The
PLANETARY REPORT

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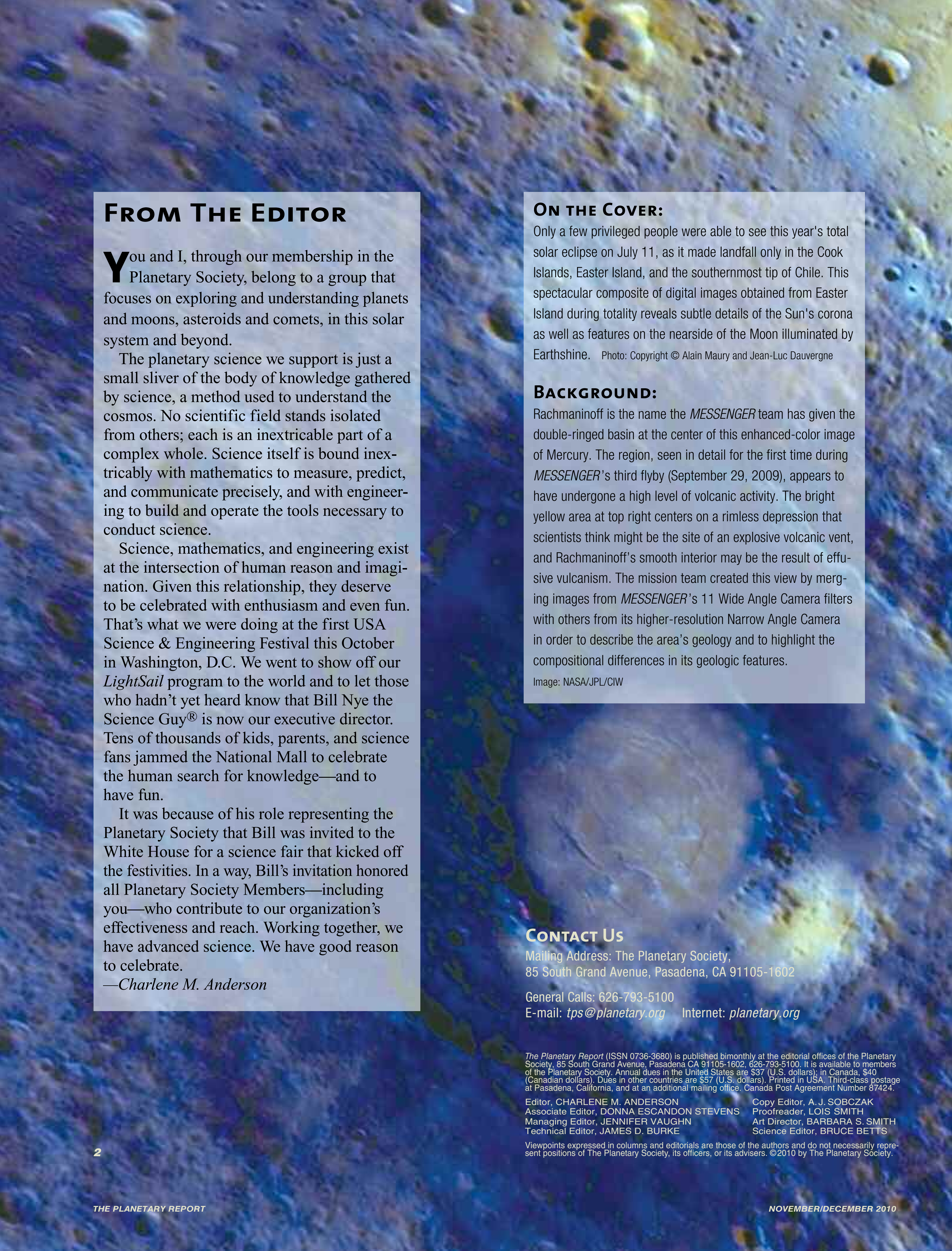
The Year in Pictures



From The Editor

You and I, through our membership in the Planetary Society, belong to a group that focuses on exploring and understanding planets and moons, asteroids and comets, in this solar system and beyond.

The planetary science we support is just a small sliver of the body of knowledge gathered by science, a method used to understand the cosmos. No scientific field stands isolated from others; each is an inextricable part of a complex whole. Science itself is bound inextricably with mathematics to measure, predict, and communicate precisely, and with engineering to build and operate the tools necessary to conduct science.

Science, mathematics, and engineering exist at the intersection of human reason and imagination. Given this relationship, they deserve to be celebrated with enthusiasm and even fun. That's what we were doing at the first USA Science & Engineering Festival this October in Washington, D.C. We went to show off our *LightSail* program to the world and to let those who hadn't yet heard know that Bill Nye the Science Guy® is now our executive director. Tens of thousands of kids, parents, and science fans jammed the National Mall to celebrate the human search for knowledge—and to have fun.

It was because of his role representing the Planetary Society that Bill was invited to the White House for a science fair that kicked off the festivities. In a way, Bill's invitation honored all Planetary Society Members—including you—who contribute to our organization's effectiveness and reach. Working together, we have advanced science. We have good reason to celebrate.

—Charlene M. Anderson

On the Cover:

Only a few privileged people were able to see this year's total solar eclipse on July 11, as it made landfall only in the Cook Islands, Easter Island, and the southernmost tip of Chile. This spectacular composite of digital images obtained from Easter Island during totality reveals subtle details of the Sun's corona as well as features on the nearside of the Moon illuminated by Earthshine. Photo: Copyright © Alain Maury and Jean-Luc Dauvergne

Background:

Rachmaninoff is the name the *MESSENGER* team has given the double-ringed basin at the center of this enhanced-color image of Mercury. The region, seen in detail for the first time during *MESSENGER*'s third flyby (September 29, 2009), appears to have undergone a high level of volcanic activity. The bright yellow area at top right centers on a rimless depression that scientists think might be the site of an explosive volcanic vent, and Rachmaninoff's smooth interior may be the result of effusive vulcanism. The mission team created this view by merging images from *MESSENGER*'s 11 Wide Angle Camera filters with others from its higher-resolution Narrow Angle Camera in order to describe the area's geology and to highlight the compositional differences in its geologic features.

Image: NASA/JPL/CIW

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A PUBLICATION OF THE PLANETARY SOCIETY

Looking Aft, Looking Forward

by Bill Nye

What first inspired you to become a space explorer? Maybe it was a picture, a book, or a clear, starry sky. Pass along that inspiration—that passion for discovery—to someone you know.

This past summer, the Hubble Space Telescope returned this inspiring image of a nebula located 20,000 light-years away in the constellation Carina. In a cavity surrounded by clouds of interstellar gas and dust (raw material for star formation), a cluster of young, hot stars called NGC 3603 sparkles like a fireworks show. Star clusters like this provide important clues to understanding the origins of massive star formation in the early, distant universe. Image: NASA, ESA, R. O'Connel, F. Paresce, E. Young, the WFC3 Science Oversight Committee, and the Hubble Heritage Team

For most planets, 30 years isn't such a big deal. For the Planetary Society, it's a long time. This year, as we've celebrated our 30-year anniversary, we've gone through some big changes. Lou Friedman, cofounder and executive director, stepped into a new role. The Society moved from the house it had occupied for the last three decades to a stately new home, still in Pasadena, two kilometers (1.25 miles) closer to the start of the Tournament of Roses Parade. Strangest of all, I'm now the Society's executive director.

Like any scientist, I am fascinated by what causes effects, or what action leads to another. My dad was an amateur astronomer, and I had an amazing astronomer for a professor in an elective course I took late in my college days. One encounter has led to another, and here we are. I'm sure each of you has come to the Planetary Society through other equally lucky means.

Looking Back—Aft of the Tail Fins

Looking back over the last few decades, we have witnessed astonishing discoveries. I remember well when the rings of Uranus were discovered, when Jupiter was photographed at close enough range to see its storms, and when the Chixulub crater was surveyed, providing us with evidence for the best theory so far that explains the disappearance of the ancient dinosaurs. Each of these discoveries started out as a news item, but for me, the way it was made—the process of science in each case—was revealed in *The Planetary Report*. We consider it our work to keep information coming. We'll continue to show you other worlds and to show you how we have come to know them.

Along with promoting and reporting exploration and discovery, the Society has a responsibility to make your voice heard among space agencies around the world. You and I have ideas about where and what our species should explore next, but space is a difficult place to get to and get around. We have to help our lawmakers to enable space exploration and direct our resources to their best uses. It can get complicated, and our members and especially our Board members are very good at sorting out all the legislation, treaties, and agreements that concern space and its exploration. It's a complex time, but we will continue to support sending machines and people farther into space. What would life be like if we just stopped exploring? Unsatisfying at best, I would venture, and dangerous at worst.

Since the beginning of the Society, we have worked to get our hardware, spacecraft components, and artifacts beyond Earth to other worlds. With your suggestions and support, we have been able to make things that fly in space. We designed and tested the remarkable Mars Balloon, with its ground anchor "snake." We tested rovers on Earth long before they journeyed to Mars. You may have signed your name to all or a few of the disks that have made their way to Mars. The MarsDials, with their message to future visitors, are casting shadows on the Red Planet even today.

Along with those successes, you probably remember *Mars Polar Lander* crashing hard near the Martian south pole. You also may have felt deep disappointment as our *Cosmos 1* solar sail disappeared in the Barents Sea. Spaceflight is risky, but I believe, in the long run, that you and I are going to be directly responsible for some good science and real exploring.

Up Ahead—Forward of the Nose Cone

Looking forward, just beyond the horizon, we will soon fly our own Living Interplanetary Flight Experiment sample tubes on the final space shuttle flight. This is a precursor to sending the same organisms into space—not just to low Earth orbit but all the way to Mars' moon Phobos and back.

Soon after that, I am confident that we will fly the very first solar sail spacecraft in Earth orbit. It will feature guidance and control systems that will allow it to tack just like a sailing ship and increase its orbital energy. You are building it; your donations and support are making it happen.

As our world becomes more technologically connected, we need to monitor the electromagnetic events—the "weather"—on the Sun. A maneuverable solar sail spacecraft is ideally suited to such a mission. You are at the forefront of this technology.

These experiments and explorations are wondrous, advancing humankind, but I often think about the future and the countless astonishing discoveries yet to be made out there.

What We Can Do Right Now—As We Reach Orbit

When it comes to stars, planets, and space, most of us became fascinated with other worlds when we were young—in elementary or primary school. I encourage people to ask their physician when he or she first wanted to become a doctor. Physicians usually say that it was when they were kids, before they were 10 years old. The same kind of early interest is present in many space explorers, such as our readers and rocket scientists. It is in that spirit that *The Planetary Report* will soon introduce a section designed especially for kids and families.

Bill Nye cuts the ribbon at the open house for the Planetary Society's new headquarters. Lending a helping hand are (from left) Rosaly Lopes, Charley Kohlhase, Lou Friedman, and Robert Picardo. **Photo: The Planetary Society**

For me, as an educator, this is not only my business—it's also fun. I'm sure that many of you have been present when someone first viewed Saturn through a telescope or made some other personal celestial discovery. The sparkle in their eyes can outshine the stars.

Sometime in the next few weeks, take a moment and share your story. Why did you become involved in the Society and space exploration? What piqued your interest? Was it a telescope and a star-viewing night? Did you build and fly model airplanes or rockets? Have you spent time at sea on a very dark night? Was it just a summer night with a clear, dark sky? Perhaps you got excited about space just by pondering pictures, modern ones showing exquisite views of places once only imagined but now made real.

I'd like you to consider doing something for all of us: tell us your story. Pass your passion along. Inspire someone. That's the future for us space explorers—surprising discoveries, new knowledge, and inspiration as we learn more about our own solar system and the worlds in orbit about other stars. With your support and passion, we learn more about our place in space and we advance knowledge for all humankind.

Let's change the world.

Bill Nye

Bill Nye

The Planetary Society's Mars Balloon drags its instrument-filled anchor "snake" across the sands of California's Mojave Desert in 1990. **Photo: Charlene M. Anderson**

Long before rovers wheeled across the Martian surface, the Planetary Society teamed American and Russian engineers to develop and test a Mars rover. In 1992, Society members joined us to watch it navigate the Mars-like terrain of California's Death Valley. **Photo: Charlene M. Anderson**

The Planetary Society's MarsDials, aside from their duties as calibration targets for the Panoramic Cameras on* Spirit *and* Opportunity*, have much to say to the Red Planet's future visitors. These before-and-after pictures show a MarsDial in the lab on Earth and, later, covered with the ruddy dust of Mars. **Images: Cornell University/NASA/JPL**

THE QUEST TO EXPLORE MERCURY

BY PETER D. BEDINI AND LOUISE M. PROCKTER

In September 2009, during MESSENGER*'s third Mercury flyby, its Wide-Angle Camera (WAC) imaged the planet through all 11 of its narrow-band color filters, giving us these true- and enhanced-color views. The image at far left, created with three of the WAC filters, shows an approximation of how Mercury's color might appear to human eyes. The view at near left, produced with data gathered by all 11 filters, accentuates the subtle color differences on the planet's surface.* Images: NASA/JHUAPL/CIW

When the *MErcury Surface, Space ENvironment, GEochemistry, and Ranging* (*MESSENGER*) spacecraft enters orbit about Mercury in March 2011, it will begin a new phase in an age-old scientific study of the innermost planet. Over the centuries, humanity has pursued a quest to understand the elusive planet and has teased out information about its motions in the sky, its relationship to the other planets, and its physical characteristics.

Despite being visible to the unaided eye, Mercury is extremely difficult to observe from Earth because of its proximity to the Sun. A great leap was made in our understanding of Mercury when the *Mariner 10* spacecraft flew past it three times in the mid-1970s, providing a rich set of close-up observations. Three decades later, *MESSENGER* has visited the planet three times as well and is poised to add significantly to the study of the planet with a year-long orbital observation campaign.

Acknowledging and Naming the Sun's Nearest Neighbor

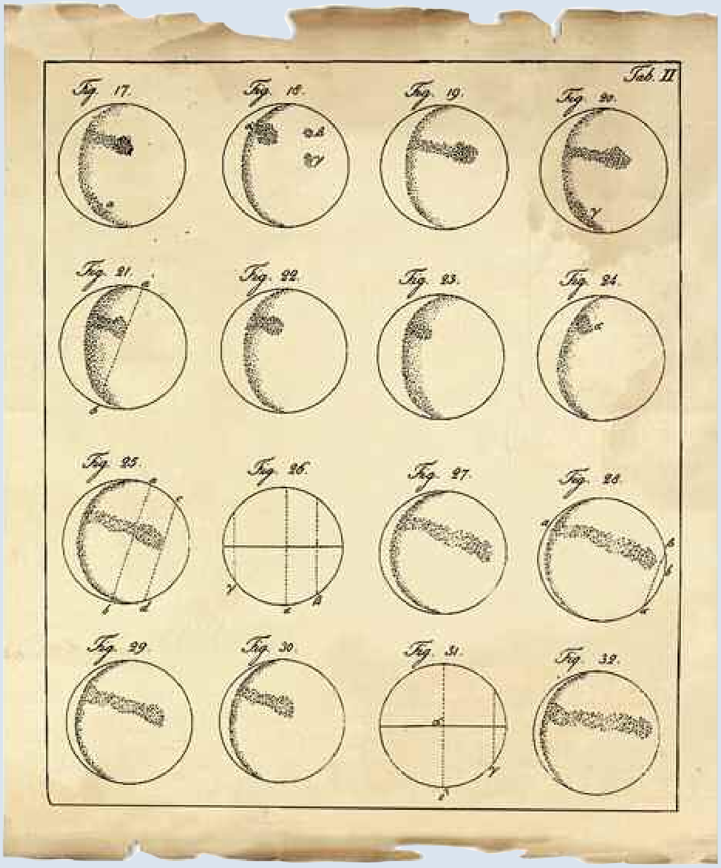
As one of the "wandering stars," Mercury has been observed since antiquity; references to it can be found in the lore of ancient civilizations around the world. The Chinese associated Mercury with the direction north and the element water. Hindu mythology refers to the planet as Budha, a god who presided over Budhavara, or Wednesday. The Norse associated Mercury with their god Odin, who also presided over the middle day of the week (Woden's Day).

Because Mercury is so close to the Sun, it travels quickly relative to other celestial bodies and can be seen only during the days surrounding its greatest elongations, when it is visible just before sunrise or after sunset. These characteristics of swiftness and elusiveness prompted a number of cultures to associate Mercury with their messenger gods, such as the Babylonian god Nabu, the Egyptian god Thoth, and the Greek god Hermes. The Maya represented Mercury as one or more owls, which served as messengers to the underworld. The English name for the planet comes from the Roman messenger god Mercurius, the Roman equivalent of Hermes.

The first known references to Mercury in writing are found from Mesopotamia in the seventh century B.C.E. The cuneiform tablets known as the MUL.APIN, most likely written by Assyrian astronomers, describe observations taken between 1300 and 1000 B.C.E. At the time that these tablets were created, the Maya also were charting the motion of the planet, and records of detailed observations can be found in the Dresden Codex.

This cuneiform tablet, made in Mesopotamia in the seventh century B.C.E.*, contains some of the first known written references to Mercury. Most likely written by Assyrian astronomers, the clay tablet, part of a series of Babylonian texts known as the MUL.APIN, describes observations taken between 1300 and 1000* B.C.E. Photo: British Museum, BM86378

Observations of Mercury figured prominently in early efforts to develop a geometric model of the heavens. The Greek astronomer Eudoxus made one of the first attempts to create such a model around 370 B.C.E. He compiled an extensive star catalog that included the visible planets, and his corresponding celestial model was extremely complex, including more than two dozen spheres to describe the observed motions of the heavenly bodies. In the second century C.E., Ptolemy published his great scientific treatise *Almagest*, in which he described a simpler geocentric model of the planets that was accepted as correct for centuries afterward.



As telescopes improved, observers were better able to draw and map celestial bodies. Because Mercury was so elusive, it wasn't until about 1800 that Johann Hieronymus Schröter was able to produce this first known map of the innermost planet. *Map: Schröter, 1800*

THE AGE OF THE TELESCOPE

Throughout the Middle Ages, astronomers continued to observe and record the movement of Mercury and the other planets using instruments of growing complexity. The invention of the telescope in 1608 revolutionized astronomy, bringing humanity closer to the heavens than ever before, but the early lenses were too crude to reveal any of Mercury's secrets.

In 1627, Johannes Kepler predicted that a transit of Mercury across the face of the Sun would occur on November 7, 1631. Although the transit occurred slightly earlier than expected, French astronomer Pierre Gassendi observed it. Two decades earlier, Kepler had mistaken a sunspot for Mercury. When a spot first appeared on the Sun's image, Gassendi believed it to be too small to be Mercury, and he concluded that it was instead a sunspot. Only after further observation did the astronomer realize that the dark object moved too quickly to be a sunspot, and that he indeed was recording the transit of Mercury. Unfortunately, Kepler died the year before his calculation was proven true. Nevertheless, the ability to predict the passage of Mercury in front of the Sun was of great importance in confirming Kepler's planetary model, which was heliocentric, like that of Copernicus, but described the orbits of planets as ellipses rather than circles.

As improvements were made to telescopes, descriptive astronomy emerged, and the features of Mars and the Moon could be characterized for the first time. Mercury, though, continued to be elusive, and not until the beginning of the 19th century did astronomers make serious attempts to map its surface.

Johann Hieronymus Schröter, working in Lilienthal, Germany, was one of the first to try to describe the features of Mercury. In 1800, he recorded seeing a mountain extending 20 kilometers (12 miles) in height and deduced a rotational period for the planet of slightly more than 24 hours.

From more than 200 observations made in Milan, Italy, between 1881 and 1889, Giovanni Virginio Schiaparelli produced a rather advanced map of Mercury that, for the first time, recorded observed features relative to a coordinate system. From comparisons of the observed surface features throughout his campaign, he deduced that Mercury's rotation was synchronous with its 88-day orbital period and that the same side of the planet always faced the Sun. Although scientists at first resisted this conclusion, it was generally accepted by the end of the century and not successfully refuted until the 1960s.

Improved capabilities of telescopes made higher-fidelity observations possible, though the interpretations did not always match that quality. For example, using the 61-centimeter (24-inch) refracting telescope in Flagstaff, Arizona, in 1896–1897, Percival Lowell described Mercury's surface as covered with long, linear, canal-like features. Needless to say, such features have not been confirmed.

For the widely held theory that Mercury's rotation was Sun-synchronous to be true, the planet's dark face would need to be extremely cold. Measurements of radio emissions revealed temperatures much higher than expected. Astronomers were reluctant to drop the synchronous rotation theory and searched for evidence of an atmosphere that might transfer heat from the day to nighttime surfaces.

A new approach to the study of Mercury was taken in June 1962, when Vladimir Kotelnikov and colleagues obtained the first radar echoes from the planet. Three years later, radar observations by Gordon Pettengill and Rolf Dyce, using the 300-meter Arecibo Observatory radio telescope in Puerto Rico, showed conclusively that Mercury's rotational period was about 59 days, thereby putting to rest, once and for all, the notion of synchronous rotation.

Italian scientist Giuseppe "Bepi" Colombo noted that the rotation value was about two thirds of Mercury's orbital period, and he proposed that the planet's orbital and

This is one of the first images of Mercury captured by a spacecraft. **Mariner 10** ***took this picture on March 28, 1974 as it approached the planet for what would be its first flyby on the following day.*** ***Image: NASA/JPL***

rotational periods were locked into a 3:2 rather than a 1:1 resonance. Despite this correction in the planet's rotational period, the early visual observations were not completely invalid. Because the planet rotates three times for every two orbits about the Sun, after three synodic periods, the same face of the planet presents itself at the same phase. Because the conditions for viewing Mercury are favorable every three synodic periods, most early observations were made at those times. As a result, the same face of Mercury was indeed being mapped.

Mercury: Up Close and Personal

With the advent of the Space Age came the first opportunity to study Mercury at close range. People had long demonstrated a desire to understand the innermost planet, and by the 1960s, the technology (and the funding) finally became available to visit the planet for the first time.

Flying through Venus' gravitational field could alter a spacecraft's trajectory, causing it to fall in toward the Sun and, with careful timing, enabling it to cross Mercury's path and encounter the planet. The discovery that such a trajectory was possible represented a breakthrough because, without the use of Venus to "slingshot" the spacecraft toward Mercury, a much larger launch vehicle would be needed, and it would be possible to fly by the planet only once on a trajectory toward the Sun.

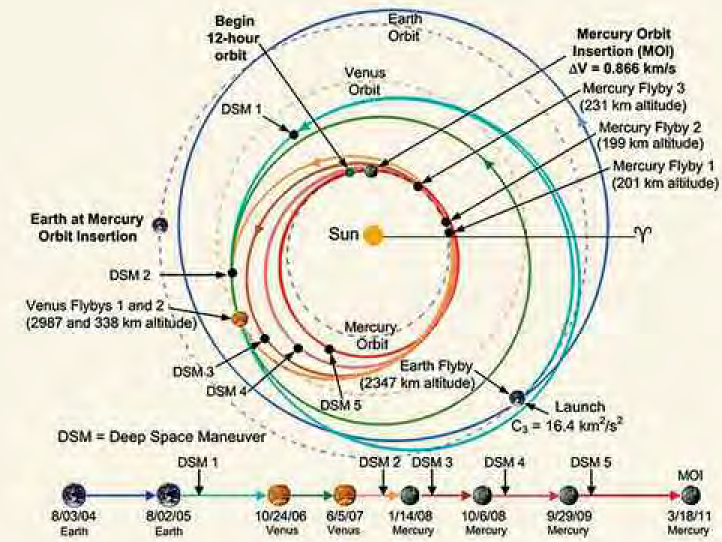
In 1969, NASA approved a mission to be launched in 1973 that would make single flybys of both Venus and Mercury. At a conference on this new mission held at the Jet Propulsion Laboratory in 1970, Giuseppe Colombo noted that once the proposed *Mariner 10* spacecraft passed Mercury, its orbital period would be approximately twice that of the planet itself. With careful choice of the point at which it passed Venus, the craft would make repeated flybys of Mercury. It was determined that three flybys could be achieved before the spacecraft exhausted its supply of propellant.

The *Mariner 10* spacecraft—with a payload of seven science experiments designed for television photography, extreme ultraviolet spectroscopy, infrared radiometry, radio science, and energetic particle, plasma, and magnetic-field detection—was launched from Cape Canaveral Air Force Station, Florida, on November 2, 1973 (UTC). After a successful encounter with Venus three months later, the spacecraft made its first flyby of Mercury on March 29, 1974, following up with two more flybys, on September 21, 1974 and March 16, 1975.

Mariner 10 was able to make close-up, unencumbered observations of Mercury for the first time and revealed a wealth of details about the elusive planet. In three passes during 1974 and 1975, the closest at an altitude of just more than 320 kilometers (200 miles), the spacecraft took images of Mercury's abundant impact features, including multiringed basins, secondary crater chains, and bright rays. Cliffs or scarps up to 1.5 kilometers (1 mile) high and 500 kilometers (300 miles) in length were visible across much of the surface, their lobate form suggesting that they were the result of compressional forces. These scarps were thought to have resulted from a readjustment of the surface in response to a slight shrinking of the planet's interior.

A huge basin situated near one of Mercury's "hot" poles—equatorial locations that are closest to the Sun

Radar observations of the half of Mercury not seen by **Mariner 10** ***revealed highly reflective regions near the planet's poles—suggesting that despite the planet's proximity to the Sun, ice might still exist in the permanently shadowed craters there. This radar image was taken from the Arecibo Observatory in July 1999.*** ***Image: Arecibo Observatory***



Gravity assists from six planetary flybys (one of Earth, two of Venus, and three of Mercury) have helped to speed* MESSENGER *along on its mission. *Graphic: NASA/JHUAPL/CIW*

at perihelion and estimated to be about 1,300 kilometers (800 miles) in diameter—was named Caloris, from the Greek word for heat. High-resolution images identified features as small as 137 meters, including ridges and fractures in the floor of this basin.

Between many of the heavily cratered areas were smooth, less-cratered plains. Observations of similar plains on the Moon had not made it clear whether these plains were volcanic in origin or if they were the result of fluidized impact ejecta, a question that remained unresolved for more than three decades.

Gravity measurements determined the mass of Mercury to an accuracy of two orders of magnitude greater than previously possible and confirmed that Mercury has a core that is surprisingly large compared with its radius. *Mariner 10*'s infrared radiometer found the surface temperature range to be extremely large: these and subsequent ground-based observations have shown that, at perihelion, the dayside equatorial temperature can reach about 720 Kelvin (roughly 450 degrees Celsius or 840 degrees Fahrenheit) or can dip as low as about 90 Kelvin (–180 degrees Celsius or –300 degrees Fahrenheit).

Perhaps the most surprising discovery was that Mercury possesses an internal magnetic field, estimated to be about two orders of magnitude smaller at the planetary surface than that of the Earth but still strong enough to deflect the solar wind around the planet, creating a magnetosphere. The field is dipolar and intrinsic to the planet, like a scaled-down version of Earth's.

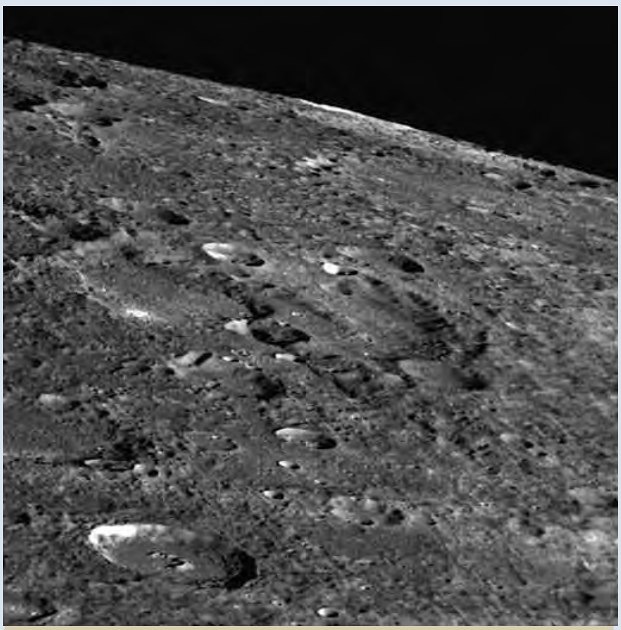
Eight days after *Mariner 10*'s third encounter with Mercury, the mission ended when the spacecraft's supply of nitrogen maneuvering gas was exhausted. The next step in Mercury exploration was widely recognized to be an orbiter, which could characterize more fully the planet's interior, surface, exosphere, and magnetosphere. In the mid-1980s, researchers discovered multiple gravity-assist trajectories that would allow Mercury orbit insertion with conventional chemical propulsion systems. It was almost 20 more years, however, before such a mission became a reality.

In the meantime, the study of Mercury continued. In 1991, radar experiments designed to image the half of Mercury not photographed by *Mariner 10* revealed highly reflective regions near the planet's poles. The similarity of the radio echoes to those of icy regions of Mars and icy outer-planet satellites strongly suggested that, despite the high temperatures at lower latitudes, ice might exist in the permanently shadowed craters near the poles.

MESSENGER ENCOUNTERS THE WINGED MESSENGER

Although the *Mariner 10* mission answered many questions about Mercury, much remained to be learned. The first proposal for the *MESSENGER* mission came to NASA's newly created Discovery program in 1996, and the proposal eventually was selected for flight in July 1999, with Sean C. Solomon of the Carnegie Institution of Washington (CIW) as principal investigator. The Johns Hopkins University Applied Physics Laboratory (JHUAPL) in Laurel, Maryland, built the spacecraft and is managing and operating the mission.

Designing a Mercury orbiter mission within the constraints of a relatively small NASA budget required innovation. To achieve orbit around Mercury using as little propellant as possible, mission planners incorporated six planetary flybys (one of Earth, two of Venus, and three of Mercury) and five deep-space maneuvers as part of the spacecraft's 6.6-year journey of 7.9 billion kilometers (4.9 billion miles).



Our spacecraft explorers have revealed mysterious Mercury to be a world of extremes. The scarp that cuts across this image from upper left to lower right is a long cliff face that may have formed when the planet's interior cooled and its surface contracted.
Image: NASA/JHUAPL/CIW

MESSENGER ***has imaged 80 percent of Mercury's surface in color. The enhanced-color images highlight subtle differences in the composition of crustal rocks on the planet's surface. The large, bull's-eye feature at top left of the upper image is Caloris basin, its bright center surrounded by a dark annulus.***

Images: NASA/JHUAPL/CIW

The custom-made propulsion system was integrated into the graphite-composite structure to save mass. To simplify the thermal design, miniaturized electronics and instruments are harbored behind a ceramic-cloth sunshade measuring 2.0 x 2.5 meters. To avoid the mass, operational complexity, and test requirements of a traditional gimbaled antenna, an electronically steerable phased-array antenna system was developed.

The data that are needed to answer the guiding science questions will be collected by a payload of seven scientific instruments: the Mercury Dual Imaging System (MDIS), the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), the Mercury Laser Altimeter (MLA), the Gamma-Ray and Neutron Spectrometer (GRNS), the X-Ray Spectrometer (XRS), the Magnetometer (MAG), and the Energetic Particle and Plasma Spectrometer (EPPS). Radio-science measurements will be made using the spacecraft's tele-communications system.

On August 3, 2004, *MESSENGER* was launched from Cape Canaveral Air Force Station, Florida, and it has now completed all six planetary encounters and five deep-space maneuvers. Although the primary purpose of *MESSENGER*'s flybys was to achieve the gravity assists needed to place the spacecraft in the desired orbit about Mercury, they also proved to be tremendously valuable in terms of science return.

During the Mercury encounters, *MESSENGER* made high-resolution measurements of the planet's exosphere and tail, which extends millions of kilometers anti-Sunward. Near-simultaneous measurements of sodium, magnesium, and calcium showed that the spatial distributions of these elements are complementary to each other and that they vary spatially and temporally.

The first measurements of ions at Mercury revealed a complex environment resulting from a mixture of solar wind plasma and species originating from the surface. Although Mercury's magnetosphere was found to be surprisingly calm, it exhibited an array of dynamic plasma physical processes similar to Earth's. Magnetometer measurements made during the flybys provide the best assessment yet of the internal field; together with *Mariner 10* measurements, they suggest that the field is predominantly dipolar, as would be expected if it were produced by a dynamo in a molten outer core.

The *MESSENGER* spacecraft returned the only magnetic data to date from the planet's western hemisphere. These data, combined with earlier results, showed that the planet's magnetic moment is closely aligned with its rotation axis, to within 2 degrees.

During all three Mercury flybys, the spacecraft passed very close to the planet, with closest-approach altitudes of approximately 200 kilometers (125 miles). These low-altitude passes enabled the collection of the first laser altimeter profiles of Mercury's surface, which indicated that Mercury's craters are shallower than similar-sized craters on the Moon, probably because of the higher surface gravity.

Whereas the geometry of its flybys allowed *Mariner 10* to view only one hemisphere of Mercury, *MESSENGER* has now imaged 80 percent of the entire planetary surface, and almost 98 percent of the planet has now been imaged by one or both of the spacecraft. During *MESSENGER*'s close approaches, it captured high-resolution (200 meters per pixel) images, and much of the surface was imaged in 11 colors, providing the most comprehensive color data of Mercury to date.

The western portion of the Caloris basin was imaged for the first time, and that basin was found to be 250 kilometers (155 miles) larger than previously thought, measuring 1,550 kilometers (960 miles) in diameter. Lobate scarps were found to be widespread across the surface, indicating that compression had been global. High spectral resolution data at near-ultraviolet, visible, and near-infrared wavelengths were obtained, providing new clues as to the composition of surface minerals.

Analysis of *MESSENGER* flyby data addressed the issue of whether Mercury's smooth plains were the re-

EXPLORE MORE

Learn more about *MESSENGER* at
messenger.jhuapl.edu.

sult of volcanic processes or were formed by impact ejecta. A number of surface features appear to have volcanic origin, such as flooded and embayed impact craters and irregular vents, thereby firmly establishing volcanism as a major process in Mercury's evolution.

THE NEXT CHAPTER

The *MESSENGER* team is now preparing for orbital operations. At the time of writing, the spacecraft is healthy, the instruments have been well tested, and trajectory analysis shows the craft to be on track to the required aim-point for orbit insertion on March 18, 2011.

The spacecraft will remain in orbit about Mercury for at least one Earth year, circling the planet twice each day. These orbits are highly elliptical in order to protect the spacecraft from the extreme thermal environment close to Mercury's surface. At periapsis, the spacecraft will pass the planet at distances ranging from 200 to 500 kilometers (125–310 miles) at 60–70 degrees north latitude, and at apoapsis up to 15,200 kilometers (9,440 miles) south of the planet.

Because of the orbital motion and spin of Mercury, at times, the spacecraft will reside in a "dawn-dusk" orbit, where it essentially flies over the terminator, which is ideal for monochrome imaging. At other times, it will occupy a "noon-midnight" orbit, which on the dayside is ideal for multispectral imaging. The *MESSENGER* orbital observation campaign will seek to characterize the planet's interior, surface, exosphere, and magnetosphere, answering questions about the nature of the planet and its history.

The next step in the study of Mercury is already under development. The *BepiColombo* mission, named for Giuseppi Colombo—the man who explained Mercury's 3:2 spin orbit resonance and suggested that *Mariner 10* could achieve multiple flybys—is an international collaboration between the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). The mission comprises a pair of spacecraft that will be placed in coplanar orbits about Mercury: one to study the magnetosphere and its interactions with the solar wind and one to characterize the planet with a variety of instruments. The two spacecraft are scheduled to launch in 2014 on a single rocket and to be inserted into orbit in 2020.

The story of humanity's quest to understand Mercury is one of perseverance and ingenuity. Just as the telescope in the 17th century transformed the planet from a featureless light in the sky to a cratered world cloaked in mystery, robotic space probes 300 years later have uncovered its true nature as a planet of intriguing extremes. The six flybys of Mercury have revealed a great deal, but much more remains to be learned. *MESSENGER*'s year-long observation campaign will return a wealth of information not previously available but will undoubtedly leave questions to be answered by *BepiColombo* and future missions.

Peter D. Bedini is a program manager at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. He has served as the project manager for MESSENGER *since 2007. Louise M. Prockter is a senior scientist at the Johns Hopkins University Applied Physics Laboratory and is a deputy project scientist and co-investigator on the* MESSENGER *mission.*

Acknowledgment: The authors thank Bob Strom, a member of both the *Mariner 10* and *MESSENGER* science teams, for inspiring us to delve deeper into the history of Mercury exploration.

Two bright dots huddle close together among a field of distant stars. These are Earth and the Moon, seen by* MESSENGER *on May 6, 2010 from its unique position much closer to the Sun, near the orbit of Mercury. In the final stages of its long cruise,* MESSENGER *is busily searching space outward from the Sun for vulcanoids, the elusive asteroids that scientists believe reside in the space between Mercury and the Sun. No such bodies have yet been discovered, but the search did yield this evocative photo of our home.* MESSENGER *is scheduled to enter orbit about Mercury in March 2011. Image: NASA/JHUAPL/CIW

2010

The Year in Pictures

We at the Planetary Society will remember 2010 as a year of both beginnings and endings. We changed leadership and moved house, welcoming our new Executive Director Bill Nye, thanking Louis Friedman for 30 years of his leadership, and taking up residence in our new digs at 85 South Grand Avenue in Pasadena.

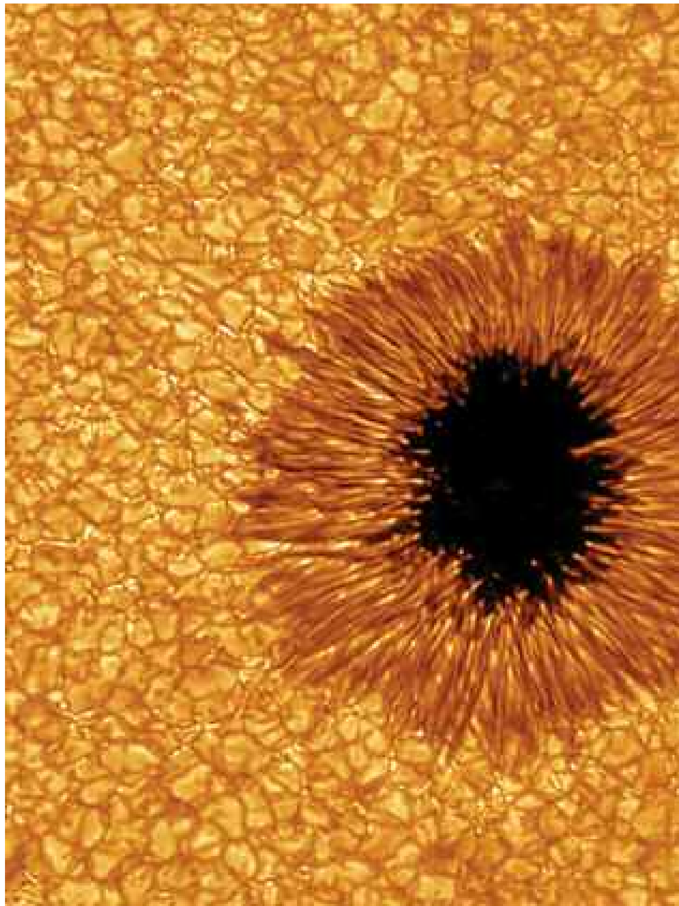
The year was full of beginnings and endings in space as well. The space shuttle *Atlantis* saw its last launch, and *Falcon 9* saw its first. We experienced some losses and endings, both planned and unplanned: the *Phoenix* Mars lander met its demise, we lost communication contact with the Mars Exploration Rover *Spirit*, and the *Hayabusa* asteroid sample return mission ended in a fiery return to Earth. Two new spacecraft launched toward Venus, *Akatsuki* and *IKAROS*, pioneering new technologies. *Rosetta* spied a large denizen of the asteroid belt, Lutetia, for the first time ever. By the time this magazine arrives in your mailboxes, *Deep Impact* will have accomplished the last planned encounter of its mission, passing within 700 kilometers (440 miles) of comet Hartley 2. China's *Chang'E2*, an improved copy of *Chang'E1*, launched into lunar orbit.

Throughout all this drama, there were, of course, plenty of spacecraft carrying on the routine operations of lengthy missions—that is, if one can ever call the exploration of worlds beyond Earth "routine." *Venus Express, Lunar Reconnaissance Orbiter, Mars Express, Mars Reconnaissance Orbiter, Mars Odyssey*, the Mars Exploration Rover *Opportunity*, and *Cassini* continued to return terabytes of data to Earth each month.

The upcoming year promises to be as good as the one just experienced: *Stardust* is zooming toward a flyby of comet Tempel 1 in February, *MESSENGER* is approaching the final months of its long cruise toward Mercury orbit insertion in March, and *Dawn* has taken up permanent residence in the asteroid belt on approach to its orbit of Vesta next July. Meanwhile, in the distant reaches of the solar system, *New Horizons* is just approaching the orbit of Uranus; we still have four years to wait before it reaches Pluto!

We have these highlights and more from 2010 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.



Sunspot in Detail

What is this? It's not a dragon's eye, nor is it the maw of a
a sunspot, imaged on July 1 from the Big Bear Solar Obser
Solar Telescope (NST). The NST's vision is assisted by adap
a resolution of 80 kilometers (50 miles) on the surface of t
years, the Sun has been unusually quiet, producing the lo
pressure of the last 50 years and the lowest number of sun
the Sun is awakening from this long solar minimum and is
its characteristic spots and storms once again. Solar storr
hazard to power grids, spacecraft electronics, astronauts,
passengers and employees. The public is being asked to h
track them at *http://solarstormwatch.com/*. Image: Big Bea

Mars Passag

The image at top l
from on Novembe
pected to survive.
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7, 2010, just befor
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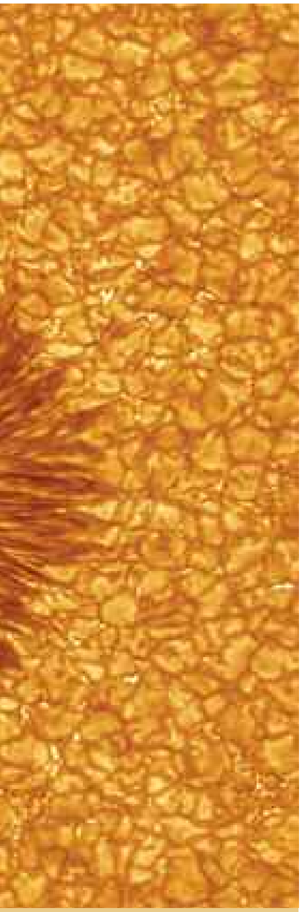
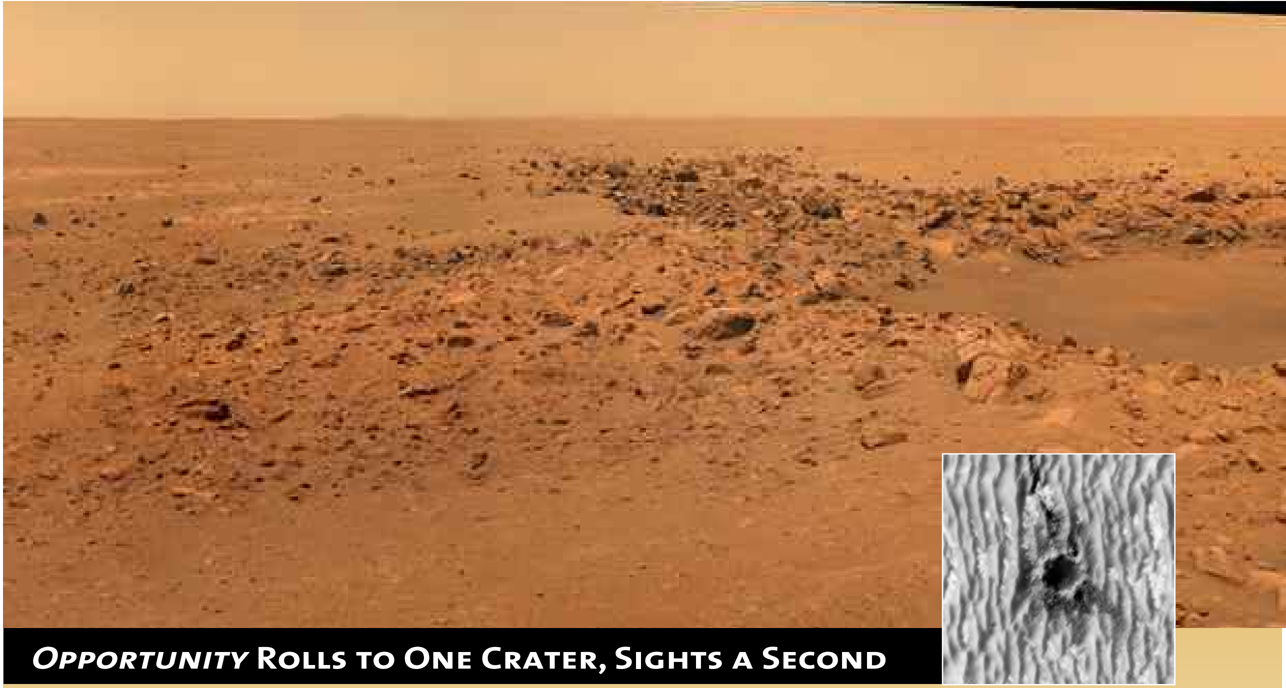
ABOVE: This is t
It's midwinter in t
and radio. Unlike *F*
Phoenix images: NAS





Opportunity Rolls to One Crater, Sights a Second

Opportunity began 2010 rolling southward, parallel to the crests of Meridiani Planum's seemingly endless dunes, making only occasional stops. One of its longer stops was at a small crater named Concepción, whose dark rays, visible from orbit, identified it as a relatively fresh crater, the freshest one either rover has explored. Seen up close, the rays are composed of blocky chunks of bedrock that are lighter in color than the sand. *Opportunity* determined that the reason the rays of light rock appear dark from orbit is that Meridiani's sandblasting winds have not had time to plane smooth the blocks; the shadows cast from those blocks darken the ground, making Concepción appear to have dark rays when viewed from high above.

Beyond Concepción, on the horizon, is a distant line of hills. This marks *Opportunity*'s first clear view of its eventual goal, the rim of an enormous, ancient crater named Endeavour, whose nearest peaks are 13 kilometers (8 miles) away. With spring and summer coming to its landing site and wheels still capable of rolling more than 100 meters per driving day, *Opportunity* looks forward to a year of steady progress while watching those distant hills rise higher and higher on the horizon.
Image: NASA/JPL/Cornell/James Canvin

INSET: A view of *Opportunity* from orbit on sol 2,153 (February 13, 2010) as it sat on the north rim of the 10-meter-diameter crater Concepción. The rover is visible at the one o'clock position, as are its dark tracks, coming from the north, and the fresh, blocky rays of the crater. Image: NASA/JPL/UA

giant tube worm. It's
vatory (BBSO)'s New
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he Sun. In the past two
west solar radiation
spots in a century. Now
beginning to develop
ms are a potential
and even airline
elp predict, spot, and
r Solar Observatory/NJIT

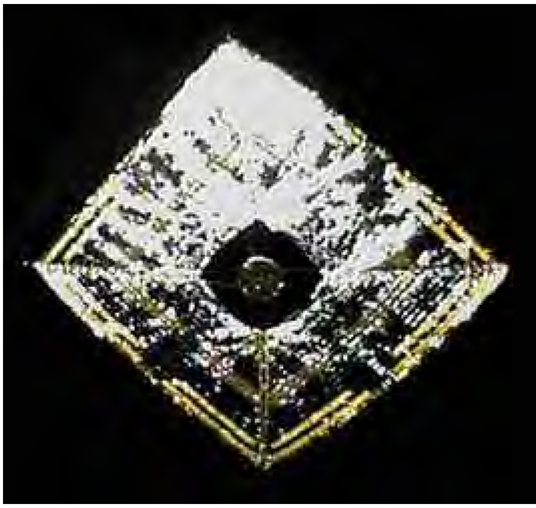
GES

eft was taken on July 20, 2008 while *Phoenix* was actively performing its polar mission. *Phoenix* was last heard
r 2, 2008. After that, it was encased in carbon dioxide through the northern polar winter, a fate it was not ex-
Nevertheless, with the return of summer to the Martian north this year, NASA made many attempts to establish
th the lander. These attempts failed, and a photo (bottom left) fro m *Mars Reconnaissance Orbiter* taken on May
e the summer solstice, suggests that the lander's solar panels collapsed under the weight of the carbon dioxide
ger cast shadows on the ground). In June, NASA officially declared the lander unrecoverable.
he very last image that the Mars Exploration Rover *Spirit* transmitted to Earth before falling silent on March 22.
he southern hemisphere, and the rover's solar panels cannot provide enough power to the electronics, heaters,
Phoenix, however, *Spirit* has a fighting chance of waking from its slumber, and NASA attempts contact daily.
A/JPL/UA; *Spirit* image: NASA/JPL

Crescent Homeworld

JAXA's spacecraft—variously named Planet-C, Venus Climate Orbiter, and *Akatsuki* (or "dawn")—launched on May 17, 2010 for a quick flight to our nearest solar system neighbor. As it departed, it turned its cameras backward to capture this unique view of a crescent Earth. *Akatsuki* will enter orbit at Venus in December, joining ESA's *Venus Express* there.

Image: JAXA/JSPEC



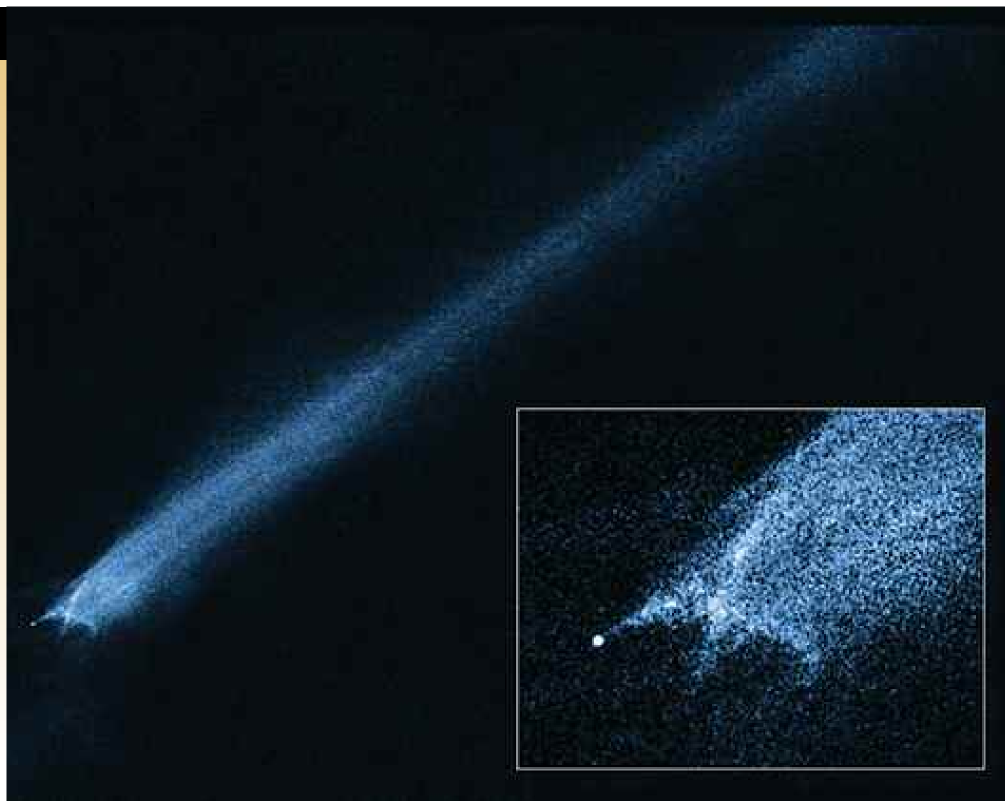
Successful Sail

Launched on the same rocket as *Akatsuki* was JAXA's *IKAROS* (*Interplanetary Kite-craft Accelerated by Radiation Of the Sun*). On June 10, *IKAROS* successfully completed the deployment of an ultrathin square sail, an event captured by two tiny deployable cameras that wirelessly transmitted their photos back to *IKAROS* for relay to Earth. *IKAROS* went on to demonstrate power generation from thin-film solar cells mounted on the sail as well as controlled solar sail flight using LCD panels to adjust the sail's reflectivity. It will follow *Akatsuki* to Venus but will not enter orbit. Image: JAXA/JSPEC

Collision in the Main Belt

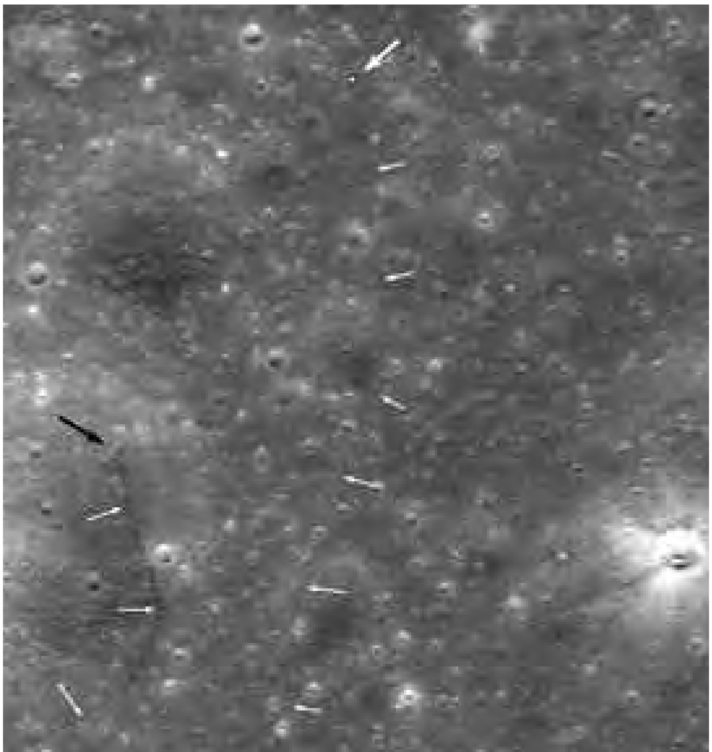
The Lincoln Near-Earth Asteroid Research Program (LINEAR) first observed an object in the main asteroid belt surrounded by a cometary fuzz on January 6. Later in the same month, when the Hubble Space Telescope's new Wide Field Camera 3 was trained on the body, called P/2010 A2, astronomers discovered an X-shaped debris pattern that is almost certainly the aftermath of a collision between two previously undetected asteroids. Although the asteroid belt contains many thousands of objects, they are separated by wide regions of empty space, and no collision has ever before been observed. Hubble repeatedly observed P/2010 A2 through the rest of the year and found the debris field to be expanding very slowly, which means that the collision must have happened in February or March of 2009.

Image: NASA/ESA/D. Jewitt (UCLA)



The Far Side of Phobos

Now many years beyond its originally planned mission, ESA's *Mars Express* orbiter has been given a new directive: to map Mars' inner, larger moon Phobos in preparation for the Russian sample return mission *Phobos-Grunt. Mars Express* is the only spacecraft since the *Viking* orbiters to be able to perform high-resolution imaging of any part of Phobos but its Mars-facing side. That's because the other spacecraft, such as *Mars Reconnaissance Orbiter, Mars Odyssey*, and *Mars Global Surveyor*, are in nearly circular orbits that skim only a few hundred kilometers above Mars' surface, whereas Phobos orbits about 6,000 kilometers (3,700 miles) above the planet and (like our own Moon) keeps the same face turned toward Mars at all times. *Mars Express* has a highly elliptical orbit, reaching to more than 11,000 kilometers (6,900 miles) above Mars' surface, so it is able to observe Phobos from both its near and its far sides, as well as above and below its poles. This view is of the far side of Phobos; the small cluster of one large and two small craters near the center of the photo is very close to the anti-Mars point. North is approximately up.
Image: ESA/DLR/FU Berlin (G. Neukum)/processed by Emily Lakdawalla



Fly Through the Northern Lights

During his tour of duty as flight engineer for International Space Station Expeditions 22 and 23, JAXA astronaut Soichi Noguchi captivated the world with stunning views from his lofty perch, sharing his photographs via Twitter (as @Astro_Soichi). He Tweeted this photo, taken on April 5, 2010 as the ISS flew through Earth's aurora at 28,000 kilometers (17,000 miles) per hour, to his (at the time) 174,000 followers. A geomagnetic storm was exciting an unusual level of auroral activity at the time. A Russian Progress module is visible, docked to the ISS in the middle ground.
Photo: NASA/Soichi Noguchi

Locating *Lunokhod*

For years we have been treated to views of Martian landers and rovers from orbiting spacecraft, but we could not enjoy similar views of our lunar hardware until the arrival of *Lunar Reconnaissance Orbiter* late last year. In this image, we can read the story of the Russian rover *Lunokhod 2*'s final activities. Near the end of its penultimate lunar day, the rover was accidentally driven into a small crater (marked by a black arrow). While it climbed out, its open lid struck the crater wall, scooping up some dirt. When the lid was closed to keep the rover warm over the lunar night, the soil was dumped on top of its thermal radiators. The next lunar day, on May 8, 1973, the lid was reopened and the rover was commanded to drive again. It rolled for two more Earth days, laying down the tracks marked by the white arrows, but the dirt on its thermal radiators impeded their performance, and the rover overheated and died. Its final resting place, discovered in a *Lunar Reconnaissance Orbiter* camera image this year through the combined efforts of Phil Stooke and Sergei Gerasimenko, is marked by the bright pixels and large white arrow. Before its death, *Lunokhod 2* was oriented so that its laser reflector could be used for laser ranging from Earth, an experiment that has continued to the present day. This image, combined with the precise knowledge of the rover retroreflector's stationary position over time from the laser reflection experiment, will help lunar cartographers establish a precise geographic control network for the Moon. Image: NASA/GSFC/ASU/Sergei Gerasimenko/Sasha Basilevsky

A Moon Through the Plumes

On May 18, 2010, as *Cassini* approached for its 11th targeted flyby of Saturn's geyser moon Enceladus, it stared directly toward the little moon's active south polar geysers. Three of the geysers can be seen here, backlit by the Sun; the lumpy curve of Enceladus' furrowed surface is at the bottom of the photo. As *Cassini* traveled toward Enceladus' south pole, Saturn's rings and largest moon, Titan, came into view in the background. The rings are seen nearly edge-on and from their southern, unilluminated face, so they are mostly dark, except for the sparse, dusty F ring, which makes a bright streak across the image. (Like the ice crystals in Enceladus' geysers or dust motes in a sunbeam, the F ring particles are strongly forward scattering, which means they appear brightest when the Sun is nearly behind them.) The Sun is also nearly behind Titan, so we see it as a very thin crescent, but Titan's thick atmosphere and high-altitude haze layers also scatter light forward to *Cassini*'s camera. This version is highly processed: a long exposure that reveals the plumes was combined with a shorter exposure of Titan and the rings. In addition, Titan has been colorized with a color image from a different date. Image: NASA/JPL/SSI/Thomas Romer/Gordan Ugarkovic

Jupiter Gains Mass but Loses a Belt

When this year's Jupiter observing season began, the giant planet had a surprise in store for astronomers: one of its two iconic, dark equatorial belts had vanished, turning from reddish brown to pale white. In retrospect, it was clear that the belt had been fading since late last year. This fading event has been observed at least 14 times since 1919 and is usually followed by the belt's reappearance a year or two later; the *Pioneer* flybys in 1973 and 1974 occurred during a previous fade.

While watching the unusual beltless planet on the night of June 3, Australian amateur astronomer Anthony Wesley spied a bright flash on that same belt, which is now understood to be the mark of a small asteroid, about 10 meters in diameter, burning up in the atmosphere. Wesley's observation was confirmed by Christopher Go from the Philippines. On August 20, another flash was spied by Japanese amateur Masayuki Tachikawa. Neither flash left any permanent mark on Jupiter's atmosphere; by the time the world's great telescopes—including Hubble, Gemini, and Keck—were trained on the planet hours afterward, no sign of either impact remained. Image: Anthony Wesley

Big and Small

ESA's *Rosetta* spacecraft is only a little past the midpoint of an extraordinarily long cruise from its launch in March 2004 to its planned rendezvous with comet 67P/Churyumov-Gerasimenko in May 2014. On the way, it has now swung past two asteroids, (2867) Steins in 2008 and (21) Lutetia in July of this year. Measuring 132 x 101 x 76 kilometers in diameter, Lutetia is by far the largest asteroid ever visited by a spacecraft. *Rosetta* performed science observations on Lutetia with nearly all of its instruments. As it approached the asteroid, celestial mechanics contrived to give the *Rosetta* team a gift: Saturn, about a billion kilometers farther away than Lutetia, drifted through the field of view of *Rosetta*'s OSIRIS camera. Image: ESA 2010 MPS for OSIRIS Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA/colorized by Gordon Vgarkovic

Explore **MORE**

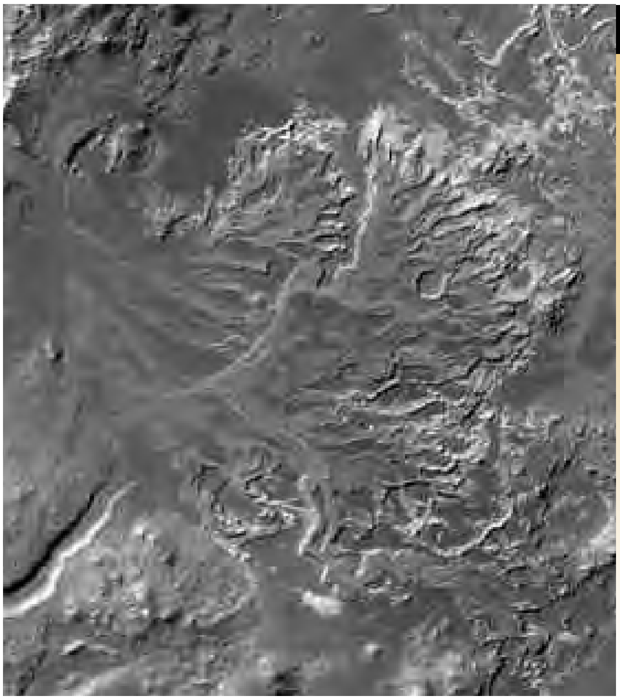
Find these images and more from 2010 at ***planetary.org/yip.***
Get your daily dose of space news, fascinating pictures, and commentary at the Planetary Society's blog: ***planetary.org/blog.***

End of One Era, Beginning of Another?

FAR LEFT: The space shuttle *Atlantis* launched on its 32nd—and last—flight on May 14. Following a successful mission to carry the Russian-built Rassvet research module and the astronauts of the STS-132 mission to the ISS, *Atlantis* returned to Earth for the final time on May 26. The future of NASA's human space program remains murky, particularly how the United States will launch humans into near-Earth orbit and beyond.

NEAR LEFT: One possible replacement for the shuttle's role of supplying the ISS enjoyed a nearly flawless maiden launch just days later, on June 4. Space Exploration Technologies Corporation's *Falcon 9* rocket is firing its first stage, which lifted the rocket to an altitude of about 80 kilometers (50 miles) before separating from the Merlin upper stage. Although the upper stage rolled more than expected during launch, it managed to insert the payload into its target orbit. *Falcon 9* is designed to launch SpaceX's *Dragon* capsule, which may begin launching cargo to the ISS next year. Eventually, SpaceX plans for *Dragon* to carry human passengers to the ISS.

Photos: Ben Cooper/launchphotography.com



Dry Delta

Mars Reconnaissance Orbiter carries two high-resolution camera systems: HiRISE, which produces spectacularly detailed photos of small areas of Mars (like the orbital photos of *Opportunity* and *Phoenix* elsewhere in this article); and the Context Camera, or CTX, which has lower resolution but covers vast areas of Mars with each image. Since the orbital mission began, CTX has photographed half of Mars at a resolution of six meters per pixel. One of the important goals of *Mars Reconnaissance Orbiter*'s mapping work is to explore potential landing sites for the next Mars rover, *Curiosity*, which will launch late next year. This photograph shows one of the candidate landing sites, the interior of Eberswalde crater, a closed basin that contains a preserved ancient delta. The delta contains evidence for persistent river flow on the surface of Mars, including cutoff river meanders as well as clay minerals, which form when water erodes rock. *Curiosity*'s landing site would be to the east of the delta deposit pictured here; the rover would drive from the floor of the crater up into the delta deposits, which (because of differential erosion) now stand higher than the crater floor.

Image: NASA/JPL/MSSS

Death of the Falcon

This brilliant fireball streaking across the Australian sky is no natural meteor; it is Japan's *Hayabusa* spacecraft, returned to Earth at last from its seven-year voyage to an asteroid and back. On June 13, 2010, it released its sample return capsule, which floated to a safe landing under parachute. The mothership, having no functional chemical propulsion system, was unable to deflect away from Earth. It followed right behind the capsule and burned up in Earth's atmosphere. The end of the spacecraft's dramatic journey captured the hearts and minds of the Japanese public, inspiring a new excitement for deep-space exploration. Photo: *The Yomiuri Shimbun,* Japanese daily newspaper

ASSEMBLING THE SPACECRAFT

BY LOUIS D. FRIEDMAN

Our preparations for *LightSail-1* continue to move at an accelerated pace. Recently, I visited Stellar Exploration in San Luis Obispo, California, to check on the hardware assembly. We are in the middle of building our *LightSail-1* spacecraft. It's a small craft, but it has many parts—approximately 1,000 of them!

Even with extensive computer-aided design and analysis, it is only when the physical hardware is assembled that we can be sure everything fits properly and weighs what we estimated it would weigh. First, we assemble an engineering model, which means that we build all the components exactly as they would be built for flight, but we do not yet electrically connect the components. After the engineering model is built and tested—including mechanical tests of all operations in a vacuum and with simulations of the space environment—we build the flight model and test it.

The illustrations and photos accompanying this article capture some of the main components as of the time of delivery and the beginning of assembly.

Our schedule now will be dictated by the launch. Because of our (relatively) high altitude requirement—above 820 kilometers (500 miles)—the opportunities for a piggyback launch are rarer than for a trip to low Earth orbit. As luck would have it, the opportunities seem to be even more limited in 2011 than in either 2010 or 2012. We are getting good cooperation and interest from NASA and from other agencies in the United States and abroad, however, and we hope that our next update will include specifics about the launch. You can keep up with our progress at *planetary.org/lightsail*.

Louis D. Friedman is a cofounder and board member of the Planetary Society. He is program director for LightSail.

Here we see the **LightSail-1** *spacecraft with its four solar panel arrays (engineering models without the actual solar cells) and one sail stowed in its storage compartment (the other storage compartments are still empty).*

The spacecraft comprises three cubesats stacked together, plus the sail module. The solar panels serve as covers until they are deployed. The sail storage compartment is built into one cubesat measuring 10 x 10 x 11 centimeters. Below it, in another cubesat, is the sail deployer mechanism with a boom partially deployed. Above the sail storage compartment is one more cubesat module, in which will be placed all the spacecraft electronics, including guidance, control, and radio systems.

All images: The Planetary Society

Here is a close-up of the boom deployer, which was invented by the engineers at Stellar Exploration. The specialized deployer was designed specifically for the cubesat, and we are now patenting the device.

The spacecraft and sail are seen in this scale model, now hanging in Planetary Society headquarters. The quarter-scale model was built by JPL engineer and Spacecraft Kits developer Dave Doody.

This photo is a top view of the LightSail-1 engineering module, showing one solar panel and the open electronics compartment with boards inside. All the spacecraft electronics—including computer, radio, guidance, and control devices—fit on 1.5 boards. The boards were designed at California Polytechnic University in San Luis Obispo.

I also went into the clean room to inspect "my" solar sail. (To reassure those who know me, I don't really handle flight hardware.) The sail material was supplied by the Orcon company and comes in rolls from which the actual sails are assembled by seaming material. Above, Stellar engineers Chris Biddy and Michael Bertino are folding the sail material in the very special way that permits smooth deployment in space. The folding of a single sail (inset) took about 20 hours.

The cubesat module is pretty small, but it is large enough for our extremely small electronics. Shown here is the electronics compartment with two of the gyros visible. Gyros are used for attitude stability to point the spacecraft in the proper direction. Together with the onboard accelerometers (not shown), the gyros will provide complete information about the spacecraft's position and velocity during flight. In the lower left of this figure, you can see the folded sail in its compartment.

None of the pictures captures the scale of the solar sail; that happens only when we lay out the full sail area of about 32 square meters. Here, Megan Nunes from Stellar shows us the sail area in the Stellar work area. The four panels together make up a sail measuring about 5.6 x 5.6 meters with 4-meter booms. The mass-to-area ratio of LightSail-1 is 144 grams per square meter, the lowest of any solar sail spacecraft to date. For comparison, Cosmos 1 was 175 grams per square meter and IKAROS was approximately 787 grams per square meter. The lower the ratio, the greater the spacecraft's acceleration.

The engineering models of our two most important instruments also have been readied. One of the two video cameras is shown above—they will be installed on the spacecraft engineering model (at the ends of two solar panels) for the mechanical tests. The Lumidyne Test Experiment sensors (nano-accelerometers) are undergoing testing in separate field experiments.

I visited Stellar Exploration to see and hold some of the hardware. Even though I have experience with planetary spacecraft such as Voyager, Galileo, VEGA, and Phobos-Grunt, the scale continues to amaze me. The revolution of miniaturization is now passing from computers to entire spacecraft, and the future belongs to the small. Miniaturization is of great benefit to the LightSail program, which relies on a small source of power to propel a spacecraft—possibly out to the stars.

The image shows me holding the engineering model, with one solar sail and one partial boom in the boom deployer. Behind me is the Stellar clean room, where flight components are handled in a totally clean environment. In that room, the aluminized and reinforced sail material is being assembled into the four flight sails.

EXPLORE MORE

Find out more about *LightSail* and the progress of the mission at ***planetary.org/lightsail.***

SHOEMAKER NEO GRANTS

by Bruce Betts

We have selected our latest round of Shoemaker Near Earth Objects (NEO) Grant winners. The winners are all doing really cool stuff, from asteroid orbital follow-up to binary asteroid studies to impact observation on Jupiter.

In 1997, the Planetary Society started the Shoemaker NEO Grants program in honor of planetary geologist Eugene Shoemaker, who pioneered our understanding of the role of impacts on Earth and who dedicated much of his life to NEO research. The purpose of the Shoemaker NEO Grants program is to increase follow-up, characterization, and discovery of NEOs by providing dedicated amateurs, observers in developing countries, and professional astronomers with seed funding to greatly expand their programs.

Great Proposals and Great Reviewers

This round, we received 29 proposals from 15 countries on 5 continents. We were fortunate once again to have an expert international advisory group review the proposals and recommend candidates to receive the grant awards.

The advisory group consisted of Planetary Society NEO Grant Coordinator Daniel D. Durda of the Southwest Research Institute, in the United States, who also contributed to this article; Alan Harris, MoreData!, United States; Petr Pravec, Ondrejov Observatory, Czech Republic; Tim Spahr, Harvard Smithsonian Center for Astrophysics-Minor Planet Center, United States; and Duncan Steel, QinetiQ, Australia.

The proposals that we anticipate funding, based on the advisers' recommendations and our expected resources, are below. They span a range of countries and topics, and all will make important contributions to the field. I'm excited to share information about the winners and what they plan to do with their grants.

And the Winners Are . . .

Russell Durkee runs the Shed of Science observatory in Minneapolis, Minnesota, which was founded in 2004 with the primary goal of measuring asteroid light curves. Asteroid light curves measure brightness versus time and provide insights into rotation rates and even the binary nature of asteroid systems. Durkee's $5,990 grant is for an SBIG ST10XE camera and filter wheel to be used with a new telescope he has acquired. The new telescope/camera system will also utilize the automation upgrades installed at the observatory using a previous Shoemaker NEO grant.

David Higgins operates the Hunters Hill Observatory in Canberra, Australia, where he runs an extremely productive asteroid light curve program. Higgins was the recipient of a 2004 Gene Shoemaker NEO grant, which funded the purchase of a secondhand SBIG ST-8 CCD camera. That camera allowed for the automation of the Hunters Hill Observatory, resulting in photometric (brightness) observations of more than 400 targets as well as uncovering the binary nature of nearly two dozen asteroids. Higgins' $7,695 grant will purchase a new SBIG STL-1001E C2 camera that will provide a much wider field of view and significantly faster image downloads. This award comes at a propitious time, as Higgins' previous main camera recently suffered a significant hardware failure.

Robert Holmes is president of the Astronomical Research Institute (ARI) in Ashmore, Illinois. In 2009, ARI made nearly 8,000 targeted observations of NEOs, more than any other observatory in the world. Holmes will extend ARI's already very productive research in NEO observations to physical studies of NEOs, utilizing a $1,405 grant to purchase four filters in BVRI (blue, visible, red, infrared) and a clear filter for focusing. The filters will be used on 0.76- and 1.3-meter telescopes.

Jaime Nomen represents the La Sagra Observatory and the La Sagra Sky Survey (LSSS) on the Spanish island of Mallorca. One of the most prolific amateur observatories anywhere, La Sagra and the LSSS have discovered that their current CCD camera provides a limited field of view and is not able to reach the faintest candidates found by larger survey telescopes. Their grant for $7,695 will fund the purchase of a new, larger-format SBIG STL-1001 CCD camera that will significantly reduce their image readout times.

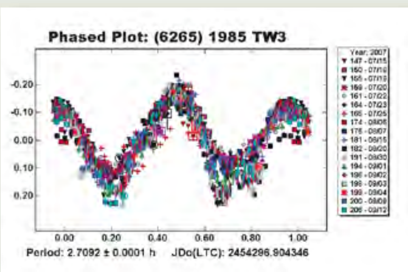
Herman Mikuž operates the Črni Vrh Observatory in Slovenia, representing a highly competent team of NEO observers. Their fully robotic, over-the-Internet program with a 60-centimeter telescope originated with the help of a 2000 Shoemaker grant and has grown to the second most prolific amateur NEO survey, with multiple discoveries per year on average. More generally, the program team has discovered more than 500 asteroids and comets. Researchers will overcome sensitivity limitations they are experiencing by using cameras with deep cooling to 60 degrees Celsius (108 degrees Fahrenheit) below ambient temperature. A grant of $8,000 will substantially complement the funds Mikuž and his team have raised to provide the approximately $15,000 needed for the purchase of a deep-cooling Apogee Alta U9000 CCD camera.

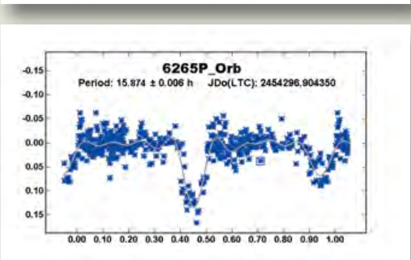
Anthony Wesley probably is best known to Planetary Society members as the Australian amateur astronomer who was the first to observe and call attention to an impact flash in the atmosphere of Jupiter on July 19, 2009, and who had a prominent role in recording yet another impact in June 2010. The Review Committee, impressed with Wesley's work and the promise offered to the field of impact studies by continuation of real-time imaging of the giant planets, allocated $2,500 to assist Wesley in making upgrades and in the continued operations of his imaginative and very productive observing program using his 14.5-inch Newtonian reflector.

The Planetary Society thanks all the grant applicants and reviewers for helping to continue a vibrant and successful program! You can find much more information about our Shoemaker NEO grant winners, as well as updates about their research, at *planetary.org/programs/projects/neo_grants/*.

Bruce Betts is director of projects for the Planetary Society.

The 60-cm, robotically conrolled Cichocki telescope used by Herman Mikuž at the Črni Vrh Observatory in Slovenia. *Photo: Črni Vrh Observatory*





Using data like these from an eclipse event, David Higgins has been involved with uncovering the binary nature of more than two dozen binary asteroids. *Images: David Higgins*

Robert Holmes of Astronomical Research Institute working with NEO data. *Photo: Astronomical Research Institute*

What's Up?

In the Sky—December and January

Jupiter is the brightest starlike object in the evening sky, appearing high overhead and very near the Moon on December 13. Venus dominates the predawn eastern sky, with dimmer Saturn above it near the star Spica. The year ends with the crescent Moon close to Venus on the morning of December 31. Don't miss the Geminids meteor shower, which peaks on December 13 and 14. Traditionally the best meteor shower of the year, the Geminids average more than 60 meteors per hour from a dark site. Viewing will be best after midnight, when the Moon has set.

Random Space Fact

Pluto orbits the Sun twice for every three times Neptune orbits the Sun.

Trivia Contest

Our May/June contest winner is Michael A. Gajewski of Clinton Township, Michigan. Congratulations!

The Question was: Where in the solar system (on what planet or moon) is Alpha Regio?

The Answer is: Venus.

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

In light-years, how far away is Proxima Centauri, the closest star to Earth besides the Sun?

E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 85 South Grand Avenue, Pasadena, CA 91105. 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, 2011. 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.*

Explore More

Learn more and help support these researchers at ***planetary.org/programs/projects/neo_grants/.***

Members' Dialogue

Our Focus

Robert J. Douglas makes some interesting points in the September/October 2010 issue; however, his assertion that the Planetary Society has abandoned manned spaceflight as a part of exploration of the solar system is inaccurate. The truth is that manned spaceflight programs themselves have abandoned exploration. Just look at how much exploration has come from manned spaceflight over the past 40 years—none.

By contrast, robotic programs—despite some setbacks—have been absolutely prolific. Yes, we have all been patiently waiting and hoping that manned spaceflight too will someday produce results and prove its value. But now, after 40 years of nothing, how much longer do we want to sink money into this failed endeavor?

—HANS K. BUHRER,
Smithsburg, Maryland

I find myself agreeing with the letter from Robert J. Douglas. Without minimizing the importance of robotic science or the environmental protection of the Earth, I must say that manned missions are what excite me and, probably, most other people. That is why personalizing robots, like the Mars rovers, is so important: it gets people to identify with them as if they were human.

Over the years, there have been many good arguments put forward for why manned missions are important, but the bottom line is that when you stop doing, you start dying.

I would like to see the Planetary Society talking about a comprehensive overhaul of the space program—not simply justifying the next incremental step. Put the focus on how we should logically explore and inhabit our solar system. Review the present technology, discuss what we need to develop, and lay out a strategic plan from both a science and a political standpoint that would allow us to move forward. Promote that plan! Think large!

The solar sail, while technically interesting, will not result in a solution to getting around the solar system. The space program needs leadership and, most important, vision. Let's follow the example of the Planetary Society's logo—a manned ship going forth boldly!

—RODERICK R. HATCHER,
Saylorsburg, Pennsylvania

Erratum

On page 12 of the September/October issue, the temperature 740 kelvins was converted to about 240 degrees Fahrenheit. The correct temperature is close to 870 degrees Fahrenheit (all figures rounded to the nearest 10 degrees).
—Editor

Please send your letters to
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or e-mail: *tps.des@planetary.org*

World Watch

After months of disagreements about how to handle the new approach to space exploration proposed by the Obama administration, the U.S. Congress passed a NASA authorization bill in the final week before adjourning prior to congressional elections. The bill endorsed the proposed budget increase and full funding for space and Earth science. The bill departed, however, from the administration's proposal for human spaceflight.

Congress endorsed the transition to commercial industry for human transportation to low Earth orbit, but at a considerably slower pace than what was proposed. Congress rejected the administration's plan to precede deep-space rocket development with a technology program and instead was in favor of starting more quickly with particular design requirements. The final bill also was more vague about steps for human spaceflight beyond Earth orbit, only briefly citing developing the capability for reaching the Moon, asteroids, and Mars.

The Planetary Society issued a statement about the bill, applauding the overall budget increase and "strong space science and a reinvigorated Earth science program," as well as the "resumption of NASA's technology funding." The statement criticized the bill's approach to human spaceflight, noting that "the NASA human spaceflight program will improve once it is allowed to focus on exploration rather than transportation. This authorization bill is too prescriptive, as it specifies rocket performance and design approaches. . . . We hope the administration and Congress will address these issues in the very near future."

The authorization bill specifies programs and funding levels, but it does not actually grant NASA a budget. The budget will come in an appropriations bill, which will not be considered until after elections (just about the time you are reading this). Appropriators will use the authorization as a guide, but they are not bound to follow it. Typically, they do not appropriate as much money as the authorization bill requests. That is expected to be the case this year because the Congress has begun discussing budget cuts. If cuts are applied, that could have a significant effect on the program plans.

As you read this, the elections will have concluded and the new shape of Congress will be determined. The session in November/December is a lame duck session; the new Congress will take office in January. All this makes for a lot of uncertainty. Keep up with the latest information on our website at *planetary.org.*

—LOUIS D. FRIEDMAN,
Planetary Society cofounder and Board member

Society News

End-of-Year Giving: A Gift to You and to the Society

Are you looking for an opportunity to make a (tax-deductible) year-end gift? You've come to the right place. Your gift is an investment in the future of the Planetary Society, and it also is an investment in the future of space exploration.

You can choose from a variety of gift-giving options. Many offer significant tax savings, and all offer you the joy of knowing that you are shaping our place in space.

Gifts made by credit card can be sent securely online at *https://planetary.org/join/ donate.html*, and gifts can also be sent via mail to Planetary Society headquarters.

Do you have a special interest in one of our projects? Your gift—large or small—will make a difference. Again, you can donate online or by mail, and you can designate the project or program that piques your interest.

You might consider donating your appreciated stock to fuel the Society's work to explore worlds beyond our own. Please, just give us a call so we know it's on the way.

Please e-mail me at *andrea.carroll@planetary.org* or call me at (626) 793-5100, extension 214, if you'd like to talk through possibilities. I'd love to hear from you.

Thank you, and best wishes from all of us for the coming year!

—Andrea Carroll, Director of Development

The Planetary Society Names a New Global Volunteer Coordinator

Although no one could replace the Planetary Society's longtime Global Volunteer Coordinator, Lonny Baker, who retired from the position this summer, we have found a wonderful volunteer who is willing to take on the job. Tom Kemp, a member of our Pasadena volunteer group, is now the Society's new Global Volunteer Coordinator, ready and eager to work with our volunteers around the world.

As we strive to modernize our volunteer network, better utilizing online databases and the remarkable skills of our volunteers, Tom will help us work through the transition. Drop Tom a line and introduce yourself if you are an established volunteer, or contact him to become part of our Volunteer Network. Tom looks forward to working with all of you. Contact him at *tomkemp@planetary.org.*

—Susan Lendroth, Manager of Events and Communications

Max Corneau in the Volunteer Spotlight

Max Corneau is a member of the Planetary Society's New Millennium Committee and a JPL Solar System Ambassador. Known as Astro Dad, Max is also a Master of Public Outreach in the Astronomical League. During his tenure as a senior space officer stationed in Washington, D.C., Max served at the National Air and Space Museum's Explore the Universe Gallery, led tours at the U.S. Naval Observatory, and was elected to the Philosophical Society of Washington. You can find hundreds of planetary and deep-space images that he has captured and created at his website, www.astrodad.com. *Here Max shares a little from a recent presentation he gave.*

Sailing Stars Through Time

by Max Corneau

On September 17, 2010, the Trammel and Margaret Crow Museum of Asian Art in downtown Dallas, Texas, celebrated Hispanic Heritage Month with an Art After Dark program titled "Black Current: Mexican Responses to Japanese Art, 17th–19th Centuries."

Somehow my name got thrown into the suggestion box as a worthy presenter for the program. Since becoming a JPL Solar System Ambassador in 2004, I had never presented a program at an art museum. This was just the chance to expand my astronomical horizons in the same manner I chose to join the Planetary Society several months ago.

The program, titled "Sailing the Stars Through Time," explained how Japanese maritime navigators voyaged from their homeland to the Americas and influenced Mexican art from the 17th to 19th centuries along the Black Current. The Black Current is the Pacific Ocean analog to the Gulf Stream. Although the program took me slightly out of my astronomical comfort zone, the audience enjoyed the historical review of celestial navigation through how I used a solar transit and the U.S. Naval Observatory master clock to set the true north line of my own astronomical observatory.

The final Q&A really cast the whole event in solid gold. Audience member "Sin" quietly asked from the back of the hall if it was accurate to consider sailing on the Black Current as analogous to the president's plan to have humans ride on an asteroid.

This audience member fed back a complex concept so elegantly that, after only a moment of reflection, I strongly agreed. You see, one of my points was that Japanese sailors were propelled through a dark, watery current that was generated by planetary forces of heat and cold. Similarly, future asteroid travelers might travel on a seemingly invisible "gravity-based" current through the blackness of space. This gravity-based propellant could be the Greatest Black Current.

Developing and executing successful programs is very rewarding, but the real reward is that one has the opportunity to interact with and continue to learn from other experts and lay members of the community. □

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Recent news that an Earth-like planet may have been discovered in its star's habitable zone was all the inspiration Dan Durda needed to create *Gliese 581g*, a world alive with new and strange vegetation and, most important, shimmering bodies of liquid water. Artistic license aside, however, Dan tried to show the correct level of lighting on a world in orbit around a red dwarf star. He also placed the sun close to the horizon because if the putative planet is tidally locked with its star, one plausible place for life to spring up is along the terminator—the line between day and night.

Dan Durda is a planetary scientist at the Southwest Research Institute in Boulder, Colorado. He has more than 20 years of experience studying the collisional and dynamic evolution of asteroids, vulcanoids, Kuiper belt objects, and interplanetary dust. Durda is an active pilot, experienced cave diver, and popular space artist with a growing interest in creating scenes of habitable extrasolar worlds.