THE PLANETARY SOCIETY

THE PLANETARY REPORT

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TREASURE TROVE

***NEW HORIZONS'* DISCOVERIES AT PLUTO**

MERCURIAN AND LUNAR ICES • MICROPHONES ON MARS • MEMBERS SOUND OFF

Congratulations to the *OSIRIS-REx* team for a successful launch! Seen from below, the Atlas V carrying *OSIRIS-REx* sits atop the mobile launch platform at Cape Canaveral on September 6, 2016, the night before launch.

Photo: United Launch Alliance

ON THE COVER: It took decades. From the time a mission was just a gleam in scientists' eyes, to the years of battling for funding, revising spacecraft designs, and, finally, just *getting* there, the pot of gold *New Horizons* found at Pluto has been worth the wait. On July 14, 2015, just minutes after its closest approach, *New Horizons* took this beautiful image of Pluto. Illuminated by the Sun, Pluto's complex atmospheric haze layers are visible, along with the southern portions of the informally named Sputnik Planitia at top of the globe. False color has been added to this view to resemble the approximate true color blue of the popular backlit Pluto image seen at planet.ly/blueskypluto.
Image: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

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BILL NYE *is chief executive officer of The Planetary Society.*

Longterm Efforts Pay Off

Education and Exploration Take Time—And Persistence

IN 2002, The Planetary Society partnered with LEGO and NASA to hold the Red Rover Goes to Mars Student Astronaut contest. This program gave young people an exciting opportunity to directly participate in the upcoming Mars Exploration Rover mission—*Spirit* and *Opportunity*—which would launch in 2004. Today, I am extremely proud to write that Abigail (Abby) Fraeman, one of the sixteen winning Student Astronauts, has been appointed deputy chief scientist on that very same mission! The investment that our members made in young people over a decade ago is now paying off in remarkable fashion.

In 1992, when my colleagues and I were developing the *Bill Nye the Science Guy* show, we met with some teachers and professional educators who convinced us that your elementary school years influence you forever. It's when you develop your lifelong passion for science. As the years have gone by, I'm convinced that this is true for just about any profession, science especially.

The idea of an education program goes back to our founders, Bruce Murray and Carl Sagan. As a board member, I heard Bruce describe the work that he and his colleagues did to develop curriculum materials that would be useful for teachers all over the world. And, of course, Carl insisted on teaching Astronomy 101 and 102 at Cornell University. He wanted to get to college-level students as soon as he could for the same reason—to imbue them with a passion for the cosmos during their college experience. My predecessor, Lou Friedman, worked with the Boys and Girls Clubs of Los Angeles to inspire those kids to pursue a career in science. And more recently, Emily Lakdawalla, our award-winning journalist, worked with Abby as a Student Astronaut when Abby was in high school. With all this in mind, we are working hard to engage science teachers and students so that the Society can help produce more space scientists and engineers.

Photo: Courtesy of Abigail Fraeman

The *OSIRIS-REx (Origins-Spectral-Identity-Security-Regolith-Explorer)* mission has successfully launched from Cape Canaveral and is on its way to asteroid Bennu. Bruce Betts, our director of science and technology, has been involved with this mission since its inception. And Planetary Society member Mike Puzio was only 8 years old when he came up with "Bennu," his winning entry for our *Name That Asteroid!* contest. Mike's choice of the winning name was inspired by Bennu, the ancient Egyptian god known as the "bringer of life." In his contest submission, Mike pointed out that Bennu was the manifestation of the god Osiris when he came back to Earth as a gray heron. He said that the Touch-and-Go Sample Mechanism (TAGSAM) arm and solar panels on *OSIRIS-REx* look like the neck and wings in drawings of Bennu. Several of us, including Michael, were present at the picture-perfect launch on September 7.

One of the many major scientific discoveries made in my lifetime is that an impactor—an asteroid or comet, or group of such objects—finished off the ancient dinosaurs. *OSIRIS-REx*

is part of the long-term effort to characterize and understand these celestial objects that are leftovers from our solar system's beginnings. And it is another step in the ongoing work of readying us inhabitants of Earth to, one day, deflect an incoming object. As a member, you are helping us to support this mission, which will help us to understand our origins. In addition, you may be helping to save our planet for humankind one day. Thank you indeed.

In the "If at first you don't succeed" department, we once again will have a chance to hear what it sounds like on the Red Planet. Many of you have been around long enough to know that we've tried to get our Mars Microphones on a number of missions in the past. You also know that persistence pays off! See page 20 for more details.

And speaking of persistence—and payoff—how about that *New Horizons* spacecraft? In summer of 1990, Alan Stern, who was to become *New Horizons*' principal investigator a decade later, co-wrote the first article on a mission to Pluto that would appear in this magazine. It was called "Pushing Back the Frontier: A Mission to the Pluto-Charon System." Alan and The Planetary Society championed, and fought for, a mission to Pluto for a long, long time. In this issue, *New Horizons* team member Kelsi Singer describes what success looks like by showing us what *New Horizons* discovered at Pluto and Charon.

Involving, educating, and engaging young people. Fighting for instruments, and spacecraft, to fly. Supporting work that helps us to understand the cosmos and our place within it—and to protect our place within it. It all takes time, and some of it takes persistence. But, because of your support, it's all possible. Thank you. Let's change the world.

Bill Nye

OPPOSITE PAGE *Four of our 16 Student Astronauts: Wei Lin Tan, Abigail Fraeman, Shih-Han Chen, and Vignan Pattamatta, celebrate* Opportunity*'s 2004 Mars landing from The Jet Propulsion Laboratory.*

ABOVE *The Atlas V carrying NASA's* Osiris-REx *spacecraft blasted off from Cape Canaveral on September 7, 2016. Its target, asteroid Bennu, may hold clues to the origin of the solar system.*

BELOW LEFT *On the day of* OSIRIS-REx*'s launch, Bill and Mike Puzio, whose suggestion of "Bennu" made him winner of our Name That Asteroid! contest, meet the press at Kennedy Space Center.*

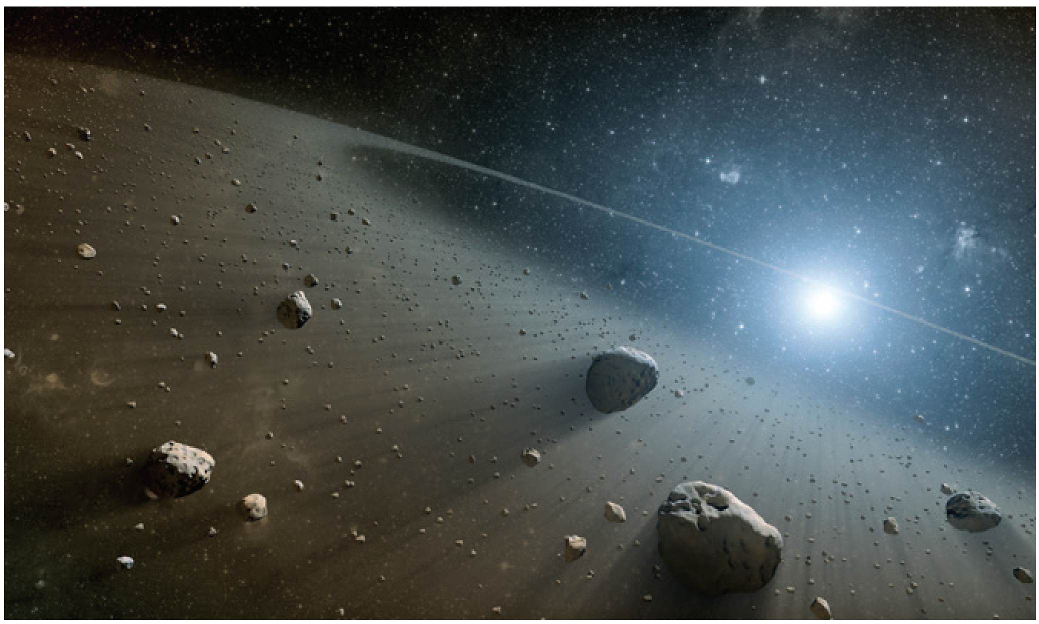
OSIRIS-REx launch photo: NASA/Sandy Joseph and Tim Terry; Bill Nye & Mike Puzio photo: The Planetary Society

THE VALUE OF SPACE ART

I hope that I may be allowed to respond to Travis Rector's blog ["Colors in Planetary Imaging"] in the March Equinox 2016 issue of *The Planetary Report*. Having been a published space artist since 1952, and as European Vice President of the International Association of Astronomical Artists (IAAA), I feel qualified to do so. He writes, "Yes, astronomy images are real. Unless it is 'space art,' these images are of real objects in outer space. They aren't creations of a graphic artist's imagination."

If Travis were referring to science fiction artists, this statement would be valid. But what "space artists," such as members of the IAAA, depict, whether in paint, digital or other media, is real. Every astronomical image requires human interpretation, as he says. The only difference between these photographs and space art is that space artists perform an essential service by visualizing what cannot be photographed. We can depict astronomical bodies from a different angle, and views from the surface of objects that can only otherwise be seen telescopically from space or from orbit, e.g., from probes and satellites. But unlike science fiction artists, we do not create these purely from our imagination, except insofar as the actual landscapes are extrapolated from what we know about the physical characteristics of the body in question–its geology, atmosphere or lack of, illumination, et cetera.

–David A. Hardy, Birmingham, England



RIGHT *Sometimes an actual image of an object is impossible to obtain with current technologies, but we can discover what it looks like by other means. Space art is often used to help provide a better understanding of the discovery when there is not a picture to help tell the story. For example, this artist's concept illustrates an asteroid belt around the bright star Vega. Evidence for this warm ring of debris was found using Spitzer and European Space Agency's Herschel Space Observatory.*

Illustration: NASA/JPL-Caltech

To say I was disappointed in Travis Rector's blog on colors in space would be an understatement. His assertion that "Unless it is 'space art,' these images are of real objects in outer space," flies in the face of everything hallowed to those of us who have dedicated our lives to the scientifically accurate depiction of astronomical subjects.

The Planetary Society has had a long and generous relationship with the international community of space artists. And the planetary science community has come to not only appreciate–but to rely upon–the talents of space artists to communicate their work to the general public. To speak in such a cavalier manner about space art is frustrating to those of us who have invested our careers in building a bridge between the scientists and the public.

We've been talking about the accurate usage of colors since before the first *Viking* surface images of Mars.

–Michael Carroll, Littleton, Colorado

I want to apologize if my blog entry gave the impression that I was dismissive of space art. The topic of astronomical imaging is, of course, much too large to cover in a single blog post and I had to leave out quite a bit of material that is part of the book [*Coloring the Universe: An Insider's Look at Making Spectacular Images of Space*]. Regarding space art, on page 102 of the book we have this image and caption (left).

As you can see, we agree with David and Michael about the importance of space art in conveying science. Unfortunately, the inelegant wording occurred when I shortened the book's text for the blog post.

–Travis Rector, Anchorage, Alaska

PARTISAN POLITICS AND SPACE

Politics being what it is, I believe that each party would use space exploration as a weapon. If proposed by Republicans, Democrats would claim it will use resources that could be used for social programs. If proposed by Democrats, the Republicans would claim that it will raise the debt. Therefore I believe that the use of quiet support and a clear path would be the best approach.

–Vince Laurelli, Mickleton, New Jersey

I believe there is something in-between a stated presidential agenda, which has too much risk of "induced political opposition," and the "speak softly" approach, which would not allow a big program like manned exploration and settlement of Mars to get a start.

This in-between approach–regarding Mars–would have the Executive Branch appoint a commission to come out with a long-term plan stated in terms of return on investment (ROI). The commission would have members from various science, industry, and sociology disciplines. It should be bipartisan for sure. It would be independent of NASA and have the ability to recommend no action. Whatever its conclusion, it could provide a very long-term (200 years) plan to accomplish identified goals, with mid-term and short-term goals also defined–and all justified by ROI. This plan would be updated every five years.

–Mike Helton, Rockville, Maryland

As Arthur C. Clarke suggested in a 1961 essay, "Space Flight and the Spirit of Man," humans have always been explorers and are meant to be. We need exploratory challenges that call for bravery, innovation, team efforts, and the hope of exciting triumph. Fighting and killing other humans on this small world are only a poor substitute for the best ways of letting out what is now a warlike spirit. In a better world, space exploration could channel military innovation, the call to battle, and our yearning for adventure, not to mention the vast economic resources now invested in the military/industrial complex, in another direction. Let spacecraft exploring other worlds, rather than bombers, make headlines and inspire competition between nations.

In this way, I believe that the exploration of space could become, in the expression of William James, a "*moral* equivalent of war."

I would love to see a presidential candidate who was willing to make a case for this kind of change of attitude and direction, and was prepared to promise working together with other nations for worldwide space enterprises that transcend the kind of conflicts that now keep the planet militarized.

Of course, the shift would need to be expressed reasonably and would not come all at once, but it should be talked about–and not only for the sake of resources out there or military applications of space technology, but above all for the sake of the human spirit, because that's who we are and need to be. Especially in depressing times, we need space to keep us looking upward.

–Robert Ellwood, Ojai, California

PLEASE SEND YOUR LETTERS TO:

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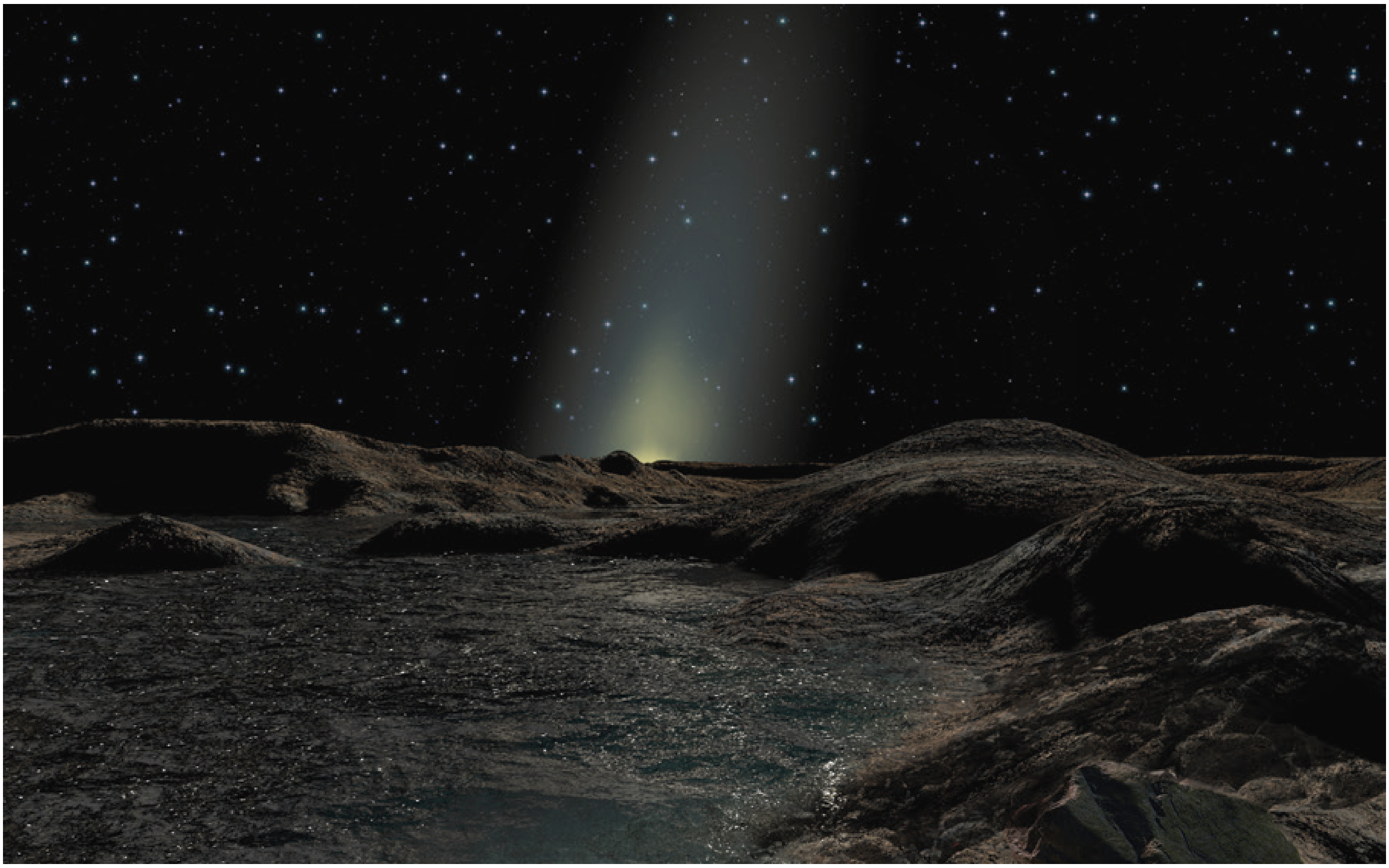
We reserve the right to edit for length and clarity.

MATT SIEGLER *is a research scientist at the Planetary Science Institute*



Cold Case

Icy Mysteries on Mercury and the Moon

ABOVE *Pure water ice twinkles from inside a polar cold trap on Mercury. Given its proximity to the Sun, it's reasonable to assume that Mercury has far less water than the Moon. But quite the opposite is true.*

Illustration: Ron Miller

WHY DOES EARTH HAVE water? We don't really know. Earth and the inner solar system are thought to have formed dry—out of gas and dust too close to the hot early Sun to allow water. So its presence on any of the inner planets is a mystery. Water could have come from comets, asteroids, volcanoes, or the solar wind.

The Moon and Mercury may offer a way to sleuth out a solution, as both of these worlds have water ice in "cold traps." The cold traps are shadowed regions near the north and south poles that stay extremely cold year round at less than 100 K on the Kelvin scale, (-280 degrees Fahrenheit or -173 degrees Celsius). At those temperatures, water ice acts like rock, losing very little material—less than one millimeter per billion years—to "wear and tear" sublimation. Given that both the Moon and Mercury have surfaces where not much has changed for a long, long time, they are inviting sites for investigation by "forensic planetologists" trying to solve this week's solar system cold case: Who Stole the Moon's Water?

FINDING ICE NEAR THE SUN

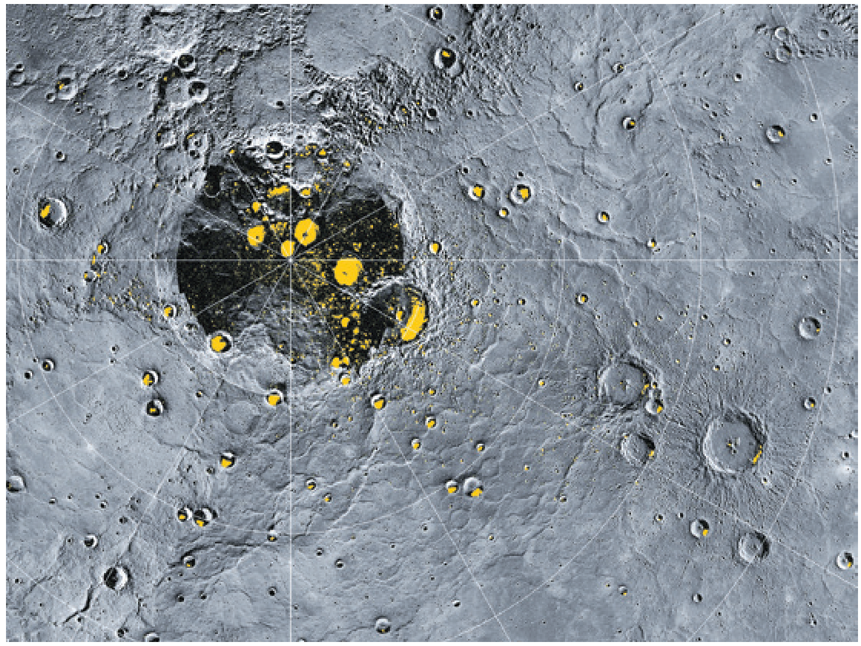
We can calculate, based on temperatures, how much real estate on the Moon and Mercury is available for water. The Moon has about 26,000 square kilometers (10,000 square miles) of surface area cold enough for ice to be stable. However, due in part to its proximity to the Sun, Mercury has only about 7,000 square kilometers (2,700 square miles) of area that never sees surface temperatures above 100 K. From temperatures alone, we should expect roughly four times more ice on the Moon than on Mercury.

This comparison becomes even more extreme if we take account of areas below the surface. Ice buried under just 10 centimeters (four inches) of lunar dust can survive surface temperatures up to 125 K (-235 degrees Fahrenheit or -148 degrees Celsius) for billions of years. On the Moon, we have about 240,000 square kilometers (90,000 square miles) of area where the top meter can protect ice; on Mercury, only about 50,000 square kilometers (20,000 square miles). Counting these underground areas, we should expect roughly five times as much ice on the Moon as on Mercury.

However, what we see is quite the opposite. Ice on Mercury was discovered about 25 years ago, when radar signals from the Arecibo (Puerto Rico) Observatory showed strong reflections near the planet's poles. Such reflections indicate very pure ice layers, akin to the surface of Europa. Similar measurements of the Moon came up, well ... dry.

In the late 1990s, *Lunar Prospector* orbited the Moon with a neutron spectrometer, an instrument that looks for neutrons knocked out of the soil by cosmic rays. A neutron and a hydrogen atom have about the same mass, so outgoing neutrons hitting hydrogen along the way lose a lot of energy. By measuring the ratio of high- to low-energy neutrons, we can precisely figure out how much hydrogen is in the ground. The answer for the Moon: the cold traps contain, at most, roughly one-half of one percent hydrogen, likely in the form of water ice. A similar measurement of Mercury by the *MESSENGER* spacecraft confirmed its radar-bright material was consistent with nearly pure (that is, 100 percent) water ice.

Image: NASA/JHUAPL/CIW



ABOVE *About 25 years ago, scientists proposed that radar-bright signals from Mercury might indicate the presence of water ice. Here, radar data from Puerto Rico's Arecibo Observatory (yellow) have been overlaid on a* MESSENGER *mosaic of the same area at Mercury's north pole, bolstering the evidence for water inside cold traps there.*

If we are optimistic about the hydrogen in the Moon's cold traps—assuming that all of it comes from water ice and that the soil contains 0.5 percent water—we still see at least 40 times the ice on Mercury as on the Moon. If we are more pessimistic about the lunar neutron-spectrometer data, limiting it to areas that are always below 100 K, we might estimate as much as 400 times more ice on Mercury than on the Moon. Farther down, below the top meter that our probes have been able to sense, Mercury is likely to have several meters (perhaps tens of meters) of ice. On the Moon, we have some evidence for deeper ice. Data from the *LCROSS* mission suggests concentrations around 4 to 5 percent, but nothing as pure as we have found on Mercury.

Including only ice in the top meter, the estimated total for ice on the Moon is equivalent to a snowball 630 meters in diameter, rivaling the world's tallest buildings. The ice on Mercury would make a snowball at least 4.6 kilometers in diameter, on par with the highest mountains on Earth (or larger if the ice is more than a few meters thick).

For planetary scientists studying the origins of water in the inner solar system, the big question is: Does the Moon have too little ice or Mercury too much? Figuring out what is "normal" in the development of rocky planets and moons is a hard question, because we don't have enough planets. To wrap our heads around the conditions we observe today, the planetary community has divided the problem into three subsets: sources, sinks, and stability.

SOURCES: SLOW TRICKLE OR RECENT IMPACT

The answers to our questions may lie in determining the source of the ice. Perhaps Mercury has been hit more often by icy objects. Compared to the Moon, Mercury is about one-third as far from the Sun, and about one and a half times bigger. Most researchers estimate that around 10 times as many objects hit Mercury as hit the Moon. Micrometeorites (from comet tails) might have hit Mercury 50 times more often.

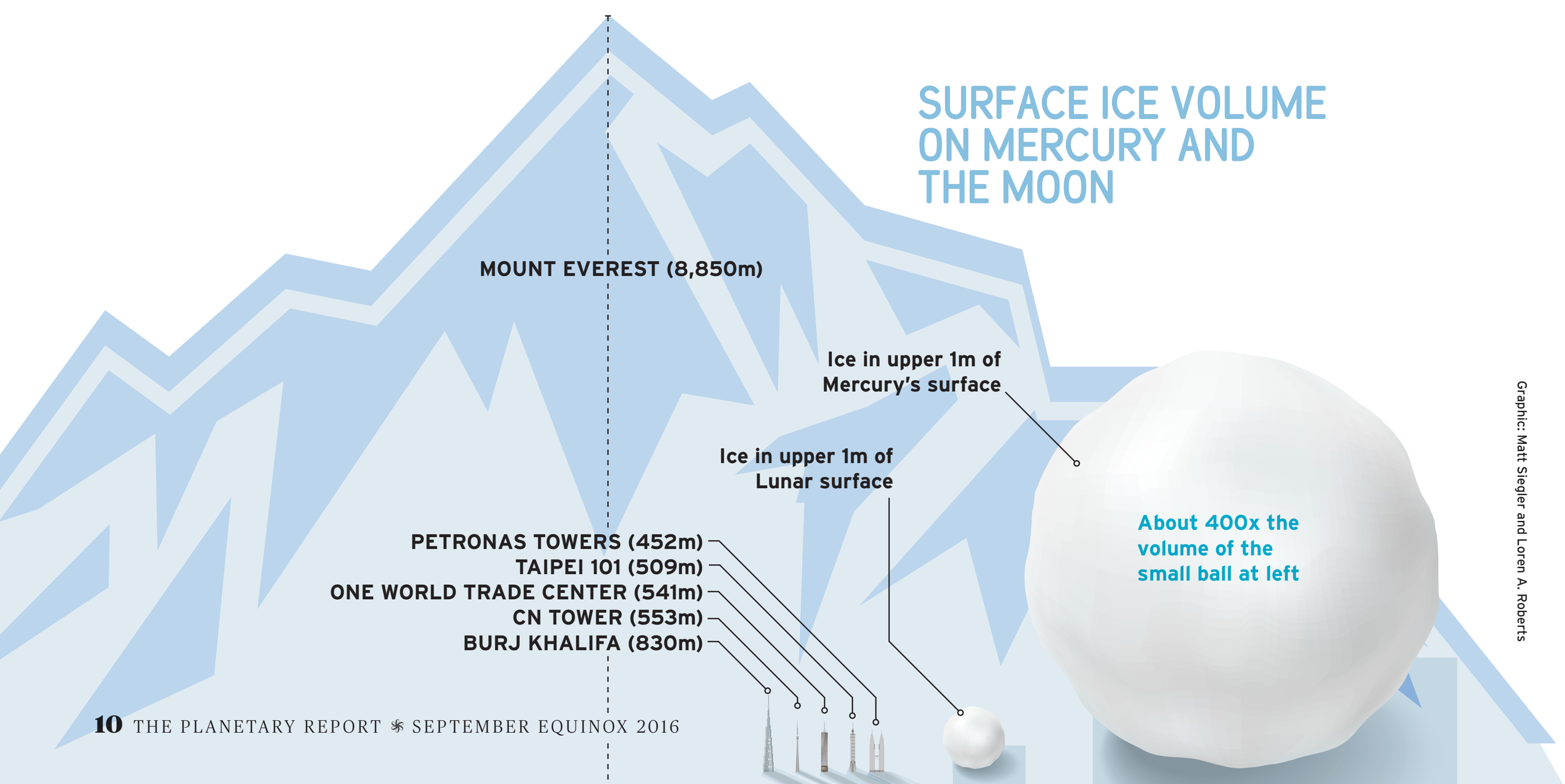
On the other hand, if impact frequency was not the decisive factor, it's possible Mercury was hit by a big object recently and the Moon has had a long, impact-free dry spell. Impact models for Mercury suggest that 85 to 90 percent of any liberated water would be lost back to space, with about 10 percent sticking around. In order to form the mountain-sized ball of icy material, we would need to hit Mercury with a comet about 5 kilometers (3 miles) in radius, something around the size of Halley's Comet. Given our estimates of how quickly ice can erode on the surface, the relatively pure ice we see on Mercury would demand that the planet was hit by a Halley-sized comet in the last 10 to 20 million years. However, this argument also demands that nothing of that sort hit the Moon for roughly a billion years.

If Mercury was just lucky and had a recent, rare impact, can we find the crater? Without further evidence, we have to assume the difference in ice between Mercury and the Moon may not be due to big impactors but rather to a slow, steady trickle of hydrogen (which forms water with oxygen already in the soil) from micrometeorites or from the solar wind. Then again, perhaps some small amount of present-day volcanism is responsible for Mercury's abundance of pure ice. Or perhaps it is not an issue of sources at all, but rather sinks—the ability to retain water ice.

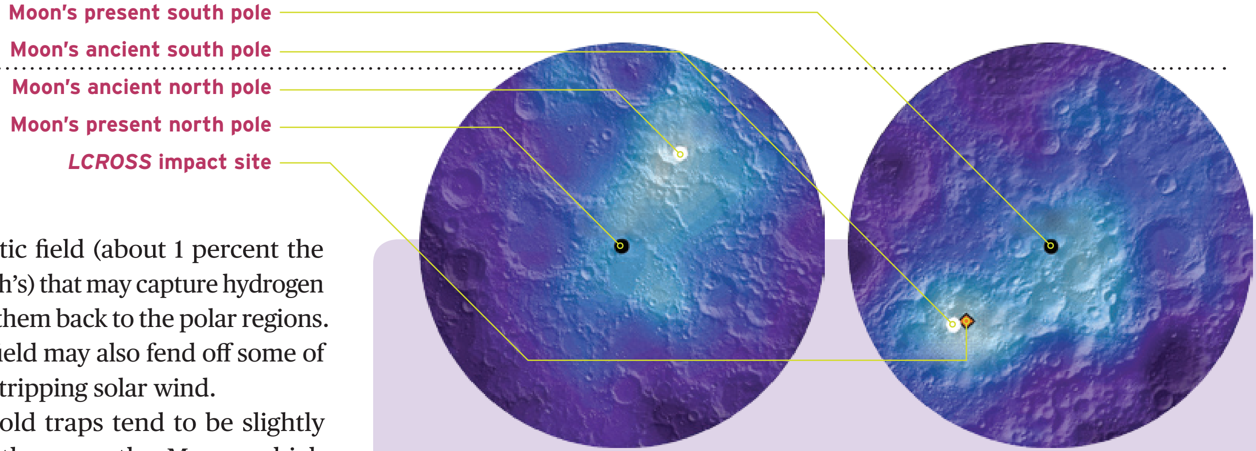
SINKS: HOW MERCURY HOLDS ITS WATER

As discussed earlier, from a temperature perspective, the Moon has a bigger catcher's mitt for water than Mercury. However, other factors might make Mercury a better "ice trap." For starters, Mercury has about two and a half times the gravity, so water molecules will stick around longer. In addition, Mercury has

BELOW *Estimated volumes of ice in the top meter of the surface of Mercury and the Moon can be compared to the world's tallest mountain versus the world's tallest buildings. We estimate there is about 400 times more ice on Mercury, despite there being about five times as much cold "real estate" for ice on the Moon.*



Graphic: Matt Siegler and Loren A. Roberts



Lunar Polar Wander?

If water ice were deposited on the Moon in the present-day temperature environment, we would expect to find it distributed fairly symmetrically in craters around the poles, as seen on Mercury. We have found ice at the poles of the Moon, but…well, it wasn't exactly at the poles. The higher concentrations of hydrogen (as mapped by neutron spectrometers) were shifted off the poles by about 5 or 6 degrees. Moreover, the shift was in opposite directions for each pole. The best explanation is that the poles have moved. If ice was once distributed evenly around the Moon's old poles—maybe in large concentrations like we see on Mercury—a shift in the poles would explain why most of the ice disappeared, leaving only the small amounts we see today near the new spin axis.

a small magnetic field (about 1 percent the strength of Earth's) that may capture hydrogen ions and bring them back to the polar regions. The magnetic field may also fend off some of the hydrogen-stripping solar wind.

Mercury's cold traps tend to be slightly warmer than those on the Moon, which may—counterintuitively—be an advantage. The "permanent shadows" of the Moon and Mercury are not devoid of day/night cycles. They receive quite a bit of reflected light and heat from illuminated areas nearby. If water is abundant enough locally (as it is on Mars), temperature oscillations can actually "pump" ice back downward (as it does on Mars). In this way, the slightly warmer temperatures and larger temperature cycles on Mercury may aid the stability of ground ice.

However, we have not shown that these effects outweigh the Moon's advantage in ice-friendly real estate. It may be that we need to step back and consider not only whether ice is stable now but whether it was stable in the past.

STABILITY: THE MOON'S MAD DANCE

Long-term ice stability is the issue I have dealt with most, so I will readily admit that personal biases lead me to give it a bit more attention than sources and sinks. That said, there is much in the history of the Moon that could explain why we see so little water ice there.

While Mercury's orbit has been fairly stable, the Moon's orbit and tilt have changed a lot in the past few billion years. Scientists generally believe the Moon formed from a ring of debris left by a giant impact on the proto-Earth. The debris was close to Earth at first, about three Earth radii away, but the Moon is now about 60 Earth radii away. How did it get so far out there? Tidal interaction between the Earth and Moon slowed down Earth's spin, allowing the Moon to drift outward.

As it migrated, the Moon's orbit and tilt were forced to do a few odd dances due to interactions with the Earth and Sun. One of the oddest dance moves was something called a Cassini State Transition. Giovanni Cassini, the seventeenth-century astronomer for whom the Saturn mission was named, noted that we never see the Moon's far side despite the precession of its orbit. That is, the Moon's orbit is an oval, and the farthest point from Earth in that oval revolves around the Earth every 18.6 years. Cassini's observation meant that the spin axis of the Moon also precesses in an 18.6-year cycle. So the Moon's orbit and its tilt are related, and they are dynamic.

The rate of orbit precession has changed as the Moon has moved outward. However,

ABOVE *NASA's Resource Prospector rover will carry out the first mining expedition on another world. The rover (now in development) will excavate volatiles such as hydrogen, oxygen, and water from the Moon.*

MATT SIEGLER *is a planetary scientist specializing in thermal processes such as subsurface temperatures, volatile stability, and geothermal heat flow on solid body planets. He is a team member on the* Lunar Reconnaissance Orbiter *and the* Mars InSight *missions. He also double-majored in film production at Cornell and worked on the 2014* Cosmos *documentary series and PhD Comics' YouTube documentaries. He is a research scientist with the Planetary Science Institute and research professor at Southern Methodist University. He is also a member of The Planetary Society.*

Lunar poles: NASA; ancient pole data: Rich Miller, University of Alabama, Huntsville; photo: NASA we know the rate of spin-axis precession has remained fairly steady. Mathematically, the only way for orbital and axial precession to have kept in sync as the Moon slipped farther from Earth would be for the Moon to have increased its tilt. Increased obliquity would change the size and speed of the circle traced by the Moon's axis on the cosmic dance floor. The bottom line is that distance from Earth controls the obliquity of the Moon. Tip the Moon too much, and ice is no longer stable.

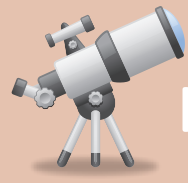
The Cassini State Transition is the big dip in our dancing analogy, a point in the Moon's orbital evolution where the Moon tipped on its side, such that its pole was not tilted 1.5 degrees relative to the Sun as it is today but about 83 degrees! For half a billion years or so, while the Moon was tipped on its side, there were no permanently shadowed craters at the poles. Exposure to direct sunlight could have boiled off the Moon's original ice—if there was any. Mercury never performed that particular dance move, so its ice might be from the very early solar system.

WATER: THE WAY FORWARD AND BACK

If the ice on the Moon and Mercury is billions of years old, it may hold the answers to our questions about the origin of water on Earth. Isotopic analysis and geologic context may help us date the ice and pinpoint its source, whether it be comets, asteroids, volcanoes, or solar wind.

New data from *MESSENGER*, *Lunar Reconnaissance Orbiter*, and other spacecraft visiting the Moon have deepened the ice mystery and given forensic planetologists critical clues. We are developing ideas and new instruments to fill the gaps in our understanding of how the solar system formed. In the next few years, we will likely have small-scale spacecraft, or "mini sats," looking at lunar polar ice with neutron spectrometers and lasers. NASA Ames is leading efforts to send the Resource Prospector rover to drill into the ground near a pole of the Moon. It's an exciting and meaningful challenge that lies ahead, and I hope The Planetary Society will share in the adventure.

WHAT'S UP? *by Bruce Betts*



IN THE SKY

Very bright Venus is in the West soon after sunset. Much dimmer, yellowish Saturn is near it late in October. Reddish Mars is to the upper left of Venus, gradually growing closer as the weeks pass. Mercury is far from Venus' lower right shortly after sunset in December. The Geminid meteor shower, typically the best meteor shower of the year, peaks December 13/14, though a nearly Full Moon will make viewing more challenging. It is still worth a look as brighter meteors will still be visible.

RANDOM SPACE FACT

The *Juno* mission, which arrived at Jupiter on July 4, 2016, is the first spacecraft to operate at Jupiter without nuclear power. It has the largest solar panels ever for a planetary mission: three 9-meter (29-foot) long panels, with a total area of about 60 square meters (650 square feet).

TRIVIA CONTEST

Our December Solstice contest winner is Kenneth E. Raisanen of Ontonagon, Michigan. Congratulations! **THE QUESTION WAS:** Who was the first person to fly on two different orbital spaceflights? **THE ANSWER:** Gordon Cooper on *Faith 7* (*Mercury* program) and *Gemini 5*.

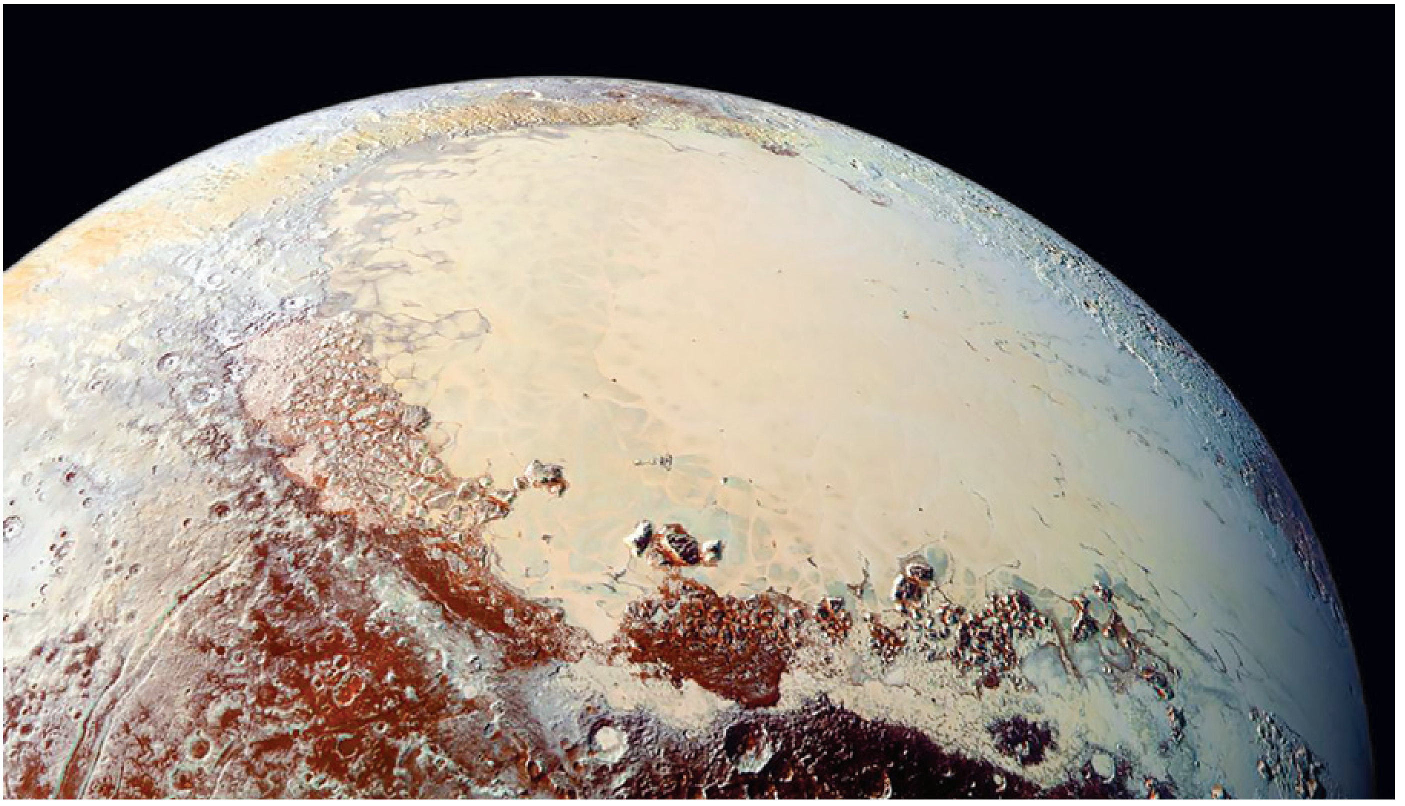
Try to win a free year's Planetary Society membership and a *Planetary Radio* T-shirt by answering this question:

About how long does it take light to travel from the Sun to the Earth?

E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 60 S. Los Robles Ave., Pasadena, CA 91101. Make sure you include the answer and your name, mailing address, and e-mail address (if you have one). By entering this contest, you are authorizing *The Planetary Report* to publish your name and hometown. Submissions must be received by December 1, 2016. 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*.

KELSI SINGER *is a post-doctoral researcher on the* New Horizons *team.*



Pluto At Last

New Horizons Reveals Worlds of Surprises

IN JANUARY OF 2006, NASA launched the relatively light and extremely capable *New Horizons* spacecraft on a powerful Atlas V rocket. This made *New Horizons* the fastest object to be flung from Earth into space. Why the hurry? Its destination was Pluto. Scientists expected Pluto's tenuous atmosphere to shrink towards the surface and eventually collapse as Pluto moved away from the Sun, and we wanted to arrive in time to study it. The distance *New Horizons* had to travel was vast, even compared to other space missions. The average one-way light time to Mars is 14 minutes, whereas the light time to Pluto when *New Horizons* arrived was 4.5 hours.

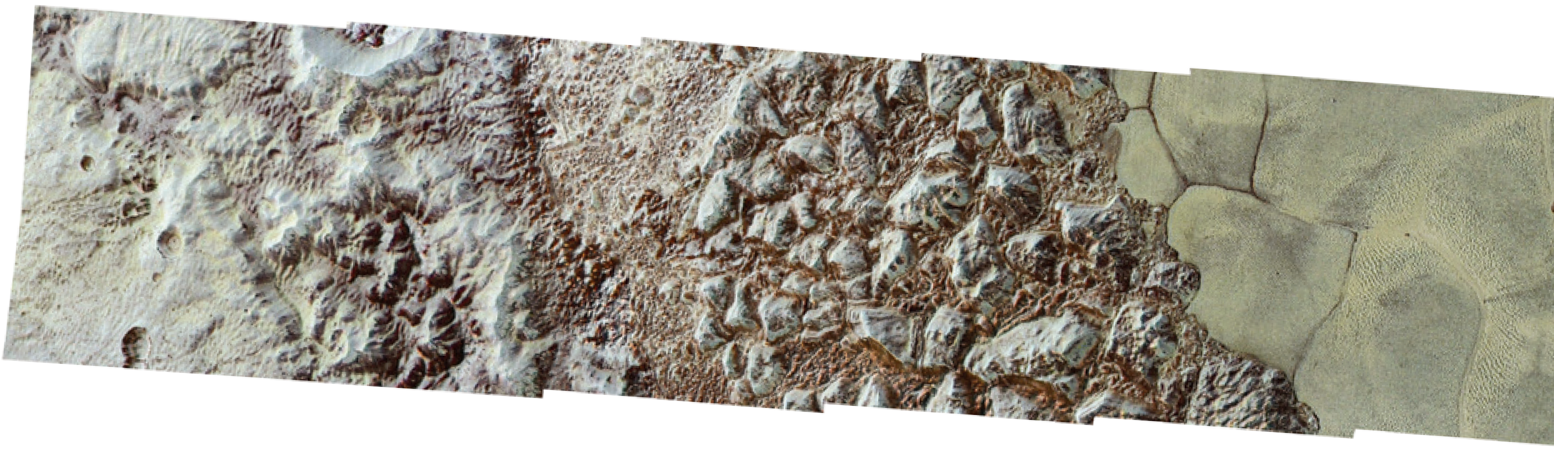
Nine and a half years later, July 14, 2015, the *New Horizons* spacecraft flew through the Pluto system, traveling at 14 kilometers (9 miles) per second. Pluto and its large moon Charon were revealed to be fascinating worlds unlike any others humanity has visited. And, fortunately, Pluto's atmosphere was still there for us to study. From the first-ever close-ups of its unexpectedly young surface features to the beautiful backlit images of its atmospheric haze, Pluto is truly a scientific bonanza. Its unique features have much to teach us about how planetary bodies of this size operate.

ENIGMATIC MARKS ON PLUTO'S GREAT PLAIN

Pluto displays many geologic features that are unique in the solar system. The left side of Pluto's bright "heart," informally termed Sputnik Planitia, is a large, basin-like depression filled with nitrogen ice. Nitrogen ice is mobile, like a glacier, at Pluto temperatures

ABOVE *From mountains, to polygons, to startlingly young surfaces, the many surprises* New Horizons *revealed instantly intrigued and challenged us to re-evaluate what we knew about the Pluto system. A major surprise was the left lobe of Pluto's huge, bright, heart-shaped feature, which contains a smooth yet active field of nitrogen ice, and dominates this enhanced color view.*

Image: NASA/JHUAPL/SwRI

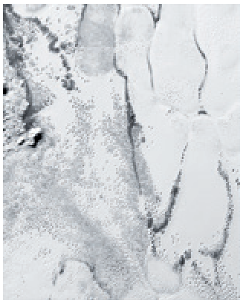


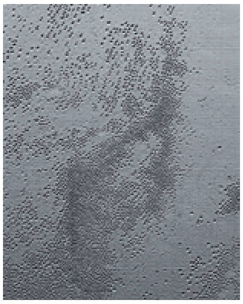
ABOVE *The images in this enhanced color mosaic are part of a sequence taken near* New Horizons' *closest approach to Pluto. With resolutions of about 76 meters per pixel, they show features about half the size of a city block. This view, northwest of Sputnik Planitia, moves across the al-Idrisi mountains, onto the heart's shoreline and just into its icy plains. For more information, go to* **planet.ly/plutocloseup**.

RIGHT *These close-ups from Sputnik Planitia reveal regions of elongated polygons (left) that may indicate a southward flow of material. Both images show unusual pits that may have formed through a combination of sublimation and ice fracturing.*

(average of 38 K on the Kelvin scale, or -391 degrees Fahrenheit, or -235 Celsius). The fact that nitrogen ice can flow explains the relatively flat surface of this large surface feature. The strange polygonal shapes in Sputnik Planitia are thought to form through convection, a process seen in the action of a lava lamp. At Sputnik Planitia, warmer ice rises from below through the center of the polygons, and cooler ice descends at the edges.

Taking a closer look, we see the surface of Sputnik Planitia becomes even more peculiar. Pits etch much of the surface, and some of them are elongated and parallel to each other. These pits likely form through sublimation, with nitrogen ice converting directly from a solid on the surface to a gas in the atmosphere. The elongation may be due to fractures in the ice and/or flow and stretching of the overall surface.



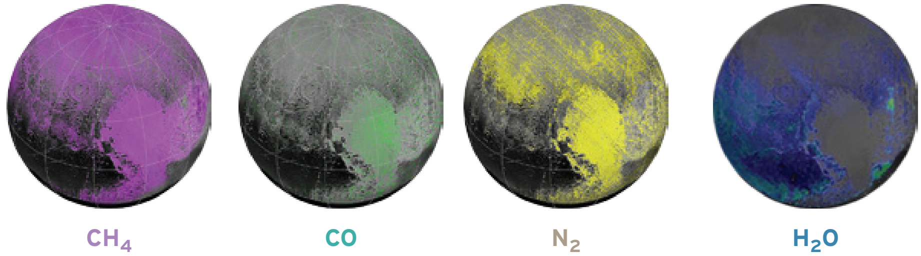


Tall mountains ring the western edge of Sputnik Planitia. Some reach as high as three miles above the plain. These mountains are mostly made up of water ice, the same ice we are familiar with on Earth. But on the surface of Pluto, water ice is so cold it acts like rock. Water ice forms the "bedrock" on Pluto, making up the bulk of the outer third of the body. This ice fractures and breaks, just like rock in fault zones on Earth. So, how did the tall mountains come to be at the edge of Sputnik Planitia? Something must have caused the breakup of the water ice into the blocky mountains we see today. It is interesting to realize that the difference in density between the rock-like water ice and the glacier-like nitrogen ice is similar to the difference in density between water ice and water itself. The water-ice blocks may have floated to their present locations.

TWO CRYOVOLCANOES: IN THE LIGHT AND DARK

A very different kind of mountain lies to the west of Sputnik Planitia's tip. The informally named Wright Mons (after the Wright brothers) is an enormous mound with a large central depression. About 160 kilometers (100 miles) wide and 4 kilometers (about 2.5 miles) high, Wright Mons is almost as wide as the Florida peninsula and twice as tall as the Grand Canyon is deep. The ropey texture of the surface and its built-up appearance suggest the mound formed through icy volcanism. Exactly what materials and mechanisms created this "cryovolcano" are not obvious. Much of Earth's volcanism is driven by magma (liquid rock), rising through the crust because it is less dense than solid rock. But water, which forms the ice-block bedrock

Images: NASA/JHUAPL/SwRI



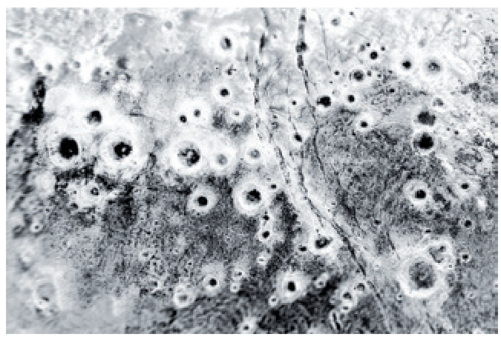
LEFT *These globes are colored to show the distribution of four ices on Pluto. Brighter colors represent higher concentrations. Water (H_2O) ice makes up the "bedrock" of Pluto, while nitrogen (N_2), carbon monoxide (CO), and methane (CH_4) are surface deposits that sublimate and redeposit during Pluto's seasonal cycles.*

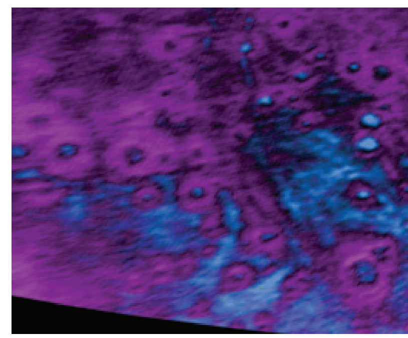
on Pluto, is more dense when liquid than it is when solid—which is why ice cubes rise to the top in your glass. Other pressures could have driven liquid to the surface, but it is also possible the flow that created Wright Mons was more like toothpaste: not a fluid, but still able to flow.

Wright Mons happened to be on the daylight side of Pluto when *New Horizons* arrived, so we got a great view of it. And then we made another discovery, thanks to Pluto's hazy atmosphere. The haze reflects light onto the ground. So, even though there was no direct sunlight, we were able to see past the terminator (the day/night line) into part of Pluto's night side. It turns out Wright Mons has a cousin just to the south, which has only been observed in haze-light. The informally named Piccard Mons (after the physicist and balloon explorer Auguste Piccard) is even larger than Wright Mons, and also contains a large central depression.

INTRIGUING ICES

New Horizons carried a suite of instruments to examine the surfaces of Pluto and its moons. Four ices and a dark, reddish material dominate Pluto's surface. The water ice bedrock is coated in many places with less familiar ices, such as nitrogen ice (N_2), methane ice (CH_4), and carbon monoxide (CO) ice. The distribution of bright ices and dark material roused scientists' curiosity. It appears that sunlight and other high-energy particles hitting Pluto convert methane into heavier hydrocarbons, which are dark in color. This dark material is also warmer, so it has the effect of preventing further deposition of bright ices like methane ice and carbon





ABOVE *In Pluto's informally named Vega Terra region is an area crowded with "bright-haloed" craters (left). The large crater at bottom right of the frame is about 50 kilometers (30 miles) across. At right, false color indicates a connection between the bright halos and methane ice (purple) and water ice (blue).*

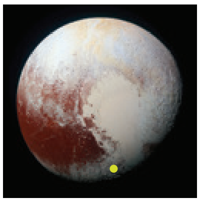
monoxide ice. Thus, a feedback cycle, with processing of hydrocarbons, may keep certain regions dark in color.

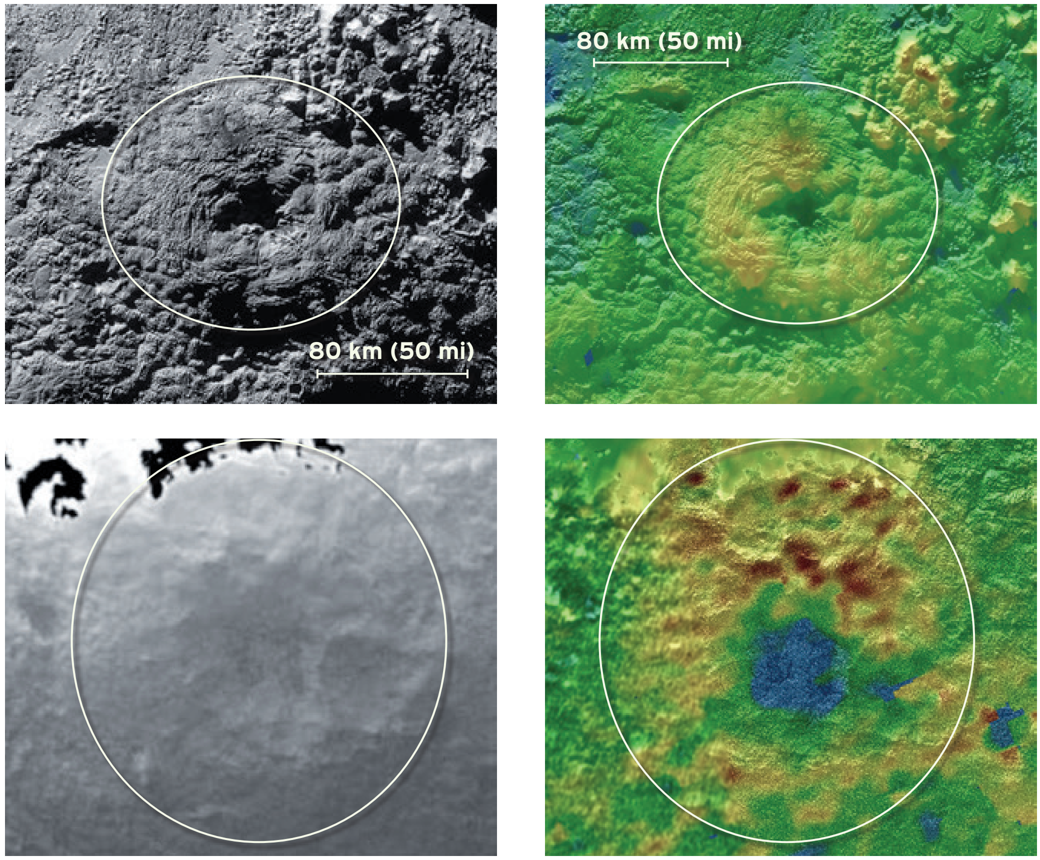
Bright ices can be seen as deposits in other areas of Pluto. In addition to nitrogen ice, Sputnik Planitia contains methane and carbon monoxide ices. Methane ice also accumulates at higher altitudes, as on the tops of crater rims and peaks of mountains. Water ice is prominent in a few spots, where it is not masked by the other ices. Often the locations associated with water are fractures or faults, which may expose a fresh surface or serve as a conduit for water ice to be spat onto the surface. Investigations continue into the reasons for the varied distribution of ices on Pluto's surface.

KELSI SINGER *conducted graduate work on the geology and geophysics of Jupiter's and Saturn's icy moons and then worked with the* Lunar Reconnaissance Orbiter *Camera team, surveying Earth's Moon, before joining* New Horizons *to study Pluto and Charon. Singer's research leverages comparative planetology to investigate universal geologic processes across the solar system, including tectonics, landslides, and impact cratering.*

The New Horizons *mission is led by the Southwest Research Institute. The spacecraft was built, and is operated by, the Johns Hopkins Applied Physics Laboratory.*

Image: NASA/JHUAPL/SwRI





RIGHT *Two large, dome-like structures with central depressions stand out on Pluto as potential cryovolcanoes. At upper left, Wright Mons is visible on Pluto's sunlit side. At lower left, Piccard Mons is visible on Pluto's night side thanks to reflected haze-light. The right column shows elevation data for the two structures, with lows shown as blue and highs as red. Above, the dot shows the spot on Pluto's limb where the features are located. Piccard is just into the dark side.*

OPPOSITE, TOP *Taken just 15 minutes after the spacecraft's closest approach, this angle highlights the sunlight coming through Pluto's tenuous, distended atmosphere, thus revealing more than a dozen layers of haze. Some dark mountains rise to the left of Sputnik Planitia's "tip." Within Sputnik Planitia, the parts that appear dark are the small pits mentioned earlier. The bright areas are smooth patches that reflect more light away from the Sun and toward the spacecraft.*

WEATHER: FRIGID WITH EXTENSIVE HAZE

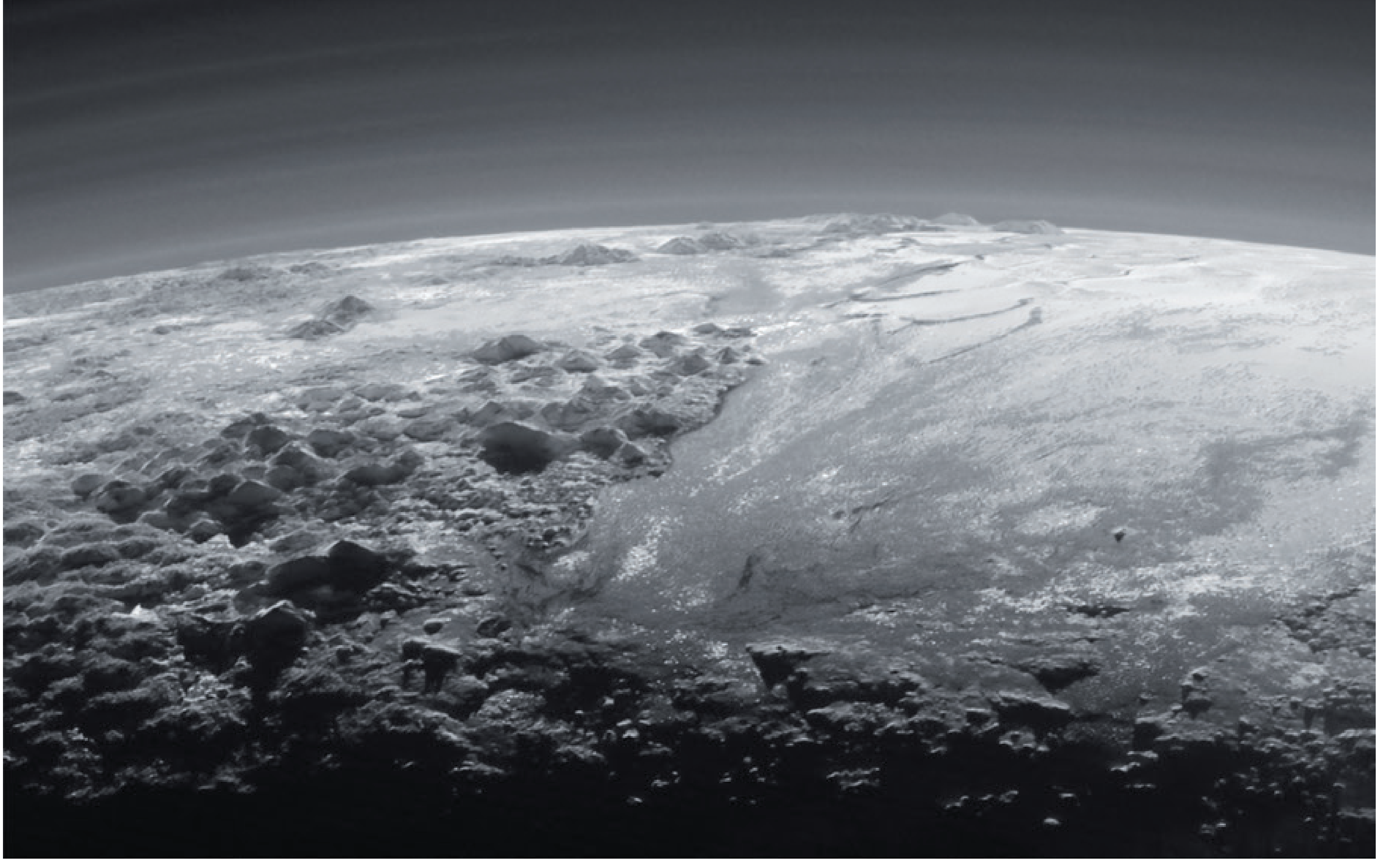
As a flyby mission, *New Horizons* went through three phases of observation at Pluto: on the way in (called the approach phase), during closest approach (when the spacecraft dove through the system), and on the way out (departing phase). While departing, the spacecraft looked back and was able to see sunlight passing through Pluto's atmosphere. Scattering of the sunlight by small particles in the atmosphere revealed the existence of a global haze extending as far as 200 kilometers (120 miles) above Pluto's surface. High-resolution grayscale imaging showed over 20 thin, embedded haze layers in this background haze, with most of the thin layers being only one or two kilometers (about a mile) thick. The thin layers may be comparable to the ripple-like clouds that sometimes form on Earth as air moves over mountains. The mechanism producing Pluto's atmospheric layers is thought to be vertically propagating buoyancy waves. Color imaging showed Pluto's atmosphere is blue.

Compositional measurements found the atmosphere was 98 percent nitrogen, with traces of methane, carbon monoxide, and hydrocyanic acid (HCN). Although Earth's and Pluto's atmospheres are similar in containing mostly nitrogen, Pluto's atmosphere is rarified (about 60,000 times lower pressure at the surface than on Earth) and is missing that oxygen we all like to breathe.

PLUTO'S ATMOSPHERE: SMALLER THAN EXPECTED

One of the mission's big surprises was that Pluto's atmosphere is much more compact than expected. We now know this is due to cooling of the upper atmosphere, and we suspect the cooling is due to hydrogen cyanide, radiating heat to space at infrared wavelengths.

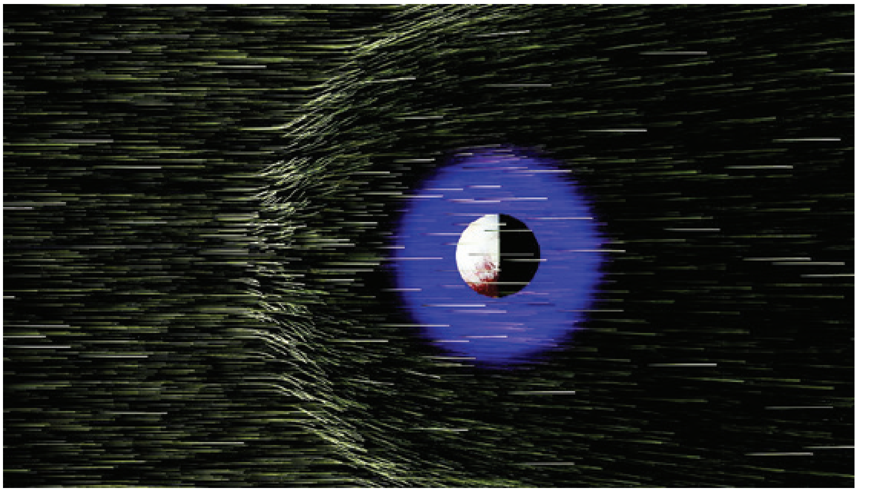
Images: NASA/JHUAPL/SwRI



With the heating efficiency of solar energy thus reduced, the upper atmosphere remains cold and compact. These conditions affect molecules, like nitrogen and methane, that escape from the top of Pluto's atmosphere. The compact atmosphere explains why we found an atmospheric escape rate that was also much smaller than expected.

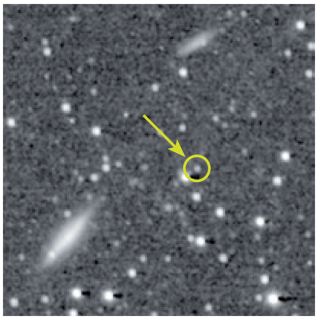
Like all objects in the solar system, Pluto is embedded in the solar wind–a flow of protons and electrons streaming out from the Sun. As solar wind particles bombard an atmosphere, the ionized outer layers of the atmosphere are stripped away. The region of interaction between the solar wind and Pluto's atmosphere is closer to the planet than expected. This means Pluto's interaction with its space environment is more like that of Mars, and less like that of a comet, than predicted.

In an elliptical orbit, Pluto is currently moving outward from the Sun. Computer models suggest that at some point in this outbound trajectory the nitrogen that makes up the atmosphere will begin to collapse (that is, freeze) onto the surface due to the decrease in solar heating. When Pluto's orbit comes back closer to the Sun again–about half a Pluto year from now, or 125 Earth years–the planet surface will heat up, and surface nitrogen will sublimate and re-form the atmosphere. Before the *New Horizons* encounter, we were concerned about reaching Pluto before the predicted annual collapse of its atmosphere. But the surface pressure observed by the radio-science instrument aboard the spacecraft showed the collapse had not yet begun. In fact, the atmosphere appears to have a higher surface pressure now than when Pluto was at its closest distance from the Sun. Pluto continues to surprise us and expand our knowledge of how small planets can operate.

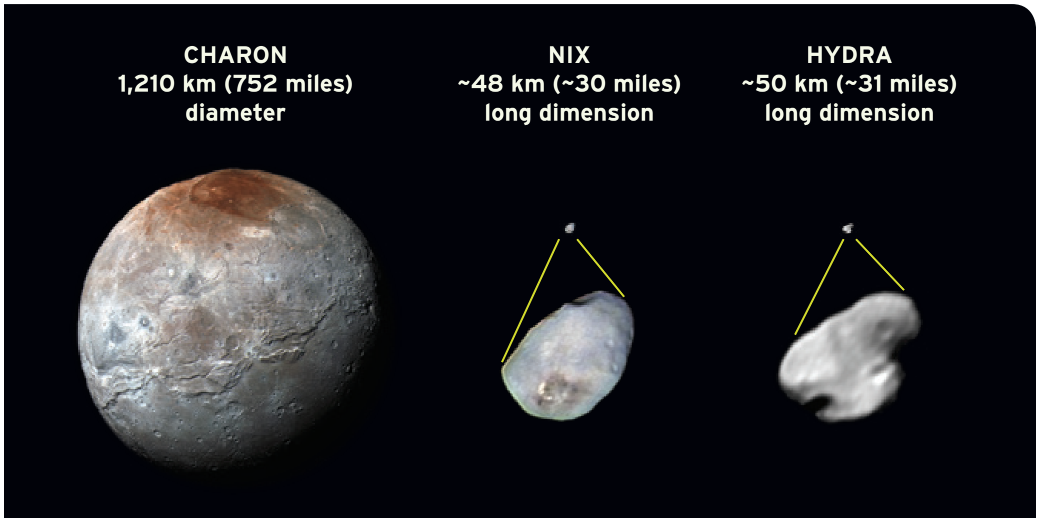


ABOVE *Pluto presents an obstacle to the solar wind, creating a bow shock similar to the curved bow wave in front of a boat.* New Horizons' *instruments measured the interaction region between Pluto's atmosphere and the solar wind.*

Image: NASA/JHUAPL/SwRI; Illustration: Steve Bartlett and NASA's Scientific Visualization Studio



ABOVE *In mid-July,* New Horizons *also caught a glimpse of Kuiper Belt object Quaoar ("Kwa-war"). At 1,100 kilometers (690 miles) across, Quaoar is roughly half the size of Pluto, or slightly smaller than Charon. In this view, Quaoar was about 6.4 billion kilometers (4 billion miles) from the Sun, and about 2 billion kilometers (1.3 billion miles) from the spacecraft. To see a short animation of Quaoar's movement, go to* **planet.ly/quaoar**.



Pluto's Moons: More Surprises

Though Pluto usually steals the show, its moons are fascinating in their own right. Charon, about half the diameter of Pluto, has a prominent red pole, many large tectonic scarps, and a smooth southern plain. The plain is likely the product of a cryovolcanic flow (or flows) early in Charon's history. Adding to the ranks of strange features on Charon, its smooth plains are interrupted by several mountain peaks that are surrounded by moats. It is possible these peaks are features that the plains material flowed up to but did not overtop.

Nix and Hydra are the two largest of Pluto's four small moons. They are only about 30 miles long (about the size of Denver) and lumpy like potatoes. Impact craters are their most prominent features. Interestingly, *New Horizons* took color views of Nix and found that its largest impact is surrounded by darker, redder material, possibly material ejected onto the surface. Impact craters are planetary excavators, revealing the subsurface material we would not otherwise see. This red material on Nix could be similar in composition to the reddish organic materials seen on Pluto and on Charon. However, the rest of Nix and the other small moons are otherwise relatively bright and colorless, which creates somewhat of a mystery: how could these surfaces remain so "clean"?

FARTHER DESTINATIONS

New Horizons is still speeding through the outer solar system. It's on its way to a close encounter with a small Kuiper Belt object (about 40 kilometers, or 25 miles, across) on January 1, 2019. The object, designated 2014 MU69, is thought to be a frozen remnant of the earliest stages of solar-system history. Because it is intermediate in size—between smaller comets and larger Kuiper Belt objects like Pluto—it should provide unique insights into planetary formation. The *New Horizons* team is hoping to fly about four times closer to 2014 MU69 than we did to Pluto, allowing for high-resolution image and composition-data collection. The entire extended mission was just approved by NASA and will go on until 2021, when *New Horizons* will reach a point 50 times the distance from Earth to the Sun.

The unique science made possible by a spacecraft venturing into the Kuiper Belt has already yielded many new insights and brought up new questions. The images of Pluto and its moons revealed stunning features, both beautiful and scientifically fascinating. Along the way to its next close encounter, our spacecraft will make remote observations of about 20 far-flung bodies, and, afterward, explore the heliosphout to 50 AU. We invite everyone to follow along as *New Horizons* explores the Kuiper Belt.

Images: NASA/JHUAPL/SwRI

Wonderful Society Adventures!

THE GREATEST LIGHT SHOW ON EARTH

MARCH 2-8, 2017

Watch the Aurora Borealis light up the night skies! See grizzlies, the highest peak in North America, and more. Astronomer Tyler Nordgren will be our guide.

SUN VALLEY IDAHO TOTAL SOLAR ECLIPSE

AUGUST 18-26, 2017

An Eclipse adventure from Boise to Grand Teton and Yellowstone National Parks! Experience the Eclipse from a mountaintop at Sun Valley. Plus, enjoy rafting the Snake River and a rodeo in Jackson Hole!

GRAND TETONS TOTAL SOLAR ECLIPSE

AUGUST 15-23, 2017

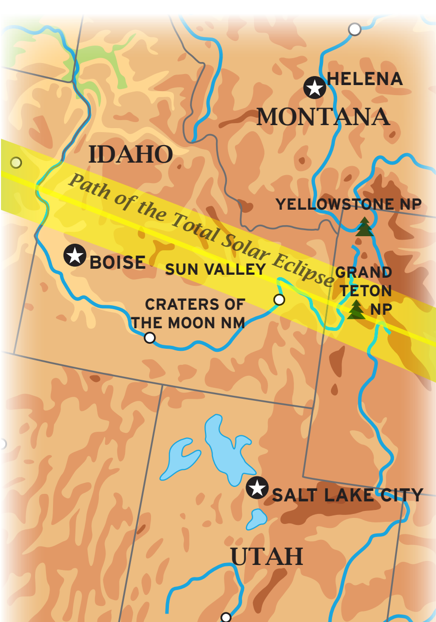
Take in the Eclipse from atop Rendezvous Peak, overlooking the Tetons and Jackson Hole! Waiting List only.

IN SEARCH OF AMELIA EARHART

JUNE 21–JULY 11, 2017

On the 80th anniversary of Amelia Earhart's Round the World flight, be a part of this expedition to search for Amelia's plane and artifacts. We will sail onboard the *Reef Endeavour* to remote Nikumaroro Island, 1,000 miles north of Fiji.

Join fellow Planetary Society members on these thrilling adventures! To learn more, call Betchart Expeditions at 800-252-4910, or visit *betchartexpeditions.com*.



Volunteer map: Tom Kemp and Loren Roberts

KATE HOWELLS *is The Planetary Society's Volunteer Network Manager.*

Thinking Globally, Acting Locally

THE PLANETARY SOCIETY'S global network of outreach coordinators continues to grow. We are very proud to say that we now have 35 outreach coordinators planning events and activities in 14 countries on five continents!

Each of these volunteers is active in their area, bringing together members, partnering with local organizations, and reaching out to the public to educate and inspire. When it's time to celebrate a mission or advocate for the future of exploration, these passionate volunteers enable us to engage in truly global outreach campaigns.

Recently, our volunteers have taken part in a fantastic array of global events. In May, volunteers across Canada participated in the nationwide Science Rendezvous festival, showcasing space and planetary science at their local events. In June, our volunteers around the world participated in Asteroid Day, a global campaign to raise awareness of the danger of asteroid impacts and the actions we must take to prevent them. At events such as movie nights and lectures at observatories, our volunteers brought people together to learn more about Earth's cosmic neighborhood and get engaged in the effort to protect our planet. And over the course of this past summer, volunteers worldwide celebrated *Juno*'s arrival at Jupiter, teaching people of all ages about this enigmatic planet and our latest mission to understand it.

We at The Planetary Society are thrilled to be able to play a major part in such events around the world. Our amazing team of volunteer outreach coordinators makes it possible.

Check out **planetary.org/about/volunteers** to see if there's an outreach coordinator near you. And to get involved, go to **planetary.org/volunteer**.

ABOVE *The Planetary Society's global network of volunteer outreach coordinators is expanding! This map shows the locations of their home bases. Thanks, everyone!*

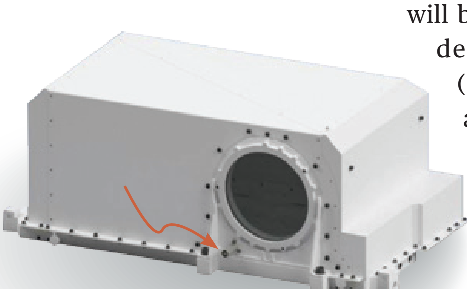
BRUCE BETTS *is director of science and technology for The Planetary Society.*

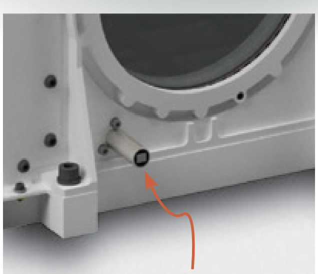
Listening to Mars

Microphones on Mars, and Our Names Fly to an Asteroid

LISTEN UP! MICROPHONES TO FLY TO MARS

What does Mars sound like? We'll get another chance to find out. The Mars 2020 mission has announced that microphones will fly on board their spacecraft, which is a near-copy of the *Curiosity* rover, with different instruments. There will be JPL-provided entry, descent, and landing (EDL) microphones, and there will be a microphone included in the SuperCam science instrument, a project led by Roger Wiens at Los Alamos National Laboratory in partnership with the French space agency CNES.





ABOVE *Here is one possibility for mounting the Mars Microphone on the Mars 2020 masthead. The microphone would be mounted on a tiny tube protruding from the warm electronics box, on the bracket holding the window for the SuperCam.*

Photos: S. Maurice et al., 47th Lunar and Planetary Science Conference

This is very exciting news for The Planetary Society and its members who have been trying to get microphones to Mars for the last 20 years. Our efforts were crucial to continually putting the idea of microphones into the consciousness of people who work on Mars exploration. Congratulations, microphones will fly again!

A BRIEF HISTORY OF NO MARTIAN SOUNDS

Planetary Society Cofounder Carl Sagan was perhaps the first to formally suggest the idea of placing a microphone on Mars. The Planetary Society flew the Mars Microphone on NASA's *Mars Polar Lander* mission in 1998 as part of a Russian Light Detection and Ranging (LIDAR) instrument. It was not only the first microphone to go to Mars, but it also was the first privately funded planetary experiment. Sadly, *Mars Polar Lander* crashed on Mars in 1999, but The Planetary Society didn't give up.

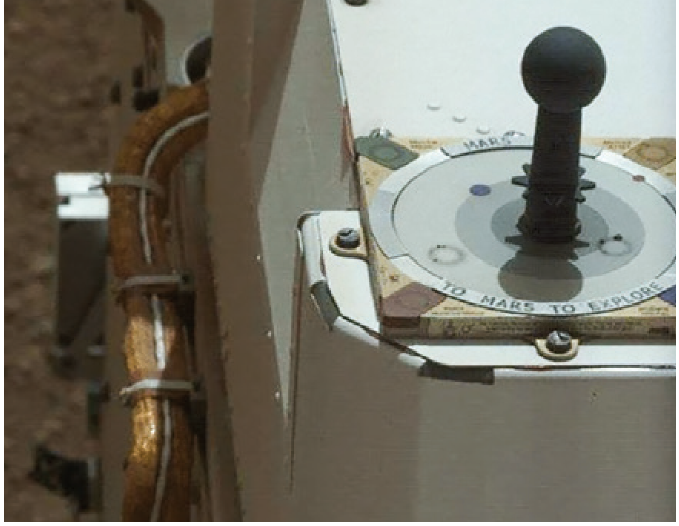
The Planetary Society Mars Microphone was later selected to fly on the ultimately cancelled CNES Mars Netlander missions. Then The Planetary Society, including Mars Microphone creator Greg Delory of U.C. Berkeley, worked with the acoustic sensor on *Cassini-Huygens* to turn science data into sound from Titan in 2005. This allowed the public to "hear" the wind sound of the spacecraft's descent through the atmosphere. In 2007, The Planetary Society partnered with Malin Space Science Systems on its microphone in the *Phoenix* descent imager, which was never turned on because of the potential for an electronic problem.

Mars remained silent. Well, really, it was more of a question of, if a dust devil moves over your spacecraft on Mars, but no microphone is there to hear it…well, you get the idea. The Planetary Society, alone or with partners, tried to get microphones on every lander that has gone to Mars since *Mars Polar Lander*. Some were detailed proposals and technical studies, and some were quick rejections. None were rejected due to technical flaws, but the challenge has been in convincing space agencies that microphones are worth the resources in terms of time, mass, data, and added complexity.

WHAT IS FLYING ON MARS 2020?

The SuperCam microphone ties specifically into the Mars 2020 mission's science. SuperCam, the follow-on to ChemCam on *Curiosity*, uses laser-induced breakdown spectroscopy (LIBS)—vaporizing rock with a laser and analyzing the spectral result to determine the rock's composition. Its microphone can enhance its science, since testing on Earth indicates that analysis of the volume of the sound (kind of a crack

Thanks! Planetary Society members have helped make these projects—and many others—possible! Thank you.



ABOVE *Once on Mars,* Curiosity*'s Mastcam took four images of its photometric calibration target (MarsDial) on sol 3 (August 9, 2012). The images, taken over about 8 minutes, show the gnomon moving slightly. To watch it move, go to* **planet.ly/marsdial**.

Images: NASA/JPL/MSSS Animation: Gordan Ugarkovic

or loud pop) can be used to study the mass of material vaporized by a laser shot. It also should be able to detect other sounds of interest to scientists, engineers, and the public, such as blowing winds and the crunch of the wheels rolling across the surface. The Planetary Society has been working with the SuperCam team and discussing possible ways to collaborate with them on their microphone. The EDL microphones and the EDL cameras will capture the never-before-seen or heard imagery and sounds of the entry, descent, and landing sequence.

HEAR IT!

The Planetary Society is ecstatic over the news that microphones will head back to Mars. If you are one of the Society members or supporters who have helped us in this endeavor, I hope you are not only ecstatic but feel proud also. We raised awareness of the very concept of a planetary microphone as something that would be of enormous public interest as well as of potential science and engineering benefit. We seeded the process by building and flying the first Mars Microphone. And now, some extremely capable organizations have picked up the ball and microphones are going to Mars once again. We're listening!

You can learn more about Mars Microphones and the sounds of Mars at **planet.ly/marsmic**.

OSIRIS-REx, AND OUR NAMES, FLY TO AN ASTEROID

The *OSIRIS-REx* asteroid sample-return mission is speeding toward its rendezvous with asteroid Bennu. All members of the Planetary Society as of October 2014 have their names flying on board, along with the names of nearly half a million others who wished to send their name to an asteroid. The Planetary Society, in its role as an education and public outreach partner with the *OSIRIS-REx* mission, carried out the Send Your Name to an Asteroid campaign to engage the public directly with the mission. One copy of the names will return to Earth in the sample-return capsule and another copy will ride on board the spacecraft, which will stay in space after dropping off the sample return capsule in 2023. The Planetary Society, in partnership with the University of Arizona and MIT Lincoln Laboratories, held the competition to name the asteroid (see winner Mike Puzio in *Your Place in Space* on page 5).

OSIRIS-REx will give us a window into the early history of the solar system, as asteroids are remnants of that time. It will also characterize a near-Earth asteroid, which is one aspect of protecting our planet from an impact. Bennu itself has a cumulative Earth impact probability of about 1 in 2,700 starting in 2175. Better tracking and measurement of its shape will likely drop that chance to zero. *OSIRIS-REx* is a NASA mission led by Principal Investigator Dante Lauretta of the University of Arizona.

ONLINE CLASS OPPORTUNITY

Watch a free Introduction to Planetary Science and Astronomy college class online with our Director of Science and Technology, Bruce Betts. The California State University Dominguez Hills 2016 class is archived at **planetary.org/bettsclass**.

CASEY DREIER *is director of space policy for The Planetary Society.*

A Statement for the Record

The Planetary Society Contributes to Congressional Hearings On Space

AS PART OF OUR *year-round advocacy work, The Planetary Society makes a point of contributing to nearly every U.S. congressional hearing on space. This sort of shoe-leather advocacy work is critical to representing you effectively, though it often flies beneath the media's (and our members') radar. Here is an excerpt from a recent statement for the record we submitted to the House Appropriations Subcommittee on Commerce, Justice, Science regarding NASA's budget. The budget process is currently stalled due to presidential politicking, but may move forward again after the national elections. Rest assured we are monitoring closely.*

[The Planetary Society] requests $20.3 billion for NASA in FY2017, including at least $1.71 billion for the Planetary Science Division. This is a growth rate of 5%—the same as in FY2016. Should Congress continue the budgetary momentum it has sustained for NASA in recent years, all major programs in human spaceflight, the Space Launch System, Orion, and Commercial Crew, could be funded at needed levels while maintaining the growth of the science divisions and Planetary Science.

Humankind is on the cusp of a scientific revolution. For the first time in history, we have the ability to actively search for new biology in habitable environments beyond Earth. Whether or not we choose to pursue this opportunity will be a legacy of our generation.

The search for life isn't the only reason to explore. Knowledge of our solar system's origins and evolution is revealed through the information returned by robotic spacecraft. The extremes in climate represented by Venus and Mars can help us understand changes to our own climate. And the act of exploration itself is a sign of an open, curious culture committed to the pursuit of knowledge. Recent triumphs in exploration by NASA have delighted the public with scientific wonders in our solar system, revealing active glaciers on Pluto, strange bright spots on the asteroid Ceres, flowing water-brines on Mars, and the seasons on Titan, to name only a few. NASA has achieved these discoveries by maintaining steady investment in its Planetary Science Division in previous

ABOVE *On sol 1419, (August 3, 2016)* Curiosity*'s left Mastcam took the images that make up this view of one of Mars' Murray buttes. To provide a sense of the butte's scale, space imaging enthusiast Seán Doran added a human explorer.*

Image: NASA/JPL/MSSS/Seán Doran

Horizon Goal: A new reporting series on NASA's Journey to Mars

NASA's "horizon goal"—a term popularized by the National Research Council in 2014—is Mars. The agency is building the Space Launch System and *Orion* to send astronauts there in the 2030s.

With the United States on the brink of its first presidential transition in eight years, what is the status of NASA's humans-to-Mars plans? How did the current program come to be, and where will it go from here?

The Planetary Society, in partnership with *The Huffington Post*, is seeking answers to these questions in a new reporting series called Horizon Goal. To read all the current story installments, visit **planetary.org/horizongoal**.

ABOVE *NASA is building the Space Launch System to someday carry astronauts through Earth's atmosphere and on to Mars.*

Illustration: NASA

decades, though in recent years it has been subject to cuts proposed by the White House, cuts that were mitigated regularly by Congress.

A healthy and vibrant space exploration program is an excellent investment to energize, engage, and inspire the next generation of scientists, engineers, educators, and citizens. Space missions contribute to thousands of high-tech jobs in the aerospace industry, at research laboratories, and in universities around the country. They stimulate the best and brightest with interesting and meaningful scientific and technical challenges that make our nation stronger and more competitive. NASA's exploration missions have repeatedly demonstrated their power in engaging and exciting the public imagination.

The human spaceflight efforts of NASA also face a critical decision point that will determine our legacy to future generations. The Planetary Society strongly supports Mars as the destination for human exploration, and has encouraged NASA to develop a clear, executable, and affordable plan to achieve this goal over the next several decades. An orbit-first architecture, where humans would first orbit Mars in 2033 and then land later in the decade, is one promising concept that could fit within the current budget with inflationary growth. NASA's proposed new start on a cislunar habitat is a critical step on the path to humans on Mars.

The upcoming Mars 2020 rover is a critical step toward Mars sample return, as well as an opportunity to inform future human exploration needs. While the Mars 2020 mission will collect and store a cache of samples on the surface of the red planet, NASA has yet to define a plan for follow-on missions to retrieve these samples and return them to Earth, or even explain how it will continue to support ground assets with a future scientific/telecommunications orbiter. We urge the committee to press NASA to clarify its plan to return these Martian samples to Earth in the 2020s.

NASA's infrastructure here on Earth, particularly the Deep Space Network (DSN), is crucial for the successful exploration of our solar system and the cosmos. We are concerned that recent budget cuts to the DSN will impact the reliability of the network and potentially impact the safety of our deep space assets. Plutonium-238 infrastructure is well-funded in the request, and we thank the administration and Congress for the continued support for restoring this production capability.

With the upcoming transition in presidential administrations, we urge Congress to build on the broad bipartisan support for the nation's space program and set NASA on a steady course forward. We believe humankind is on the brink of revolutionary discoveries, but only if we choose to pursue them.

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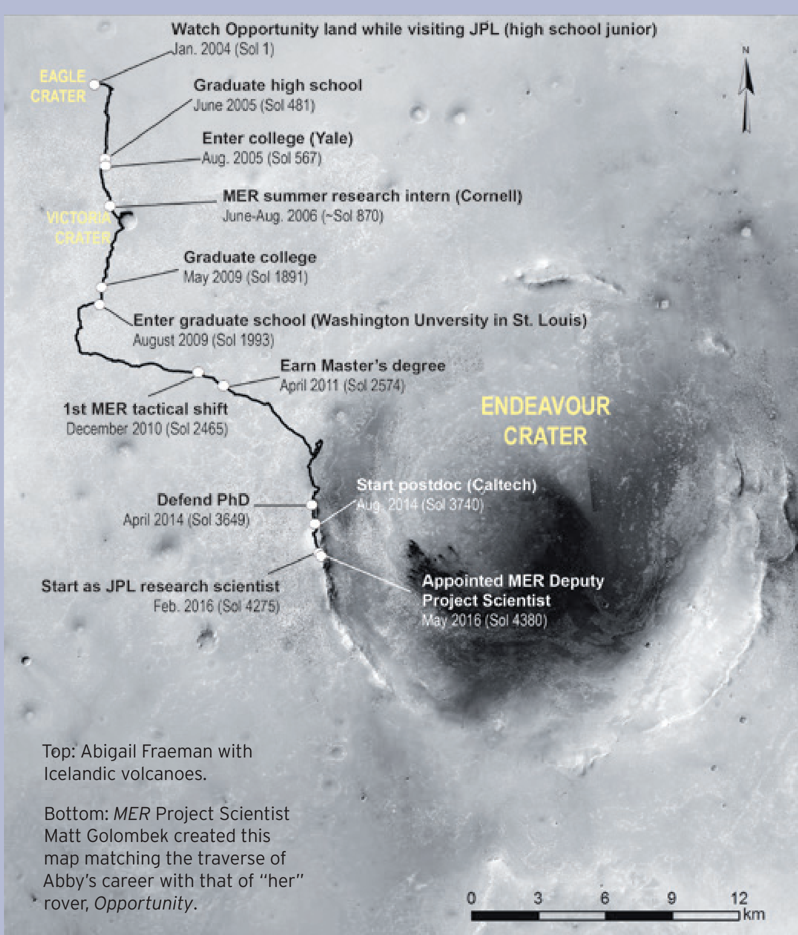

Top: Abigail Fraeman with Icelandic volcanoes.

Bottom: *MER* Project Scientist Matt Golombek created this map matching the traverse of Abby's career with that of "her" rover, *Opportunity*.

Photo: Courtesy of Abigail Fraeman; map: NASA/JPL/M. Golombek

Congratulations, Abby!

If you've been a Planetary Society member for more than a decade, you may remember Abigail (Abby) Fraeman as one of the teenaged winners of our Red Rover Goes to Mars Student Astronaut contest. In January 2004, she and sixteen other students from twelve countries witnessed the landing of the *Opportunity* rover on Mars and wrote us dispatches from inside mission operations at the Jet Propulsion Laboratory. Only 12 years later, Abigail—now Dr. Fraeman—has completed high school, college, and graduate school, and has recently been promoted to deputy project scientist of the Mars Exploration Rover mission. She now guides the science on the same rover!

Abby (a long-time Society member) told us, "My experience as a student astronaut inspired me to become a planetary scientist. Seeing *Opportunity*'s first images return while sitting alongside the scientists and engineers at JPL was thrilling, and I owe The Planetary Society so much for opening my eyes to the possibility of a career in solar system exploration."

The "traverse" of Abby's career has been quite a journey, and The Planetary Society is very proud to have played a small part in it.