The PLANETARY REPORT

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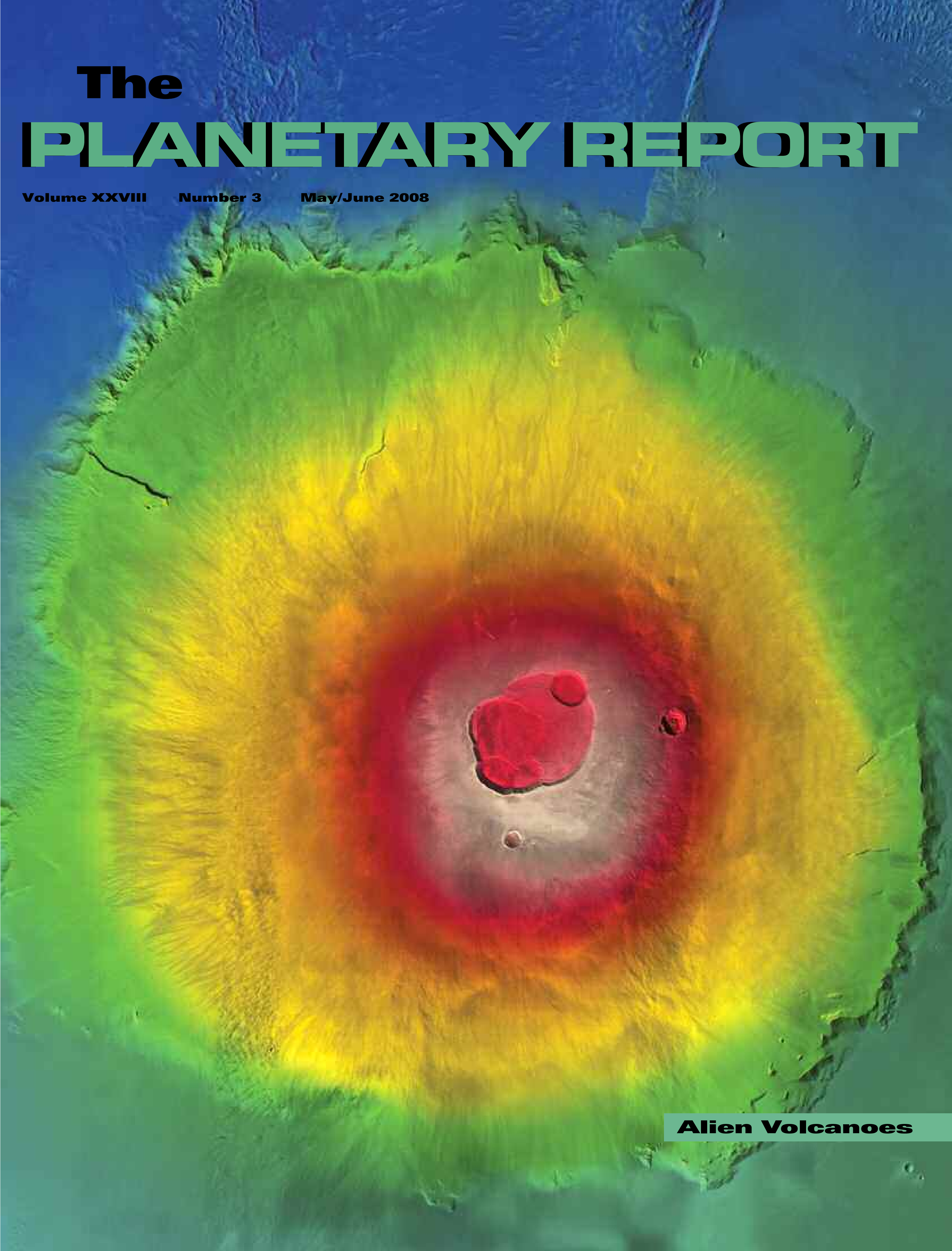


Alien Volcanoes

From The Editor

Humans like to mark the passage of time with special dates to help us remember who we were and how far we have come. This issue of *The Planetary Report* falls between two 50-year anniversaries—the launch of *Explorer 1* in January 1958 and the founding of NASA in October 1958. Both events were triggered, of course, by *Sputnik*'s 1957 launch.

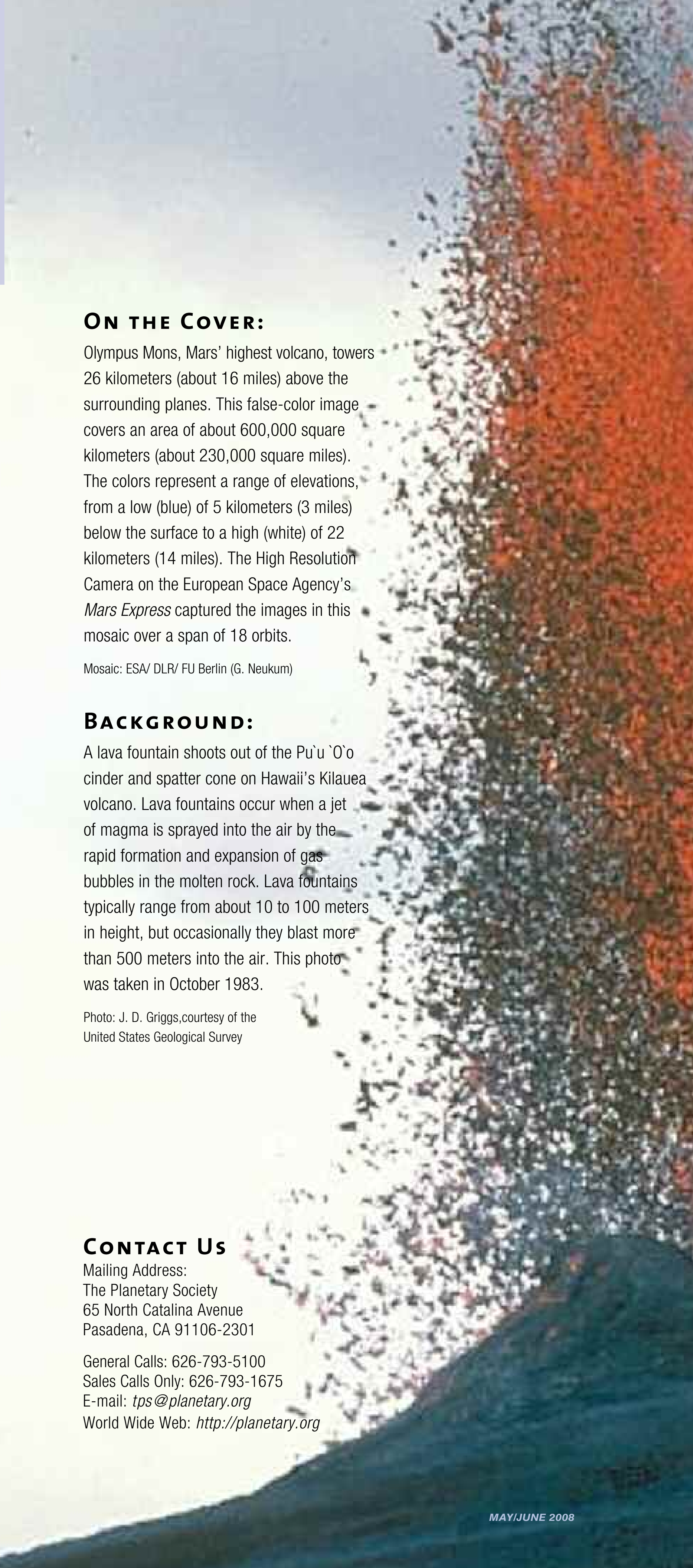
In those 50 years, we have visited every major planet in our star system, flown through their retinues of moons, and seen them transform from tiny, dim images in telescopes to worlds we have come to know as individuals, each one astonishingly distinct.

We saw these worlds for the first time, and the first-time experience never can be repeated. The planets are now familiar faces, neighbors in our small corner of the Milky Way. These first 50 years of the Space Age opened the solar system to our exploring species, and the generations that lived through these years know that they have been extraordinarily privileged.

As we mark these anniversaries, I can't help but wonder what the coming generations will see for the first time. Will they drill beneath Europa's icy crust to explore the ocean that lies beneath? Will they sail across the hydrocarbon lakes of Titan? Will they leave footprints in the rusty sands of Mars?

My questions are inadequate to address the potential wonders they will see 50 years from these anniversaries. I envy them.

—Charlene M. Anderson



On the Cover:

Olympus Mons, Mars' highest volcano, towers 26 kilometers (about 16 miles) above the surrounding planes. This false-color image covers an area of about 600,000 square kilometers (about 230,000 square miles). The colors represent a range of elevations, from a low (blue) of 5 kilometers (3 miles) below the surface to a high (white) of 22 kilometers (14 miles). The High Resolution Camera on the European Space Agency's *Mars Express* captured the images in this mosaic over a span of 18 orbits.

Mosaic: ESA/ DLR/ FU Berlin (G. Neukum)

Background:

A lava fountain shoots out of the Pu`u `O`o cinder and spatter cone on Hawaii's Kilauea volcano. Lava fountains occur when a jet of magma is sprayed into the air by the rapid formation and expansion of gas bubbles in the molten rock. Lava fountains typically range from about 10 to 100 meters in height, but occasionally they blast more than 500 meters into the air. This photo was taken in October 1983.

Photo: J. D. Griggs,courtesy of the United States Geological Survey

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A PUBLICATION OF THE PLANETARY SOCIETY

NASA at 50
A Personal View

by James D. Burke

Employed at NASA's Jet Propulsion Laboratory from 1949 until his retirement in 2001, James D. Burke participated in all the early efforts to send robotic spacecraft to the Moon.

Much will be written as NASA reaches its fiftieth anniversary in 2008. Here, I intend to share with readers of *The Planetary Report* a personal view—not a learned history but, rather, a search for the essence of humans' and their nations' experience in a world of unprecedented discovery and change.

Let's begin with Robert Hooke. Among other episodes in his complicated and difficult life, he was for a time charged with preparing experiments to entertain and enlighten the gentlemen of 17th-century London. Their Royal Society, then as now, was the epitome of such institutions worldwide, many flourishing today after existing for hundreds of years. Hooke, curious about everything, saw to it that the great debate about the origin of lunar craters—impact or volcanic—would get attention: in an experiment around 1670, he dropped balls into pots of mud and boiled mud in pots.

Meanwhile, science had been emerging from its ancient realm of the intellect into the arenas of commerce, industry, politics, and war. America, founded by the likes of Benjamin Franklin and Thomas Jefferson—both enthusiastic scientists—was full of tinkerers and entrepreneurs and hence was fertile ground for this florescence. By the middle of the 19th century, the American Association for the Advancement of Science was complemented by the National Academy of Sciences, President Abraham Lincoln's 1863 launch of a permanent connection between government and the research community.

Then, at last, the dream of centuries—human flight—became reality, emerging out of the workshops of previously ignored inventors into sporting contests and sheds where seamstresses covered wooden wing frames with cloth. Governments took notice. In March 1915, U.S. President Woodrow Wilson announced the founding of the National Advisory Committee for Aeronautics (NACA).

NACA went on to greatness. The aeronautical field centers—Langley (1917), Ames (1919), Lewis (1940), and Dryden (1946)—in partnership with universities and industry, compiled a stellar record of achievement

This is the official seal for the National Advisory Committee for Aeronautics (NACA), established by an act of Congress in March 1915. The seal depicts the first human-controlled, powered flight, made by the Wright brothers in December 1903 at Kitty Hawk, North Carolina. In 1958, NACA was incorporated into the National Aeronautics and Space Administration. Photo: NASA

in applied research. America's world leadership in aviation was one result.

While this was happening, an even more revolutionary movement was struggling to be born. Rocket dreamers, impelled by science fiction and an inchoate longing to sail the vast dark spaces among the stars, laid mathematical foundations and took tiny experimental steps toward space. Governments did not take notice. But then, in wartime desperation and, arguably, lunacy, the German Army put the V2 into production. With stunning swiftness, intercontinental ballistic missile projects followed.

Here, between the two great Cold War adversaries, there was an asymmetry: with its global reach of allied bases and nuclear-armed, long-range bombers, the United States could threaten to annihilate any Soviet city. The

Workmen in the Langley Research Center's pattern makers' shop manufacture a wing skeleton for a Thomas-Morse MB-3 airplane in June 1922. The airplane was used for pressure distribution studies in flight.
Photo: NACA

Above: These are the original NACA aircraft hangars, photographed at Langley Research Center in 1931. The plane parked to the right is the Fairchild owned by NACA. Just outside the hangar door is a modified Ford Model A that was used to start aircraft engines.
Photo: NACA

In 1957, news of Russia's launch of Sputnik 1 *shocked the world and, in the United States, ignited the competitive spirit that resulted in the* Apollo *Moon landings.*
Photo: Dmitri Kessel/ Time & Life Pictures/Getty Images

USSR, unable to do the same by air to the U.S., secretly aimed to even the odds with rockets. In both countries there was competition between the bomber and missile people, but in the USSR the rocket builders had an edge.

While the strategic struggles of World Wars I and II and the Cold War had been going on, with ever-increasing entanglement between the realms of science and government, scientists became more and more aware of Earth as a planet and able to use modern tools—aircraft, balloons, sounding rockets, radar—to investigate the space around it. International Polar Years (launched in 1882, 1932, and 2007) and the International Geophysical Year (IGY) in 1957 were expressions of this drive to explore the unknown. It was natural then for scientists in both the U.S. and the USSR to advocate the next logical step, sending instruments into orbit. In 1956 both countries announced that they would take this step during the IGY.

On January 31, 1958, the United States Army launched **Explorer 1**, *America's first Earth satellite. The three men responsible for* **Explorer 1** *posed with a prototype for the press. At left is William H. Pickering, then director of JPL, which built and operated the satellite. James A. Van Allen (center), of the State University of Iowa, designed and built the instrument on* **Explorer 1** *that discovered the radiation belts circling Earth (now bearing his name). At right is Wernher von Braun, leader of the Army's Redstone Arsenal team, which built the first-stage Redstone rocket that launched* **Explorer 1**. *Photo: NASA/JPL*

The delivery on this promise changed the future. In the U.S., for a good strategic reason and in spite of strong objections, President Dwight Eisenhower insisted at first on a nonmilitary approach. Meanwhile in the USSR, a similar dispute occurred, owing to competition between the urgent need for a demonstrated strategic deterrent and the desire of space enthusiasts to use a missile to launch a satellite. In each nation there was fear that the other might succeed first, and in the USSR it resulted in a decision to postpone an IGY scientific mission and instead orbit the simplest satellite that could be seen and tracked worldwide.

Nobody predicted the upheaval that followed *Sputnik*. Even the Soviets themselves were surprised at what they had wrought, though they were quick enough to use it for propaganda advantage. In the United States it had the peculiar effect of causing a huge commotion over science education and the relation between science and government. As the dust began to settle, a new agency was born: NASA.

At first it could have been expected that the National Aeronautics and Space Administration, formed of NACA plus the Jet Propulsion Lab (JPL) and part of the Army's rocket enterprise including the von Braun team, would continue the NACA pattern of applied research. NASA would launch scientific satellites and eventually human missions to low Earth orbit, while in the parallel secret world surveillance satellites would take advantage of Eisenhower's wise policy—his open skies proposal a way of forcing orbital overflight not to be regarded as an airspace violation.

The secret part did happen as planned. Led by the CIA, the urgent Corona program, after many failures, began to yield unprecedented coverage of the Soviet Union's strategic capacities. This helped greatly in dispelling exaggerated fears. A similar Soviet program gave enough coverage of the United States that, in the end, satellite reconnaissance by both parties did much to stabilize deterrence.

On May 25, 1961, in his historic message to a joint session of Congress, President John F. Kennedy declared, "I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth." This goal was achieved when Neil A. Armstrong became the first human to set foot on the Moon on July 20, 1969. Shown in the background are Vice President Lyndon Johnson and Speaker of the House Sam T. Rayburn. Photo: NASA

The civil program, however, did not go as expected. On April 12, 1961, Yuri Gagarin made one circuit of the Earth. President John Kennedy, already viewing the USSR as a main threat to U.S. world leadership, asked his advisers to define a program with which "we can win." The result was *Apollo*, soon followed by an enormous but unsuccessful competing Soviet program. While the human lunar missions were being prepared, each country launched a series of robotic lunar missions.

It was a golden age for the Moon, and we participants count ourselves as unbelievably fortunate to have been there during humanity's first step toward becoming a two-planet civilization. But the glory did not last. After the monstrous Soviet N-1 lunar vehicle failed for the fourth time, the United States, mired in Vietnam and riven by discord at home, called *Apollo* quits, and both nations fell back into a future limited to paddling around in the home lagoon, no longer daring to set out on Kennedy's great "new ocean" of space.

Today, some of we members of the NASA family see ourselves as bearers of the proud traditions of an institution that has fallen upon hard times. It has magnificent achievements—both robotic and human—and many more to come.

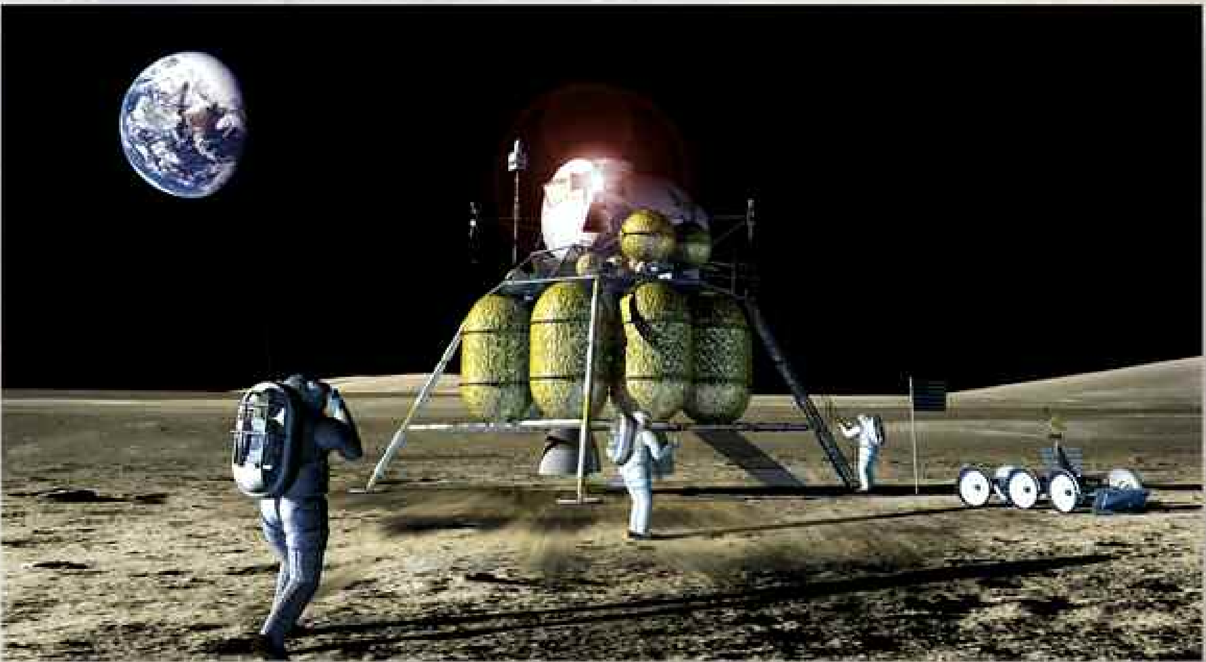
Four human artifacts—two *Pioneer*s and two *Voyager*s—flung onward by the gravity of the giant outer planets, are entering interstellar space, leaving the Sun's domain forever. A huge new industry has spun off into commerce. Telescopes beyond the atmosphere have revealed the astonishing complexity and beauty of the evolving universe. Other nations are following the opened path. *Apollo* and its giant failed Soviet competitor were a brave beginning whose long-term consequences have yet to become fully understood.

NASA has thousands and thousands of wonderful, smart, and devoted people. Its budget, though huge in absolute magnitude, is a pathetically tiny fraction of the American government's total. Three shuttle orbiters remain from the original fleet of 5; 20 or 50 should have been built, or else some other plan devised for space access. In contrast, more than a thousand of the USSR's powerful Soyuz rockets, derived from the original R-7 ICBM that launched *Sputnik*, have been launched from Baikonur and Plesetsk. NASA does now have the mission of returning to the Moon, but many years will pass, and unknown events will occur, before humans can again tread the lunar surface.

And yet—and yet . . . The time may come when the first 50 years of NASA are seen not as the ups and downs of a government agency (every agency has those) but, rather, as the first bewildered strivings of a bold, free, and generous people, with all sorts of other problems in their daily lives, to move toward a peaceful and abundant future in space.

James D. Burke is technical editor of The Planetary Report.

The Ares 1 launcher is part of NASA's Constellation program. The rocket will be topped with the* Orion *space capsule that will carry astronauts to the International Space Station in low Earth orbit. Later, the rocket will loft* Orion *and its astronauts on the first leg of a trip to the Moon. This artist's concept shows an Ares 1 booster lifting off from Kennedy Space Center. The first test launch of Ares 1 is scheduled for April 2009.
Illustration: NASA



Human explorers have landed, once again, on the lunar surface. How many years will pass before this scene becomes a reality? NASA is working—through its Constellation program—on the new spacecraft that will return astronauts to the Moon and blaze a trail to Mars and beyond.
Illustration: John Frassanito and Associates

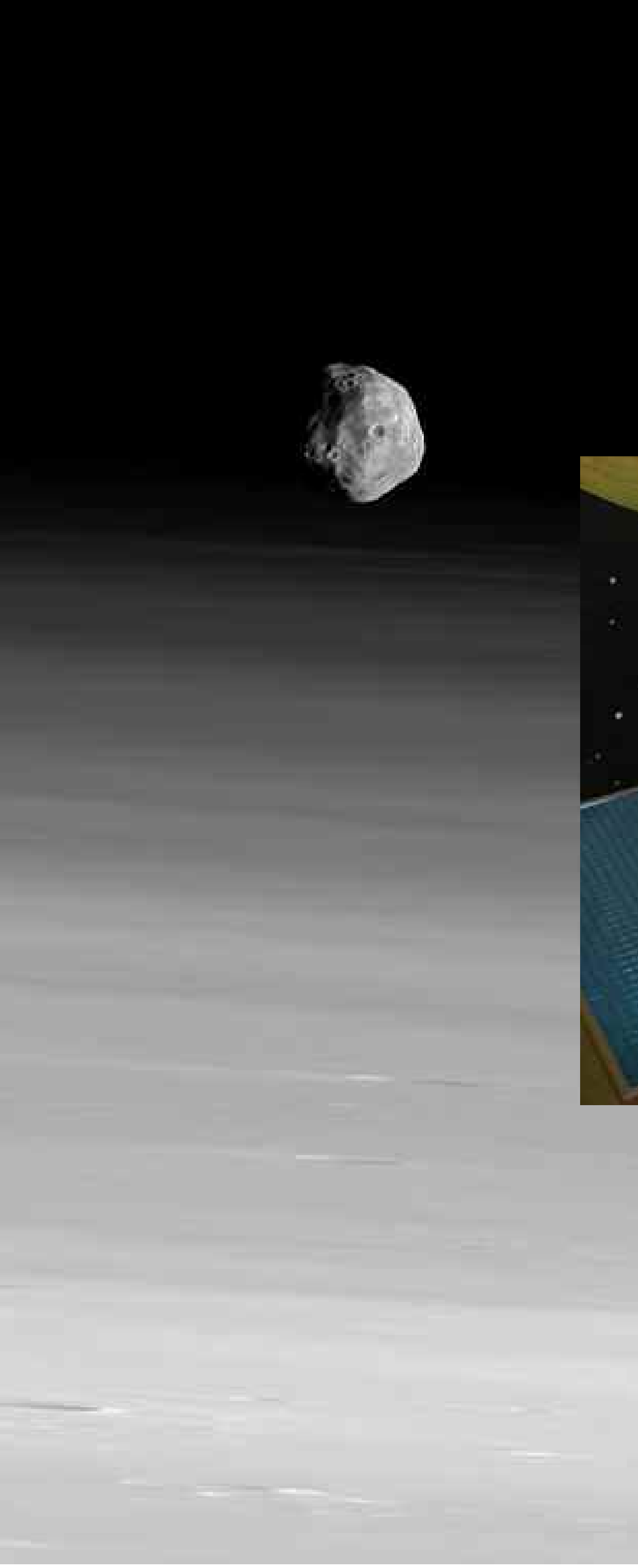
We Make It **Happen!** by Bruce Betts

LIFE Flying to Phobos and Back!

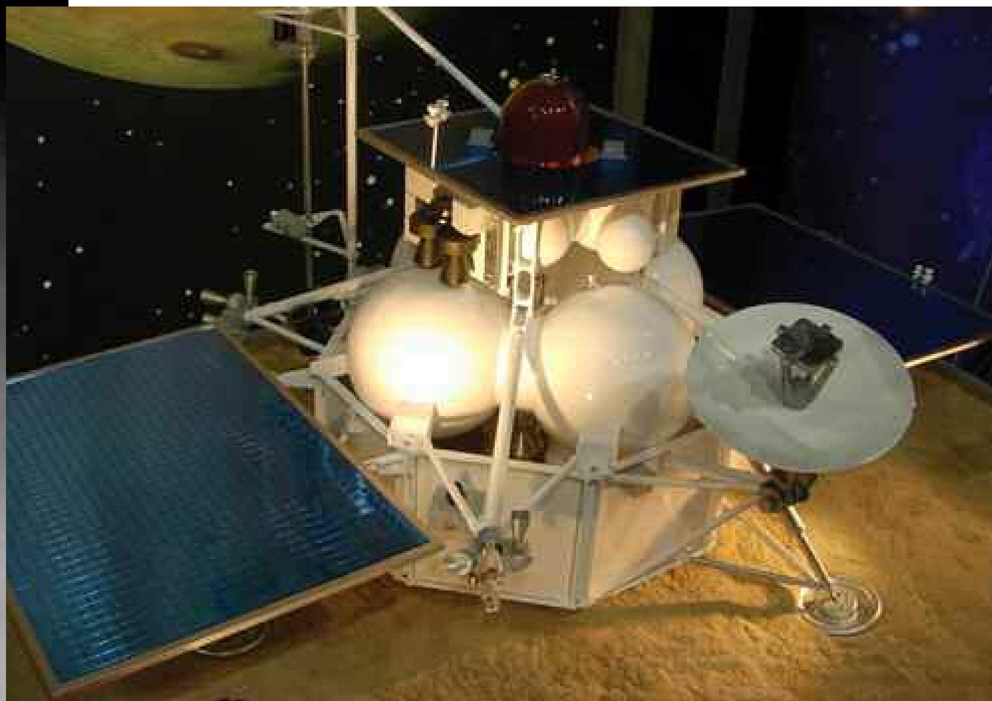
Our experiment, LIFE, will go to Mars' moon Phobos. This color image of Phobos, taken by the Mars Reconnaissance Orbiter*'s HiRISE camera, has been stretched to exaggerate color variations within and around the prominent crater Stickney. The floor of Stickney appears dark, with cascades of multicolored material sliding down its walls, revealing that the moon is bright on the inside.*

Image: NASA/JPL/University of Arizona

Is it possible for life to transfer naturally from one planet to another? In an ambitious initiative, The Planetary Society is sending a collection of living organisms on a three-year trip to the Martian moon Phobos and back to Earth. The experiment—called LIFE (Living Interplanetary Flight Experiment)—will help scientists better understand the nature of life, its robustness, and its ability—or not—to move between planets.



Left: Phobos floats just above the limb of the planet Mars in this image taken by Mars Express *during its 3,868th orbit (January 10, 2007). Phobos is the larger of Mars' two moons and the one closer to the planet. The image has been enhanced slightly to bring out details on the moon.*
Image: ESA/DLR/FU Berlin (G. Neukum)



This model of the Phobos-Grunt *spacecraft is shown on display at the 2007 Paris Air Show at Le Bourget.* *Photo: Paolo Ulivi*

The Transpermia Hypothesis

The journey will test one aspect of the transpermia hypothesis—the possibility that life can move between planets inside rocks, blasted from one planetary surface by an impact and eventually landing on another planetary surface. We will fly selected organisms inside a simulated meteoroid—a small canister on board a Russian sample return spacecraft—over a three-year mission.

This type of experiment—combining a multiyear period and exposure to a deep-space environment, beyond the protection of Earth's magnetosphere—has never been done before.

The European experiments Biostack 1 and 2 (carried aboard *Apollo 16* and *17,* respectively) took biological samples outside the magnetosphere, but only for periods of many days. Since then, various European, Russian, and American biological survival experiments have flown in low Earth orbit and demonstrated that microorganisms and certain other classes of terrestrial life (such as plant seeds) are not destroyed by exposure to the space environment. These experiments, however, did not fly beyond Earth's protective magnetosphere.

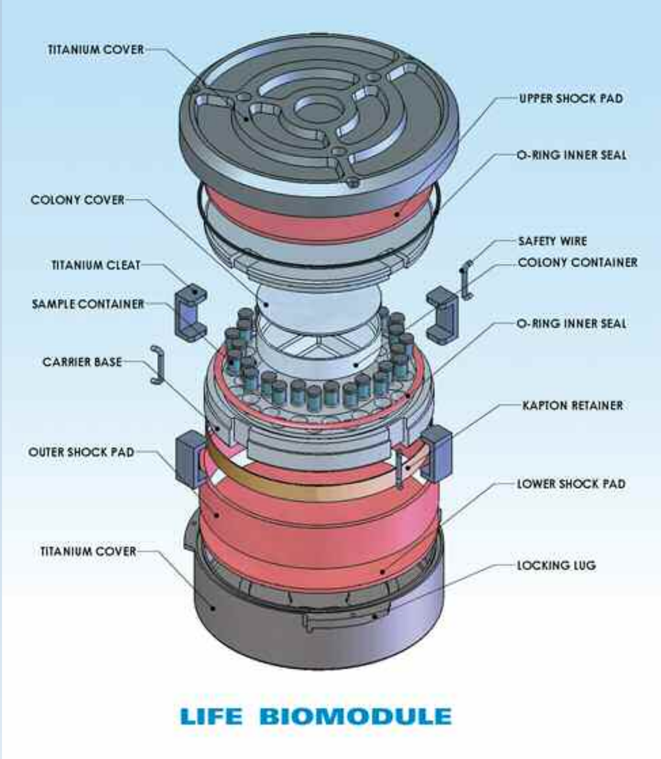
LIFE will test whether microbial life can survive outside the magnetosphere for three years. Will some microbes survive the brutal space environment for this long? We will have to wait and see.

If no microbes survive, the result will not rule out the possibility of transpermia, but it certainly will un-

Our Simulated **Meteoroid**

The biomodule (patent pending), simulating a meteoroid, is compact, rugged, and simple. The outer housing is titanium, which is both strong and lightweight. The shell is machined with pockets, which reduce weight but do not diminish its strength. The inner carrier is a polymer material called Delrin®, which has an excellent history of space travel and many appealing properties, including ease of machining.

To hold the microbe and seed samples, there are 30 Delrin tubes, each three millimeters in diameter (about one tenth of an inch). Several sealing mechanisms keep the samples secure. First, end caps close the tubes. The Delrin inner carrier holds the tubes, and the carrier's top further prevents the end caps from separating during flight. Next, a silicone O-ring seal is sandwiched between the top and bottom of the carrier, adding another layer of containment.



LIFE Biomodule *Illustration: The Planetary Society*

Three titanium clips keep the two parts of the carrier under sealing pressure. These clips are reinforced by a wrap of Kapton® tape. The carrier then will be surrounded by a layer of polymer foam known as Poron® (urethane) to mitigate launch and landing shocks.

The sealed and wrapped assembly will be placed inside the titanium housing. Three integral locking lugs will hold the top and bottom of the housing together, and the lugs will be safety-wired to prevent the top from backing out. As the housing is locked shut, a wire made of indium will be squeezed between the top and bottom parts to provide a metallic seal.

The biomodule is designed so it would not leak even if both internal seals were to fail. Conversely, even if the indium wire seal were to fail, the inner carrier's O-ring and the capped tubes would still provide containment.

We are making sure LIFE complies with the planetary protection guidelines set forth by COSPAR (Committee on Space Research of the International Council for Science) to prevent accidental contamination of Mars.

We've produced prototypes of all the components, and they are undergoing testing at the time of this writing. —*BB*

derscore doubts about the hypothesis. If some of the organisms do make it to Phobos and back alive, then at a minimum we will know that some life could survive an interplanetary journey inside a rock over a three-year period. Tests on the returned organisms will give us further information about each of the types of life and effects of the space environment.

Round Trip to Phobos

In 2009, the Russian space agency will launch a sample return mission named *Phobos-Grunt* (soil) to the Martian moon Phobos. The spacecraft will land on Phobos, collect dirt and rocks from the surface, and then head back home. As it swoops by Earth in 2012, the spacecraft will drop off a capsule containing the samples gathered on Phobos. The capsule will be picked up by scientific teams who are eager to begin analysis of the first-ever samples from the surface of a planetary body beyond the Moon. *Phobos-Grunt* is the only interplanetary sample return mission in development by any country. It offers an excellent opportunity for a transpermia experiment.

Attached to the capsule for the entire 34 months of the journey will be a small, flattened cylinder containing a collection of organisms, carefully selected and sealed before launch. In its flight, the cylinder will serve as a simulated space rock, subject to the same extreme conditions as a Martian meteoroid drifting to Earth.

Carefully packed and sequestered with multiple seals, the LIFE samples will spend a full 34 months in space before being opened and examined back on Earth.

What Organisms Are We Testing?

The list of organisms to be sent on the mission is still being finalized, but it will include selections from these categories: microbes that already have been flown in near-Earth space on short missions, microbes that have been studied extensively, microbes that are resistant to environmental factors such as radiation, and well-studied plant seeds.

The organisms will be nonpathogenic (not causing disease) and will represent all three domains of life: bacteria, eukaryota, and archaea. We anticipate flying 10 species in 30 discrete samples, with each species represented in triplicate to see if results are consistent.

To give the microbes and seeds the maximum chance of surviving the trip, they will travel in a desiccated, inactive, nonreplicating state. These conditions are the least conducive to change in a microbe gene pool, so mutation in transit is extremely improbable.

Even with these very low probabilities, we will take great care with the samples and follow standard biological protocols. Our policy for containment is one of extreme caution.

Partnerships and Big Opportunity

As to project resources, in addition to an excellent science and engineering team, as well as our partnerships with Russian space science organizations, we are formalizing additional collaborations that will significantly strengthen our experiment. We'll update youon those in the near future.

This is a big undertaking for The Planetary Society and a big opportunity for science. We are facilitating a cutting-edge experimental project. We've had to move quickly to seize the opportunity, with excellent success so far. Which organisms, if any, will survive the transpermian challenge of travel from planet to planet? That's what we aim to find out.

Bruce Betts is director of projects at The Planetary Society and the LIFE experiment manager.

What's **Up?**

In the Sky— June, July, and August 2008

(There will be no "What's Up" in the July/August issue, but it will return in September/October.)

Reddish Mars and yellowish Saturn appear in the evening in the west, getting lower throughout the summer. They will appear to grow closer together until their very close conjunction on July 10. Very bright Jupiter is high overhead in the predawn sky, moving to low in the west by the end of summer. By July, Jupiter also can be seen rising in the east in the early evening. The Perseid meteor shower peaks on August 12, when viewers may see up to 60 meteors per hour from a dark site. There will be a total solar eclipse on August 1, with a partial eclipse visible throughout much of Europe and Asia. A partial lunar eclipse will be visible on August 16 throughout most of South America, Europe, Africa, Asia, and Australia.

Random Space Fact

The longest flight by dogs in space was by Veterok and Ugolyok, launched on February 22, 1966 on board *Cosmos 110* and successfully returned to Earth 22 days later.

Trivia Contest

Our January/February contest winner is William Kruzel of Chicago, Illinois. Congratulations!

The Question was: What is the oldest spacecraft still in space?

The Answer is: Vanguard 1, launched in March 1958.

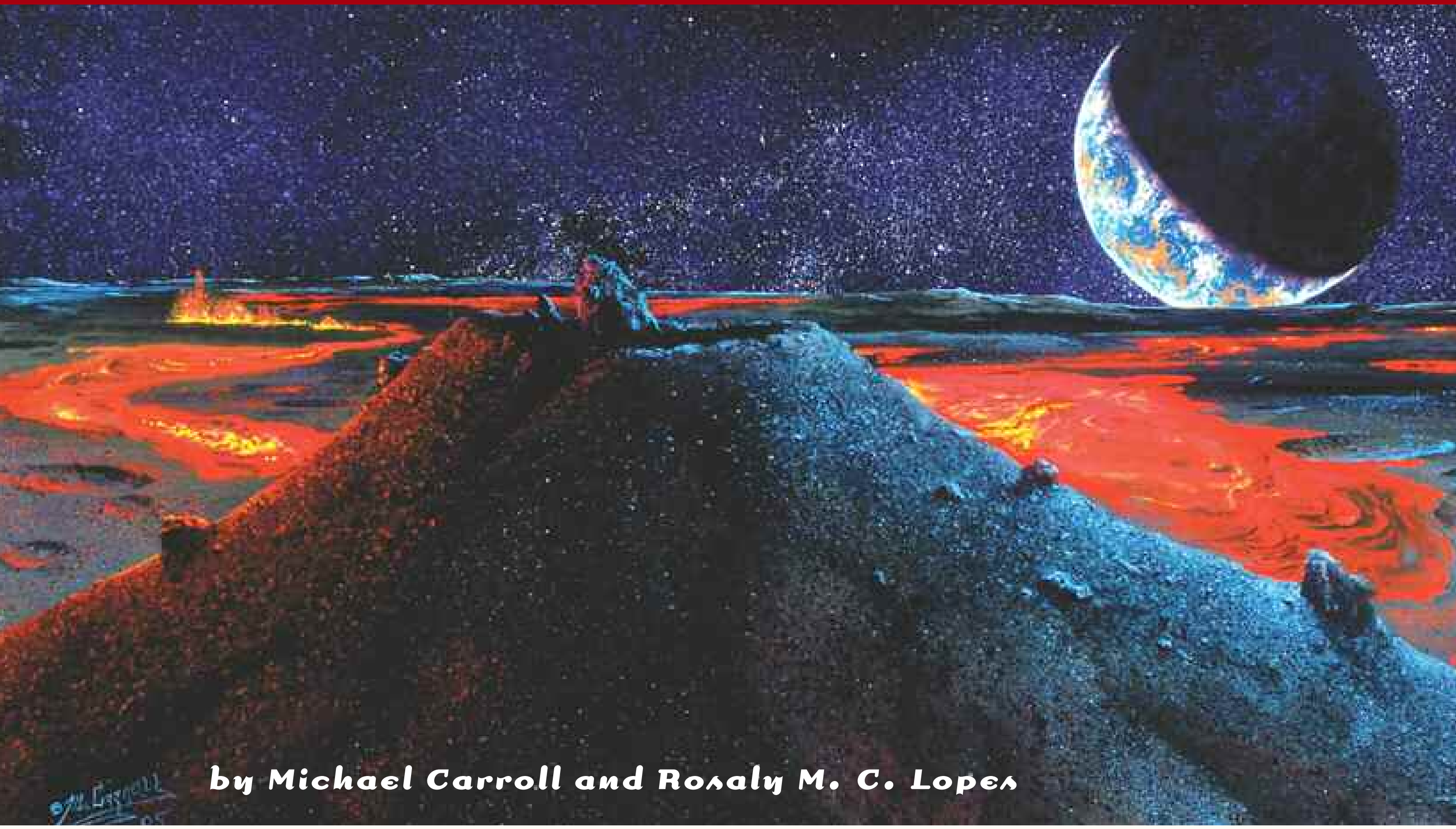
Try to win a free year's Planetary Society membership and a Planetary Radio T-shirt by answering this question:

Which astronauts have flown in space on seven separate flights?

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 September 1, 2008. 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*.

Alien Volcanoes—A



by Michael Carroll and Rosaly M. C. Lopes

Look up at the sky on a moonlit night, and you will see a face staring back. The "Man in the Moon" gazes across a quarter of a million miles, his dark features standing out against the glowing lunar highlands. People used to think the dark areas on the Moon were oceans and gave them names like the Sea of Storms and the Bay of Rainbows. The idea seems quaint today, but they were right . . . almost.

It turns out that the Moon once did have seas; its shores were washed not by water but by molten rock. All the inner planets and Earth's Moon appear to have gone through at least early volcanism. To understand the volcanoes of the terrestrial planets (so called because, like Earth, they are of rocky composition), it helps to survey the volcanoes at home.

Approximately 600 volcanoes are dormant or erupting across Earth at this moment—on its continents, islands, and ocean floor. Most of the air we breathe came from the hearts of volcanoes, as gases recycled by the hot breath of eruptions. Earth's volcanism traces to its formative years, nearly 4.5 billion years in the past. Earth was a fully mature planet with a dense core nested within less dense outer layers. The process of "settling out" layers, called *differentiation*, happens relatively quickly in a planet's evolution.

Today, Earth's structure is arranged in much the same way as it was back then. At the center of our world sits a core of iron and nickel nearly the size of Mars. Near the core's edge, lower pressure allows the nickel-iron to liquefy. Outside the core lies the mantle, dense hot rock rich in metals. This region is very important to volcanism, as the heat there is trying to push out into space. A crust some tens of miles thick tops the mantle. It is thickest under the continents, where its 40-kilometer (25-mile) depth upholds continental slabs—called *plates*—like ice floating on a lake. Many of the world's volcanoes and other geothermal hot spots lie along the boundaries between plates.

But heat beneath the crust is only half of our story. Radioactive elements within our planet add to the internal energy. In nature's attempt to bring a cosmic balance to the planet, heat must escape, and its escape often takes place through the pressure valves of volcanoes.

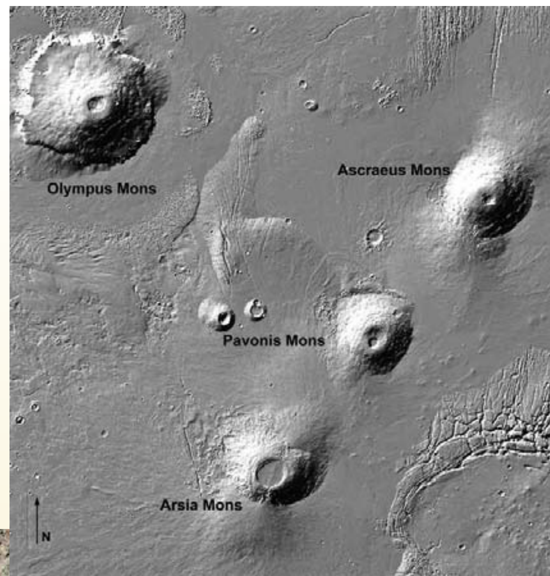
Although they can be destructive, Earth's volcanoes recycle biologically important materials, infusing our atmosphere with carbon dioxide and water vapor and recharging the minerals in soils. Without volcanoes, Earth's life-sustaining environment would soon be starved of critical minerals and gases. On the nearby terrestrial worlds, we see familiar processes and structures, but the role of volcanoes there is alien indeed.

The Moon and Mercury: Dead Worlds?

Volcanism has played a dramatic part in the history of all the terrestrial planets (Mercury, Venus, Earth, and Mars). Close to home, our Moon's volcanoes probably fell silent over a billion years ago. Extensive lava flows probably began just after the early solar system's heaviest rain of asteroids, about

On January 14, 2008, MESSENGER *took this picture of Mercury from 11,590 kilometers (7,240 miles) above the surface. The large crater at lower left measures about 230 kilometers (140 miles) in diameter and has a prominent crater (about 85 kilometers, or 53 miles, across) nestled inside, south of its center. Both of these craters are filled with a material that appears to have started out in a relatively fluid form. The larger crater is filled almost to its rim with a smooth plains material that scientists believe is volcanic in origin.*
Image: NASA/Johns Hopkins University Applied Physics Laboratory (APL)/Carnegie Institution of Washington

Left: As a young Earth shines in the distance, glowing magma floods the lunar surface. Eventually, the cooled, darkened remains of this red-hot lava will form the vast dark expanses known to us as the lunar seas, or maria, *contrasting with the bright regions called highlands, or* terrae. *On the side of the Moon facing Earth, these dark and light terrains form the placid-looking features we know today as the "Man in the Moon."*
All paintings by Michael Carroll

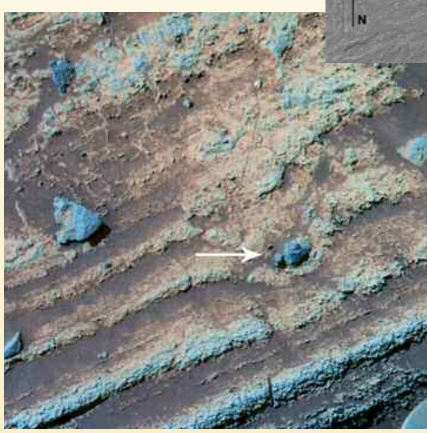


Mars' Olympus Mons is shown here with its neighbors: Arsia Mons, Pavonis Mons, and Ascraeus Mons. This is a shaded relief image derived from data returned by the Mars Orbiter Laser Altimeter (MOLA), which flew on board Mars Global Surveyor. *This image covers an area 300 kilometers (about 200 miles) high. Image: NASA*

3.9 billion years ago. (Evidence of earlier volcanic flows on the Moon was largely obliterated by impacts.) Along with *Apollo* and *Luna* surface samples, mineral surveys taken from orbiting spacecraft such as *Clementine*, *Lunar Prospector*, and *Smart 1* reveal a peak in volcanic activity during a period from 3.6 to just over 3 billion years ago.

Because of their small size, both the Moon and the planet Mercury cooled more quickly than did Earth, Mars, and Venus. Today a thick basalt crust on both smaller worlds imprisons any fluid magma that might simmer inside.

At about the time the Moon was geologically dying, Mercury probably was in its last throes of volcanic activity. Impact scars predominate across the 45 percent of the surface imaged by *Mariner 10* in the mid-1970s, camouflaging any record of volcanism. Recent images of other regions from the *MESSENGER* spacecraft, however, reveal more. After the first of three flybys that will lead to an orbit in 2011, researchers think they see clear evidence of volcanism. "We have seen extensive smooth plains deposits on the new ground covered by *MESSENGER*," says project scientist Mark Robinson. "The floor of Caloris [basin, one of the largest craters in the solar system] is covered in such a way, and there are many smaller patches of smooth plains deposits in the southern hemisphere. The large extent of polar smooth plains known as Borealis Planitia extends into the newly explored region. There is little doubt the majority of smooth plains are indeed volcanic in nature." More detailed images may reveal specific volcanic sources.



Spirit *has discovered evidence of an ancient volcanic explosion in Mars' Gusev crater. The arrow points to a 4-centimeter (1.5-inch) feature scientists interpret as a "bomb sag." On Earth, bomb sags occur in volcanic explosions when rocks ejected skyward fall into soft deposits, which deform as the rocks land.*
Image: NASA/JPL/United States Geological Survey/Cornell University

Mars—Home to the Solar System's Largest Volcano

Ever since *Mariner 9* dropped into orbit around Mars in 1971, the Red Planet has been famous for hosting the largest volcano in the solar system. Olympus Mons towers

Magellan's radar peered underneath Venus' opaque, toxic atmosphere and found the most varied assortment of volcanic features on any of the terrestrial worlds in our solar system. Scientists gave these weird forms informal names like "ticks," "anemones," "arachnoids," and "pancakes." In this view, two large pancake volcanoes loom in the distance. On Venus, these slightly domed or flat-topped features are roundish when viewed from overhead, averaging 25 kilometers (15 miles) in diameter and close to 800 meters (2,600 feet) in height.

some 24 kilometers (almost 15 miles) above the Martian plains, nearly three times the height of Mount Everest.

Olympus Mons joins several volcanic behemoths on a massive dome called the Tharsis bulge. Tharsis spreads 4,000 kilometers (2,500 miles) across and is capped by dozens of volcanic structures ranging in size from small cinder cones to volcanoes in the class of Olympus Mons itself.

Some of the youngest lava flows on the planet drape the Elysium plateau on Mars' opposite hemisphere. Here, outflow channels score the flanks of many volcanoes. In the past, geothermal sources may have melted frozen groundwater, triggering flash floods.

The Mars Exploration Rovers, *Spirit* and *Opportunity*, have provided surface evidence of Martian volcanism. *Spirit*'s landing site inside the Connecticut-sized Gusev crater has yielded extensive geochemical evidence of volcanic activity. In the Columbia Hills, *Spirit* focused its instruments on samples containing olivine, pyroxene, and magnetite, all of which are common in volcanic rock. Columbia Hills layers resemble rock formed by volcanic ash fall or ash flow.

Further evidence of recent volcanism comes from the rare Martian meteorites known as SNCs (named after the first three areas—Shergotty, India; Nhahkla, Egypt; and Chassigny, France—where this type of meteorite was found). Some samples of SNCs were found to have crystallized out of lavas as recently as 170 million years ago. Their composition and structure show that the meteorites were born in magma more than seven kilometers (four miles) below the Martian surface, where they cooled slowly and then were erupted. These chunks of basaltic lava came to the surface in geologically modern times, and later they were blasted aloft by a meteorite impact and drifted to Earth.

To some researchers, the best evidence of active Mars volcanism comes from Earth-based infrared telescopes. The telescope at Cerro Pachon, Chile, and the Keck II telescope on the summit of Hawaii's Mauna Kea have detected small amounts of methane in the Martian atmosphere. In the Martian environment, methane is an unstable gas, lasting only a few centuries. Something is replenishing methane continually, and a common source of the gas is volcanism. The European Space Agency's *Mars Express* recently confirmed the methane detection.

Venus—Planet Volcano

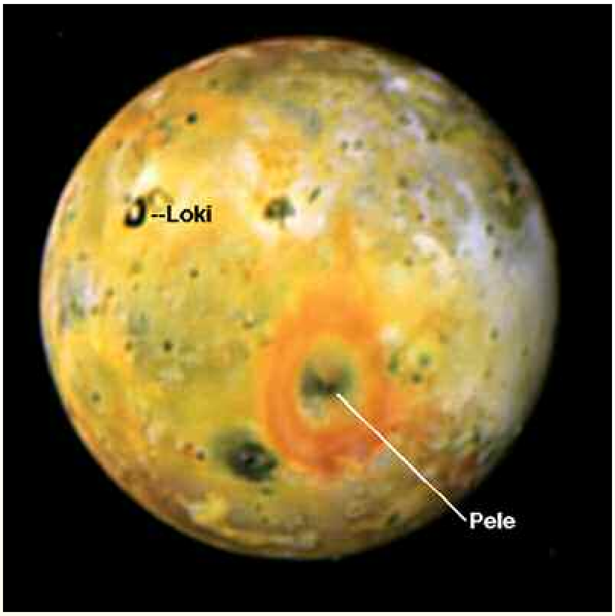
Venus has a wider variety of volcanic features per square mile than any other real estate in the solar system. Venus has a surface temperature simmering at more than 500 degrees Celsius (900 degrees Fahrenheit) and an air pressure 90 times that of Earth at sea level, making Venusian volcanoes resemble those on Earth's ocean floor. Venus' plains are spattered with hundreds of thousands of small shield volcanoes. Some Venus shields have grown to titanic size, towering nearly 8,000 meters (26,000 feet) into the sulfuric acid haze.

Scientists have given the Venusian menagerie of eruptive sites a wild set of names, including "arachnoids," "ticks," "anemones," and even "pancakes." The roughly disk-shaped pancake domes average 25 kilometers (15 miles) in diameter and nearly 800 meters (2,600 feet) in height. More than 150 have been identified. Some pancake domes may degrade into ticks. Ridges of a tick radiate outward from a dome and terminate in sharp ends, giving the appearance of the legs of this nasty parasite.

Anemones are yet another member of the Venusian volcano "club." Overlapping petals of lava extend outward in flower-like patterns capped by elongated vents. A related class of features are the arachnoids: domes surrounded by a cobweb of fractures. Russian scientists first saw these bizarre features in *Venera* radar images. The weblike lines radiating from the arachnoids may be cracks forced open by upwelling magma. Given the planet's pristinely preserved features and some telltale atmospheric evidence, many scientists suspect there could be active volcanism on Venus today.

Radioactive minerals and heat from initial planetary formation fire the erupting mountains on terrestrial planets, but volcanoes of the outer solar system are driven by far more alien forces. The "poster child" of alien volcanoes is Io.

As we move farther outward, the look and character of solar system volcanoes change—starting at Europa, Jupiter's fourth-largest satellite. This water ice coated world bears evidence of cryovolcanism, a process in which volatiles such as water, ammonia, or methane take the place of hot magma. Images from Voyager *and* Galileo *show ridges, cracks, and stains that may be the result of tidal friction from the moon's warm interior causing liquid to erupt. Here a lake of "cryolava" forms on Europa's frozen surface.*



Jupiter's moon Io is a tortured world, pushed and pulled by the gravity of its giant parent and larger siblings Ganymede, Callisto, and Europa. Tidal friction generates a great deal of internal heat within Io, driving eruptions onto the tiny moon's surface—a place that may contain more active volcanoes than all the land areas on Earth. Two of Io's major volcanoes, Loki and Pele, are visible in this Galileo *image, taken in December 2000.* Image: NASA/JPL

Io—The Pizza Moon

Jupiter's tiny moon Io is a world tortured by gravity and soaked in radiation. Sulfurous plumes soar hundreds of kilometers into the airless sky, painting the surface in the bright colors of a rotten pizza. The volcanoes that tear at the Ionian landscape are the most powerful in our solar system. Io's small surface—equal to the North and South American continents combined—may contain more active volcanoes than all the land areas on Earth.

The key to Io's violent activity is a cosmic "taffy pull" called *tidal friction*. The interior of Io is constantly pushed and pulled by gravity from Jupiter and the other massive Galilean satellites. The surface of Io rises and falls by some 50 meters (150 feet) each day. The forced movement generates internal heat, and that heat comes out as eruptions.

Io is dominated by lava lakes such as Loki, a volcanic crater—or *caldera*—some 200 kilometers (125 miles) across. Within its dark, viscous liquid stands an island covered by frozen sulfur dioxide the size of Rhode Island. Other prominent volcanic features include the Amirani lava flows, which are 300 kilometers long (nearly 200 miles), and the Pillanian eruptions, which eject the highest plumes seen anywhere in the solar system—up to 500 kilometers (300 miles) in altitude.

Ice Worlds—Cryovolcanism in the Outer Solar System

The volcanoes of the inner solar system and on Io have hearts of molten rock, but such conventional lavas are not the only prescription for volcanic eruptions. Exotic magmas—superchilled water mixed with ammonia, methanol, and other strange brews—may power eruptions we see in the outer solar system. This alien phenomenon is known as *cryovolcanism*.

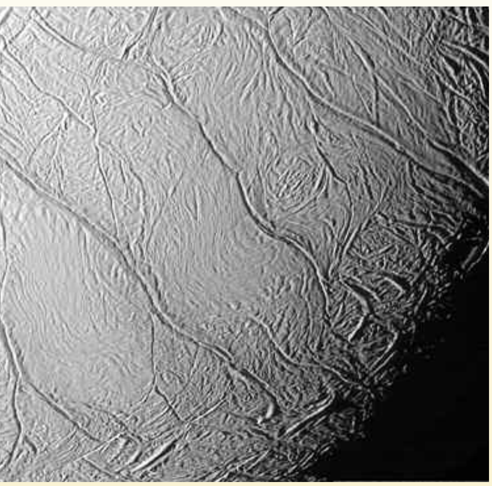
Europa. The surface of Jupiter's fourth-largest moon, Europa, glistens with a coating of nearly pure water ice that may cloak an ocean 100 kilometers (60 miles) deep. If Europa does host such an alien sea, its liquids may make their way to the surface. Such a journey would end violently. Images taken by both of the *Voyager* spacecraft and by the *Galileo* orbiter reveal ridged ice surfaces that have fractured, shifted, and rotated before freezing solid again. Also supporting the possibility of a Europan ocean, the moon generates a magnetic field that is consistent with liquid saltwater. Though more subdued than on its sibling Io, tidal friction warms Europa's interior. Earth-like volcanism may occur on Europa's "sea floor," at the interface of the silicate core and the water ocean.

Dozens of sites indicate past Europan eruptions. Material stains the ice from beneath the surface, and "cryolavas" appear to pool on the surface from subsurface sources. Domes and collapse features may result from undermining plumes of hot water or warm ice.

Cryovolcanism may have left its mark on other icy bodies as well. Like Europa, Ganymede (the largest moon in the solar system) generates its own magnetic field, similar to that of an ocean, and the moon's caldera-like features and bright linear zones look like they could be scars of cryovolcanism. Long-dead cryovolcanic sources may also explain the remarkable morphology of Uranus' tiny moon Miranda.

Titan. Saturn's largest moon has the second-densest atmosphere of any of the solid worlds, second only to Venus. Researchers long suspected that Titan's fog hid volcanic activity. The moon, with a diameter of 5,150 kilometers (3,200 miles), has a density suggesting that plenty of gravitational and radiogenic energy is available for central heating. Its eccentric orbit around Saturn adds energy in

Some researchers predicted that the surface of Saturn's moon Titan would display cryovolcanic flows and, perhaps, domes similar to Venus' pancakes.* Cassini *results suggest that cryovolcanism has indeed been a significant geologic process on Titan and may be a major contributor to its atmospheric methane.



Cassini *images have surprised us with plumes (image at right) of liquid water and organic material emanating from Saturn's tiny moon Enceladus. What's more surprising is that the plumes appear to shoot out from an array of fissures (upper left), nicknamed "tiger stripes," which are centered on the moon's south pole. Researchers think Enceladus' high level of activity might be triggered by tidal forces, given that the moon's orbital eccentricity is similar to Io's.* *Images: NASA/JPL/Space Science Institute*

the form of tidal friction. There also is evidence of volcanism in the air: as on Mars, the thick atmosphere of Titan has methane that is being replenished.

Aboard the Saturn-orbiting *Cassini* spacecraft, Synthetic Aperture Radar (SAR) imaged a circular formation interpreted to be a cryovolcanic dome, later named Ganesa (after the Hindu god of good fortune). Ganesa, 180 kilometers (110 miles) in diameter, is similar in form to the pancake domes of Venus. Some flow features on Titan appear to emanate from elongated depressions that resemble lava channels.

The European Space Agency's *Huygens* probe, which landed on Titan on January 14, 2005, detected an isotope of argon (40Ar) in Titan's atmosphere. The presence of this gas means that the atmosphere must be in contact with subsurface potassium. It is likely that most of the potassium-bearing material lies within silicate rocks in Titan's core. Cryovolcanism is one process by which this material might be brought to the surface.

Enceladus. One of the highlights of the *Cassini-Huygens* Saturn mission has been the discovery of remarkable geysers on Enceladus. At a scant 504 kilometers (313 miles) across, the ice moon was thought to be too small to host any geologic activity. Nevertheless, *Cassini* images show plumes erupting from a series of complex fissures called "tiger stripes." These cracks cross a circular province

The radar images reveal a prominent circular feature, interpreted to be a cryovolcanic dome, which scientists have named Ganesa (after the Hindu god of good fortune). Ganesa is roughly 180 kilometers (about 110 miles) in diameter, making it larger than the pancake domes on Venus.

centered on Enceladus' south pole.

Cassini flew within 168 kilometers (104 miles) of the surface on July 14, 2005, passing directly through an extended plume of material. It detected water vapor, carbon dioxide, methane, trace amounts of acetylene and propane, and possibly carbon monoxide and molecular nitrogen.

The power source behind the cryovolcanic outbursts is a baffling question. Tidal heating does not seem to be strong enough at Enceladus to forge such eruptions. Researchers are testing models involving the heat-generating friction of ice faults and heat that might originate in clathrates, dense compounds of ice that may be present in the upper crust of Enceladus. Based on its strange brew of liquid water and organic material, astrobiologists have added tiny Enceladus to the list of sites where we may find life beyond Earth.

Triton. With a diminutive diameter of 2,706 kilometers (1,681 miles) and a surface temperature of only 38 kelvins (–235 degrees Celsius or –390 degrees Fahrenheit), Neptune's moon Triton may seem an unlikely place for volcanic activity. When *Voyager 2* flew above Triton's south pole in the summer of 1989, however, its cameras spotted several tall plumes reaching 8 kilometers (5 miles) above the surface and leaving trails 150 kilometers (about 90 miles) long.

Similar geysers have draped more than 100 dark deposits across the moon's frozen landscape. Scientists are still unsure of the specific processes involved in Triton's unique cryovolcanism, but a likely scenario involves sunlight penetrating a transparent layer of nitrogen ice. Inside the ice, a solid-state greenhouse effect occurs, causing the interior ice to become gaseous. The expanding gas explodes into the near-vacuum of Triton's environment. Whatever the explanation ultimately proves to be, Triton joins ranks with sulfurous Io, watery Enceladus, and methane-driven Titan as its own bizarre variation on the volcanic activity we see throughout our solar system.

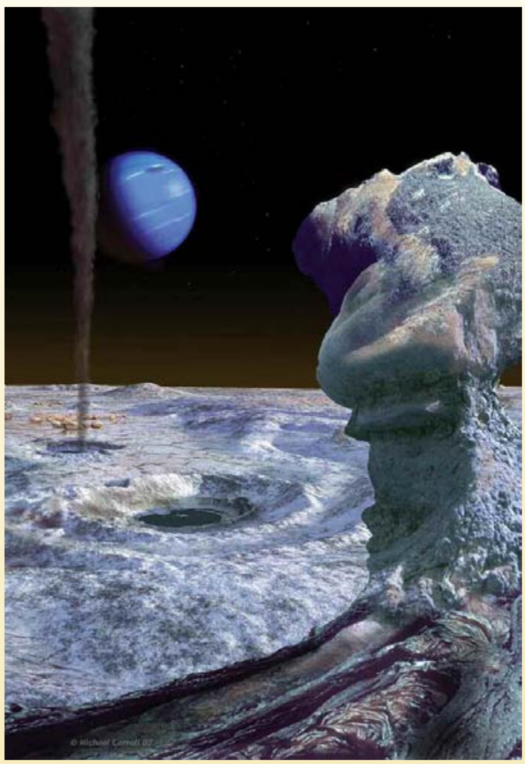
More to Explore

From Pompeii to St. Helens, volcanoes have been uncomfortable companions to humankind. They enrich Earth's environment, they inspire songs, influence traditions, and infuse our literature. Tolkein gave us Mount Doom. Verne sent his journeying explorers down the throat of Iceland's Mount Snaefells. More recently, Jimmy Buffett penned the words, "I don't know where I'm a-gonna go when the volcano blows."

People have long been fascinated and threatened by volcanoes. The discovery of eruptions from Mercury to the outermost moons promises that volcanoes will continue to inform and inspire humankind.

Michael Carroll is a science writer and artist specializing in astronomical imagery. Rosaly M. C. Lopes is an expert on terrestrial and planetary volcanism, a principal scientist at NASA's Jet Propulsion Laboratory, and the investigation scientist for the Cassini *radar instrument.*

Paintings and portions of this article are excerpted from the new book *Alien Volcanoes* by Michael Carroll and Rosaly M. C. Lopes, Johns Hopkins University Press, May 2008.



Voyager 2 *flew past the south pole of Neptune's moon Triton on August 25, 1989, taking stereo images that showed two dark, tall plumes reaching about 8 kilometers (5 miles) above the surface. Other images of Triton's southern polar region revealed more than 100 dark, streaky deposits, presumably a result of other plumes. We don't know how widespread plume activity is on Triton, because the northern polar regions were in darkness during the* Voyager *flyby. At lower latitudes, however, images showed a peculiar terrain with flow-like features, probably resulting from cryovolcanic flooding of older topography.*

Members' Dialogue

The Road to Mars

Robert Farquhar's interesting opinion piece "On the Road to Mars" [see the March/April 2008 issue of *The Planetary Report*] exposes a very troubling mind-set among Americans (though I reside in Australia, I am one). He writes, "If NASA's lunar base strategy is allowed to proceed, human missions to Mars will be delayed by at least 50 years."

Regardless of the merits of his argument, for him to suggest that NASA's decisions will dictate human activity in space over the next half century ignores the fact that other nations, most notably China, are rapidly developing space capabilities. Given that the United States went from almost scratch to a Moon landing in less than 10 years and that NASA is being starved of funds due to federal budget problems, Americans should not assume that theirs is the only nation that will be able to put humans on Mars within 50 years. While the United States spends a huge amount of national treasure on things like Iraq, other nations are investing in nonmilitary technology, like space exploration. Credible observers think that China could match U.S. space capabilities within the next decade.

We need to start thinking of issues like Mars exploration in international terms—though our current policy makes full cooperation with China complicated due to fears of technology leaks. Mr. Farquhar's article reveals a mind-set that must be reconsidered regarding space exploration.
—RADE THOMAS MUSULIN,
Sydney, Australia

Hans Buhrer expresses my sentiments on Mars exploration very well [see "Members' Dialogue" in the March/April 2008 issue]. I have written you about four times about this, and it is the reason I dropped my membership. Mr. Farquhar is obviously of the opposite opinion—that we have to send humans to Mars' surface. May I paraphrase him slightly? "Exploration of the Moon's [substitute Mars'?] surface, if it is a goal worth pursuing, can be accomplished more efficiently by robotic spacecraft, and at a much lower cost."
—EUGENE KOSSO,
Gualala, California

In *The Planetary Report*, there are many pictures and discussions of astronauts walking around on Mars. I never see any mention or discussion as to how they would be protected from the lethal gamma rays that would bombard them as soon as they left Earth's atmosphere. Any shielding against the rays would be far too heavy. During the round trip to Mars, this exposure would cause all kinds of damage such as cancer and cataracts, and it would, at best, shorten the lives of the astronauts.

The Planetary Report ignores this issue, even though it is of critical importance. In fact, the whole concept of humans and Mars has to address this—all the rest of the discussion is relatively trivial.
—DENIS EDKINS,
Peabody, Massachusetts

Humans Versus Robots

In the debate concerning human versus robotic exploration, the notion that space funding is a fixed sum of money that cannot be expanded may be a self-fulfilling prophecy. While human and robotic exploration may have different purposes—the former ultimately aimed at expanding human presence in space, and the latter seeking scientific discovery—it probably is clear to most people that both types of exploration are not only valid but also complementary.

Proponents of both sides of the issue are spending much time and energy finding reasons and arguments to favor one type of spaceflight over the other. This may lead to confusion and frustration in our politicians, who must sort through these internecine fights in order to appropriate funds to space agencies. I wonder if it would not be more productive for each side to work together to "grow the pie" rather than to try to get a bigger share of a shrinking pie. Both camps should be convincing funding agencies that all space exploration is a valuable investment for society.

The Planetary Society, with the support of all its members, is ideally placed to find synergies between robotic and human programs and to argue forcefully to the government that both fields of space exploration are worthy of increased funding.
—SIMON DELAGRAVE,
Stoneham, Massachusetts

Life in the Universe

Members who want to follow up on Tobias Owen's answer to Trace Bissinger's question about water-based life [March/April 2008] should have a look at a 2007 publication of the National Research Council titled "The Limits of Organic Life in Planetary Systems." It is available as a free PDF at *http://www.nap.edu/catalog.php?record_id=11919*.

The report addresses topics such as the chemistry of carbon-based life, the boundaries of life, the origin of life, and alternatives to water as a solvent. Those who speak Organic Chemistry will, I'm sure, get even more out of this publication than I did, but it can provide any reader with lots to think about regarding the nature of life in the universe.
—KEN PERKINS,
Belmont, California

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or e-mail: *tps.des@planetary.org*

World Watch

Low Earth Orbit—What has been happening at the International Space Station (ISS) is a magnificent story of engineering accomplishment and international cooperation. It is also largely an unsung story, one that has not captured much public interest.

From February to April this year, the American space shuttles *Atlantis* and *Endeavour* docked with the ISS and delivered the European *Columbus*, the first element of the Japanese *Kibo*, and the Canadian *Dextre* arm. The Russian *Progress* and European *Jules Verne* cargo carriers arrived, and the Russian Soyuz carried Korea's first astronaut to join the crew.

Astronauts also carried out some complicated, stressful, and exciting spacewalks to do construction and maintenance work on and around the vehicles. In many ways, these operations were every bit as exciting and dramatic as anything that humans have done in space.

This sort of cooperation among spacefaring nations serves, in my opinion, as a model for future great endeavors. Each country involved is making enormous national advances while negotiating complex international interactions. Planetary Society cofounder Bruce Murray used to point out that *Apollo* was a reminder of what one nation can do, so imagine what a world of nations could do.

Why is this a largely unsung story? Perhaps because the purpose of the ISS is hard to explain and understand. If these activities on and around the ISS were leading to Mars the way that the *Mercury* and *Gemini* flights led to the Moon, the media and the public might be following this story with more enthusiasm. The United States explicitly rejected the ISS as a step toward Mars, and the other international partners do not yet have such a pathway for human exploration.

It didn't have to be this way. In the late 1980s, as the space station was being defined, The Planetary Society testified to Congress and criticized the existing plan, calling for "A Space Station Worth the Cost." We urged that the station be devoted to preparing humans to make the long interplanetary voyage to Mars, but, unfortunately, the requirements for that objective were dropped.

We do not want to lose the way to Mars again. With a new U.S. administration to be elected soon, we have a responsibility and an opportunity to again point the way toward that destination. The Planetary Society is rising to the occasion with workshops, town hall–style meetings, and advocacy documents for our political leaders and space policy decision makers around the world. Please help our efforts and visit *planetary.org/programs/projects/space_advocacy/*.

Stanford University—As a first step toward influencing the next administration's space policy, The Planetary Society joined with the Stanford University Department of Aeronautics and Astronautics to convene a February workshop, "Examining the Vision: Balancing Science and Exploration." Over two days, we addressed a wide range of issues that could influence the course of human spaceflight, including Moon and Mars exploration, alternative destinations in space, launch vehicles, robotic and human roles, international cooperation, and Earth science objectives. Scott Hubbard of Stanford and former astronaut Kathy Thornton co-led the workshop. Wesley T. Huntress Jr. and I served on the organizing committee, and 50 space experts participated.

The participants offered a political rationale for human spaceflight based on international cooperation and the popular goal of Mars exploration. The budget tensions and problems resulting from underfunding of the Vision for Space Exploration also were discussed. Creating a stronger political and popular framework for human spaceflight is critical, we believe, for dealing with the budget problems.

Workshop participants agreed to these five statements:

- It is time to go beyond low Earth orbit with people as explorers. The purpose of sustained human exploration is to go to Mars and beyond. The significance of the Moon and other intermediate destinations is to serve as steppingstones on the path to that goal.
- Bringing together scientists, astronauts, engineers, policy analysts, and industry executives in a single conversation created an environment in which insights across traditional boundaries occurred.
- Human space exploration is undertaken to serve national and international interests. It provides important opportunities to advance science, but science is not the primary motivation.
- Sustained human exploration requires enhanced international collaboration and offers the United States an opportunity for global leadership.
- NASA has not received the budget increases to support the mandated human exploration program, as well as other vital parts of the NASA portfolio, including space science, aeronautics, technology requirements, and especially Earth observations, given the urgency of global climate change.

To maintain our momentum from the workshop, The Planetary Society is organizing a series of Town Hall meetings (see page 22) to engage the public in this discussion. We'll take what we hear in these discussions to produce a roadmap for space exploration—addressing robotic missions, human spaceflight, and international partnerships—that we will use to influence the next U.S. administration and Congress.

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

Questions and Answers

We received the following questions in response to Amy Simon-Miller's article "Global Upheaval on Jupiter: Change Is Good!" which appeared in our January/February 2008 issue. Here the author provides some brief answers.
—Editor

The incidence of light from the Sun and its reflection to us can never be exactly perpendicular, so is it ever possible for us on Earth to see a perfectly full Moon?
—Jamie Matthews
Denton, Texas

I like this sort of question because it makes a person think! With the Sun and Moon exactly opposite each other, you would at first think the full Moon is invisible. But read on. One way to work toward a solution is to ask what the situation would look like to an observer on the Moon. Assuming that the Moon and Earth are perfect spheres and ignoring our atmosphere, when the Sun, Earth, and Moon are all in a line, you could not see the Sun from the Moon because Earth, subtending about two degrees in the sky, would hide the one-half-degree Sun. The Moon would have only starlight and would reflect no sunlight. Thus, to see the Moon, an observer on Earth would need either to be in a very dark place or to have a sensitive instrument. Even without those conditions, however, a persistent terrestrial observer could make out the Moon's shape by watching as it occulted stars.

Now let's look at the real situation: during a lunar eclipse, our observer on the Moon would see the Earth as a ring of red light refracted through Earth's atmosphere. That's why, with the Sun, Earth, and Moon aligned as they really are, we see the Moon as dim and reddish during lunar eclipses. In principle, a perfect alignment could show us a perfectly fully eclipsed Moon. That's probably a very rare event, but that does not matter for this thought experiment.
—JAMES. D. BURKE,
Technical Editor

After looking at the picture of Jupiter on your recent cover, as well as other, earlier photos of the planet, I have a question. It seems that the fluid dynamics of the various elements and the temperatures of the planet's atmosphere make the whole scene take on a thick and heavy soup-like physical quality—never mixing to a homogeneous state. Would it be a kind of closed-loop situation, where mixing goes on but ultimately breaks down, only to start all over again with the separation of the molecules into their various elements?

Just what is at work to keep all this from ultimately and thoroughly mixing?
—Mike Martinez
Inver Grove Heights, Minnesota

Although the streaming colors of Jupiter's atmosphere make it look like the constituents stay separated, Jupiter's atmosphere is fairly well mixed. The majority of the atmo-

Factinos

Cassini has returned evidence of an underground ocean of water and ammonia on Saturn's moon Titan. "With its organic dunes, lakes, channels and mountains, Titan has one of the most varied, active, and Earth-like surfaces in the solar system," said Ralph Lorenz of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. "Now we see changes in the way Titan rotates, giving us a window into Titan's interior beneath the surface." Lorenz is the lead author of a report on these findings that appeared in the March 21, 2008 issue of *Science*.

The team used *Cassini*'s Synthetic Aperture Radar to collect imaging data during 19 separate passes over Titan between October 2005 and May 2007. Using data from the radar's early observations, the scientists and radar engineers established the locations of 50 unique landmarks on Titan's surface. They then searched for these same lakes, canyons, and mountains in the data returned by *Cassini* in its later flybys of Titan. They found that prominent surface features had shifted from their expected positions by as much as 19 miles. A systematic displacement of surface features would be difficult to explain unless the moon's icy crust is decoupled from its core by an internal ocean, making it easier for the crust to move.

"We believe that about 62 miles beneath the ice and organic-rich surface is an internal ocean of liquid water mixed with ammonia," said JPL's Bryan Stiles, a contributing author of the *Science* paper.
—from Johns Hopkins Applied Physics Laboratory

New heat maps of the surface of Saturn's moon Enceladus show higher temperatures than previously known in the south polar region, with hot tracks running the length of the giant fissures there (see page 16 for more information on these features). *Cassini* "tasted" and sampled a surprising organic brew erupting in geyser-like fashion from Enceladus during a close flyby on March 12, 2008. Scientists are amazed that this tiny moon is so active, "hot," and brimming with water vapor and organic chemicals.

"A completely unexpected surprise is that the chemistry of Enceladus—what's coming out from inside—resembles sphere is hydrogen, with small amounts of helium and heavier elements. The conditions are correct also to have molecules like water and ammonia, which will freeze out and form clouds at the proper temperatures and altitudes. The majority of what we see in visible wavelength images is those clouds. Because Jupiter's strong winds channel the clouds into latitude bands, we see obvious wind shear, vortices, and eddies in the cloud formations—just as we would see in any fluid dynamics experiment. This does not require a very dense fluid to be true, and the pressures at these altitudes are similar to the air pressure at the surface of Earth.

With regard to vertical motion, we see obvious convection (such as thunderstorms) that lofts water and ammonia ice higher into the atmosphere. The water and ammonia would then rain out again and fall again. In general, there is a net balance between rising and sinking air in Jupiter's atmosphere, though this also acts to mix the atmosphere in the weather layers.

After looking at your January/February 2008 issue, I got to thinking about the pictures of the Great Red Spot and the eddies near it. In a stream, those eddies might be caused by rocks. We are told that Jupiter has no "surface," but is this written in stone or merely presumed? Might some deep solid feature account for the Great Red Spot's stability, and for the eddy-like features?
—Jon Glazer
Horse Creek, California

We know that Jupiter has no surface based on its overall size and density, along with gravity measurements made by spacecraft missions. There is likely a small, rocky core, but it is covered by an extremely thick atmosphere.

Rocks do cause eddies in streams, and islands will disrupt wind flow in a similar way. Anything that blocks fluid flow, however, will do the same thing. In this case, the Great Red Spot blocks the wind streams, causing them to flow around it and generating the downstream eddies. The Great Red Spot is not solid, though, because unlike a feature tied to a surface, it drifts in latitude and longitude, and it even changes color and size.

In her very informative article, Amy Simon-Miller says, "on Jupiter, we know there is no underlying planetary crust." That would seem to mean that Jupiter is nothing but a mass of gases. I understood that it was supposed to have a relatively solid core. In that case, it would appear that it has a crust.

Can you please straighten me out on that?
—Robin Hess
Vashon, Washington

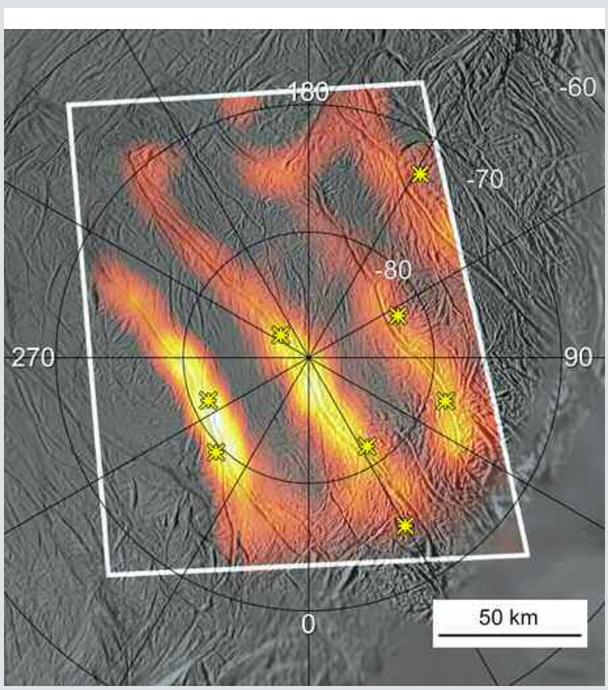
We think Jupiter has a small, rocky core no bigger than a few times the mass of Earth (we hope the *Juno* mission will give us a more exact number!). This is very small, relative to the planet's mass. Above the core, the hydrogen atmosphere is so compressed that the hydrogen acts like a metal in which all the atoms share their electrons. This is not solid, though the atmospheric pressure is millions of times larger than the air pressure at Earth's surface.

Moving outward in radius, Jupiter's hydrogen becomes less and less dense. There is not a "crust" or lithosphere as on a terrestrial planet, just a very dense atmosphere. Note that the *Galileo* mission's atmospheric probe was crushed at pressures roughly 20 times the normal Earth atmospheric pressure, and this was only a small fraction of the way into Jupiter's atmosphere!
—AMY SIMON-MILLER,
Goddard Space Flight Center

that of a comet," said Hunter Waite of the Southwest Research Institute in San Antonio. "Enceladus' activity is powered by internal heat while comet activity is powered by sunlight. Enceladus' brew is like carbonated water with an essence of natural gas," said Waite.

The Ion and Neutral Mass Spectrometer recorded a much higher density of volatile gases, water vapor, carbon dioxide, and carbon monoxide, as well as organic materials some 20 times more dense than expected. This dramatic increase in density was evident as the spacecraft flew over the area of the plumes.

"These spectacular new data will really help us understand what powers the geysers. The surprisingly high temperatures make it more likely that there's liquid water not far below the surface," said *Cassini* team member John Spencer of the Southwest Research Institute in Boulder, Colorado.
—from the Jet Propulsion Laboratory



Heat radiating from fractures 150 kilometers (95 miles) long is visible in this best-yet heat map of the active south polar region of Saturn's moon Enceladus. The warmest parts of these "tiger stripe" fractures tend to lie on locations of the plume jets identified in earlier images and represented here with yellow stars. The measurements were obtained by* Cassini*'s Composite Infrared Spectrometer during its close flyby of the moon on March 12, 2008.
Map: NASA/JPL/ Space Science Institute

For more detail on these stories, visit *planetary.org*.

Society News

Planetary Radio Is on the Air with Bill Nye the Science Guy®

Planetary Radio now features a special segment from Planetary Society Vice President Bill Nye the Science Guy, one of America's most popular and entertaining educators. A grant from the Kenneth T. and Eileen L. Norris Foundation to The Planetary Society provides funding for the two-minute commentaries, in which Nye will touch on wide-ranging topics, such as rockets, rovers, and rendezvous with planets.

The Planetary Society's audio coverage of space exploration continues to expand at lightspeed. More than 120 public radio stations have added the half-hour weekly program to their schedules, with more picking it up every week. Listeners also catch the series directly from Earth orbit via XM Satellite Radio or download the shows from our website, *planetary.org/radio*.

In the last few weeks, Planetary Radio has checked in with the principal investigator of the Mars Exploration Rovers, Steve Squyres; planetary scientist John Spencer, who took us on a tour of Enceladus' geysers; *Pioneer* anomaly expert John Anderson, who explained the "flyby anomaly"; and Mercury scientist Sean Solomon speaking about *MESSENGER*'s flyby of Mercury. We also aired a special tribute to Sir Arthur C. Clarke, including Clarke's greeting to future Martians recorded for *Visions of Mars* and placed on board the *Phoenix* Mars lander. If you missed any of these shows, you can still catch them at *planetary.org/radio*.

We hope you join Bill Nye, Bruce Betts, Emily Lakdawalla, host Mat Kaplan, and special guests on their next audio outing.

—Mat Kaplan, Planetary Radio Producer and Host

Thank You, Sponsors!

We extend our thanks to the following companies, which helped to sponsor ***Planetfest '08: New Visions of Mars.***

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NASA Jet Propulsion Laboratory
The Space Foundation

Phobos
California Space Authority

Tribute Gifts—Arthur C. Clarke

Science fiction author and Planetary Society Adviser Sir Arthur C. Clarke touched the lives of people around the world. With his recent passing, members mourned him by celebrating his life's work.

One member made a gift to the Society of $10,000 to honor Clarke's memory. We'll use that gift to seek other worlds and other life, a fitting tribute to a man who envisioned a human presence beyond Earth.

Thank you to all of you members and donors who share and are helping us realize that dream.

—Andrea Carroll, Director of Development

Annual Audit Completed

The firm of Hensiek & Caron has completed its yearly audit of The Planetary Society. The firm determined that the Society's 2007 financial statement was in conformity with generally accepted accounting principles.

Copies of the financial statement are available upon request.

—Lu Coffing, Financial Manager

Planetary Society Holds Town Halls on U.S. Space Policy

The Planetary Society has launched a series of Town Hall meetings to engage the public in charting a course for human space exploration beyond Earth orbit. Two have already been held—in Brookline, Massachusetts and Atlanta, Georgia—and more are being planned.

Our first Town Hall meeting was hosted by the Clay Center Observatory of the Dexter and Southfield Schools in Brookline in March. Planetary Society Vice President Bill Nye conducted the meeting, which included a short presentation by Planetary Society Board member and scientist Heidi Hammel.

Our second Town Hall, held in early May, was hosted by the Center for Space Systems at the Georgia Institute of Technology in Atlanta. Again, Bill Nye moderated the event, this time joined by Lon Levin, president of SkySevenVentures, cofounder of XM Radio, and a member of The Planetary Society's Board of Directors.

Each Town Hall also included panelists representing the "Generation Y" perspective and a citizen/taxpayer viewpoint.

Town Hall meetings are free and open to the public. To look for Town Hall meetings and other events in your area, visit *planetary.org/participate/events/*.

—Susan Lendroth, Manager of Events and Communications

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Planetary Society Key Ring Medallion

This elegant key ring medallion features our Planetary Society logo—planet, rings, and sailing ship—etched in black on solid brass. 1 lb. **#677**
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Planetary Society Cap

Our redesigned Planetary Society cap is 100% cotton with an adjustable Velcro band. The royal blue cap features our logo on the front and *planetary.org* on the back. 1 lb. **#673**
Regular price: $15.00 **Member price: $13.50**

We're Saving Space for You!

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Regular price: $3.33
Member price: $3.00

Commemorate *Phoenix*'s Mars Landing!

Mars Marble Key Fob

We're going to Mars! The names of a quarter million people—including all Planetary Society members—are on the way to Mars on board the *Phoenix* spacecraft, which launched in August 2007.

Our Mars replica key fob is emblazoned with the words "I'm Going Here!" with an arrow pointing to the Martian north pole. Don't miss your chance to get this commemorative Mars marble key fob, which features:

- 1-inch-diameter Mars marble made from recycled glass
- Geographic details, including white polar caps, dark canyons, mountains, and volcanoes
- Silver-plated hardware allowing Mars to spin freely

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"Is Anybody Out There?" Poster

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Regular price: $15.00 **Member price: $13.50**

Nebula Poster

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Regular price: $15.00 **Member price: $13.50**

Pale Blue Dot Poster

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Surf Titan T-Shirt

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Regular price: $22.22 **Member price: $20.00**

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The awesome beauty and destructive power of volcanoes have inspired many cultures on Earth to revere them as gods and goddesses. That is no wonder; by continuously spilling Earth's rich molten interior out onto its surface, these fountains of liquid rock have done more to alter the face of our planet than any other geologic feature. *Vesuvius* depicts a group of people and a mule surprised by the volcano's sudden eruption.

Michael Wutky (1739–1823) is best known for his landscape paintings. Wutky left his native Austria to work in Italy from 1776 to 1801; he painted *Vesuvius* in 1780. In 1998, *Vesuvius* was acquired by the Louvre.

Photo: Imagno/Hulton Archive/Getty Images

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