The PLANETARY REPORT

Volume XXXI Number 2 March/April 2011

Lava Lakes

From The Editor

This spring, we on Earth are celebrating two 50-year anniversaries in space exploration. In April 1961, Yuri Gagarin's flight made him the first human in space; in May, John F. Kennedy's speech set the United States on its path to the Moon.

Around our planet, people are celebrating both milestones, but the partying is tinged with a bit of sadness and disappointment. If you're like I am, you once confidently believed that Gagarin's flight and Armstrong and Aldrin's steps onto the Moon were only the beginning of humanity's breakout into space. Since the *Apollo* program ended, however, human explorers have been restricted to low Earth orbit, flying little higher than Gagarin did 50 years ago.

Look how far we haven't come.

This spring, as I watch the budget process in Washington, D.C. and see space exploration reduced to a political football game, it's hard to feel like celebrating. Honest politicians admit it: the space program has become a jobs program. Senators are designing rockets, based on how many jobs the parts will provide in their states.

When you read about lava lakes that are known in only two places in our solar system—on Earth and on Io—can you help but ask if our spacecraft will ever return to the outer solar system? If the current political situation in the United States holds, the answer must be "Not in our lifetimes."

Can you and I do anything to put humanity back on course to space? I believe we can, if we work together and apply pressure where it's most effective: directly on the politicians who control space agencies' budgets. Tell them what you want to see in space. Help your Planetary Society amplify the voices of thousands like you to demand that the journey begun by Gagarin and Kennedy must not end.

– Charlene M. Anderson

On the Cover:

Lava lakes are beautiful, fascinating, and formidable expressions of active volcanism. They, and the volcanoes they top, are portals to Earth's hot, roiling depths. Nyiragongo volcano, in the Democratic Republic of the Congo, is one of less than a handful of volcanoes on Earth with an active, long-lived lava lake. In January 2006, Tom Pfeiffer took this photo from only 600 meters above Nyiragongo's lava lake.

Photo: Tom Pfeiffer, *volcanodiscovery.com*

Background:

The crew of *Apollo 11* awaits pickup by a helicopter from the *USS Hornet*, the prime recovery ship for the first lunar landing. The fourth person in the life raft is a swimmer from a U.S. Navy underwater demolition team. All four men are wearing biological isolation garments. Neil Armstrong, Buzz Aldrin, and Michael Collins splashed down in command module *Columbia* on July 24, 1969, about 812 nautical miles southwest of Hawaii. Photo: NASA

Contact Us

Mailing Address: The Planetary Society,
85 South Grand Avenue, Pasadena, CA 91105-1602

General Calls: 626-793-5100
E-mail: *tps@planetary.org* Internet: planetary.org

The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of the Planetary Society, 85 South Grand Avenue, Pasadena CA 91105-1602, 626-793-5100. It is available to members of the Planetary Society. Annual dues in the United States are $37 (U.S. dollars); in Canada, $40 (Canadian dollars). Dues in other countries are $57 (U.S. dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

Editor, CHARLENE M. ANDERSON
Associate Editor, DONNA ESCANDON STEVENS
Managing Editor, JENNIFER VAUGHN
Technical Editor, JAMES D. BURKE
Copy Editor, A. J. SOBCZAK
Proofreader, LOIS SMITH
Art Director, LOREN A. ROBERTS/HEARKEN CREATIVE
Science Editor, BRUCE BETTS

Contents

Dear Members, Readers, and Friends:

Unexpected production issues resulted in the delay of this edition of our magazine, and, for that, we sincerely apologize. We are working diligently to get on schedule as we give *The Planetary Report* a fresh new look—and introduce a "Bill Nye" section especially for children. We thank you for your patience, understanding, and membership in the Planetary Society.

A PUBLICATION OF THE PLANETARY SOCIETY

YOUR PLACE IN SPACE

Oh, To Be Young and Spacefaring

When a meteor or a rocket or a runner is really moving, sometimes we say it or she is "just streaking." To study the flow of air over a wing at speeds near the natural speed of molecules, which is the speed of sound, the Douglas Aircraft Company built a plane called the *Skystreak* back in 1949. The *Skystreak*—what a fabulous name. As a kid, and now as an old kid, I flew and fly a balsa rendering of the *Skystreak*. It changed my life. I became fascinated with flight and science when I was very young. Most of us do.

The Douglas Aircraft *Skystreak* lands on the Dryden Flight Research Center's lakebed in 1949.
Photo: NASA

That's even more true for Planetary Society Members. We're generally fascinated by flight and space exploration, and most of us got that first jolt of excitement about space when we were kids. To those who became excited about outer space later, I submit that you were still young at heart.

Science education, and especially planetary science education, is best started when children are in elementary school, before they're 10 years old. I came to this conclusion both from personal experience and from extensive discussions with various consultants back when the Science Guy® show was being created.

Worldwide Technical Difficulty

We now have what might be called a technical difficulty, and it's all over the world. Societies are becoming increasingly dependent on technology, and, at the same time, fewer and fewer people truly know much about how all that technology works. We have automated teller machines, electronic transfers of funds, thermostats that continually reprogram themselves, and mobile phones that have their communication links transferred from cell to cell as we drive or walk. We raise food with precise cultivation techniques, using methods and machines that allow agriculturalists to produce crops for thousands rather than dozens. Perhaps most important, we use an astonishing amount of energy. It's sobering to note that even an elite world-class bicyclist on a stationary bike hooked up to an electrical generator could generate barely enough power to run a conventional plug-in hair dryer. It takes a lot of coal, gas, gasoline, wind, photons, and neutrons to generate the power to run our world. Again, a smaller and smaller fraction of citizens understand how it all works.

Energy Is Misunderstood

To give yourself an idea of how much we use technology and how few of us comprehend it, compare the number of people who presented ideas to clean up the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 with the number of people who presented ideas to cool or shut down the Fukushima nuclear reactors on the Pacific Ocean in 2011. Oil spills are commonplace. Those of us who are around automobiles experience small oil spills daily. Thinking that such a common occurrence as an oil spill should be easy to fix, people had plenty of criticism for the authorities who had responsibility for the oil gusher. Almost none of us, on the other hand, has any experience whatsoever with radioactive material and how to produce energy from nuclear fission.

Our technology has outstripped our general knowledge of it. This is a formula for disaster. We need better science education worldwide, and we need more scientifically literate citizens everywhere. It is to this end that *The Planetary Report* will begin including material for kids, to help them on their voyage of scientific discovery and knowledge. Starting with the next issue, we will be adding four pages of family-related content, including a home demo of a science project that even adult kids will enjoy. These additional pages are thanks to the generous support of the Foundation For The Carolinas' Clarence Foster Stanback Donor Fund, which is helping us jump-start our program for kids.

This venture is very much in the spirit of our founders: Bruce Murray worked on school curricula, and Carl Sagan was a big supporter of science education. He worked hard to establish and build the Sciencenter in Ithaca, New York, where he lived. They recognized that a scientifically literate and engaged population starts with kids.

I submit that the more we know about Earth and its place in the cosmos, the more we will be able to adequately address the myriad issues that our planet faces, among them overpopulation, the spread of diseases, and especially climate change.

We're going to engage people, young and old, in space science and work to promote science literacy, while helping people everywhere know and appreciate our place in space.

Bill Nye

SNAPSHOTS FROM SPACE

Comet Crash

by Emily Stewart Lakdawalla

An incandescent flare lights up the location on comet Tempel 1 where an impactor—half of the *Deep Impact* spacecraft—met oblivion on July 4, 2005. The 364-kilogram (802-pound) impactor spacecraft, guided by a navigational camera and maneuvering rockets under autonomous control, had steered itself to a collision with the comet at a speed of more than 10 kilometers (6 miles) per second.

Streamers of dusty comet material arc outward from the impact site into space. This dust obscured the impact site from view by the *Deep Impact* flyby spacecraft, which was watching from a safe distance to take this photo using its Medium Resolution Imager. Most of the surface of the comet appears brown, but white patches reveal zones of fresher ice.

Successful imaging of the impact site finally took place this year, when *Stardust* became the first spacecraft to revisit a comet after one perihelion passage.

Image: NASA/JPL/UMD/color composite by Gordan Ugarkovic

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

Explore More

You can learn more about this image at *planetary.org/snapshots*

Discover more about amateur image processing and learn how to get involved at *planetary.org/programs/projects/amateur*

Get your daily dose of space news, fascinating pictures, and commentary through the Planetary Society's blog at *planetary.org/blog*

Once, We Went to the Moon

by John M. Logsdon

A half century ago, President John F. Kennedy proposed sending American astronauts to the Moon and returning them safely to Earth "before this decade is out." In response, the United States, through Project *Apollo*, mobilized the immense financial and human resources required to turn JFK's proposal into reality, and 12 humans visited the lunar surface between July 1969 and December 1972. Looking back 50 years, it seems almost unbelievable that *Apollo* happened. It is worth reflecting on what made the achievements of *Apollo* possible and whether anything like that undertaking can—or should—happen again.

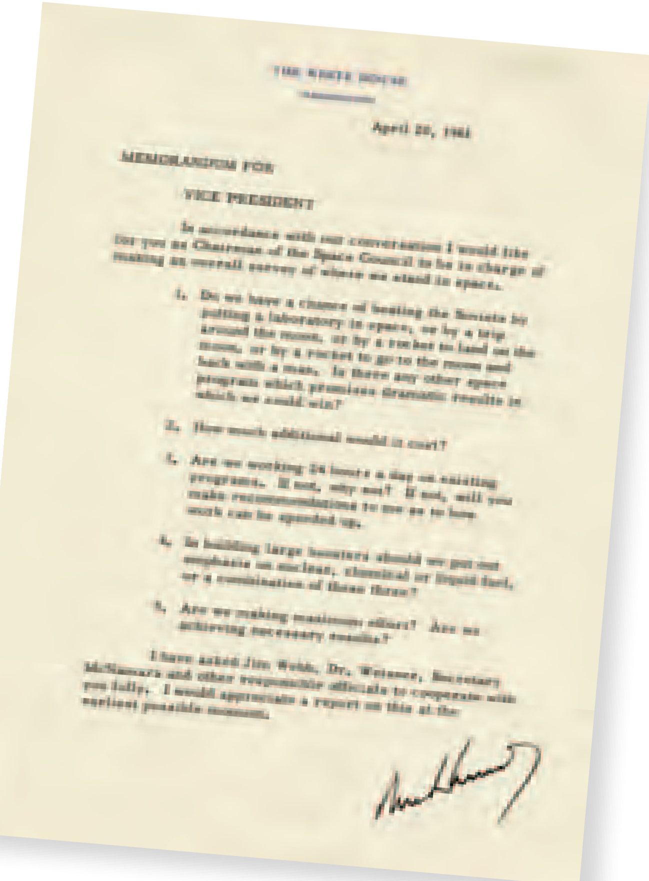
Kennedy and Space

I explore these issues in my new book, *John F. Kennedy and the Race to the Moon* (Palgrave Macmillan, 2010). The book first traces in detail how Kennedy, who entered the White House in January 1961 knowing and caring little about the U.S. space effort, quickly became convinced that the United States could not, by default, cede space leadership to the Soviet Union. In the aftermath of the April 12, 1961 orbital flight of Soviet cosmonaut Yuri Gagarin, Kennedy decided that the United States had to enter, and win, a space race with the Soviet Union, and he asked his advisers to identify "a space program which promises dramatic results in which we could win."

The answer came in two parts, technical and political. Technically, landing people on the Moon would require that the successful country, whether the Soviet Union or the United States, build a new rocket. Kennedy was assured that in this rocket-building competition, the United States could prevail. Politically, Kennedy was told, "it is man, not merely machines, that captures the imagination of the world," and that the international prestige accruing from space leadership was "part of the battle along the fluid front of the Cold War." He accepted these assessments, and on May 25, 1961, before a joint session of Congress, he called on the nation to undertake "a great new American enterprise."

John F. Kennedy's decision to send astronauts to the Moon is, 50 years later, an enduring hallmark of his presidency. The *Apollo* lunar landing program, the most expensive peacetime initiative in U.S. history, remains a beacon of national resolve and commitment. On November 16, 1963, Wernher von Braun (center) briefs Kennedy on an upcoming Saturn I launch during a visit to Cape Canaveral. NASA Associate Administrator Robert Seamans looks on at left. Photo: NASA

Yuri Gagarin's successful Earth-orbital flight on April 12, 1961, was influential in Kennedy's decision-making process regarding the U.S. space program. In this memo to Vice President Lyndon B. Johnson, the new chair of the National Aeronautics and Space Council, the president asked Johnson to identify a space program "in which we could win."
Photo: Lyndon Baines Johnson Library and Museum


THE WHITE HOUSE

April 20, 1961

MEMORANDUM FOR

VICE PRESIDENT

In accordance with our conversation I would like for you as Chairman of the Space Council to be in charge of making an overall survey of where we stand in space.

1. Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the moon, or by a rocket to land on the moon, or by a rocket to go to the moon and back with a man. Is there any other space program which promises dramatic results in which we could win?

2. How much additional would it cost?

3. Are we working 24 hours a day on existing programs. If not, why not? If not, will you make recommendations to me as to how work can be speeded up.

4. In building large boosters should we put out emphasis on nuclear, chemical or liquid fuel, or a combination of these three?

5. Are we making maximum effort? Are we achieving necessary results?

I have asked Jim Webb, Dr. Weisner, Secretary McNamara and other responsible officials to cooperate with you fully. I would appreciate a report on this at the earliest possible moment.

On May 5, 1961, Alan Shepard became the first U.S. astronaut to go into space. Here, Kennedy watches the launch from his secretary's office. Also present were, from left, national security adviser McGeorge Bundy, Lyndon Johnson, presidential assistant Arthur Schlesinger, chief of naval operations Admiral Arleigh Burke, and Jacqueline Kennedy. According to Kennedy's science adviser, Jerome Weisner, as of April 1961, "Kennedy was, and was not, for space." According to Weisner, "He said to me 'Why don't you find something else we can do?' We couldn't … we had to do something, but the decision was painful for him."
Photo: John F. Kennedy Presidential Library and Museum

This part of the story of how the United States reached for the Moon has been well known for some time. I told it in detail in my 1970 book *The Decision to Go to the Moon: Project Apollo and the National Interest*, a study that became the standard account of how Kennedy made his choice. So why, 40 years later, have I revisited the topic of John Kennedy and space?

The reasons are several. The story of JFK's involvement with the lunar landing effort between May 1961 and November 1963 had never been told from his perspective, and my new study fills that gap in the record of his presidency. Kennedy not only "talked the talk," he also "walked the walk." During the 30 months between his May 1961 speech and his assassination, Kennedy continued to give his personal support to the space program and, despite his concerns over its costs and about the growing criticism of the priority given to the lunar landing effort, to approve the exponentially increasing NASA budgets needed to meet the "end of the decade" goal. Kennedy approved an increase in the NASA budget of more than 400 percent in his short time in office. He told NASA Administrator James Webb in late 1962 that he was willing to make such a financial commitment only because leadership in space was important "for international political reasons. . . . The Soviet Union has made this a test of the system. So that's why we're doing it." Otherwise, said Kennedy, he was "not that interested in space."

These words were uttered in the privacy of the White House and were secretly recorded, but Kennedy's public rhetoric also was consistent with the idea that being first on the Moon was primarily a way of very visibly, and peacefully, demonstrating U.S. technological and organizational power. In his most famous space speech, made in Houston on September 12, 1962, JFK declared, "we choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard." (These words, incidentally, did not originate with Kennedy or his speechwriter Theodore Sorensen; they were part of NASA's input into the speech preparation process.) A clear conclusion of my study is that Kennedy was not a space visionary but, instead, a pragmatic national leader who saw the race to the Moon primarily as a means to advance broader national interests, not as the first step in a sustained program of space exploration.

Cooperating in Going to the Moon: Pursuit of an Illusion?

Another reason for the new study is that, in the first book, I completely missed an important reality: competing with the Soviet Union in space was in fact Kennedy's second choice. He would much rather have found a way to make space an arena for cooperation between the two superpowers, and, at the end of his life, he was pushing hard to turn the lunar landing effort into a joint U.S.–Soviet project. Few know, or remember, that aspect of his space record.

In 1961 and 1962, Kennedy was driven by an imperative to match and then surpass Soviet space

President Kennedy and Soviet leader Nikita Khrushchev are shown during their only face-to-face meeting, in Vienna, Austria on June 3 and 4, 1961. Twice during their summit meeting, Kennedy proposed that the United States and the Soviet Union cooperate in going to the Moon. Khrushchev rejected this proposal in 1961, but when Kennedy repeated it in September 1963, Khrushchev reportedly was willing to accept the idea of a joint lunar mission. Photo: John F. Kennedy Presidential Library and Museum

capabilities. During 1963, he came to the conclusion that the United States was making enough progress that the danger of Soviet domination of what he called "this new ocean" was rapidly fading. Bolstered by the U.S. "victory" in the Cuban missile crisis, worried by the high costs of continuing the race to the Moon, reacting to the growing criticism of the priority given to *Apollo*, and hoping—in the wake of the Limited Test Ban Treaty—to make space the next area of U.S.–Soviet rapprochement, in September 1963 Kennedy went before the General Assembly of the United Nations and asked, "Why should man's first flight to the Moon be a matter of national competition?" As an alternative, he proposed sending to the Moon, sometime during the decade, not the representatives of a single nation but representatives of all countries, with the United States and the Soviet Union in lead positions.

This proposal is little remembered because it runs so counter to the accepted history of U.S. unilateral success in Project *Apollo*. I conclude that Kennedy was quite serious. Cooperation in space had been his hope as he became president; in his inaugural address, he had said to the Soviet Union, "Let us explore the stars together." Up to the day of the Gagarin flight and JFK's decision that he had to compete in space, his science and foreign policy advisers had been working on proposals for U.S.–Soviet space cooperation. These proposals formed the basis of Kennedy's June 1961 offer to Soviet leader Nikita Khrushchev to cooperate in lunar exploration.

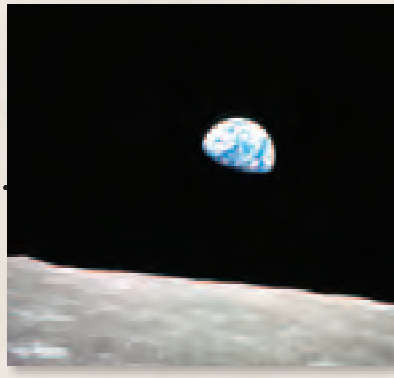
The two met face-to-face for the only time just 10 days after Kennedy announced his decision to go to the Moon. Khrushchev rejected this offer in 1961. What might have happened if Kennedy had lived can only be a matter of speculation. By the fall of 1963, the Soviet Union still had not decided whether it would try to send cosmonauts to the Moon, so Kennedy's proposal came at a sensitive time in the Soviet space program. Khrushchev may well have seen cooperation with the United States as a way of undertaking a lunar effort without paying all its costs. Whether cooperation in lunar missions might have been possible or was only a false hope on JFK's part will never be known. His assassination ended the exploration of a joint lunar program; instead, Project *Apollo* became a memorial to a fallen president.

The Lessons of *Apollo*

Three presidents since Kennedy have proposed resuming human space exploration: George H. W. Bush in 1989, George W. Bush in 2004, and Barack Obama in 2010. The first two proposals went nowhere, and the fate of the third remains uncertain. It is worth asking what Kennedy did to turn his 1961 proposal into the grand achievement that was Project *Apollo* and compare his actions with those of his successors as they proposed, without success, similar journeys of exploration.

First, Kennedy was willing to provide the resources required. The NASA budgets he approved after his May 1961 announcement of the lunar landing goal

On September 12, 1962, Kennedy delivered his most memorable space speech before a crowd of 40,000 people on the football field of Houston's Rice University. In that speech, he delivered the famous phrase, "we choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard." By the time Kennedy returned to the White House, his attitude regarding the goal of sending Americans to the Moon had escalated from one of high priority to one of asking, "How soon can we get there?" Photo: NASA



Apollo 8, the first human mission to the Moon, entered lunar orbit on December 24, 1968. That night, astronauts Frank Borman, Jim Lovell, and William Anders broadcast live from lunar orbit and showed pictures of the Moon as seen from their spacecraft. Anders took this iconic photo—the first color view of Earth from space—which became known simply as *Earthrise*. Anders later said, "Back in the '60s it gave us a sense that the world was a place we all shared together. We couldn't see any boundaries from space." Photo: NASA

On July 20, 1969, the United States achieved its goal. Neil Armstrong took this photo of Buzz Aldrin standing next to the American flag on the Moon. In response to what has transpired since that remarkable period in space history, Buzz Aldrin has said: "We've got to go [back to the moon]. But we don't want to stay too long … The ultimate goal is Mars." Photo: NASA

provided the funding needed to get started on a fast-paced program. More recent presidents, beginning with Richard Nixon, have not followed through on their space proposals with adequate budgets, and as a result, NASA has struggled in the four decades since *Apollo*, trying to do too much with too little. Kennedy, unlike his successors, also stayed closely involved with the program, visiting Cape Canaveral three times and viewing other NASA installations in September 1962.

Kennedy's frequent press conference statements on space provided continuing political support. On his last visit to the Cape, just six days before he was killed, he was visibly excited by the progress being made in U.S. rocket capability. Although slowing down or even stopping *Apollo* was under serious consideration by the White House in November 1963, it is unlikely that Kennedy would have approved a drastic shift in his space plans had he served two full terms as president.

Kennedy's support for *Apollo* came within the Cold War context of the 1960s; the world today is very different. I conclude in *John F. Kennedy and the Race to the Moon* that "the lunar landing decision and the efforts that turned it into reality were unique occurrences, once-in-a-generation [or much longer] phenomena in which a heterogeneous mixture of factors almost coincidentally converged to create a national commitment and enough momentum to support that commitment through to its fulfillment." Trying to repeat the *Apollo* experience is a recipe for frustration and probable failure; other approaches to space exploration are needed if such exploration is to be sustained.

In September 1963, as noted earlier, Kennedy asked as he addressed the United Nations, "Why should man's first flight to the Moon be a matter of national competition?" As an alternative, he proposed sending representatives of all countries. That prescient element of Kennedy's space legacy remains relevant today. In 1963, he recognized that it would be preferable to take a global approach to space exploration, with the United States in a leading position. This is even more the case in the 21st century.

Committing the United States to a leadership position in space exploration is perhaps a more challenging prospect now than the one Kennedy faced half a century ago. Continuing forward with the same approach to space that has been pursued over the past four decades, driven primarily by narrow political interests, is not likely to result in a space effort that is "worthy of a great nation," as sought by the 2009 Augustine Committee. In his 1962 Houston speech, Kennedy called for a space effort that would "organize and measure the best of our energies and skills." Does this country and its leadership retain today the will to answer JFK's call from a half century ago?

John M. Logsdon is a professor emeritus at the Elliott School of International Affairs of The George Washington University. He joined the GW faculty in 1970 and founded its Space Policy Institute in 1987. Dr. Logsdon frequently comments on space issues in the print and electronic media. He is a member of the Planetary Society's Board of Directors.

LAVA LAKES ON EARTH AND IO

by Ashley Gerard Davies

Ashley Davies on Antarctica's Erebus volcano in December 2005.
Photo: A. G. Davies

Standing on the edge of a crater containing a lava lake, such as at Erta'Ale volcano in Ethiopia, all of the senses are fully entertained. The lava lake is a treat for the eyes as the lava churns away under a thin, pliable crust, and lava fountains merrily play—this is an especially impressive sight at night. Escaping gas hisses loudly, terrific radiant heat desiccates the skin, and noxious fumes irritate the nose and throat. Although it's just geology at work, one cannot get over an irrational impression that the lava lake is, somehow, a living creature. Watching a lava lake up close evokes the same feelings as watching a prowling tiger—beautiful, but potentially deadly.

Bubbling, boiling, sloshing, hissing, and occasionally exploding—lava lakes are astonishing, fascinating expressions of active volcanism. Like the products of all ongoing volcanic processes, lava lakes are indicators of a dynamic, evolving world that is driven by internal heat sources powerful enough to melt part of a planetary mantle.

If the eyes are the windows to the soul, then volcanoes are windows to a planet's inner life. Aside from Earth, the only other active lava lakes known to exist in our solar system are on Jupiter's moon Io. Nyiragongo's lava lake is the largest in the world, and the level is rising. Here, the Moon, covered by a plume of escaping gas, lights the night sky as molten lava illuminates the caldera's walls.
Photo: Martin Rietz, *mrietz.com*

Volcanoes thus provide a window into the interior of a planet. Lava that is erupted onto the surface reveals details of interior conditions to instruments on spacecraft, and in this respect a volcano is a planetary scientist's best friend. The temperature of the lava as it erupts is a reflection of the lava's composition, which can be used to understand internal chemistry and mantle state.

High-temperature lava lakes and other results of silicate volcanic activity currently are found only on Earth and Io, the intensely volcanic moon of Jupiter. Earth is volcanically active because it is heated by the decay of radioisotopes that were incorporated into the planet when it formed. Io, on the other hand, is heated by external forces. Io is caught in a well-known orbital resonance with Europa and Ganymede. The resulting gravitational tug-of-war leads to regular flexing of Io (and also of Europa and Ganymede, to lesser degrees), and this causes heating. In Io's case, this internal heating manifests itself at the surface as satellite-wide volcanism on scales that dwarf contemporary activity on Earth.

Knowing the state and composition of the mantle is vitally important in determining the degree, and even the location, of tidal heating within Io. Much of the volcanic activity on Io takes place within paterae, which are wide, deep, caldera-like structures, and it has been proposed that lava lakes, confined within paterae walls, may therefore be a common feature on Io.

Lava Lakes on Earth

Long-lived lava lakes are rare on Earth—fewer than a handful exist. The most persistent lava lakes are found in locations of crustal extension and mantle hot spots, where the crust is thin and where ascending magma feeds magma chambers a few kilometers below the surface.

Terrestrial lava lakes have been classified into two types: active and inactive. It is important to separate these two classes because they have different formation processes and temporal evolutions. Active lava lakes can develop at the summit or on the flanks of a volcano and can be considered as the top of a column of magma. An active lava lake is therefore an open, convecting system, where surface activity is related directly to processes taking place deep underground. Inactive lava lakes, on the other hand, are rootless and stagnant, and they do not form directly at the top of a magma column. Instead, such lakes form by ponding of lava in depressions—for example, where lava flows into a crater. Inactive lava lakes soon solidify and cool; therefore, they can be differentiated from active lava lakes by their long-term thermal behavior.

Most of Earth's active lava lakes happen to be found in particularly extreme environments. I have been fortunate to visit such rare volcanological phenomena in Antarctica (the coldest place on Earth) and Ethiopia (in the Afar region, coincidentally the hottest place on Earth). Data collected at these lava lakes have helped volcanologists understand the workings of the physical processes of lake overturn and magma supply as well as how lava lakes can be identified through the use of remote sensing data, even at low spatial resolution. This latter point is especially important in the study of Io, because almost all of the data we have are at very low spatial resolutions, with an entire lava lake located within a single pixel. This paucity of high-resolution data will remain the case until a future space mission reaches Io.

Lava lakes are ideal targets for such a mission because they may help to answer the biggest question left open after the *Galileo* mission—whether Io's volcanism is dominated by basaltic or higher-temperature ultramafic lavas. Lava lakes provide long-lived, stable thermal sources of data on the temperature of lava at eruption. To understand how best to observe activity in Io's lava lakes, I embarked on a study of the same features on Earth, both using spacecraft and by getting "up close and personal."

Antarctica

Mount Erebus volcano is located on Ross Island, Antarctica, and is the world's most southerly active volcano. Erebus, with the two extinct volcanoes that make up Ross Island, is located on the West Antarctica Rift. It was erupting when first spotted by Captain James Ross in 1841, and since 1972 it has been erupting constantly.

In November 2005, I traveled to Antarctica with scientists from the New Mexico Institute of Technology (Socorro, New Mexico) and camped on Erebus volcano. The goal of the expedition was to determine the temperature and area distribution of the lava lake using a FLIR (Forward Looking InfraRed) hand-held thermal imager, a device that has revolutionized field volcanology. These data would establish ground truth for infrared data collected by a range of instruments on three spacecraft (*Terra*, *Aqua*, and *Earth Observing-1*) in Earth orbit. In addition, they could be used to test the accuracy of models of volcanic thermal emission designed expressly for Io's volcanoes. We have no ground truth for Io, so this was an opportunity to see how well the models worked, once we made appropriate changes for the terrestrial environment. (The models performed better than I would have imagined, accurately reproducing the measured eruption parameters.)

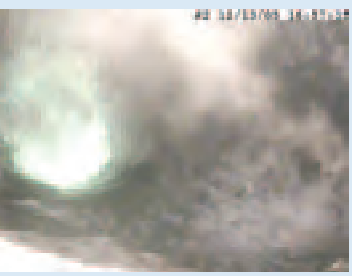
Traveling to Antarctica and climbing Erebus was an amazing experience. From the summit of Erebus at 3,794 meters (12,448 feet), we could see clearly for hundreds of kilometers, because the atmosphere contained no dust and only a trace of water vapor and pollution (almost all of which was generated by the volcano). It was bitterly cold: the ambient temperature was typically –40 degrees Celsius (–40 degrees Fahrenheit), not figuring in wind chill.

At the bottom of a deep crater, in an inner pit, was the

OBSERVING LAVA LAKES

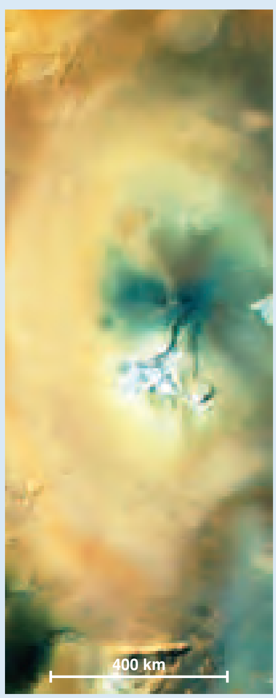
The Erebus lava lake as it looked on December 13, 2005. The lake's surface area was about 820 square meters. Photo: A. G. Davies

EXPLODING LAVA



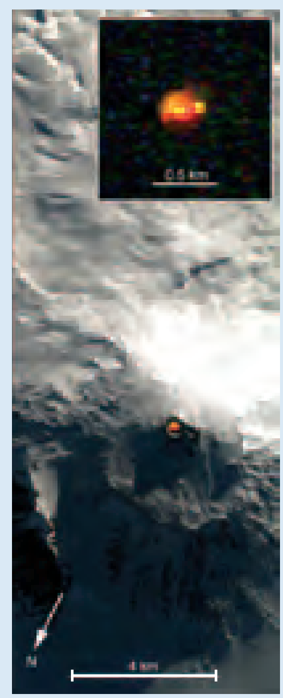
A few times a day, the Erebus lava lake exploded spectacularly, ejecting lava bombs capable of traveling great distances. A fixed camera on the crater's rim took this false-color image. It is a frame from a video of the explosion recorded by the Mount Erebus Volcano Observatory in Socorro, New Mexico. To watch the YouTube video, go to ***http://bit.ly/frROM9.*** Image: Mount Erebus Volcano Observatory

UP CLOSE FROM FAR AWAY



Left: This enhanced-color close-up of Io's largest volcano, Pele, and its surroundings was taken by *Voyager 1*. Pele's volcanic vent is at the top of the wedge of mountains, where the dark fans of erupting matter begin. The ejected material falls back over a region approximately 1,400 kilometers (870 miles) across. By the time *Voyager 2* flew by four months later, eruptions had filled the notch at the bottom right of the frame. Because Io's volcanism is driven by tidal heating rather than by radioactive decay, the study of its volcanoes is essential to understanding tidal heating. Image: NASA/USGS/Science Photo Library

Right: One reason for our expedition to Erebus was to establish ground truth for infrared observations taken by instruments on three spacecraft in Earth orbit: *Terra*, *Aqua*, and *Earth Observing-1*. This image of the Erebus lava lake is particularly noteworthy because it was obtained without human interaction. When the Space Technology 6 Autonomous Sciencecraft Experiment imaged Erebus on May 7, 2004, it detected volcanic activity. The software, sensing heat from the lava lake, reprogrammed the instrument to take more data. For more details on this image, go to *http://bit.ly/fJJPct.* Image: NASA/JPL



lava lake. It varies in size from year to year; in December 2005, it had a surface area of about 820 square meters (980 square yards). Magma circulates between the surface of the lava lake and a deep-seated magma chamber. At the surface, lava slowly welled up at the center of the lake and spread laterally, disappearing at the lake margins. A crust formed rapidly as the exposed lava solidified and cooled, although very hot lava could be seen through cracks in the thickening crust.

The magma in the lava lake at Erebus is of unusual

composition (anorthoclase phonolite) and contains large crystals of anorthoclase feldspar, some up to 15 centimeters (6 inches) in length. The magma is at a temperature of about 1,000 degrees Celsius (about 1,800 degrees Fahrenheit). The lake feeds a plume of acidic gases and aerosols that the team kept well away from. In 2005, Erebus was particularly active. Although most of the time the surface of the lava lake was replaced quiescently through gentle overturning, every six to nine hours, the lake underwent a spectacular Strombolian eruption, the result of gas buildup in the magma. The resulting explosions ejected lava bombs (some quite large) at high velocity from the lava lake, throwing them out of the summit crater to land as far as away as three quarters of a kilometer (half a mile).

Analysis and modeling of the Erebus FLIR data showed that models of thermal emission accurately reproduced temperature and area distributions in data that had been degraded to a low spatial resolution. This agreement with ground truth increased confidence in the analysis of data that had been obtained by large telescopes and spacecraft (such as *Galileo*) from Pele, a feature on Io that some have proposed is a lava lake. Additionally, the Erebus data had a peak in thermal emission at short infrared wavelengths, very similar to the data from Pele. The Pele infrared data, collected by the *Galileo* Near Infrared Mapping Spectrometer (NIMS), exhibited additional thermal emission at shorter wavelengths than in the Erebus data, indicating either the presence of higher-temperature lava at Pele or a more vigorous style of activity there. In the latter case, proportionally larger areas at high temperatures would be exposed, most likely due to disruption of the surface crust by gas violently escaping into a near-vacuum, feeding the giant Pele volcanic plume.

Ethiopia

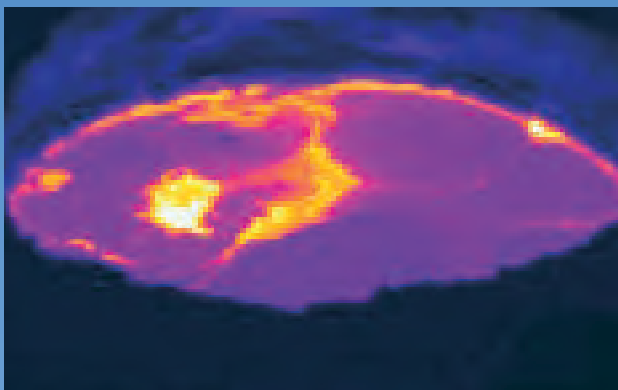
Two other persistent terrestrial lava lakes are found at Erta'Ale volcano in Ethiopia and at Nyiragongo volcano in the Democratic Republic of the Congo. These volcanoes are situated in the East African Rift System, a zone of crustal spreading where Africa is slowly tearing apart. In September 2009, I traveled to Erta'Ale, which is in the remote Afar region of Ethiopia.

I accompanied a film crew shooting the BBC documentary series *Wonders of the Solar System*. The crew's globe-trotting schedule meant that the trip to Ethiopia was possible only at the end of August, the hottest time of the year, when temperatures during the day often exceeded 50 degrees Celsius (122 degrees Fahrenheit). The astonishing sight of the lava lake, however, all but erased any discomfort. The Erta'Ale lava lake contains basalt that erupts at a temperature of about 1,140 degrees Celsius (2,080 degrees Fahrenheit). This temperature indicates that it probably is a better analog for Io's silicate lavas than the cooler, more viscous Erebus phonolite.

My objective for the 2009 Erta'Ale deployment was to collect more FLIR data to aid in understanding the rate at which thermal emission changed at short wavelengths as a function of activity style. The science goals were to gain a better understanding of the eruption processes taking place and to establish the best way to image the hottest areas present (which were very small). This information would be used to understand the complexities of measuring eruption temperature with remote-sensing instruments.

The FLIR data collected at Erta'Ale included observations of small lava fountains. As expected, the appearance of these fountains was accompanied by an increase in short-wavelength thermal emission. Analysis of the FLIR data showed that thermal emission at visible and short infrared wavelengths varied rapidly. The data were then used to simulate typical spacecraft imager operations, in which data are obtained one wavelength at a time. Usually, observations at two wavelengths (or more, ideally) are needed to determine temperature. The FLIR data were used to simulate the effects of different time delays on the estimation of temperature. It was found that data at multiple wavelengths need to be obtained very quickly to capture the temperature of the hottest areas present (the major science measurement for a future mission to Io).

These results were used to help design a multispectral imager for possible use on *Io Volcano Observer*,



Far left: The author is pictured here collecting data at the Erta'Ale lava lake with a Forward Looking InfraRed (FLIR) thermal imager in September 2009. The ambient temperature there was 56 degrees Celsius (133 degrees Fahrenheit), making the region about 100 degrees hotter than at Erebus. Photo: Courtesy of A. G. Davies
Middle: Erta'Ale volcano is located in Ethiopia's Afar region, the hottest place on Earth. Like other active lava lakes, Erta'Ale has a thin, pliable crust that is constantly moving and cracking, exposing hot magma and releasing noxious gases. This photo shows the lake at dusk on August 31, 2009. Photo: A. G. Davies
Left: This FLIR thermal map of the Erta'Ale lake shows a small lava fountain. The map also reveals surface temperatures, some as high as 1,140 degrees Celsius (2,084 degrees Fahrenheit). Map: A. G. Davies
Right: A reddish ring of ejected sulfur-rich material surrounds Pele in this global view of Io. Photo: NASA

a Discovery-class mission to Io proposed by Alfred McEwen of the University of Arizona.

Lava Lakes on Io

As mentioned earlier, behavior similar to that observed at Erta'Ale is exhibited at Pele on Io, only on a much larger scale. Pele apparently is a lava lake some 40 kilometers (25 miles) across. Evidence that Pele is a lava lake comes from a variety of observations. Pele is a persistent hot spot and has been seen in every appropriate telescope and spacecraft observation since it was discovered by *Voyager*. The shape of the infrared thermal emission spectrum as seen by *Galileo* indicates a vigorous style of volcanic activity. This same spectrum is very similar in shape to those of Erebus and Erta'Ale, indicating similar surface temperature distributions. Both the infrared spectrometer and visible wavelength camera on *Galileo* indicated temperatures at Pele exceeding 1,130 degrees Celsius (2,070 degrees Fahrenheit). Given that the eruption has persisted for years and that the areal extent of the thermal source has not changed greatly, it appears that the activity is topographically confined. The simplest explanation is that Pele is an active lava lake. Additionally, in visible-wavelength data obtained at a temporal resolution of minutes, the *Cassini* imager indicated that thermal emission changed rapidly, much as in the data collected at Erta'Ale.

This last point is particularly important. Data on terrestrial lava lakes show that lava fountain activity changes so rapidly, and cooling of the hottest exposed areas is so rapid, that data must be collected very quickly at multiple wavelengths (with acquisition on a time scale much shorter than 1 second) in order to "freeze" the action. Such considerations have been used to design operation limits for instruments that will image Io's violent volcanic eruptions, so that Io's lava eruption temperature can be estimated robustly.

Mention should be made of another prime candidate for a lava lake on Io, at Loki Patera, Io's most powerful volcano. Incredibly, the potential lava lake covers an area of more than 21,000 square kilometers (8,000 square miles); by comparison, in 2009 the lava lake at Erta'Ale in 2009 covered about 2,000 square meters. Loki Patera does not exhibit the same thermal structure as the Pele, Erebus, and Erta'Ale lava lakes; its sheer size may result in different mechanisms of surface crust replacement. There is nothing even remotely comparable on Earth. Understanding what is happening at Loki Patera will be an important objective for any future mission to Io.

What's Next?

We now have most of the pieces of the puzzle. We know how to recognize the characteristic behavior of active lava lakes on Io, even from great distances. We have models of behavior that explain how they are overturning. And we know what observations need to be made in order to answer the all-important scientific question: how hot are the erupting lavas? Now we need the data! Getting these data depends on a return mission to Jupiter and Io, such as the proposed NASA *Europa System Jupiter Mission* or Alfred McEwen's proposed *Io Volcano Observer*. The latter has instruments designed expressly for Io's unique and exciting volcanic environment and processes. Any such mission contains huge potential for greatly expanding our understanding of the volcanological processes that continue to shape Earth and one of its planetary neighbors.

This work was performed at the Jet Propulsion Laboratory—California Institute of Technology under contract to NASA and was supported by the NASA Planetary Geology and Geophysics Program.

Ashley Gerard Davies, PhD, is a volcanologist and planetary scientist at the NASA Jet Propulsion Laboratory—California Institute of Technology. He is the author of Volcanism on Io—A Comparison with Earth *(Cambridge University Press), the definitive guide to Io's volcanoes. He believes he has the best, most exciting job in the world, and is happiest when tramping about on an erupting volcano.*

WE MAKE IT HAPPEN!

FINDS: One Step Closer to Faraway Earths

BY AMIR ALEXANDER

◀ **DEBRA FISCHER** *of Yale University and Geoff Marcy of UC Berkeley are the most successful planet-hunting team on Earth. To date, they have found more than half of all exoplanets discovered from the ground, aided in part by the Planetary Society and its Members.*

Today, Fischer and Marcy are once again pushing the boundaries of planet hunting. Armed with a $40,000 grant from the Planetary Society, they built an innovative instrument they call the "Fiber-optic Improved Next-generation Doppler Search for Exo-Earths," or, more simply, FINDS Exo-Earths. The new instrument already has proven its value: when attached to the three-meter telescope at California's Lick Observatory, it greatly improved the telescope's sensitivity and its ability to detect lower-mass exoplanets.

Encouraged by this success, and wise in the ways of grants, Fischer and Marcy used our original grant as "seed money," successfully applying to NASA for an additional $400,000. This means that every dollar we provided leveraged 10 times its value!

Here, Amir Alexander describes the FINDS Exo-Earths project further and explains how it will help planet hunters detect distant Earths in the depths of space.

A Hunter on the Trail

Debra Fischer is a veteran planet hunter. In 1997, when she first joined the field, the search for exoplanets was in its infancy, requiring scientists to operate on the very edge of the sensitivity of their instruments. The planets that could be detected at the time were oddballs—gas giants orbiting very close to their star, nicknamed "hot Jupiters." As the years went by, and as techniques and instrumentation improved, smaller planets orbiting at greater distances could be detected. As a result, astronomers today can see not only distant planets but also entire planetary systems, and they are gaining a deeper understanding of the dynamics and prevalence of those systems.

Despite this impressive progress, the search for exoplanets has now reached a crossroads. Recent ground-based searches have been able to detect planets as small as two to four Earth masses, an enormous advance over the early days. Improving on this, however, has proven to be extremely challenging, because it requires a level of precision in measurement that seems nearly unattainable. The holy grail of the exoplanet search, the detection of Earth-mass planets in the depths of space, remains just beyond reach.

The Quest for Precision

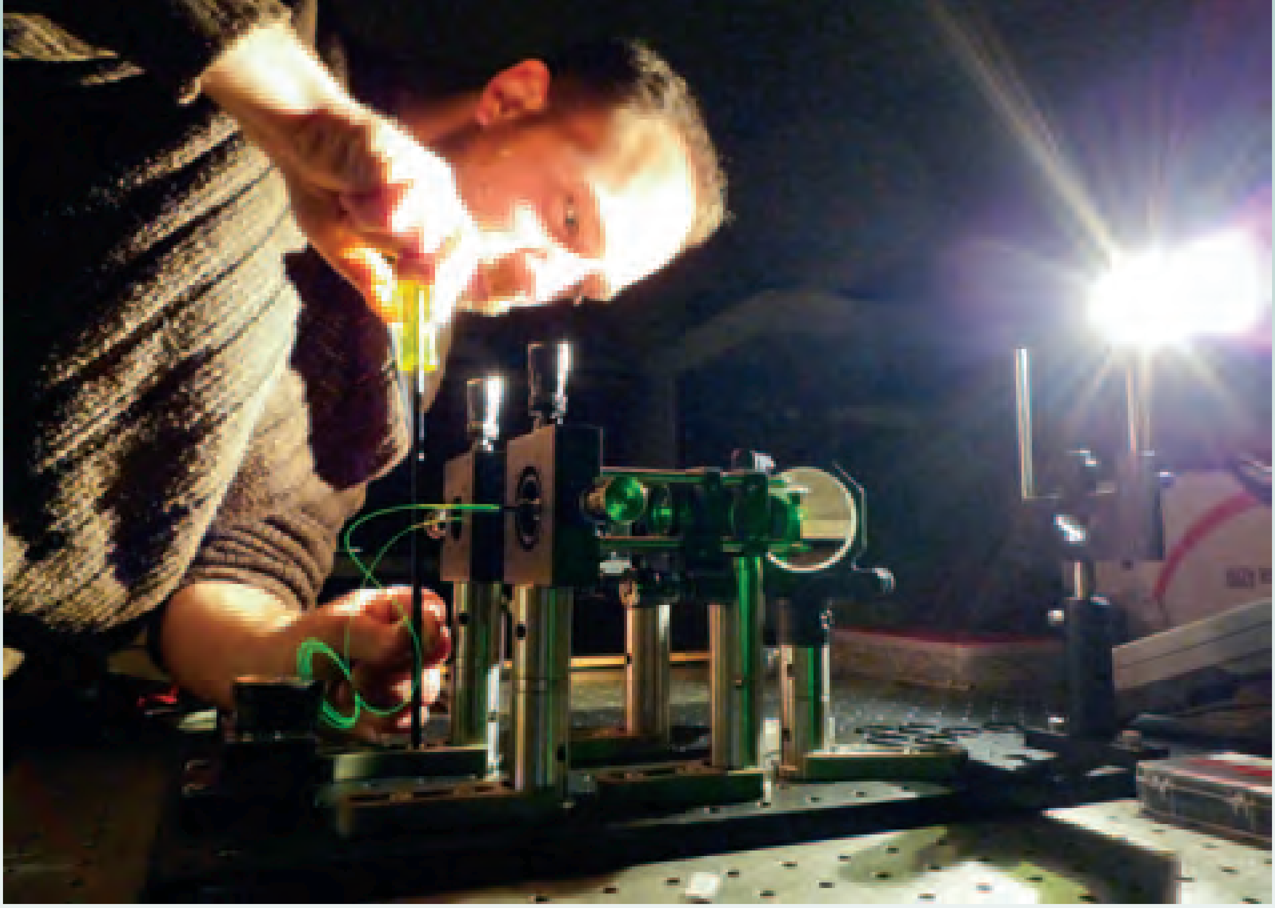
Fischer and her team, however, were undeterred. In their quest to detect a true exo-Earth, they set out to improve the precision of the technique in which they specialize—radial velocity searches. In this approach, scientists use large telescopes to monitor the light spectrum of distant stars. If a star's spectrum shifts toward the blue and then toward the red at fixed intervals, this is a strong indication that the star is moving—rocking back and forth to the tug of an orbiting planet.

Naturally, a massive planet is easier to detect than a low-mass planet, because it causes the star to move more rapidly. Over time, planet hunters have improved their measurements to the point that they can now detect a star's motion even if it is as slow as a few meters per second. To find true Earth-mass planets, however, astronomers will have to detect stars moving at less than 1 meter per second—the pace of a leisurely stroll.

To break the impasse, Fischer and her colleagues looked for creative ways to squeeze every possible ounce of precision out of existing instruments. They came up with a new concept that they called Fiber-optic Improved Next-generation Doppler Search for Exo-Earths, or simply FINDS Exo-Earths. Then they called the Planetary Society to ask for funding. We knew a good investment when we saw it, so we said yes.

A Simple Solution to a Difficult Problem

To understand how FINDS Exo-Earths works, consider the basic setup of a radial velocity exoplanet search. First comes the telescope, collecting light from



Julian Spronck, a postdoctoral scholar on Debra Fischer's team, was tasked with designing and building the prototype FINDS instrument, which is now installed on the Lick Observatory's Hamilton spectrograph. Photo: Matt Giguere/Yale University

the observed star. The light is then passed through a narrow slit and onto a highly sensitive spectrometer, where spectrum fluctuations are recorded.

This simple configuration has led to the detection of hundreds of exoplanets, but to Fischer and her colleagues, this was not enough: the light that passes through the slit, they found, illuminates the spectrograph in slightly different ways at different times, introducing an error into the measurements. The error is slight, even minuscule, but at the extreme level of precision sought by Fischer's team, it is nonetheless significant. FINDS Exo-Earths was specifically designed to correct it.

As Fischer tells it, the most troublesome changes in illumination are those that occur suddenly, over a span of seconds or minutes. These might be caused by gusts of wind, but the most common culprit is the guiding system of the telescope itself. As the star makes its way across the night sky, the guiding system is programmed to keep it always in the telescope's sights, shining directly through the center of the slit and onto the spectrograph. If a slight guiding error causes the star to be positioned momentarily at the right or left edge of the slit, the starlight will still be collected, but the illumination pattern shifts, introducing an error into the spectrum measurements.

How does one correct for such an unpredictable error? The solution, according to Fischer and her colleagues, is to place an optical fiber between the slit and the spectrograph. Now the light from the telescope going through the slit first passes through the optical fiber before continuing on to the spectrograph. The fiber scrambles the light from the slit, so that the precise position of the star no longer matters. Instead of reacting to the slightest shift in the position of the star, the optical fiber shines a steady and even cone of light onto the spectrograph. Fischer's team was hopeful that in the long run the improved precision would make it possible to detect stars moving at less than 1 meter per second.

Testing an Idea

The job of designing and building FINDS fell to Julian Spronck, a postdoctoral scholar on Fischer's team. The prototype he created included a 100-micron-diameter optical fiber as well as an elaborate set of mirrors and lenses. These, explained Spronck, were needed to ensure maximum preservation of the starlight collected by the telescope as it passes through FINDS. Spronck's completed instrument measured 2 feet by 1 foot and fitted neatly onto the Hamilton spectrograph at the Lick Observatory.

The FINDS prototype has been in place at the Lick Observatory for several months now, and the results are impressive. The illumination of the spectrograph now seems nearly immune to slight guiding errors. The light that passes through FINDS shines on the

Above: At first glance, one might mistake this watery, life-filled landscape for our own beautiful, living planet. Earth-mass planets in their stars' habitable zones remain the holy grail of planet hunters' quests. Illustration: Dan Durda

spectrograph in a clear, even cone, more than 10 times steadier than before. This, in turn, drastically reduces the error in measuring a star's rocking motion. By comparing measurements of three selected stars with and without the FINDS, Fischer and Spronck showed that the instrument reduces error by an average of 30 percent. "This is dramatic," Fischer said. "We usually fight to squeeze out improvements of a few percent."

Spronck is currently working to improve the FINDS prototype, trying out different types of optical fiber, different diameters, and even differently shaped cross sections. For the time being, he must be personally present at the Lick Observatory whenever FINDS is used, but once the permanent instrument is installed, it will require no special attention. Furthermore, the spectrograph measurements will then be calibrated to the precise type of fiber used, resulting in even higher precision than has been achieved so far.

On to the Big Leagues

While perfecting the prototype at the Lick Observatory, Fischer and her team are also intent on trying their instrument at the Keck Observatory in Hawaii. If FINDS is to fulfill its promise of detecting Earth-like planets, it will do so with giant instruments like the Keck's 10-meter reflector, one of the world's most powerful telescopes. Because there was no room at the Keck for the instrument built for the Lick, Spronck created "matchbox FINDS," measuring only 1 by 3 inches, whereas the Lick instrument measured 2 feet by 1 foot. On the night of September 29, 2010, Fischer and Spronck tried out the matchbox design at the Keck. They compared 25 measurements taken with FINDS that night with 147 measurements taken without it over the previous six years. The results were striking: FINDS improved the stability of the spectrograph illumination by a factor of 10!

Like all good things, the improvement in precision achieved by FINDS comes at a price. Inevitably, some of the light gathered by the telescope is lost when it is passed through an optical fiber. A certain loss is acceptable, said Fischer, and is more than compensated for by the increased precision. Currently, the light losses at the Lick are around 20 percent, which is close to the goal Fischer has set. The results at the Keck so far, however, have not been what Fischer and Spronck had hoped for: the prototype "matchbox" FINDS fit snugly within the space available at the Keck and effectively stabilized the spectrograph illumination, but it also lost almost 60 percent of the light gathered by the telescope. That, says Fischer, is simply too high a price to pay.

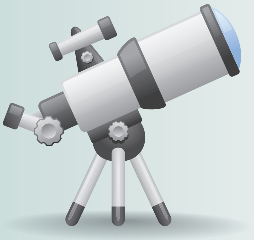
Fischer and Spronck are hard at work on a new design of the FINDS instrument for the Keck. To accomplish their goals, they need more funding, and once again they have asked the Planetary Society to help. In April 2011, we turned to our Members with a simple request: help Fischer and her team, and ensure that the promise of FINDS Exo-Earths is not wasted for lack of funds.

FINDS Exo-Earths already has shown that it can make a difference in the race to discover faraway Earths. As prototypes are replaced by permanent instruments, its already impressive results will continue

Because there was no room on Hawaii's Keck 10-meter telescope for another FINDS instrument like that on the Lick, Spronck built a miniaturized version only 1 by 3 inches in size. Already, the "matchbook" FINDS is returning strikingly precise measurements. Courtesy W. M. Keck Observatory

to improve. But FINDS is also something else: a creative, low-cost solution to a persistent problem that has challenged even the best-funded groups using the most expensive and sophisticated instruments. It is a project in which a modest investment can reap huge scientific and technological dividends. It is, in other words, what the Planetary Society does best.

Amir Alexander is an author and historian of science who works with and writes about Planetary Society projects, including exoplanets, SETI, and the Pioneer *anomaly.*



Explore More

Learn more about FINDS
www.planetary.org/programs/projects/finds/

Find out more about projects that the Planetary Society funds
www.planetary.org/programs/list/

Help us continue the work!
www.planetary.org/join/programs/discovery_team.html

What's Up?

In the Sky

Throughout May and June, the predawn sky is busy with planets, but you have to look low on the eastern horizon to see most of them. Venus is the brightest starlike object, and it is joined by next-brightest Jupiter, dimmer Mercury, and reddish Mars. The four jockey for position, sometimes forming very tight conjunctions. The crescent Moon gets in the middle of things on May 30. In early June, Mercury drops back below the horizon, and Venus slowly goes below the horizon over June and July. Mars and Jupiter continue to get higher in the sky. In the evening sky, yellowish Saturn rises in the east in the early evening. There will be a total lunar eclipse on June 15, visible from much of South America, Europe, Africa, Asia, and Australia.

Random Space Fact

The International Space Station (ISS), at 119 yards (109 meters), is approximately the length of an American football field including end zones and within the size variation allowed for the length of soccer fields. Unfortunately, the ISS lacks the stadium capacity to host a Super Bowl or World Cup.

Trivia Contest

Our November/December contest winner from Las Vegas, Nevada wishes to remain anonymous. Congratulations!

The Question was: What was the name of the first cat in space?

The Answer is: Felix, launched by the French in 1963 on a sounding rocket and recovered safely.

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

What is the largest moon of Uranus?

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 July 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*.

Questions and Answers

Does Europa experience tidal activity beneath its ice crust? It seems that it must, at least to some degree, if tidal heating is what keeps Europa's ocean liquid. But what would be the nature of these tides? Would they be relatively mild, like Earth's, or would they be enormous, under-ice tsunamis? Would these tides be so great as to preclude the possibility of exploring under the ice with remotely operated underwater vehicles?
—Ed Hood
Topeka, Kansas

If Europa's ice shell is thin, the maximum vertical tide would be 30 meters, given that we expect the ocean depth there to be 100 to 150 kilometers (about 60 to 90 miles). Scaled down, the tide would be relative to your bath water rocking up and down by one tenth of a millimeter. The resulting oceanic currents may dissipate a good bit of energy, nonetheless, and help keep the shell thin. If the shell is sufficiently thick, the tides would be suppressed and would not lead to Earth-like tsunamis (which rely on oceanic gravity waves breaking in near-shore shallows). Hence, they would not generate the large-amplitude waves we've seen recently following a large earthquake.

If underwater "Europaquakes" were to generate gravity waves in its ocean, they would circle the satellite again and again (and at very low amplitude) until the energy dissipated. These waves, however, would likely be imperceptible to plankton, squid, and deep-sea divers alike. Europa's larger daily tides (3.55 Earth days) and the resulting oscillations (or *librations*) of the icy shell might cause some difficulty if you were attempting deep-sea drilling, however.
—PAUL SCHENK,
Lunar and Planetary Institute

Factinos

Stardust has returned new images of comet Tempel 1, some of which show a scar resulting from 2005's *Deep Impact* mission.

On the night of February 14, 2011, *Stardust* made its closest approach to Tempel 1, at a distance of about 178 kilometers (111 miles). The spacecraft took high-resolution images of the comet and gathered data on the dust in its coma. This was the spacecraft's second mission of exploration, called *Stardust-NExT*. The craft completed its prime mission of collecting particles of comet Wild 2 and returning them to Earth in 2006.

"This mission is 100 percent successful," said Principal Investigator Joe Veverka of Cornell University. "We saw a lot of new things that we didn't expect, and we'll be working hard to figure out what Tempel 1 is trying to tell us."
—from the Jet Propulsion Laboratory

At left: *Stardust-NExT* captured this image of comet Tempel 1 at 8:39 p.m. (Pacific Standard Time) on February 14, 2011. The picture was taken during closest approach from a distance of 185 kilometers (115 miles). The vast majority of terrain in this view has not been seen until now.
Image: NASA/JPL-Caltech/Cornell
Insets: At left is a composite of Tempel 1 images taken by *Deep Impact* just before the spacecraft's copper projectile crashed into the comet's surface. The arrows in the *Stardust-NExT* picture at right point to the rim of the crater left by that impactor. Scientists estimate that the crater is about 150 meters wide. It has a central mound of material, most likely created when impact-generated debris fell back inside.
Images: NASA/JPL-Caltech/University of Maryland/Cornell

Would landing humans or robots on an asteroid affect that body's mass and center of gravity and, therefore, its rotation and orbit? In addition, what would be the effects, if any, of the vehicle's engine efflux during approach, landing, and departure?
—Jim Franks
Aviemore, Scotland

Most near-Earth asteroids that we are looking at as targets for future robotic sample return, and for human exploration missions, are pretty small—less than 100 meters across and, in many cases, just tens of meters wide. This makes some of them similar in scale to the largest blocks we've seen on Itokawa. Their small size in no way makes them less scientifically interesting, but it might provide some interesting operational challenges.

None of the candidate targets is large enough to consider for an actual landing. Also, engineering and mission safety constraints dictate that no spacecraft could touch them in any way, so there's no danger of changing an asteroid's heliocentric orbit. Future human operations on these targets are going to be similarly gentle, but I imagine that for the very smallest targets, we might impart some tiny, measurable "tip off"rates (setting them into a tumbling motion while pushing on them in zero gravity) to their spin if we can get a good grip on them. Robotic spacecraft that might contact an object for sample return probably will not be massive enough and certainly wouldn't run into the object fast enough (you don't want to damage your spacecraft) to appreciably affect an asteroid's spin state.

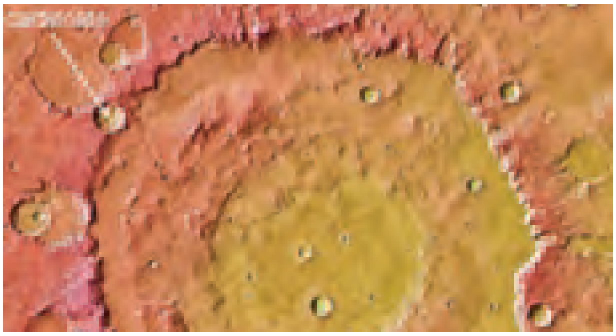
Vehicle thruster efflux is important to keep in mind when we plan operations so that we don't alter or contaminate the surfaces and samples we are taking so much trouble to study in situ. We want to study the presence and properties of any loose, fine material resting on or adhering to the surfaces of even the tiniest space rocks. Blowing those materials away on initial approach would ruin that part of our valuable field geology opportunity.

Chemical contamination probably can be recognized as terrestrial in origin during laboratory analysis of returned samples, but it would be best not to introduce it in the first place, especially if the target object is primitive and if a focus of in-situ investigation is to determine the presence and properties of any native volatile compounds.
—DAN DURDA,
Southwest Research Institute

Scientists have new clues concerning the disappearance of the carbon dioxide (CO_2) that may have been a large part of Mars' once-thicker atmosphere.

Recent observations by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on *Mars Reconnaissance Orbiter* show carbonate minerals in several places where cratering has exposed material from five kilometers (three miles) below the surface at Huygens crater. Although these are not the first detections of carbonates at the Red Planet, they look more like what some have long theorized when discussing the whereabouts of Mars' "missing" carbon. If deeply buried carbonate layers turn out to be widespread, they might help explain the disappearance of Mars' ancient atmosphere, which is thought to have been thick and made up mostly of CO_2. The high-resolution images reveal spectral characteristics of calcium or iron carbonate at this site. Clay minerals found in previous low-resolution CRISM maps are visible close to the carbonates. Both types of minerals typically form in wet environments.

"We're looking at a pretty lucky location in terms of exposing something that was deep beneath the surface," said James Wray of Cornell University as he reported these findings at the Lunar and Planetary Science Conference in Houston in March 2011.



This image, dominated by Mars' Huygens crater, covers an area about 560 kilometers (350 miles) across. The arrow shows an unnamed crater, about 35 kilometers (22 miles) across, that has punched through the uplifted rim, exposing rocks containing carbonate minerals. These minerals are leading scientists to consider where most of Mars' predominantly carbon dioxide atmosphere may have gone.
Image: NASA/Arizona State University

These findings reinforce a recent report by Joseph Michalski of the Planetary Science Institute and Paul Niles of NASA concerning the same types of carbonate and clay minerals seen in CRISM observations of a site about 1,000 kilometers (620 miles) away. There, a meteor impact has exposed rocks from deep underground inside Leighton crater. Michalski and Niles reported that the carbonates at Leighton "might be only a small part of a much more extensive ancient sedimentary record that has been buried by volcanic resurfacing and impact ejecta."

Wray said the carbonates at Huygens and Leighton "fit what would be expected from atmospheric CO_2 interacting with ancient bodies of water on Mars."
—from NASA/JPL/JHU

Members' Dialogue

Let's Enjoy Talking

Bill Nye's writings are, in my opinion, never less than great. But Bill, your message "Here and Now: Our Unique Perspective," in the January/February 2011 issue, chimed an especially resonant tube with me. You eloquently surfaced something I've long felt but was never smart enough to crystallize: "some among our ancient ancestors . . . realized that our home would be tallied as just another world." Of course, they must have. Repeatedly.

Just why those "prescient few" didn't rewrite the daily dogma may be about more than just having the proof. It might also have been due to a lack of critical mass (of accepters), which implies interaction. Both of these needs are addressed by our Planetary Society. Conversant communication of world-changing perspectives based on new evidence is what we do here together, and digital media can amplify that conversation dramatically.

Science's journey has stumbled into more than a few cul-de-sacs of isolated independent discoveries and lost arts. It's a sobering thought: smart ideas can die out. Perhaps intelligent species that die out are the ones that fail to contact other intelligent cultures.

Let's, by all means, enjoy talking with one another. But let's each resolve to talk to twice as many of those who haven't yet heard these joyful news items. Bill quoted Carl Sagan as having said, "When you're in love, you want to tell the world." Don't hold back. Share the ecstasy. When they call you a geek, own it. Enlightened outcasts, unite!

Thanks, Bill, for slipping us the catalyst. Again.

—DAVE BRODY,
Edgewater, New Jersey

Get Past the Debate

I can understand how Roderick R. Hatcher (see "Members' Dialogue" for January/February 2011) gets more excited about humans in flight. But his bottom line, "when you stop doing, you start dying," is not accurate.

Space enthusiasts of all ages were excited when the first *Viking* photos came back from Mars, and spectacular images keep coming, with more and more detail, including signs of water on the Red Planet. And all of you great members of the Planetary Society, tell me you were not excited by *Voyager*'s pictures of active volcanoes on Io and very strange landscapes and activities on Neptune's super-cold moon Triton!

We are so fortunate to witness, in a single lifetime, the progression from early satellites and probes to missions to the edge of the solar system, with more to come, such as *New Horizons*' mission to Pluto and the Kuiper belt.

Robotic missions are clearly safer and much more economical than human missions, and they provide some very exciting science!

—EARL FINKLER,
Medford, Wisconsin

Human spaceflight has not waned or died. As our technology has evolved, so has our utilization of it, and as this robotic intelligence becomes more advanced, it adds greater control, flexibility, and virtuality to the humans controlling each flight. Every flight is manned by a team of humans, sometimes inside the spacecraft, but always here on Earth at mission control. So, every flight is manned, in my way of looking at it.

Some of the great successes of human spaceflight in recent years have been the multiple repair missions of the Hubble Space Telescope. Without them, none of Hubble's great exploration and discoveries would have been made. Humans in space can do infinite and very complex tasks. Intelligent robotic devices in space can do finite and less complex tasks. Should the economics of tasks that need to be performed dictate who or what should be used to complete them? I care not about humans in space; I care about the exploration and the discoveries. Humans and robots are two of the tools in the space science toolbox for us to use, and not until we get past the debate can we focus on the vision.

—JOE DES ROSIER,
Palmetto, Florida

Check the Records

There is an error in "The Quest to Explore Mercury" in the November/December 2010 issue. The article states, "The cuneiform tablets . . . 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."

Mayan culture did not exist in the period between 1300 and 1000 B.C.E. Their earliest inscriptions date to the first few centuries of the current era. The Dresden Codex is believed to have been written circa 1100 C.E.

—YALE ZUSSMAN,
Weymouth, Massachusetts

Please send your letters to
Members' Dialogue
The Planetary Society
85 South Grand Avenue
Pasadena, CA 91105
or e-mail: *tps.des@planetary.org*

Society News

Create a Lasting Gift—Make a Bequest

Last week, I got two calls, of the kind that remind me why I work at the Planetary Society.

Both callers were passionate about space exploration, and in their desire to make a lasting and positive difference for the future, each wanted to find out more about creating a bequest in their estate plans to benefit the Planetary Society.

I was moved by their reasons for making such a gift.

Mary told me that she takes great satisfaction in being a Charter Member of the Planetary Society—a member since our founding by Carl Sagan, Bruce Murray, and Louis Friedman 30 years ago. I asked her to tell me more. She explained, "I'm proud, and I'm a little amazed. I've literally helped change our future in space. My name is on other worlds. We're going to fly our solar sail. We know so much more about the cosmos and about the possibility of life on other planets. I want to be sure that the Planetary Society is around to give other people the same exciting opportunity I've had."

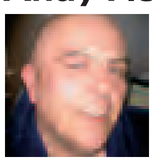
Bill, living in a rural community, said that *The Planetary Report*, Planetary Radio, and our blog keep him connected and up-to-date concerning space exploration. He'd been inspired to start volunteering in the local schools—to introduce young people to the night sky, planetary missions, the quest for exoplanets, and wondering about the cosmos and appreciating our place within it. He said he wanted to continue the legacy of our founders and to create his own legacy of space education with an investment in the future of the Planetary Society.

Each of you has a story about your interest in deep space exploration. Perhaps like Bill and Mary, you are considering naming the Planetary Society in your estate plans. Your bequest, including the Society in your will or trust, is a simple and generous way to make a lasting gift.

Thank you, Mary and Bill, and all of you Legacy Members who have told us that you have named the Society in your estate plans. You are helping to ensure a vibrant future of space exploration, one in which humanity is exploring new worlds, better understanding our own, and searching for life elsewhere.

To learn more about becoming a Planetary Society Legacy Member, or to become one, please contact Andrea Carroll, Director of Development, at *andrea.carroll@planetary.org* or (626) 793-5100, extension 214.
—Andrea Carroll, Director of Development

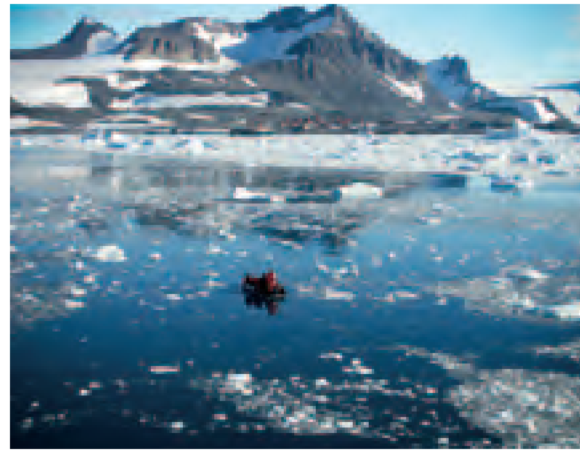
Volunteer Spotlight: Andy Fleming



We'd like to shine the volunteer spotlight on Andy Fleming, one of our United Kingdom volunteers, for showcasing the Planetary Society at the Cleveland and Darlington Astronomical Society meeting.

Andy created a PowerPoint presentation (his first time using the software!) covering 30 years of Planetary Society projects and programs. He even included a montage of audio files from our weekly Planetary Radio show. Not only did Andy create the show, but he also promoted his presentation via local media and set up a booth that night to distribute literature to the attendees. Thank you, Andy, for helping us spread the word.

We are growing our Planetary Society volunteer community and hope you will consider participating. For more information on becoming a Planetary Society Volunteer, contact Tom Kemp, Global Volunteer Coordinator, at *tom.kemp@planetary.org*.
—Susan Lendroth, Events and Communications Manager



Travel with the Planetary Society

Have you ever wanted to visit an alien landscape of wind-scoured terrain and sculpted ice? How about a world where ribbons of light envelop the night sky? Or perhaps you prefer seeing the fiery corona of the Sun?

The Planetary Society is calling all such explorers to travel with us to remote, beautiful, and even alien regions on planet Earth, to witness some of our world's most breathtaking wonders. Escorted by knowledgeable guides and speakers, the tours we offer through Betchart Expeditions span the globe.

Join us on one of these great adventures!

The Treasures of TURKEY and the Draconid Meteor Shower
October 3–14, 2011

MAYA WORLD and the Great Dinosaur Extinction
November 10–18, 2011

ANTARCTICA!
December 30–January 11, 2012

ARECIBO and the Lesser Antilles on board the five-masted yacht *Royal Clipper*!
January 26–February 4, 2012

ALASKA's Aurora Borealis
March 15–21, 2012

SIBERIA and LAKE BAIKAL for the Transit of Venus
June 1–12, 2012

Discover HAWAII
June 4–12, 2012

THE PLANETARY SOCIETY
85 South Grand Avenue
Pasadena, CA 91105-1602

Printed in USA

Our understanding of the cosmos took a giant leap forward when Galileo realized that the four points of light he saw near Jupiter in his telescope were actually moons of the giant planet. Four hundred years later, spacecraft have made Io, Europa, Ganymede, and Callisto familiar to us as denizens of our planetary consciousness. In *Galilean Moons*, Carol Kucera has abstracted the order and surfaces of these awe-inspiring worlds; instead of reproducing them exactly as seen, she has interpreted their unique essences.

Carol Kucera's abstract paintings celebrate the beauty and mystery of the natural world—on our own planet and beyond. Her artwork has been commissioned by NASA, the National Endowment for the Arts, and MCI and is owned by many private collectors. Carol's eponymous gallery is in Santa Fe, New Mexico.

Photo of painting: Eric Swanson