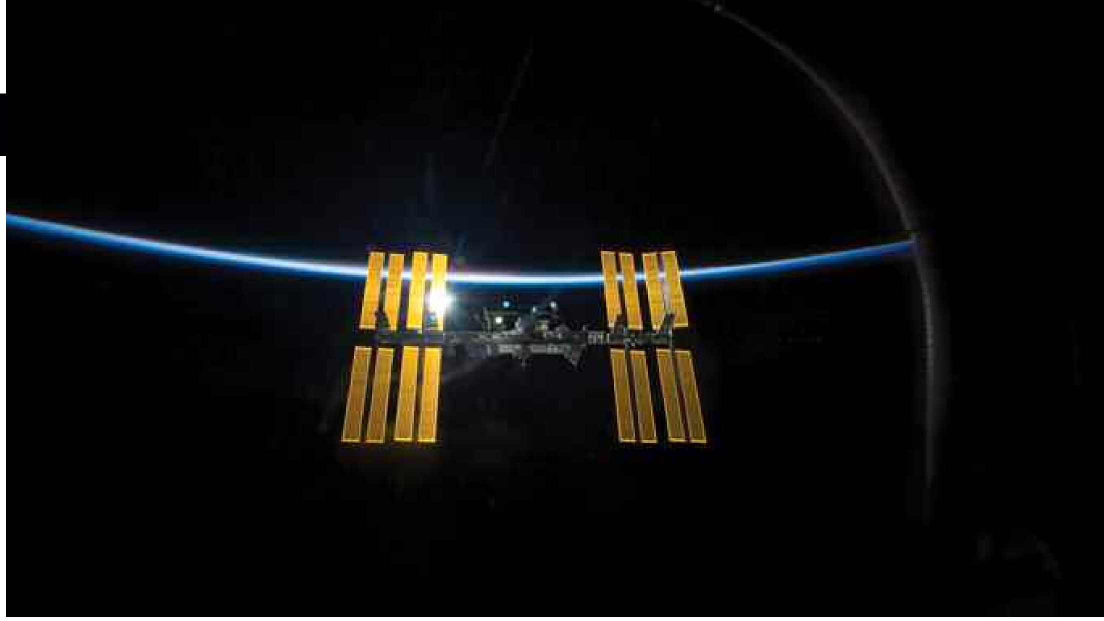
The Mars Exploration Rover *Opportunity* has spent 2009 on a road trip, steadily driving southward on a nearly 20-kilometer (12-mile) journey toward Endeavour crater. The dune-filled landscape of Meridiani Planum is numbingly similar day after day, with rare but interesting small craters and cobbles providing fodder for images as *Opportunity* drives by. Two days after it roved by this rock, *Opportunity*'s scientists realized they'd passed something special, so they turned around and returned to it, spending nearly two months examining it with all instruments.

Opportunity's studies confirmed that the rock, now named "Block Island," is an enormous iron-nickel meteorite. At more than half a meter in length and likely more than half a ton in mass, it is larger than any other known meteorite on Mars, large enough to be visible from the HiRISE camera on *Mars Reconnaissance Orbiter*. In fact, it is so big that its existence on the Martian surface is problematic: at Mars' current atmospheric pressure, Block Island should have come in with so much velocity that it should have shattered. The fact that it is intact suggests to scientists that when it landed, the atmosphere was thicker than it is now. Image: NASA/JPL/Cornell/color mosaic by James Canvin

Block Island Up Close

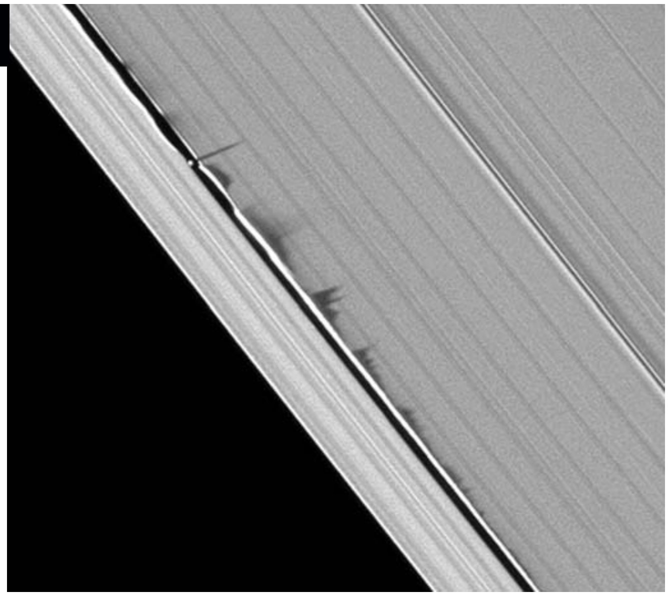
Opportunity used its Microscopic Imager to study the texture of Block Island up close. The triangular patterns in the rock are characteristic of iron-nickel meteorites found on Earth. Vertical white streaks in a few places on the image are artifacts caused by the Sun glinting off shiny metallic facets. This image shows an area that is 32 millimeters (1.3 inches) square. Image: NASA/JPL/Cornell/USGS

Full Power

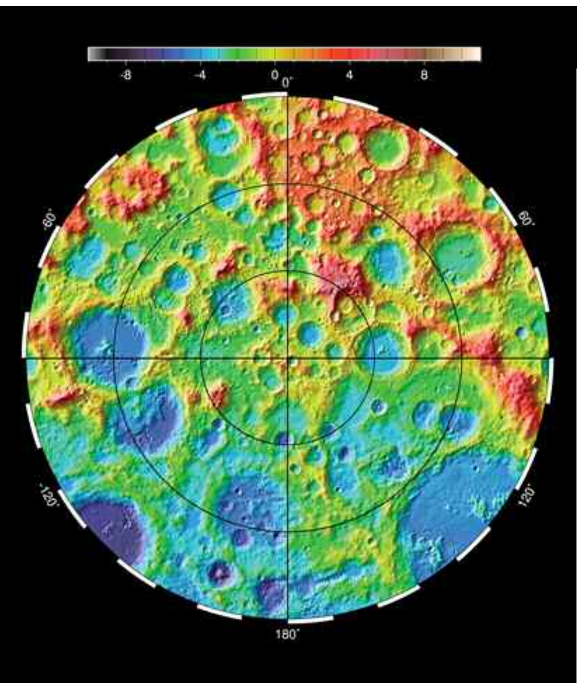


As the space shuttle *Discovery* drifted away from its STS-119 destination at the International Space Station, astronauts photographed their handiwork. They had just completed installing the fourth and final set of solar panels, finally providing enough power to the station to support its full complement of resident astronauts. For years, the station has been a bright naked-eye object when it passes overhead just before dawn or just after dusk, but its reflecting area is now so large that it's visible to experienced observers even in the daytime.
Image: NASA

Side-Lit Structures in Saturn's Rings



August 11, 2009 marked the equinox on Saturn, a once-in-15-years event when the Sun passes through Saturn's ring plane. With the Sun striking the vast, flat ring system from the side, tiny vertical perturbations in the rings' flatness were brought into relief as they cast long shadows. Here, the tiny moon Daphnis, about 8 kilometers (5 miles) in diameter, orbits within the Keeler gap in the A ring, casting a needle-like shadow onto the A ring. Also casting shadows are sawtooth structures on the edges of the Keeler gap. These structures are vertical perturbations in the ring particles caused by up-and-down gravitational tugs from Daphnis, which has a slightly inclined orbit. Particles closer to Saturn than Daphnis, on the right side of the Keeler gap, orbit Saturn faster than Daphnis does, so the sawtooth pattern spreads out ahead of Daphnis in its orbit. Particles farther from Saturn than Daphnis, on the left side of the Keeler gap, orbit Saturn more slowly, so that half of the sawtooth pattern spreads out behind Daphnis in its orbit. *Cassini*'s scientists employed the extremely low angle lighting geometry around the equinox as a probe to observe previously undiscovered vertical structures in Saturn's rings. Image: NASA/JPL/SSI



Lasers Map the Moon's Shape

The two most critical types of data for planning future landings on the Moon are photos of the surface and information on the topography, including slope and roughness, of the surface. The Lunar Orbiter Laser Altimeter (LOLA) is gathering the second type of data, providing maps of lunar topography that have already helped mission planners to select the target point for the *LCROSS* lunar impactor mission. This topographic map of the lunar south pole (showing everything poleward of 75 degrees south latitude, with the near side on the top and far side on the bottom) was produced from the first two months' worth of LOLA data and includes many of the permanently shadowed craters that might contain reservoirs of water ice. The scale at the top of the image indicates how color corresponds to elevation in kilometers; there are more than 10 kilometers (6 miles) of relief in this map. The *LCROSS* target, the crater Cabeus, is a medium-blue depression at about 10:30 on the innermost circle on this map, corresponding to a position of about 85 degrees south, 45 degrees west. Curving across the image from the center to the right-hand edge is a ridge of particularly high topography that marks the rim of the South Pole–Aitken basin, an enormous impact scar that mars the Moon's far side. The lowest topography is found on the bottom (far side) part of the LOLA map, where the landscape marches down into the bottom of the basin. The South Pole–Aitken basin is a favorite target for a future planned sample-return mission or even human landing, as the impact crater should provide access to rocks that originally formed deep within the Moon. Image: NASA/GSFC

Zoom to the Center of the Milky Way

Gigagalaxy Zoom is one of many exciting public astronomy events that unfolded this year under the umbrella of the International Year of Astronomy 2009. Organized by the European Southern Observatory (ESO), Gigagalaxy Zoom set out to capture three views of the night sky that were unprecedented in their detail, each containing hundreds of millions of pixels. The first view was of the Milky Way as seen by the human eye from a dark observing site. The second, shown here, is of the center of the Milky Way as seen through a modestly sized (10-centimeter, or 4-inch) amateur astronomer's telescope. The third, of the Lagoon nebula, shows a huge area of the sky as seen through a world-class professional telescope, the 2.2-meter instrument at the La Silla Observatory in Chile.

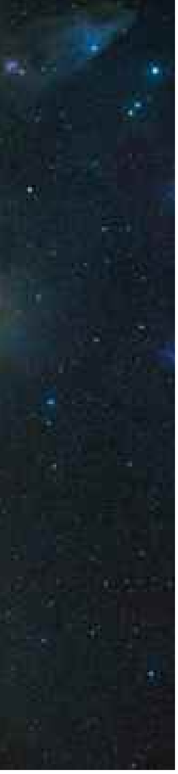
This image covers an area 34 x 20 degrees in size. It was assembled by astrophotographer and ESO engineer Stéphane Guisard from about 1,200 individual images collected over 29 nights and totaling more than 200 hours of exposure time. Although Guisard used a small telescope, he had the benefit of some of the darkest, clearest skies on Earth, those over ESO's Paranal Observatory in Chile. The image covers the constellations of Sagittarius and Scorpius and the dark, dusty lane that marks the plane of the Milky Way, as well as a colorful region (right) that includes the stars Rho Ophiuchi (within the blue nebula) and Antares (a supergiant star that lights up the yellow nebula), Sigma Scorpii (lighting up the red nebula to the right of Antares), and a distant globular cluster, M4 (the ball of stars below and between Antares and Sigma Scorpii). The Lagoon nebula is the bright pink feature at upper left. Image: ESO/S. Guisard

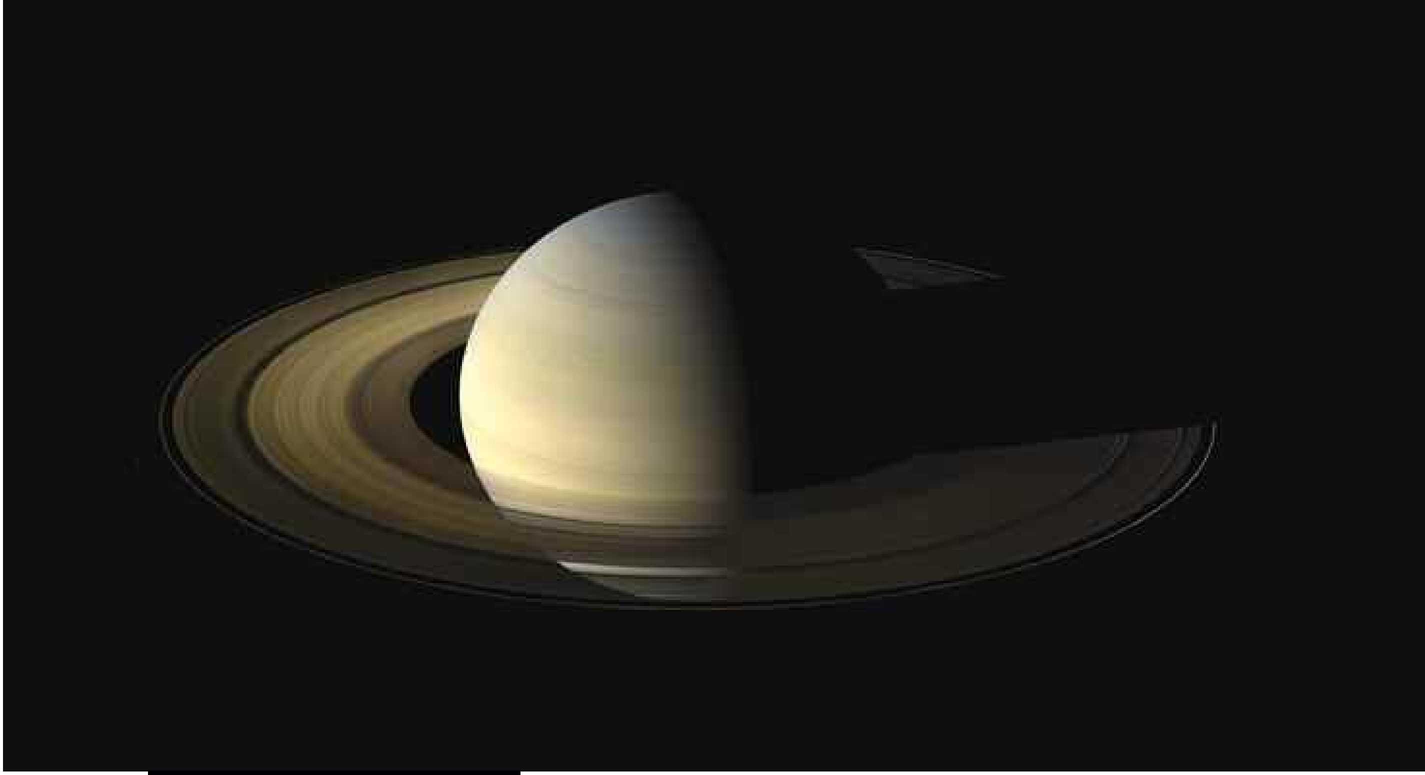
The New Pillars of Creation

On our cover (inset) is a colorful pillar of gas and dust photographed by Hubble's ultraviolet and visible channel of the Wide Field Camera 3 (WFC3). Here, we are looking at the same pillar, only this image is in the infrared.

The structure we see is a three-light-year-long cloud of dense material, shaped by its interaction with radiation from stars both within and without. The cloud is opaque in visible wavelengths, but when we look at the same region in the infrared, the cloud becomes a transparent, ghostlike feature, and four bright newborn stars are now visible. One of the stars has two jets blasting from its poles. Such activity is observed only in stars under 100,000 years old.

WFC3 was installed on the Hubble Space Telescope by the astronauts of the space shuttle *Atlantis* in May of this year. WFC3 replaced the workhorse Wide Field and Planetary Camera 2, upgrading its ultraviolet- and visible-light wide-field imaging to a slightly wider field of view at slightly higher resolution. WFC3 also added the capability of wide-field imaging in infrared wavelengths. Image: NASA/ESA/Hubble SM4 ERO Team

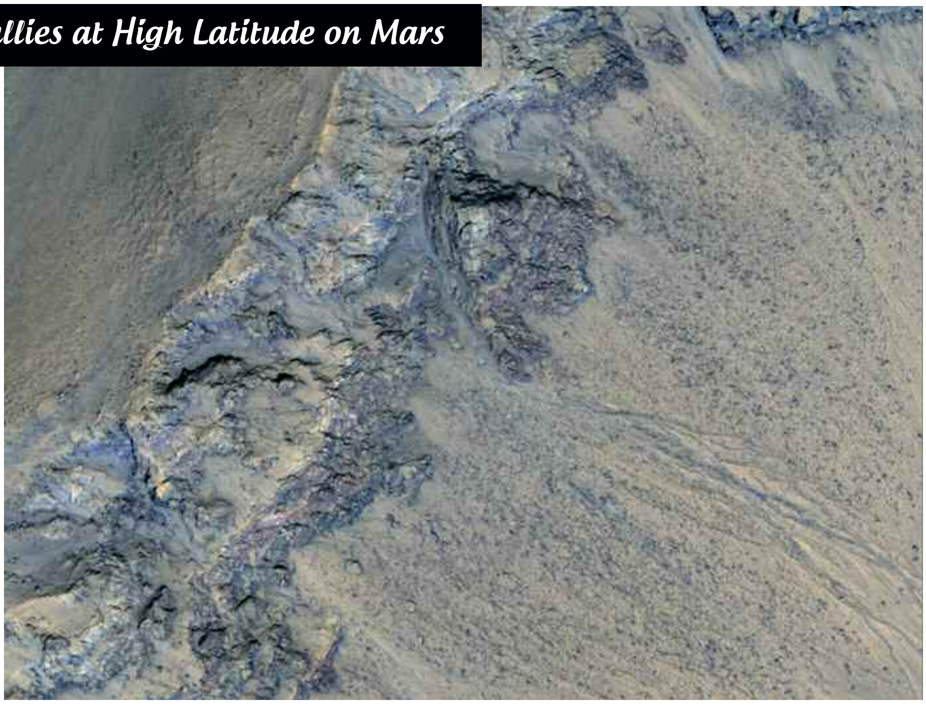




Saturn at Equinox

On August 11, 2009, the Sun perched in the plane of Saturn's rings and lit both poles of the planet. Saturn's entire globe enjoyed a full day of sunlight, with only the skinniest stripe of clouds at the equator experiencing any shadowing from the vast ring system. Although the rings are brilliantly reflective, at this one time of the year, it is twilight on the rings and they are nearly totally dark. The only light they receive is the sunlight that has been reflected off Saturn's globe, making the upper (sunward) arc of the rings brighter than the lower arc. To make them visible in this mosaic, the whole ring system has been brightened by a factor of 20. Image: NASA/JPL/SSI

Very Recent Gullies at High Latitude on Mars



This High Resolution Imaging Science Experiment (HiRISE) image covers the rim of a geologically recent impact crater located at a high southern latitude (52.87 degrees south, 234.7 degrees east). The crater has excavated subsurface layers of varying-colored rocks, which were later eroded by gullies. Gullies are common in Mars' middle latitudes (between 35 and 45 degrees north and south) but rare at higher latitudes, perhaps because there are very few steep slopes at high latitudes due to abundant ground ice. Recent impact craters have new steep topography in which gullies can form.

This image covers an area 800 x 600 meters in size. The HiRISE team released hundreds of images to the public in 2009, amounting to terabytes of data. Every image rewards close inspection with views of landscapes that are simultaneously familiar and alien. Image: NASA/JPL/UA

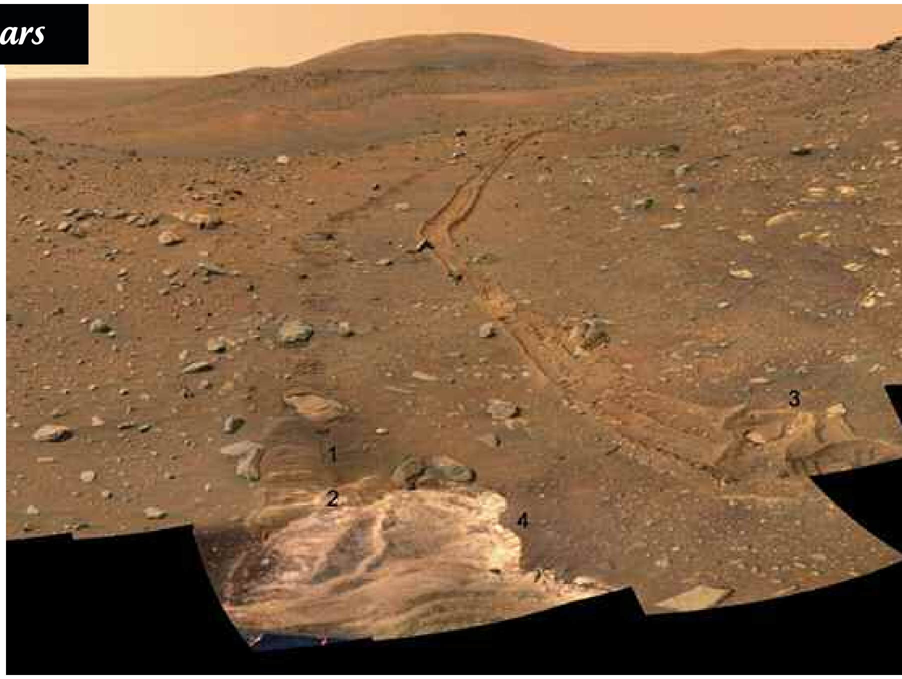
Celestial Object Found on Earth

One of the biggest stories of 2008 was the discovery of an asteroid, briefly named 2008 TC3, just hours before it crashed into Earth. When it entered the atmosphere and burned up on October 6 over a remote area of northern Sudan, most people assumed that was the end of the story, but not Peter Jenniskens, a meteor astronomer at the Carl Sagan Center at the SETI Institute. He teamed up with Muawia Shaddad, an astronomer at the University of Khartoum, to organize an expedition to hunt for any fragments of the asteroid that may have survived the trip through the atmosphere.

In December, Jenniskens, Shaddad, and 45 students and staff set out from Station 6 of the local railway line, following the flight trajectory of 2008 TC3. Within hours, they found the first tiny fragment and named it "Almahata Sitta," Arabic for Station 6. As the expedition members walked along the flight path over the coming days, they gradually saw the size of the meteorites increase from small pebbles to that of chicken eggs. This photo is from the third day of the expedition; Jenniskens, Shaddad, and a number of University of Khartoum students point to one of those larger pieces.

Study of the meteorites proved that they were a very unusual type, called a *ureilite*. Study of the spectra of the parent asteroid, 2008 TC3, showed that it, too, was unusual, an F-class asteroid. These results were announced in the March 26 issue of *Nature* magazine. Image: Peter Jenniskens/SETI Institute

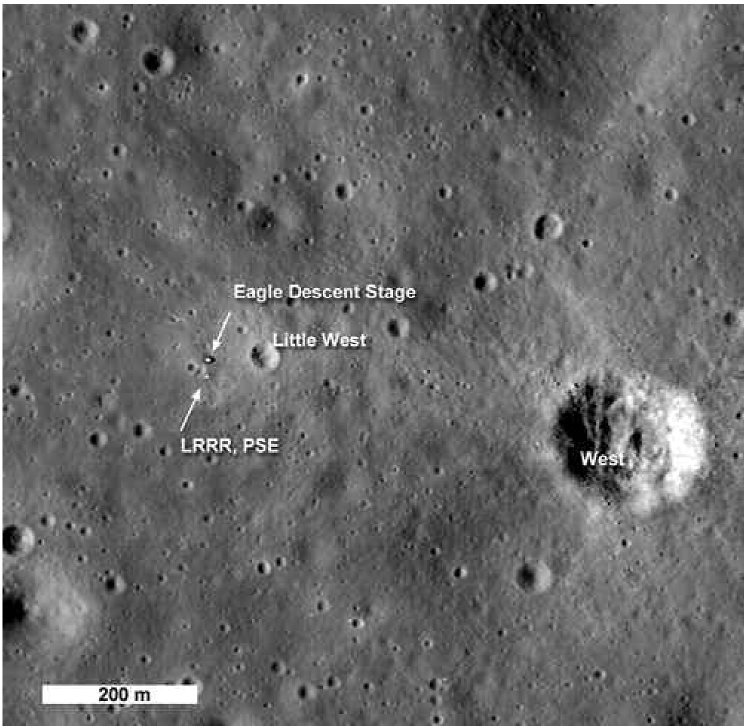
Mired Up to the Hubcaps on Mars

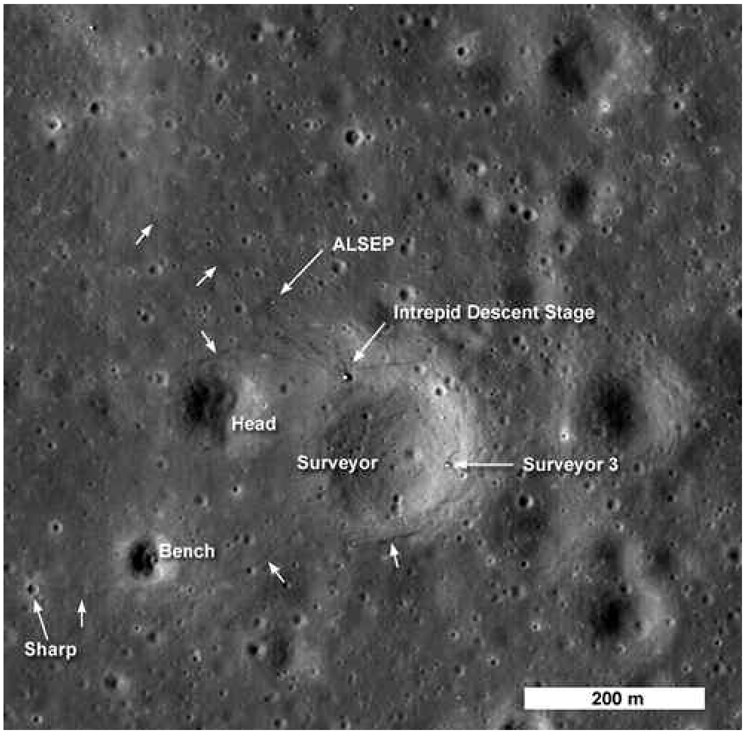


Having spent 2008 sitting at a steep angle on the north edge of Home Plate to gather sunlight through the cold Martian winter, *Spirit* began 2009 with an attempt to climb back atop the rocky plateau it's been studying for almost two Mars years. The immobile right front wheel acted like an anchor for *Spirit*, however, and the climb was unsuccessful. In February, mission managers decided to abandon efforts to climb up Home Plate and instead directed the rover to embark on a drive counterclockwise around it. On sol 1,889 (April 26, 2009), as *Spirit* was hugging the western slope of Home Plate, its forward motion suddenly ceased, and the wheels began digging in. A few subsequent attempts to move *Spirit* resulted in further entrenchment, with five wheels buried up to their hubcaps—the right front wheel, unable to rotate, did not bury itself. As *Spirit* dug in, its belly may have come into contact with a sharp rock, possibly leaving the rover "high-centered," which would make extrication even more difficult. The rest of the summer was spent studying possible rover extrication methods using a rover mockup at the Jet Propulsion Laboratory; extrication efforts began in mid-November.

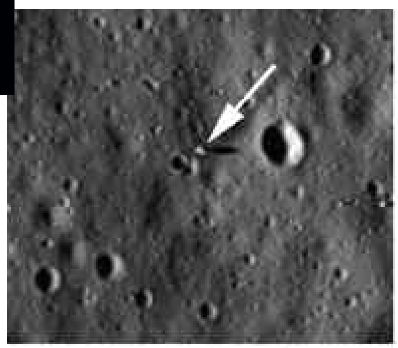
There has been good news: while in this parking spot, now dubbed "Troy," *Spirit* experienced several "cleaning events" that have significantly increased its available power. It used that power to perform science, including gathering a 360-degree panorama from its current position. In the segment of the panorama shown here, we are looking back at *Spirit*'s tracks through West Valley. In the far distance, toward the horizon at left, are the open plains of Gusev crater, where *Spirit* landed more than five Earth years (three Mars years) ago.

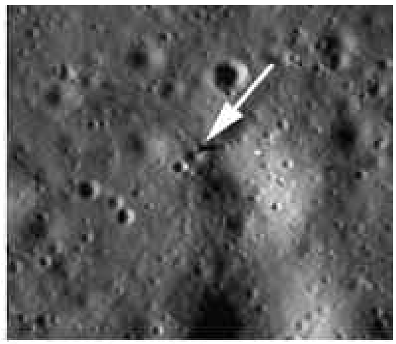
The tracks tell the story of *Spirit*'s entrapment. When *Spirit* got stuck, it was driving backwards, dragging the right front wheel behind it. At first, *Spirit* left tracks in the firm soil on the left side of this view while the dragging wheel created a shallow trench on the right side. At Point 1, the soil began to get looser. At Point 2, the left-side wheels broke through the firmer surface crust, exposing softer, brighter (and, it turns out, sulfate-rich) soil underneath. At Point 3, right-side progress slowed as the other five wheels began to dig down. The frozen right front wheel did not break through and began to act as a pivot, causing the whole rover to veer to one side. At Point 4, we see the steep walls of the left-side trench *Spirit* dug as it sank into the sand. The shape of the wall was carved partly by the left-side wheels as *Spirit* steered and attempted to turn back on course. Imge: NASA/JPL/Cornell/color mosaic by James Canvin

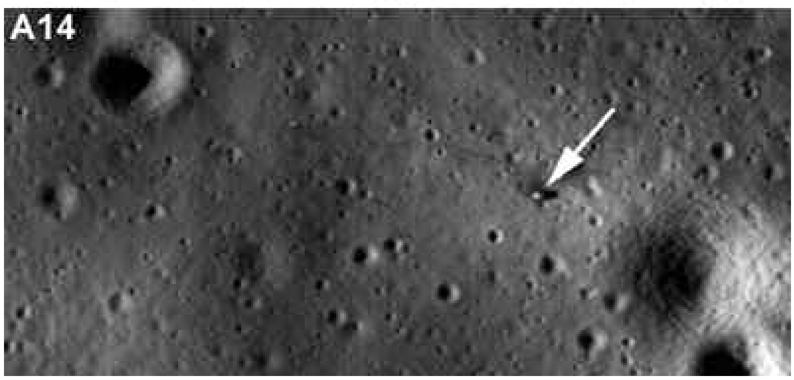




Relics of Human Exploration of the Moon Spotted from Orbit







The Planetary Society declared the opening of the International Lunar Decade in 2007 with the launches of Japan's *Kaguya* and China's *Chang'E* spacecraft; they were followed by India's *Chandrayaan-1* in 2008. Although all these spacecraft performed new and unique science, none carried a camera with the resolution necessary to spot the spacecraft that have landed (or crashed) on the Moon since 1959. *Lunar Reconnaissance Orbiter* changed that; it launched in June of this year and quickly used its camera to capture images of every one of the *Apollo* landing sites. The photos were taken under late afternoon lighting conditions; the lunar module descent stages are easy to spot because their vertical structures cast long shadows. At many of the landing sites, astronaut or rover tracks still show up as dark paths in the dusty regolith.

These pictures were taken while *Lunar Reconnaissance Orbiter* was still in its commissioning phase, in a high orbit. It began its science phase on September 15 by lowering its orbit to one that passes only 50 kilometers (30 miles) above the lunar surface. Because of the lower orbit, future images of the *Apollo* landing sites will have more than twice as much detail as those shown here. Higher resolution views, captured after *LRO*'s transition to science orbit, will be available in 2009—The Year In Pictures at *planetary.org*. As exciting as it is to see these relics of past exploration activity sitting on the surface, *Lunar Reconnaissance Orbiter*'s real purpose is to gather the data needed to plan future landings.

Image: NASA/GSFC/ASU

Rejuvenating Hubble

In a grueling mission that included five spacewalks, seven astronauts on the STS-125 mission aboard space shuttle *Atlantis* performed repairs and upgrades to the Hubble Space Telescope that should allow it to carry on its program of astronomical observations for at least five more years. They installed two new instruments, repaired two others, replaced gyroscopes and batteries, and added new thermal insulation blankets.

This photo was taken during the final spacewalk, as astronauts John Grunsfeld (positioned on the end of *Atlantis*' robotic arm) and Andrew Feustel (foreground) worked on the spacecraft with a cloudy Earth floating in the background. Image: NASA

Amateur Astronomer Discovers a Jupiter Impact

In the late summer of 2009, Jupiter was a popular focus of amateur astronomers. It was a brilliant target high in the sky (opposition was on August 14), and because its equinox was on June 22, there were many opportunities to capture mutual events of moons and shadow transits of the moons across the disk. July 19, therefore, was a routine night of fun Jupiter observing for Australian amateur Anthony Wesley, who views the sky using a 14.5-inch telescope at his home in Murrumbateman, New South Wales.

Because conditions for observing were not particularly good that evening, he almost quit but instead left the telescope and returned half an hour later to see if things had improved. Not only had conditions improved, but a dark mark had also rotated into view near Jupiter's south pole. Wesley quickly realized it was the wrong size and in the wrong position to be a moon's shadow, and moreover it was moving too slowly; in fact, it was rotating in sync with a nearby white oval. Wesley had discovered a new impact feature on Jupiter's clouds, about 15 years to the day after the Shoemaker-Levy 9 comet impact. Over the subsequent weeks, amateur and professional telescopes around the world, including the Hubble Space Telescope (which was still in its commissioning phase following the May servicing mission), monitored the decay of the impact feature as it was torn apart by Jupiter's atmospheric currents. Image: Anthony Wesley

Moon Princess Returns Home

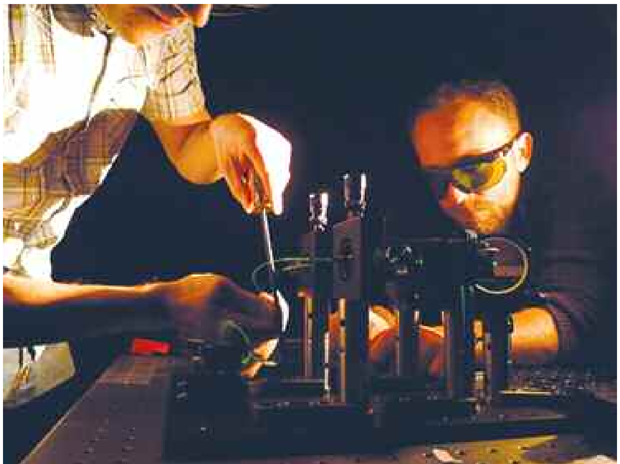
The *Kaguya* lunar orbiter, named for a Moon princess from a Japanese folk tale, ended its productive mission as planned on June 11, 2009 by crashing into the lunar surface near the crater Gill. All of its instruments were operating during its final orbit around the Moon, including the high-definition TV camera funded by the Japanese broadcasting corporation NHK. This is one of the final views of the Moon from *Kaguya*, taken at an altitude of 27,800 meters, looking toward some mountainous peaks near the Moon's south pole, close to the crater Boltzmann (which is just out of frame to the left). Image: JAXA/NHK

We Make It Happen!

Wrapping Up 2009

***A**s the year comes to a close, I've heard from many of our project team leaders updating me on their progress. Lou Friedman has already briefed you on our exciting* **LightSail** *program (see page 4). Since our last issue, we've also learned that our new FINDS Exo-Earths project is moving along quickly, our SETI programs are improving, and our LIFE project will have to wait an additional two years before setting off on its adventure to Phobos and back.*

by Bruce Betts



Julien Spronck with the FINDS Exo-Earths prototype.
Photo: Courtesy Debra Fischer

FINDS Exo-Earths Starts Up

Thanks to Planetary Society members, planet hunters Debra Fischer, Julien Spronck (Yale), and Geoff Marcy (UC Berkeley) have been able to start moving forward with the Fiberoptic Improved Next-generation Doppler Search for Exo-Earths (FINDS Exo-Earths) project. This endeavor will improve our ability to find exoplanets from Lick Observatory and will pave the way for a potential follow-on system that may be able to find Earth-sized exoplanets.

These scientists have begun work with a prototype of the fiber-optic feed system that will increase the precision of their measurements. In recent months, they have twice taken the prototype of the fiber-feed system to Lick, installed it, aligned it, and gotten first light. They obtained spectra through the fiber and confirmed the remarkable stability that motivated the project. Current work involves upgrading some of the hardware to move from a prototype to a working instrument that eventually will be operated remotely. The working instrument will have much better throughput/signal. Fischer and colleagues' to-do list includes antireflection coatings for the optics, a higher throughput fiber, piezo motors for the table, and the addition of adaptive optics capability.

Check out a complete update from Debra Fischer on our website under project FINDS Exo-Earths at *planetary.org/programs/projects/finds/*.

Phobos-Grunt Mission Delayed

The Russian space agency, Roscosmos, decided to delay the launch of the *Phobos-Grunt* mission from 2009 to 2011. The *Phobos-Grunt* mission was to include The Planetary Society's LIFE (Living Interplanetary Flight Experiment) biomodule, designed to test the ability of microorganisms to survive deep-space flight.

Because of the relative orbits of Earth and Mars, favorable launch opportunities to the Martian system occur only every 26 months. Mars mission delays are not uncommon; in fact, they seem more the norm than the exception these days. In December last year, NASA decided on a similar delay for its Mars Science Laboratory mission from 2009 to 2011, and ESA has delayed its ExoMars lander several times, with the latest delay to 2018.

In recent months, the *Phobos-Grunt* mission team has been making every effort to meet the October 2009 launch period, and that included preparation of The Planetary Society's project—LIFE—which was delivered and integrated into the spacecraft over the summer. Project planners determined that integrated spacecraft tests could

The Phobos LIFE biomodule.
Photo: Bruce Betts/The Planetary Society

What’s **Up?**

In the Sky—December and January

Jupiter is the brightest starlike object in the evening sky, appearing in the lower west. Before dawn, extremely bright Venus is low in the east and falls below the horizon in December. Saturn is significantly above the horizon and gets higher as the weeks pass. Bright, reddish Mars rises in the late evening in the east, brightening as the weeks pass until its opposition (opposite side of the Earth from the Sun) on January 29. Mercury is very low in the west in mid-December. The Geminids meteor shower peaks on December 14. Traditionally the best of the year, the Geminids averages more than 60 meteors per hour from a dark site, and this year it occurs around the time of the New Moon, providing particularly dark skies.

Random Space Fact

The *Deep Impact* spacecraft found that comet Tempel 1 has a density of only 0.4 grams per cubic centimeter (water has a density of 1 in those units) and a porosity greater than 65 percent, so the comet is about two thirds empty space.

Trivia Contest

Our May/June contest winner is Rick Cogan of Melbourne, Florida. Congratulations!

The Question was: Who was the only astronaut to fly to space on board all five space shuttles? *The Answer is*: Story Musgrave.

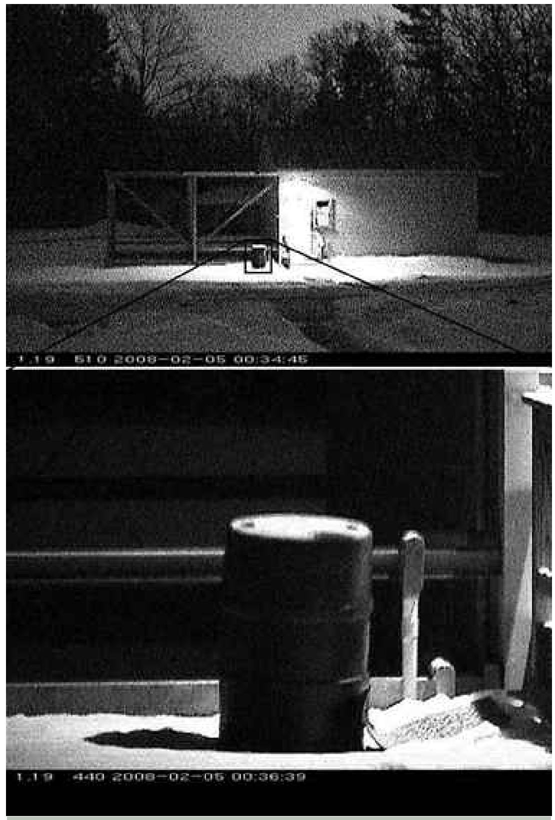
Try to win a free year’s Planetary Society membership and a Planetary Radio T-shirt by answering this question:

How many engines did the first stage of the Saturn V rocket have?

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 February 1, 2010. 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.*



The night vision camera on The Planetary Society's All-Sky Optical SETI Telescope.
Image: Harvard University

not be completed in time to ensure the spacecraft’s readiness for launch. Although human nature makes us want to fly the LIFE project sooner rather than later, we recognize that it is far more important to take the time to prepare a successful interplanetary mission.

The Planetary Society’s LIFE project will be the first test of whether life can survive the deep-space environment for a multiyear duration. Our LIFE team has one flight biomodule and three duplicate Earth control biomodules that are fully loaded with the microorganisms that were chosen to fly to Phobos and back. LIFE acts as a simulated meteoroid with organisms inside. When it does fly, LIFE will help us to understand one aspect of transpermia, whether life can be transported between the planets. *Phobos-Grunt* is the only scheduled deep-space sample-return mission from any space agency and a great opportunity for the LIFE project.

For now, the LIFE biomodules will remain sealed while the Phobos LIFE science team decides what to do with them over the next two years. The current biomodules provide an opportunity to accumulate science data during this time on the ground to better anticipate and interpret results from our eventual spaceflight. At this time, we anticipate loading new organisms in 2011 into a flight module for launch on *Phobos-Grunt*, so as to focus on the period when the organisms are in space. However, all options will be considered by the science team over the coming weeks and months.

We thank our Planetary Society members, donors, and partners on the Phobos LIFE project for making this experiment possible and for understanding the challenges of the space business, which can lead to delays like this one. By its nature, spaceflight is risky and challenging. Phobos LIFE will launch, and when it does, it will be a fascinating and important test of life's ability to move between the planets.

Keep up with the latest information on our Phobos LIFE project on our website in the LIFE project section at *planetary.org/programs/projects/life/*.

Optical SETI Observing and Improvements

Paul Horowitz and his team at Harvard have had a very productive year with The Planetary Society All-Sky Optical SETI Telescope, the only such telescope dedicated to the search for exterrestrial intelligence. Since Paul's November/December 2008 *Planetary Report* article, they've followed up on their promised next steps.

1. The team installed a precision readout of the telescope axis angle (accurate to 1/320,000th of a rotation) and a dedicated camera that looks inward at the detector array. As a result, they know exactly where in the sky any event originates, thus facilitating accurate follow-up of any interesting signals.

2. They added a camera that has sensitive night vision and is controllable remotely, which lets them check out snow and ice conditions.

3. Graduate student Curtis Mead perfected the design of his novel FPGA multichannel flash ADC, a breakthrough that can increase, by a factor of 16, Optical SETI's signal capture capability.

4. The team has racked up 3,182 hours of observations and covered the full northern sky three times. They've had occasional interesting "hits" but nothing that has repeated even once. The improvements just described increase the odds of a successful detection if there is a signal out there.

"The Second Iberoamerican School of Astrobiology: From the Big Bang to the Civilizations," held in Montevideo in September 2009.
Photo: Courtesy Guillermo Lemarchand

Check out Paul Horowitz's complete project update on our website in the Optical SETI section at *planetary.org/programs/projects/seti_optical_searches/*. It includes some great techie facts.

Southern Radio SETI

Guillermo Lemarchand and his team at Instituto Argentino de Radioastronomía continue their radio survey of the Southern Hemisphere sky from Argentina. Theirs is the only consistent survey that samples the southern sky, including the galactic center.

They are not only observing but also training. For the first time, a U.N. agency sponsored a graduate school program concerning the search for life in the universe. The United Nations Educational, Scientific, and Cultural Organization (UNESCO), in cooperation with the School of Sciences from the Universidad de la República (Montevideo, Uruguay) and The Planetary Society SETI Program of the Instituto Argentino de Radioastronomía (CONICET, Argentina), organized "The Second Iberoamerican School of Astrobiology: From the Big Bang to the Civilizations," held in Montevideo in September 2009. Attending this major event were 78 graduate students from 16 Latin American countries and 18 professors from the region, the United States, and Europe. The event included public lectures and teacher training. Guillermo said, "When I started working in SETI 25 years ago, I was the only graduate working on the search for life in the universe in the whole Latin America region. Now almost 80 students are working on their Ph.D.s in related topics."

Find out more about Southern Radio SETI on our website at *planetary.org/programs/projects/seti_radio_searches/*.

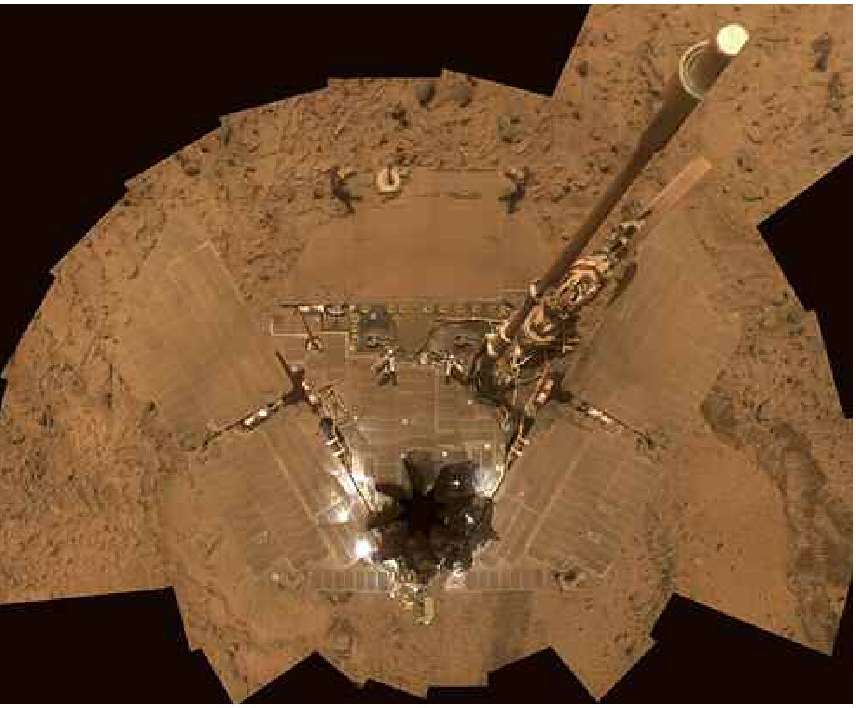
Bruce Betts is director of projects for The Planetary Society.

Questions and Answers

While following the missions of* Spirit *and* Opportunity *these past five years, I've noticed that a persistent problem for both rovers has been reduced battery power resulting from dust buildup on their solar panels. Does the Jet Propulsion Laboratory plan on incorporating a mechanism to remove dust into any future rovers?
—Michael George
Burlington, Vermont

We're not sure when we'll next use solar panels on the surface of Mars. On our next rover, the Mars Science Laboratory, we plan to use radioisotope thermoelectric generators, which avoid the dust problem.

Still, it is likely that we will use solar panels on some future mission to Mars' surface. We've been researching ways to remove dust in case Mars does not oblige us with the cleaning events that we've seen repeatedly on the *Spirit*



Spirit *is so covered with dust that it nearly blends into the background in this nearly true-color self-portrait composed of Pancam images taken in late October 2007. Dust on the rover's solar panels reduces the amount of electrical power the spacecraft can generate from sunlight.* *Image: NASA/JPL*

and *Opportunity* rovers. (Read more about these events at *http://planetary.org/news/2009/0531_Mars_Exploration_Rovers_Update_Spirit.html.*) Vibration, which removes some—though not all—of the dust, appears to be the best approach so far. Work continues on that technology, which is in an early stage of development.

We can also do what we did with the Mars Exploration Rovers, which was simply to make the solar panels big enough to compensate for the power losses resulting from dust during the primary mission. That may be the lowest-cost approach, depending on the duration of a future mission.
—MARK ADLER,
Jet Propulsion Laboratory

Estimates of the maximum point of oil production (peak oil) on Earth range from 2008 to 2030, or beyond. Are there ways of conducting planetary exploration without the use of fossil fuels? Could rocket fuel be produced from biofuels? What about nuclear power or other forms of energy?
—Keith Akers
Denver, Colorado

Planetary exploration consumes virtually no fossil fuels. In part, this is because planetary missions are few and far between, with only two or three new missions launched worldwide each year. Even if these missions were loaded with ultra-premium gasoline, the total amount consumed would still be exceedingly small in comparison with worldwide usage. More important, however, is the fact that the challenges of planetary exploration make it incompatible with the use of fossil fuels.

Most planetary spacecraft carry with them a rocket engine that is used for midcourse corrections during interplanetary flight and for orbit insertion or braking upon arrival at the target. Such engines generally use a fuel such as hydrazine, which has a much higher energy density than gasoline. This allows the engine to provide the very high impulse (boost) required while minimizing spacecraft mass, which is critical for all missions. In addition, hydrazine rocket engines do not require an oxidizer (such as oxygen) in order for the fuel to burn, whereas fossil fuel engines cannot operate in the vacuum of space. (Some rocket engines do combine hydrazine with an oxidizer, usually nitrogen tetroxide, if the impulse required by the mission is large.)

Some planetary missions do not require traditional rocket engines at all; they are powered by electric propulsion driven by solar energy and are extremely efficient. Eventually the power for electric propulsion may be provided by small nuclear reactors, but that technology is still a decade or more away from being usable. The ultimate efficiency for planetary missions is solar sail propulsion, which uses solar radiation pressure and does not require any propellant. The Planetary Society, a leading proponent of solar sails, is preparing a small demonstration mission for launch in the next year or so. This will be followed by more extensive solar sail flights and, if all goes well, by full integration of this revolutionary technique into the world's space science missions (see story on page 4).

The only use of fossil fuel for planetary missions is in the launch vehicles that lift the spacecraft from Earth's surface. Many present-day launch vehicles use a highly refined form of kerosene known as RP-1 in their first-stage (and sometimes second-stage) engines. This is usually carried along with liquid oxygen as the oxidizer and constitutes a relatively low cost and highly reliable propulsion system. More powerful rockets, including the space shuttle, use cryogenic propulsion systems with liquid hydrogen as the fuel and liquid oxygen as the oxidizer.

Some launch vehicles being planned for the future will use smaller cryogenic systems or may rely on solid propellant first-stage motors, further reducing fossil fuel use. Even without those advances, though, the amount of fossil fuel used in the launch of planetary missions is an extremely small fraction of the world's total consumption. The benefits of planetary exploration, in terms of scientific knowledge as well as in the development of new technologies for efficient energy production and storage, far outweigh this small cost in fossil fuel.

—DOUG STETSON,
Planetary Society consultant

Factinos

NASA scientists have announced that, based on new calculations of the path of asteroid Apophis, Earth is in much less danger of a hazardous impact in 2036 than they previously believed. Steve Chesley and Paul Chodas of the Jet Propulsion Laboratory made this discovery by upgrading data compiled by Dave Tholen and collaborators and the University of Hawaii's Institute for Astronomy.

Tholen had pored over hundreds of previously unreleased images of the night sky made with the University of Hawaii's 2.2-meter (88-inch) telescope, located near the summit of Mauna Kea. He then made improved measurements of the asteroid's position in the images, enabling him to provide Chesley and Chodas with new, more precise information on Apophis. In his calculations, Chesley also used measurements from the Steward Observatory's 2.3-meter (90-inch) Bok telescope on Arizona's Kitt Peak, and Puerto Rico's Arecibo Observatory.

"Apophis has been one of those celestial bodies that has captured the public's interest since it was discovered in 2004," said Chesley. "Updated computational techniques and newly available data indicate the probability of an Earth encounter on April 13, 2036, for Apophis has dropped from one in 45,000 to about four in a million."

"The refined orbital determination further reinforces that Apophis is an asteroid we can look to as an opportunity for exciting science and not something that should be feared," said Don Yeomans, manager of JPL's Near-Earth Object Program Office.

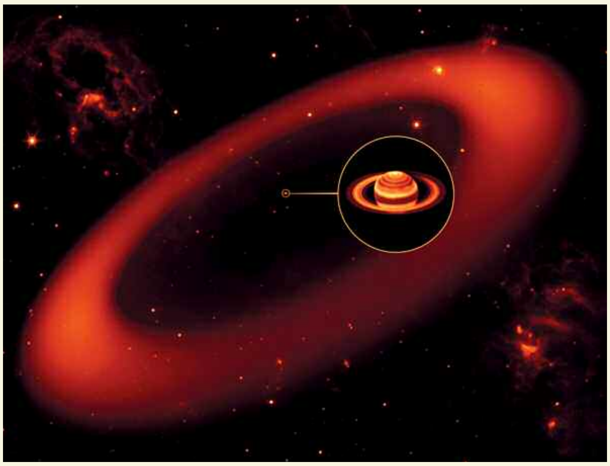
—from the Jet Propulsion Laboratory

An enormous ring around Saturn has been discovered by scientists using the Spitzer Space Telescope (see illustration at right). The huge ring is tenuous and is composed of a thin array of ice and dust particles. Phoebe, one of Saturn's farthest moons, orbits inside the ring and is most likely the source of its material. With an orbit tilted 27 degrees from the planet's main ring plane, the new band lies at the far reaches of the Saturnian system.

"This is one supersized ring," said Anne Verbiscer, an astronomer at the University of Virginia, Charlottesville. "If you could see the ring, it would span the width of two full moons' worth of sky, one on either side of Saturn."

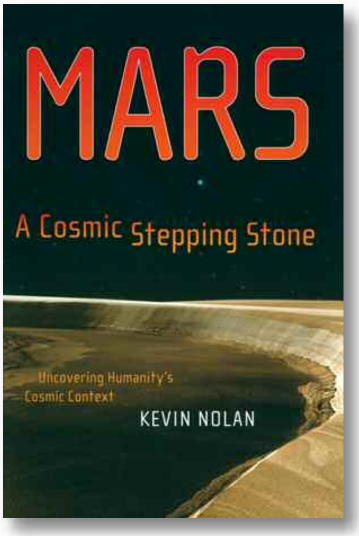
Verbiscer and colleagues used Spitzer's longer-wavelength infrared camera to scan through a patch of sky far from Saturn and a bit inside of Phoebe's orbit. The astronomers suspected that Phoebe might be orbiting in a belt of dust kicked up from its minor collisions with comets—a process similar to that around stars with dusty disks of planetary debris. Sure enough, when the scientists took a first look at their Spitzer data, a band of dust jumped out. Spitzer was able to sense the glow of the cool dust, which is only about 80 kelvins (–315 degrees Fahrenheit). Cool objects shine with infrared, or thermal, radiation. For example, even a cup of ice cream is blazing with infrared light. "By focusing on the glow of the ring's cool dust, Spitzer made it easy to find," said Verbiscer. The relatively small numbers of particles in the ring wouldn't reflect much visible light, especially at the distance from the Sun to Saturn, where sunlight is weak.The group reported their discovery on October 7, 2009 in *Nature*'s online publication.

—from NASA/JPL-Caltech



In this illustration, Saturn appears as just a small dot inside Spitzer's recently discovered ring of ice and dust. The bulk of the giant ring's material starts about 6 million kilometers (3.7 million miles) from the planet and extends outward about 12 million kilometers (7.4 million miles). The new ring's diameter is equivalent to roughly 300 Saturns lined up side by side. *Illustration: NASA/JPL-Caltech*

Society News



Mars, A Cosmic Stepping Stone: Uncovering Humanity's Cosmic Context

by Kevin Nolan
Springer, 358 pp.
$27.50, hardcover

One of our own, Kevin Nolan, Planetary Society regional coordinator in Ireland, has written an exciting and interesting book: *Mars, A Cosmic Stepping Stone: Uncovering Humanity's Cosmic Context*. The only criticism I have of it is the title—I think it should have included the word "life." Kevin tells us much about *what* Mars exploration has been, is, and will be, but even more, he tells us *why*. Mars is the only extraterrestrial planet to which human explorers can travel, and therefore it is the destination upon which humankind will determine whether traveling beyond Earth is destiny or an insurmountable task and whether we will become a multiplanet species. In addition, for a long time, Mars will also be the only world accessible to us on whose surface we can explore for evidence of other life.

Kevin captures these important motivations for exploring Mars while describing the many interesting results of past and current missions. The book details the scientific discoveries of individual Mars missions and integrates them by describing the "roadmap" and how the separate missions synergistically combine to form a whole program. Kevin also motivates us to anticipate future exploration with robots and humans.

We'd like to think his long and devoted relationship with The Planetary Society contributed to this book; after all, it is our mission to inspire people everywhere about such exploration. Kevin is a noted researcher and lecturer in Europe, an active space scientist and educator, and a frequent popularizer of space science and exploration. We're lucky to have him as part of The Planetary Society. Congratulations on a fine book!

—Louis D. Friedman,
Executive Director

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Please let me know if you have any questions—call me at (626) 793-5100, extension 214, or e-mail me at *andrea.carroll@planetary.org*. It's always great to hear from you.

Together, you and I, and our fellow Planetary Society Members worldwide, are charting a course for the future.

Thank you for all of your past gifts, and in advance for future ones. Best wishes from all of us for the coming year!

—Andrea Carroll,
Director of Development

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—AC

Members' Dialogue

Save Earth First

The debate about human versus robotic exploration and your cover article, "Planetology: Viewing Earth in Context," in the September/October 2009 issue, are both missing a vital point. Earth itself is in crisis right now—unless you do not view its climate change to an unknown hotter state and the attendant droughts, famines, floods, hurricanes, and underwater coastal cities for generations to come as a problem.

As much as I cherish humanity's push off the planet, there is a time for that. Right now, Earth needs our best and brightest to focus on reversing atmospheric carbon pollution back down to 350 parts per million. Space is a great vantage point from which to study the millions of square miles of the oceans. Researching the oceans' carbon cycle should be our Moonshot.

Delay Bush's ill-timed proposal for human exploration and take care of our own planet first. Continue the high-return, high-value robotic science missions, compare planets, and research propulsion and living in space, but put the expensive manned extra-orbital programs into preparatory modes and focus, for 10 or 20 years, on resolving our greatest planetary challenge.

What will we say to our grandchildren if we didn't thoroughly study the oceans' carbon cycle—potentially preventing climate change—when we could have? This generation of astronauts and space scientists has a vital mission: Save the Earth.
—RAND WROBEL,
Alameda, California

I'm a longtime member of The Planetary Society and, needless to say, I support the various objectives of the Society. But concerning solar system exploration, I feel that there is one planet that receives little attention in your coverage: Earth!

I realize there is a lot to cover regarding Earth, but I think a little more information about impacts and how they shaped this planet would be welcome.
—OWEN POWERS,
Chevy Chase, Maryland

Both Types of Missions

Robots are great for obtaining a great deal of information on what you expect to find. In addition, because they are generally one-way missions, their cost per gigabyte of data is quite attractive. The biggest problem with robots, at least at this time, is that you are not likely to find anything that you were not looking for in the first place—that is, their adaptability is limited.

In the end, after you have found what you can by robot, send in the humans to see if there is anything that you were not looking for. To paraphrase Wernher von Braun, what are robots but computers, and the most versatile computer is the human mind. Besides, it can be mass-produced by unskilled labor.
—JAY L. CUMMINGS,
Cincinnati, Ohio

ExoEarths

In "Searching for New Worlds" (July/August 2009), Debra Fischer raises the question of what criteria would show that an exoplanet is Earth-like. As James Lovelock pointed out, no planet could have any appreciable amount of free oxygen in its atmosphere without photosynthesis, or a similar reducing process that could be carried out only by living organisms. Thus, while the right size, mass, distance from the home star, orbital stability, and the possible presence of water are all good indications that a planet might be capable of supporting life, the detection of free oxygen in an exoplanet's atmosphere is an ironclad guarantee that something is growing down there.

One way to detect oxygen might be to look for absorption lines in the light transmitted through the exoplanet's atmosphere as it transits its home star. For the time being, this may be too much to ask when it is still a technical challenge to even detect the presence of an exoplanet the size of the Earth. But that is the gold standard: if we find free oxygen, we have found life.
—KENT A. PEACOCK,
Lethbridge, Alberta, Canada

Please send your letters to
Members' Dialogue
The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106-2301
or e-mail: *tps.des@planetary.org*

THE PLANETARY SOCIETY
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Pasadena, CA 91106-2301

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For thousands of years, humanity has navigated the watery surface of this planet using wind-propelled sails. The Planetary Society plans to take us to the next step—sailing through outer space powered by only the pressure of light. In this view, titled *LightSail-1*, Earth and the Sun are reflected in the blades of our new solar sail as it embarks on its maiden voyage 800 kilometers (500 miles) above its home world. This shimmering sliver of a spacecraft will demonstrate that we can explore space using no fuel. Instead, we can fly on particles of sunshine.

Rick Sternbach has been a space and science fiction artist since the early 1970s. His clients include NASA, *Sky & Telescope*, Random House, *Smithsonian*, *Astronomy*, and Time-Life Books. Rick is a founding member of the International Association of Astronomical Artists. His television and film credits include *Star Trek* series and films as well as *COSMOS*, for which he and other art team members received the first Emmy Award for visual effects.