THE PLANETARY SOCIETY

THE PLANETARY REPORT

MARCH EQUINOX 2018
VOLUME 38, NUMBER 1
planetary.org

MARS AS AN EXOPLANET

USING *MAVEN* TO UNDERSTAND ALIEN WORLDS

THE PLANETARY SCIENCE CAUCUS ✲ DWARF PLANETS ✲ SHOEMAKER GRANT WINNERS

EMILY STEWART LAKDAWALLA
blogs at planetary.org/blog.

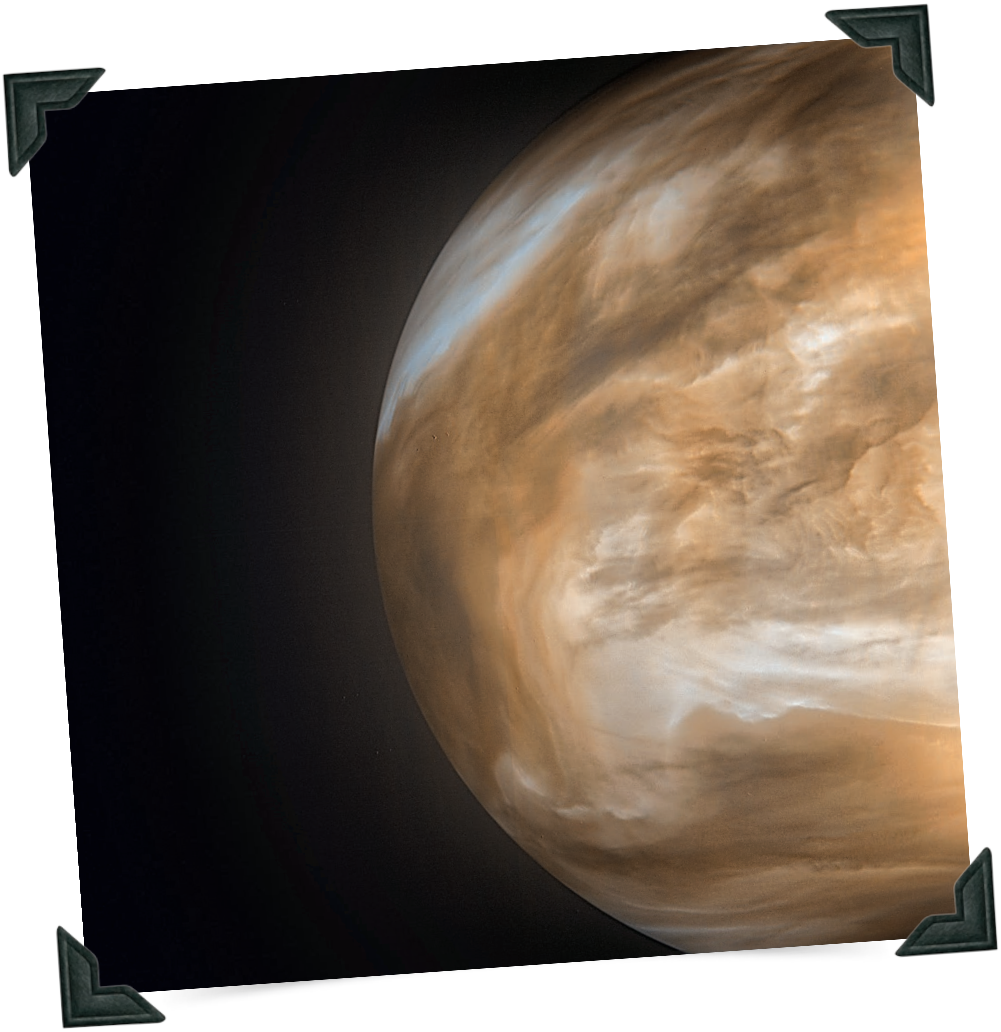

Image: JAXA/ISAS/DARTS/Damia Bouic

AFTER SURVIVING a near-death experience on its first attempt to enter Venus' orbit, Japan's *Akatsuki* spacecraft successfully began its science mission in 2015. With infrared vision, *Akatsuki* sees the warm glow emanating from Venus' lower atmosphere on the sweltering planet's night side. In areas where Venus' sulfuric-acid clouds are thicker, the planet's radiation is blocked, giving a dark appearance. When amateur image-processor Damia Bouic took this set of infrared images out of JAXA's science archive, processed them into the beautiful portrait you see here, and posted them in a guest blog on the Society's website, she revealed a new perspective on the *Akatsuki* data set that could trigger new insights and channels of research.

–Emily Stewart Lakdawalla

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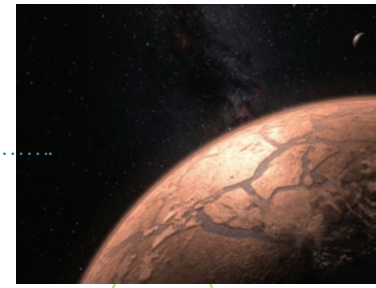

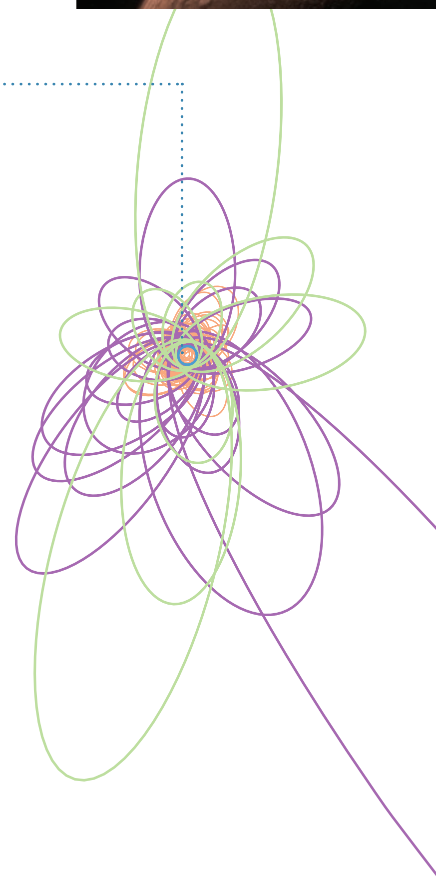

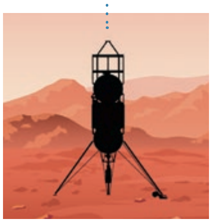

ON THE COVER: Data from the *Mars Atmosphere and Volatile Evolution (MAVEN)* spacecraft are helping scientists unravel the mystery of the Red Planet's evolution from a warmer, wetter world to the cold, dry place we know today. The insights gained will help them better judge which exoplanets might be hospitable to life as we know it. This feature, imaged by the High Resolution Imaging Science Experiment on *Mars Reconnaissance Orbiter*, is a portion of an inverted fluvial canal in the Aeolis/Zephyria Plana region near Mars' equator. *Image: NASA/JPL-Caltech/UA*

ERRATUM: In "There Goes the Sun" (December Solstice 2017), the first sentence should have read, "Total solar eclipses are not rare on Earth, but this past summer's eclipse was the first total solar eclipse to cross the U.S. from its Pacific to Atlantic coasts since 1918."

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The Planetary Report (ISSN 0736-3680) is published quarterly at the editorial offices of The Planetary Society, 60 South Los Robles Avenue, Pasadena, CA 91101-2016, 626-793-5100. It is available to members of The Planetary Society. Annual dues are $50 (U.S. dollars) for members in the United States, as well as in Canada and other countries. Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

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

Historic Times

We're Moving Space Science Forward in Big Ways

IN THE 37.5 YEARS since The Planetary Society was founded, it has communicated your wishes to those who govern the world's largest space agency, but we have never had the support of an organized caucus in the U.S. Congress—and now we do, with the establishment of the Planetary Science Caucus. A formal caucus is established by a charter in the House of Representatives (by long tradition, the Senate has only informal caucuses, and the Senate did indeed establish an informal caucus to support the House's work). This means we will have a bipartisan, bicameral group of members of the U.S. Congress working together to advance space science and exploration. I am proud of the work being done by our Director of Space Policy Casey Dreier and his Washington, D.C.-based team of Jason Callahan and Matt Renninger. Read more about this in a new opinion-editorial by Caucus Cochairs John Culberson (R-TX) and Derek Kilmer (D-WA) on page 22 of this issue.

The Planetary Society will support the growth and activities of this caucus, and to that end Matt, Jason, and I visited 16 congressional offices on the day I attended the State of the Union address. On a second visit on the 14th of March, we had a breakfast with several members of Congress at the beautiful Kluge Center in the Library of Congress. JPL scientist Amy Mainzer did a presentation about planetary defense, and we recruited several more members. By the time you read this, I expect we'll have over 30 Caucus members. At every opportunity, we will promote the Caucus. Please join us. We've set up a special form where you can ask your congressperson to join at **planetary.org/caucus**.

THE FALCON HEAVY BLASTS OFF

A week after the speech, the first SpaceX Falcon Heavy rocket, the largest rocket to fly since the Apollo era's Saturn 5, blasted off from Cape Canaveral's famous Pad 39A. I was there for the launch. After a delay due to winds, the Falcon Heavy lifted off and deployed its payload of a red Tesla roadster into a very large solar orbit. Although the mighty rocket's center booster core just missed landing upright on its drone ship down range, its two side boosters spectacularly returned to Earth and touched down, upright, on their target landing pads. It was a remarkable display of rocketry and a result of very large, very smart investments in engineering. Simply put, wow!

SpaceX's achievement is a fantastic milestone (or kilometer marker) for you and me and for our *LightSail 2* spacecraft, which you supported and helped build, because we're a part of the payload on the next Falcon Heavy. Its launch "period," as it's called, may "open" as early as June. I hope you'll consider a trip to the Cape to witness the launch with many other Society members. This launch will be historic and spectacular. *LightSail 2* will fly higher than our *LightSail 1* test vehicle. It will maneuver in space, build orbital energy, and capture some spectacular views of the sail and Earth below. With your support, we're advancing planetary science by developing an extraordinary technology that can enable missions to many destinations in the solar system, including monitoring the Sun's weather and searching for Earth-orbit-crossing asteroids.

SHOEMAKER NEO GRANTS

As you know, when it comes to asteroids, we take them seriously. That's why we have awarded a new round of Shoemaker Near Earth Object Grants this year. These grant winners are advanced amateur astronomers whose observations and tracking of near-Earth objects contribute to real advances in the science of planetary defense. We do not want our home world to get struck by a potentially devastating impactor. Thanks for your support of these grants, which may one day make a difference between life and death. In this issue, our chief scientist Bruce Betts provides details about the Shoemaker NEO Grant winners and how they will use their prize money.

GUESTS FROM DOWN UNDER

To give you an idea of how influential The Planetary Society is becoming, a busload of about 37 Australian legislators, staffers, and business leaders stopped at our Headquarters recently to take a tour and to meet with our staff. They were on their way to SpaceX after visiting the Jet Propulsion Laboratory. They took the time to meet with us because we link people like you to the discoveries and adventures of space exploration. Australia just established, or reestablished, its official space agency. We talked about supporting science education, the mission of the Society, and the ways we can work together. What I took away from our exchange is that, in either hemisphere, the skies are not the limit.

AN EXCITING NEW PARTNERSHIP

The Society has formed a new partnership with the information technology company Intel. We want people to understand the value of artificial intelligence (AI) in space exploration, so fellow Board Member Robert Picardo and I performed in some videos promoting that very understanding. We point out that computing machines don't come from the ether; people create them. And those people can program machines to adjust or modify their programs and enhance our ability to process huge amounts of data and explore farther. The videos are fun. Look out for them in late May.

We're living in historic times. As Carl Sagan used to say, "We stand on the edge of the cosmic ocean." We are poised to sail to unknown worlds and to make discoveries that will affect the course of human history. Thank you for your help in making this future possible. I couldn't be more excited about what lies ahead for us.

Bill Nye

Antonio Peronace for The Planetary Society

TOP *Caucus member Rep. Randy Hultgren (R-IL) and Bill Nye discuss* Lightsail 2 *during a January meeting on Capitol Hill.*

BOTTOM *Bill meeting with Rep. Pramila Jayapal (D-WA). Rep. Jayapal's district had one of the highest response rates to the Society's recent advocacy drive.*

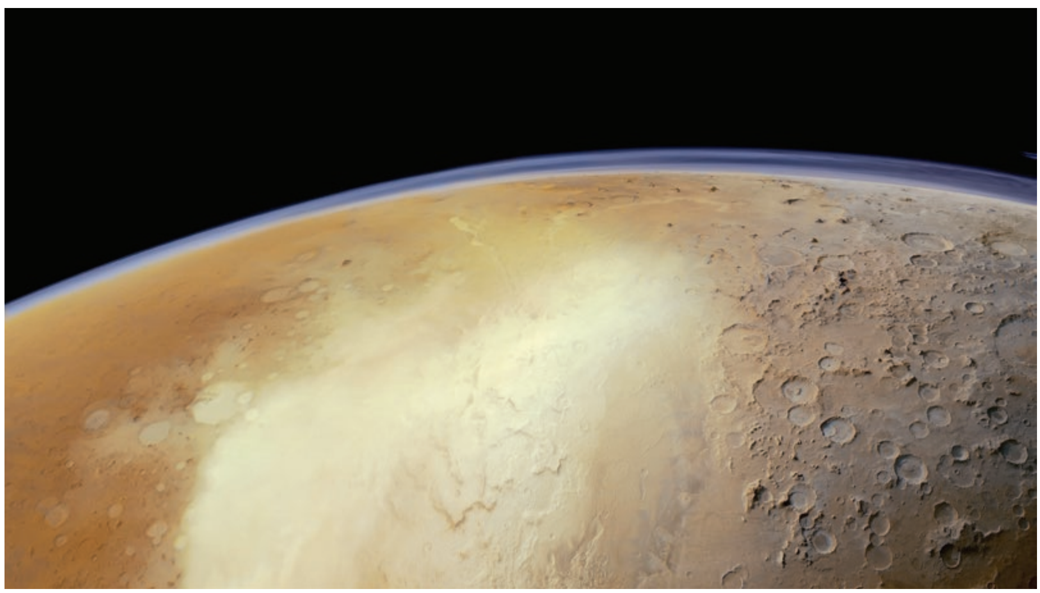
BRUCE JAKOSKY *is principal investigator of the* MAVEN *mission currently orbiting Mars.* **DAVID BRAIN** *is deputy principal investigator of* MAVEN.

Through *MAVEN*'s Eyes

Studying Mars' Evolution to Understand Exoplanet Habitability

THE PLANETARY SCIENCE community finds itself in an odd situation with regard to our understanding of exoplanets. We know of nearly 3,000 planets around other stars, and we have good statistics on planet mass and orbit and on multiple-planet systems. But we know very little about each of the planets themselves. Addressing the key question of whether they have the potential to harbor life is extremely difficult without more information. However, we can to some extent use the planets in our own solar system as a guide to the range of behaviors and planetary outcomes that we can expect. This lets us talk about whether it is possible or even likely that exoplanets could be habitable.

In our solar system, Venus, Earth, and Mars form a remarkable triad. With these three planets, nature has carried out the experiments for us of how the climate and habitability of planets can be affected by planet mass, distance from the Sun, presence or absence of a global magnetic field, and atmospheric thickness. Although we can't necessarily match each exoplanet with one of these three planets, we can use our understanding of the processes involved in atmospheric evolution, developed by studying these three planets in detail, to ask how planets around other stars could have evolved.



THIS PAGE *Cold, dry, and nearby, Mars is a valuable laboratory for the study of how alien planets might evolve—or devolve—as places that could support life. Here, a large dust storm swirls inside Hellas basin. The lower part of Mars' atmosphere is visible as a blue haze on the horizon. The* Mars Atmosphere and Volatile Evolution (MAVEN) *spacecraft is examining the atmosphere's upper levels (not visible here).*

Image: ESA/DLR/FU Berlin/Justin Cowart

NEXT PAGE, TOP Curiosity *has returned data confirming that an ancient lake once filled Gale crater, which the rover has been exploring since it landed in 2012. In this view, the strata in the foreground dip toward the base of Mt. Sharp, indicating a flow of water toward a basin that existed before the mountain fully formed. (The sky appears blue because this image has been "white balanced" to adjust for lighting on Mars.)*

BRUCE JAKOSKY *is professor of geological sciences and associate director of the Laboratory for Atmospheric and Space Physics at the University of Colorado. He has been exploring Mars since he was an undergraduate, working on the* Viking *missions in the 1970s. He is principal investigator of the* MAVEN *mission, currently orbiting Mars.* **DAVID BRAIN** *is associate professor of planetary sciences at the University of Colorado and deputy principal investigator of the* MAVEN *mission. He was born 2.5 years before* Viking 1 *launched.*

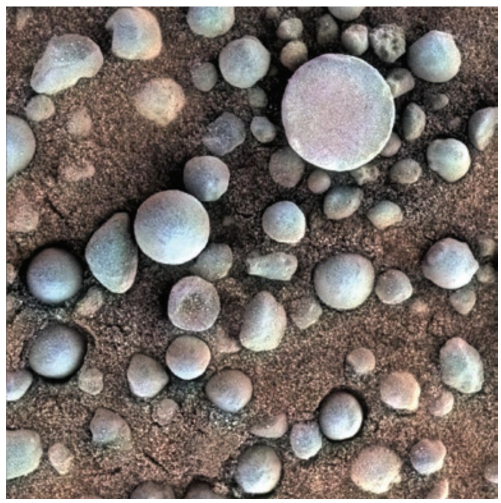
The new information that we can bring to bear is a detailed understanding of the evolution of the Martian atmosphere based on results from the *Mars Atmosphere and Volatile Evolution (MAVEN)* mission, which has been orbiting Mars since Fall of 2014. *MAVEN* has provided fundamental new results on the escape of Mars' atmospheric gas to space and the history of its climate. We can ask how these same escape processes might have operated on exoplanets, taking into account the differences in the characteristics of the host star and in the planet's orbit. In essence, we are asking how Mars would have evolved in orbit around other stars, and what the history of the habitability of Mars might have been as an exoplanet.

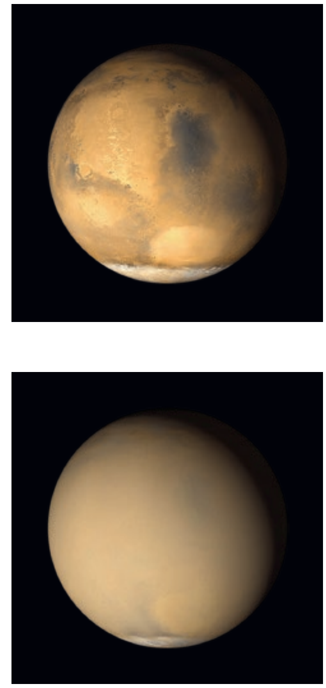
BASELINE ATTRIBUTES OF MARS

Mars is of particular interest because it appears to have had a climate that has changed dramatically throughout its history. Mars today is a cold and dry place. Temperatures average around –55 degrees C (–67 degrees F), and the atmospheric pressure at the surface is only 6 millibars, less than 1 percent of the pressure at the surface of the Earth. Liquid water is not stable today; in Mars' cold and dry environment, it would evaporate or else freeze and then sublimate (go directly from solid ice to water vapor) into the atmosphere very quickly. Although there are recent geological features whose formation might have involved liquid water, such as gullies or the "recurring slope linneae," any liquid water would have to have been in a transient phase and would not have been stable at the surface.

In contrast, many geological features on ancient Martian surfaces show clear evidence of the long-term presence or stability of liquid water. Valley networks appear to have been carved by runoff of surface water. Degradation of large features and the complete removal of impact craters smaller than about 15 kilometers (9 miles) in diameter suggest widespread and substantial erosion by liquid water. And there are sedimentary deposits suggesting that many ancient impact craters once contained lakes. At the surface, rovers have observed features indicating that some of the sediments were deposited in surface water, and there are minerals and concretions that can form only when liquid water is present.

Although one cannot determine unique environmental conditions on ancient Mars solely from these observations, most scientists believe that the surface temperature must have averaged near (or above) 0 degrees C (32 degrees F). A temperature this high would have



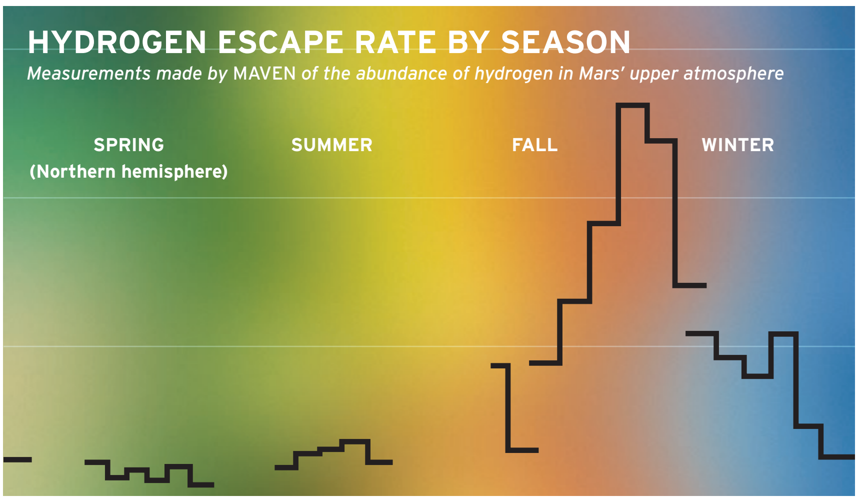


ABOVE *A recent study of* Mars Reconnaissance Orbiter *data suggests that global dust storms play a role in the ongoing process of hydrogen, and thus water, escaping from the top of Mars' atmosphere. In 2001, these before and after dust storm views were taken a month apart by* Mars Global Surveyor.

LEFT *These small spherules, nicknamed "blueberries," on Mars' surface were imaged by* Opportunity *in 2004. Because hematite-rich concretions such as these form in the presence of water, they point to a watery past on the Red Planet. The area shown is 3 centimeters (about 1.2 inches) across.*

Mars globes: NASA/JPL/MSSS; Gale crater: NASA/JPL-Caltech/MSSS; "blueberries" image: NASA/JPL-Caltech/Cornell/USGS required significant greenhouse warming, with at least a large part of that warming due to increased atmospheric CO_2 (carbon dioxide).

Given the absence of a regolith or crustal deposit of carbon-bearing minerals that could hold the CO_2 from an early, thick atmosphere, *MAVEN* has been looking at the role that loss of atmospheric gas to space could have played in changing the Martian climate. We have made observations of the present-day loss of gas to space throughout a full Mars year. We can extrapolate those loss rates into the past based on our understanding of the loss processes, the history of the Sun, and the solar drivers of escape. Our conclusion is that escape of atmospheric gas to space was substantial, especially early in Mars' history, and that it likely was a major cause of the change in climate reflected in the geological features.



ABOVE *Mars' atmospheric hydrogen is lost at rates that vary by season. The 20-fold change with season probably relates to the role of dust in raising atmospheric temperature and allowing water to move higher into the atmosphere during southern-hemisphere summer.*

STARS UNLIKE THE SUN

How would these same escape processes operate for a Mars-like planet orbiting another star? First, we have to consider the type of star that we're looking at. Stars differ based on their mass and their age. The largest stars can be ten times as massive as our Sun; they live for only a few tens of millions of years, and that probably is not long enough for life to have originated on any planets orbiting them.

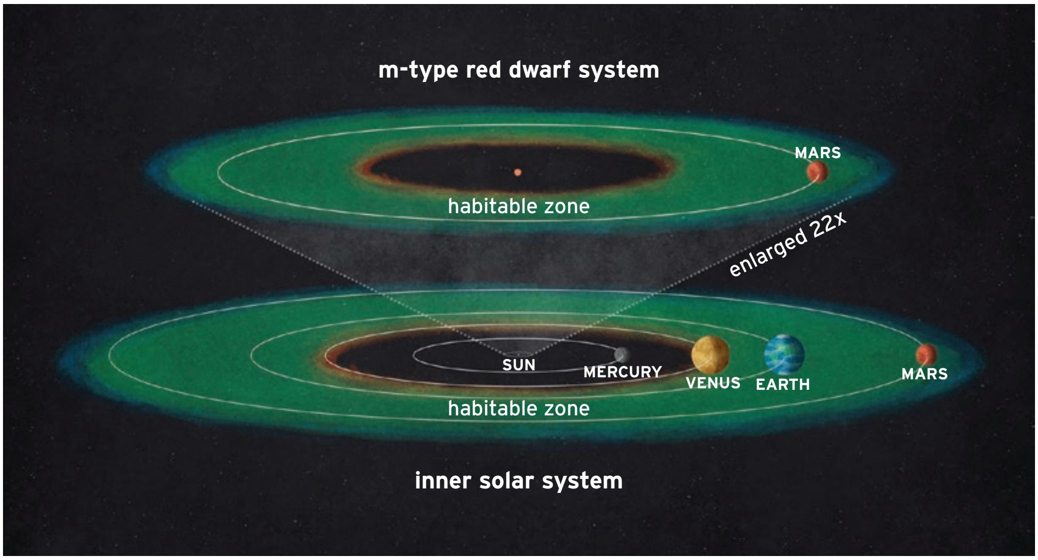
The most common stars in our galaxy are called M stars and have masses about 0.1 to 0.8 times the mass of the Sun. These are the most abundant type because more small stars than large stars form as pre-stellar gas clouds collapse and, perhaps more importantly, because they have lifetimes longer than the age of the galaxy. That is, every M star that has ever formed in our galaxy still exists. In the billions of years that the stars burn, much longer than the lifetime of our Sun, it's conceivable that life could have formed on their planets.

Do these M stars have planets? Ground-based telescopes and spacecraft missions such as Kepler now are giving us good statistics on the distribution of planets. M stars seem to be among the best at having planets, typically with about one roughly Earth-sized planet per star.

Many of these planets reside in their star's habitable zone. The habitable zone (HZ) around a star is the region that is neither too hot nor too cold for liquid water to exist at the surface. In our solar system, the inner edge of the HZ is defined by the process that turned Venus into a hellish planet—a runaway greenhouse. In the runaway greenhouse, the planet is hot enough that any oceans will evaporate into the atmosphere, and the additional greenhouse warming from the water vapor produces positive feedback and further increases the atmospheric temperatures. The rising temperatures cause CO_2 contained in minerals to be released into the atmosphere as well. The end result is a planet where all of the water and CO_2 are in the atmosphere and their greenhouse effect makes temperatures extremely high. Even if all of the water is broken apart by sunlight and the hydrogen atoms escape to space, the dense CO_2 atmosphere remains and is stable. A planet that receives as much energy from its star as Venus does from our Sun would undergo this runaway greenhouse effect. Life under these conditions is not thought to be possible.

The outer edge of the HZ in our solar system is defined by Mars. A Mars with a thicker atmosphere could be warm enough that lakes

Diagram: Bruce Jakosky/Loren A. Roberts, Hearken Creative



ABOVE *Compared to our solar system's habitable zone (HZ), the HZ around an M-type red dwarf would be much smaller. A planet there would have to orbit much closer to its star than Mercury is to our star to receive the same amount of starlight that Mars gets from the Sun.*

Illustration: NASA/GSFC

and oceans would exist. But if that same planet were farther from the Sun and received less sunlight, it would freeze regardless of what gases were in its atmosphere.

Thus, in our solar system, the HZ is thought to extend roughly from the orbit of Venus to the orbit of Mars. Earth, sitting in between, is right in the middle of the Sun's HZ.

The HZ around an M star would be closer in to the star, because the star is less massive and emits less energy than our Sun. This is analogous to having to get closer in to a dimmer campfire in order to stay warm. An M star HZ would be roughly 0.03 to 0.3 astronomical units (AU = distance between Earth and the Sun) from the star. By itself, this isn't a harsh constraint. However, M stars, especially young ones, can be more active in emitting extreme ultraviolet (EUV) wavelengths of light and in having solar-like storms. These events tend to enhance atmospheric escape, so that being closer in to the star means that these drivers may be more effective. In our campfire example, it's analogous to being closer in and more exposed to the popping and sputtering that takes place in the fire.

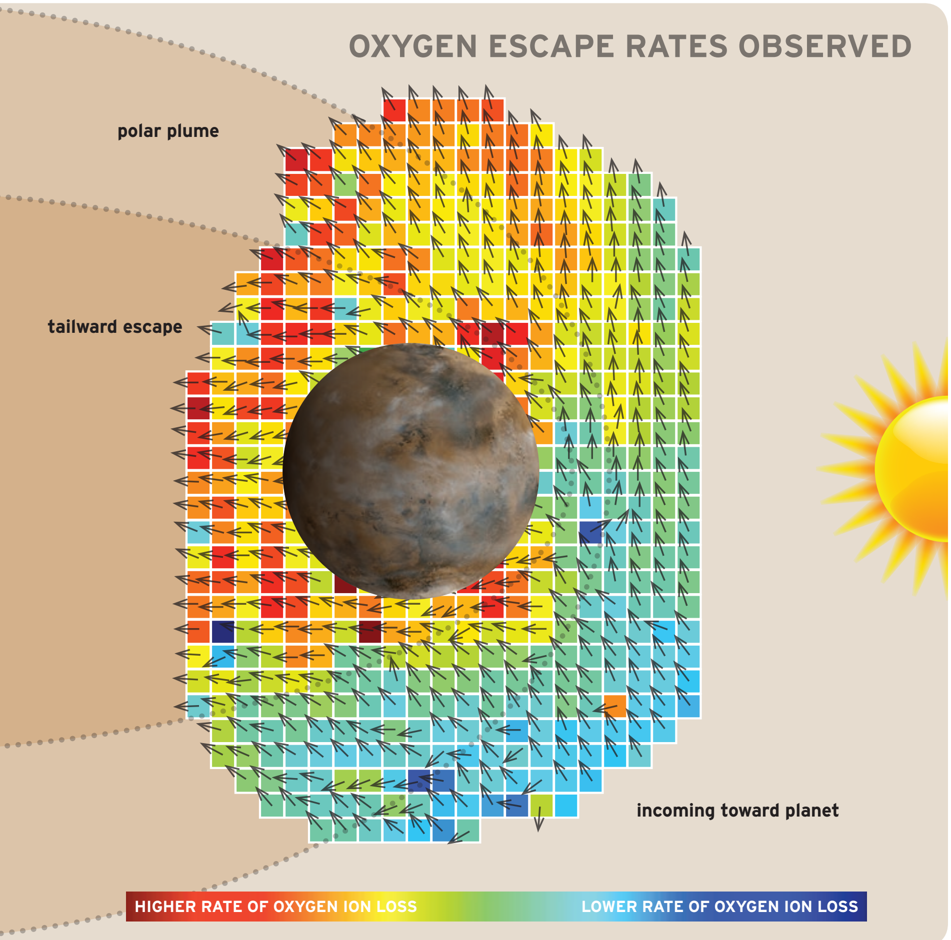
ATMOSPHERE ESCAPING TO SPACE

Would atmospheric escape rates that are enhanced by the solar activity around an M star cause a planet to lose its atmosphere more quickly? We have to look at the individual loss processes that result in escape of atmosphere to space. Most of the key loss processes for Mars involve the behavior of ions in its ionosphere. They're produced when an EUV photon from the Sun is absorbed by a molecule, ejecting an electron and leaving the molecule ionized. *MAVEN* observations have shown that a number of things can happen after ionization:

ION LOSS Ions can be picked up by the magnetic field of the solar wind as it encounters Mars, and accelerated to velocities great enough for escape from the planet. Once removed from the upper atmosphere, ions are gone and won't come back.

PHOTOCHEMICAL LOSS If a free electron recombines with a positively charged oxygen or nitrogen ion (O_2^+ or N_2^+), trying to form a neutral molecule again, there is a release of energy that will not only split the molecule but also will give each atom additional energy in the form of high velocity. The two now-split atoms shoot off in opposite directions, and the one that is moving upward can escape if it doesn't collide with anything first.

SPUTTERING LOSS In addition to being accelerated away from the planet, ions in some locations can be accelerated by the solar wind toward the planet. These can collide with atoms in the upper atmosphere, and can physically knock them into space. This process is termed "sputtering." Sputtering is somewhat similar to a break shot when shooting pool, with one energetic particle (the cue ball) hitting the others and sending them all flying off in different directions with high velocities.



ABOVE *Represented here are all MAVEN's measurements of escaping oxygen made through almost an entire Mars year. The colors represent the rate at which ions are being lost, and the arrows show the direction in which they are moving. (Not shown are the arrows moving tailward around both sides of the planet.) These observations give us important clues as to the processes responsible for removing oxygen from the upper atmosphere.*

Diagram: Bruce Jakosky/David Brain/Loren A. Roberts, Hearken Creative

Two other avenues of escape are important. First, H_2O molecules can be broken apart by EUV photons. The resulting hydrogen atoms are light enough to escape to space directly, in a process termed thermal escape.

Second, there are solar storms–large eruptions of material sent out by the Sun with much higher densities and velocities than the regular solar wind. As seen on Mars, such storms can significantly enhance the loss rate for a day or two. While these may not hit Mars often enough to be a major driver of atmospheric loss today, they would have been much more significant early in Martian history, when the Sun was more active. There may have been almost continuous solar storms hitting Mars, and the loss induced by them may have dominated early atmospheric depletion.

All added up for Mars, we think that these processes could have removed more than a half bar of atmosphere over time, equivalent to half the atmospheric pressure today on Earth. This loss was great enough that it appears to have been the major cause of Mars' transition from having a climate with liquid water early in its history to the cold, dry state that we see today.

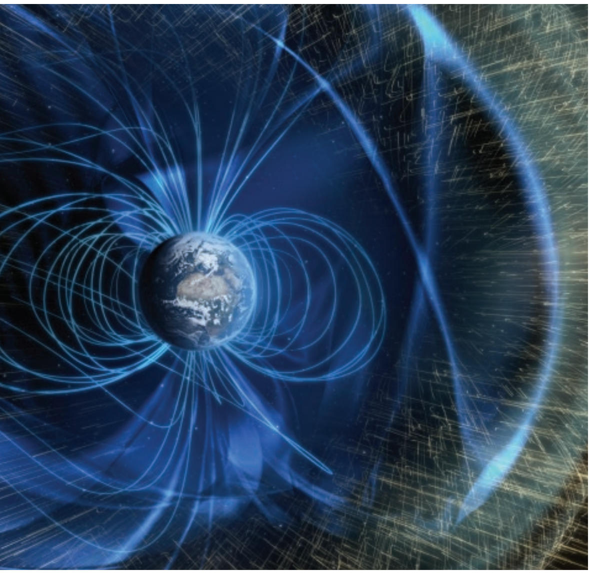
M STAR EFFECTS ON A MARS-LIKE ATMOSPHERE

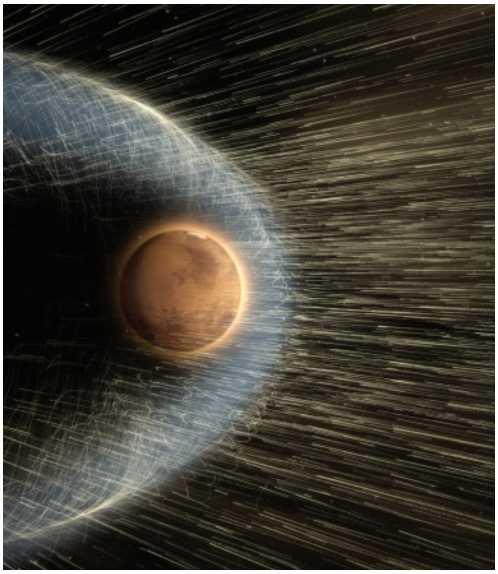
What happens to these processes around an M star? The EUV flux from an M star is 5 to 10 times greater than that from the Sun. Its stellar wind is more intense and creates a dynamic pressure (related to both density and velocity) that can be 100 times greater than that of the solar wind from our Sun. This greater EUV flux and stellar wind both can increase atmospheric loss. Our calculations suggest that ion loss would be several times greater for a Mars-like planet in the HZ around an M star. Photochemical loss would increase by 5 to 10 times. Sputtering loss would also increase by 5 to 10 times.

It's hard to know what would happen with regard to thermal escape by hydrogen. Although the increased EUV flux should produce more hydrogen atoms, the escape of Martian hydrogen to space today is thought to be limited by its ability to diffuse into the upper atmosphere; thermal escape conditions might not be very different for Mars around an M star.

The biggest difference for a Mars-like atmosphere in an M star system might be in the effect of stellar storms. Extreme stellar events could be 10 to 100 times as intense, and they could be up to 1,000 times more frequent than for Mars. These could combine to give an integrated loss rate for young M stars as much as 10^3 to 10^4 times greater than around our Sun. These estimates are very uncertain, but point toward "Mars around an M star" having a much shorter lifetime against atmospheric loss and a much shorter habitable lifetime than around our own Sun.

The biggest outstanding questions may not





LEFT & RIGHT *Knowing if exoplanets have a magnetosphere could prove decisive as we search for life on other worlds. Looking to Mars as an example, we see a planet that does not have an internally produced magnetic field like Earth's (left). Instead it has a much smaller magnetosphere, formed by the flow of the solar wind around the planet. Here Mars is shown larger than scale for purposes of illustration.*

be about the processes that drive escape of gas from the Martian atmosphere to space. Instead, they may center on things that we cannot easily predict about exoplanets:

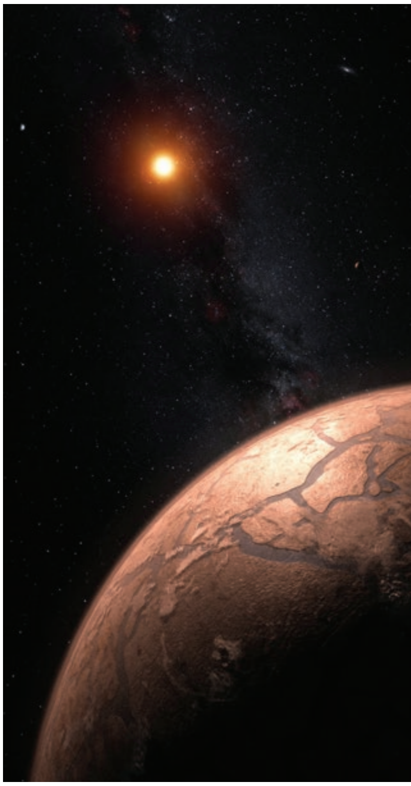
Do exoplanets have an internal magnetic field? Many loss processes are driven by the magnetic influence that the stellar wind has on an ion. A planetary magnetic field would cause the stellar wind to stand off at a larger distance from the planet, much as it does on Earth, and not interact with the upper atmosphere directly. This could protect the atmosphere from stripping by the stellar wind. Although the degree to which it really protects the atmosphere is uncertain, we think that the turn-off of an early Martian magnetic field could have allowed the turn-on of stripping of the atmosphere by the stellar wind.

Do exoplanets around M stars have a composition similar to the rocky planets in our solar system? Do the formation processes allow incorporation of volatiles, especially H_2O and CO_2, that can be released to form an atmosphere and an ocean? Does the rocky component contain enough of the different elements that life could be possible? These factors will determine the nature of the atmosphere and of the habitability of an exoplanet.

Planets orbiting within the HZ of an M star may be close enough to the star that they run the risk of being de-spun by tides. After de-spinning, one side would always point toward the star and the other side away from it. What does this do to the stability of an atmosphere or an ocean, to the formation of an internal magnetic field, to the ongoing geological processes that might affect an origin of life, or to the stability or existence of life itself?

One of the most surprising things about the discovery and cataloging of exoplanets is that the planetary systems seem so different from our own solar system. Gas giants can migrate within their planetary systems, and they can end up in orbits close in to their star, for instance. We should not assume that we can guess correctly what exoplanets will look like or what the driving forces behind their evolution will be. We can use our own solar system as a guide to what we might see, and especially we can use the triad of Venus/Earth/Mars to guess at how exoplanets might behave. But questions of habitability and life are amenable to being explored through the increasingly sophisticated observations that are becoming possible. And we should not be surprised if the results turn out to be completely different from the predictions.

BELOW *New observations and analysis of the recently discovered planets orbiting the ultra-cool red dwarf star TRAPPIST-1 have produced good estimates of their densities. The data suggest that all seven of these Earth-size planets are rich in volatile materials and probably water.*



Earth and Mars graphic: Courtesy of the author; Exoplanet illustration: ESO-M. Kornmesser

KATE HOWELLS *is The Planetary Society's Global Community Outreach Manager.*

Vital Support

Society Volunteers Help Make an Impact in Washington, D.C.

ALL OVER THE WORLD, The Planetary Society's volunteers tailor their work to their own communities. They engage with the public, partner with local organizations, and find ways to make the adventure of space exploration relevant to their particular "here and now."

RIGHT *From comic conventions to Capitol Hill, The Planetary Society's volunteers are essential to advancing our mission and spreading the news that space science is important–and fun! Here, Jack Kiraly (left) and Matt Renninger are interviewed at Awesome Con 2017, where The Planetary Society's booth was judged Fan Favorite in the convention's Future Con zone.*

Photo: Garrett Dalman

In Washington, D.C., our volunteers work in a very special environment. Washington is the center of U.S. space policy, and it is where some of the most influential decisions about the future of space exploration are made. This creates fantastic opportunities for volunteers to mobilize the public and to push exploration forward.

Leading our D.C. volunteers is Outreach Coordinator Jack Kiraly. "Here in Washington," says Jack, "we've really taken the Society's values and mission and put them to action. We've participated in wide-ranging events, such as conducting public outreach at comic conventions, giving educational programs at local universities, and teaching our members about the past, present, and future of space policy advocacy. All of this is done with the goal of empowering the world's citizens to support space science and exploration."

Jack and his volunteers work closely with The Planetary Society's space policy team to help them make an impact in Washington. Matt Renninger, the Society's senior manager of government relations, knows what a difference our volunteer effort makes.

"In 2017, The Planetary Society worked with members of Congress to establish the first-ever Planetary Science Caucus, helped advocate for the addition of millions of dollars to the federal budget for Mars exploration, held numerous briefings and events on Capitol Hill, broadened our international outreach by partnering with embassies in town, and generated tens of thousands of contacts with Congressional offices as well as more than one hundred in-person meetings," said Matt.

"Without the support of our members and volunteers, almost none of these advocacy achievements would have gotten off the ground. This truly is a grassroots organization, built totally on human agency. If we want to advance exploration, find life beyond Earth, and change the world in our lifetimes, we're going to have to continue to do it together," he added.

Beyond Washington's beltway, The Planetary Society's volunteers are actively conducting outreach and planting seeds for future advocacy efforts. Through our international volunteers, we can learn how to advance space exploration across the board and around the world.

To sign up for volunteer opportunities in your community, check out our website at **planetary.org/volunteer**.

MICHELE BANNISTER *studies the solar system's minor planets at Queen's University, Belfast.*

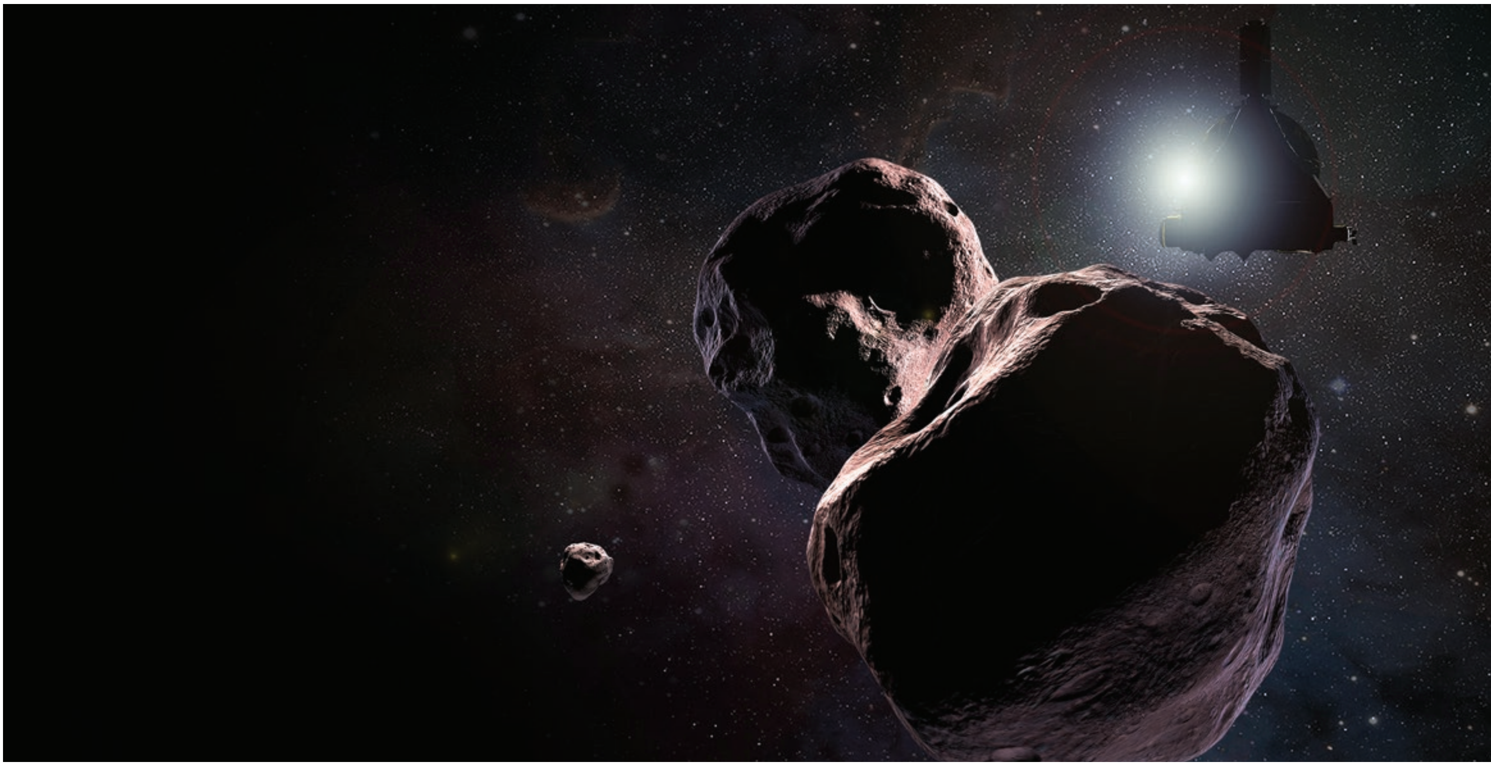


Illustration: NASA/JHU/SwRI/Steve Gribben

Beyond Neptune

Distant Minor Planets (840 of them!) Reveal the Outer Solar System

MAPPING THE OUTER solar system is a science that touches on art. For decades it has involved painstaking measurement of images by a combination of machine and person. The brassy gleam of the "blink comparator" of Clyde Tombaugh's time, a device for checking each point of light in paired images for motion over time, has given way to the digital era. Software now matches stationary stars and galaxies between images taken hours or days apart, discards the static dots of light, and keeps the ones that have shifted from one place to another. From these transient detections, we can piece together the slow tracks on the sky of tiny worlds, far from the Sun.

Trans-Neptunian objects (TNOs), orbiting at more than 30 times the distance between Earth and the Sun (the Earth-Sun distance = one astronomical unit, or AU, 150 million kilometers, or 93 million miles), are the remnant material of the early days of the solar system. Where we find TNOs provides evidence that the solar system as we see it today is not as it once was. Their present paths around the Sun pick out the traces of an ancient mystery: the outward migration of the outer planets, at least four billion years ago.

More than a fifth of trans-Neptunian bodies are in mean-motion resonances with Neptune. Resonant TNOs move in an orbital ballet of beat frequencies, where Neptune makes a round number of turns around the Sun for every orbit by these more distant worlds. Pluto is the best known of

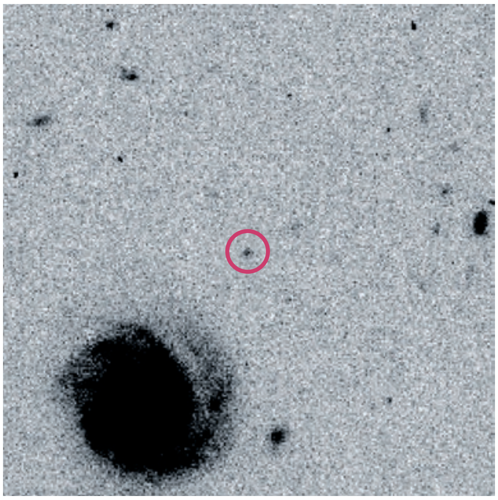
ABOVE *Studies of Trans-Neptunian Objects (TNOs) have revealed that Neptune has many of them entrained in resonant orbits. Soon, we will get a close-up view of MU69, a TNO first seen by the Hubble Space Telescope. As shown in this artist's concept,* New Horizons *will fly by MU69 in 2019.*

the resonant TNOs, at a mean distance of 39 AU, making two turns for every three by Neptune. Smaller kin in the 3:2 resonance are known as the "plutinos." Resonances appear on a map of orbits as thin regions that filigree the vast volume of the outermost solar system. Only a migration of Neptune, spiraling outward over millions of years, can have snowplowed so many of the TNOs out to orbits in these tiny volumes of strange, poised stability. What remains unknown is the way this migration happened. Was the ice giant Neptune thrust outward, by interactions with other giant planets and with the disk of tiny proto-planets–in a slow glide or perhaps a quick dart? The answer lies in the current pattern and populations of resonant TNOs.

DISTANT, TINY, AND HARD TO SPOT: HOW TO FIND MORE TNOs?

After two decades of mapping the sky, beginning in the 1990s, barely a thousand of the telltale TNOs had been discovered: a tiny fraction of the population that had to be out there. TNOs are faint and hard to find. They are on distant, often elongated, eccentric orbits, and have a steep luminosity distribution. Many are a few hundred kilometers in diameter or smaller; a few are larger, dwarf planets. Seen only by reflected sunlight, the smaller objects are hard to detect unless they are at perihelion, when they are closest and brightest. Every TNO discovery in the early years hinted at a much larger population, too faint to be seen. To describe how Neptune's migration happened was going to require many more discoveries.

An opportunity came at the 2011 meeting of planetary scientists in Nantes, France. Nearly two thousand astronomers and geologists gathered in one place. What better time to discuss how to take the next step in mapping the outer solar system? I was a graduate student at the time, just finishing up a survey of the southern hemisphere sky, looking for bright TNOs by analyzing images from a small telescope in Australia. The consensus of the community of interested scientists was clear: we needed a survey that imaged deeply and across a wide area of sky, at least 150 degrees square, near the plane of the solar system, where TNOs are found



RIGHT *The red circle surrounds the first sighting by human eyes of one of the 840 Trans-Neptunian Objects detected by OSSOS. The dark object nearby is a spiral galaxy.*

OPPOSITE PAGE *The small blue circle at the center of this tangle of TNO orbits represents the orbit of Neptune. This graphic illustrates the vast extent of the trans-Neptunian populations and the challenges of searching across such distances for small objects lit only by the Sun. Precise, triple-checked data made it possible to calculate and later confirm the orbits of TNOs spotted by OSSOS.*

Image: Canada-France-Hawaii Telescope, courtesy of the author

in the greatest numbers. Such a program would detect hundreds of faint TNOs, but to be awarded time on the highly competitive large telescopes for such a large scale survey would need a powerhouse of collaboration. The nascent program brought together nearly 50 researchers from around the world, including scientists from Canada, France, the U.S., Taiwan, the U.K., Finland, Slovakia, and Japan.

THE NEW NET GOES FISHING

The Outer Solar System Origins Survey (OSSOS) was approved as a Large Program

MICHELE BANNISTER *is a postdoctoral research fellow and Director's Outreach Fellow at Queen's University Belfast, United Kingdom. Originally from New Zealand, Bannister has worked at institutes in Australia, the U.S., and Canada. In 2017, she was honored by the International Astronomical Union with asteroid (10463) Bannister.*

on the 3.6-meter Canada-France-Hawaii Telescope (CFHT) on Maunakea, Hawaii, in 2012, and started observing in 2013. For the next five years, CFHT acquired images for OSSOS every month of the year.

We designed the survey to act as a fine-meshed net for distant icy worlds. TNOs move across the sky in large loops, like writing with a fountain pen, a pattern produced by the more rapid yearly motion of our Earth around the Sun. A snapshot of a patch of sky will snare a sample of TNOs. Over time, this "group" of TNOs will disperse, depending on their individual orbits. This predictable large-scale motion allowed us to automate our first year of observation for each survey region of sky. Instead of pointing the telescope at each TNO and trying to chase them all individually–which would have led to a lot of spillage from loss of TNOs on unusual orbits, wriggling away–we tracked four big, 20-degree square patches of sky, at the mean looping rate of TNO drift across the sky for the half-year that each patch was visible.

Our discoveries were fished out when each patch of sky came to its opposition point from the Sun. At this geometry, the TNOs' motion relative to Earth is at its speediest, making them easier to detect. Painstaking calibration of our software ensured we could quantify how precisely we were detecting TNOs with different rates of motion–from the speedy Centaurs to the slow-drifting Sednas. The exquisite calibrations mean OSSOS's great product is as much a matter of empty spaces where we know there was nothing to find, as the hundreds of TNOs we discovered.

Because CFHT is a queue-scheduled telescope, as the OSSOS operations lead, I would send programming to Waimea, Hawaii, from Victoria, BC, and the schedulers and observers in Waimea would plan and put into practice our requests. From the second year of observing onward, our eight-person OSSOS core team worked under a hectic pace of scheduling observations, adjusting the cadence if weather prevented observing success, and dealing with the stream of arriving observations. All the while we were analyzing the images for discoveries and piecing together their paths across the sky into confirmed new TNOs, ensuring all discoveries above a threshold brightness would be safely tracked. These icy worlds would then be imaged again each year with targeted snapshots, pinning them with 20 to 60 points on the sky, calibrated against the *Gaia* spacecraft's star maps. Each TNO was imaged until all their orbits had such

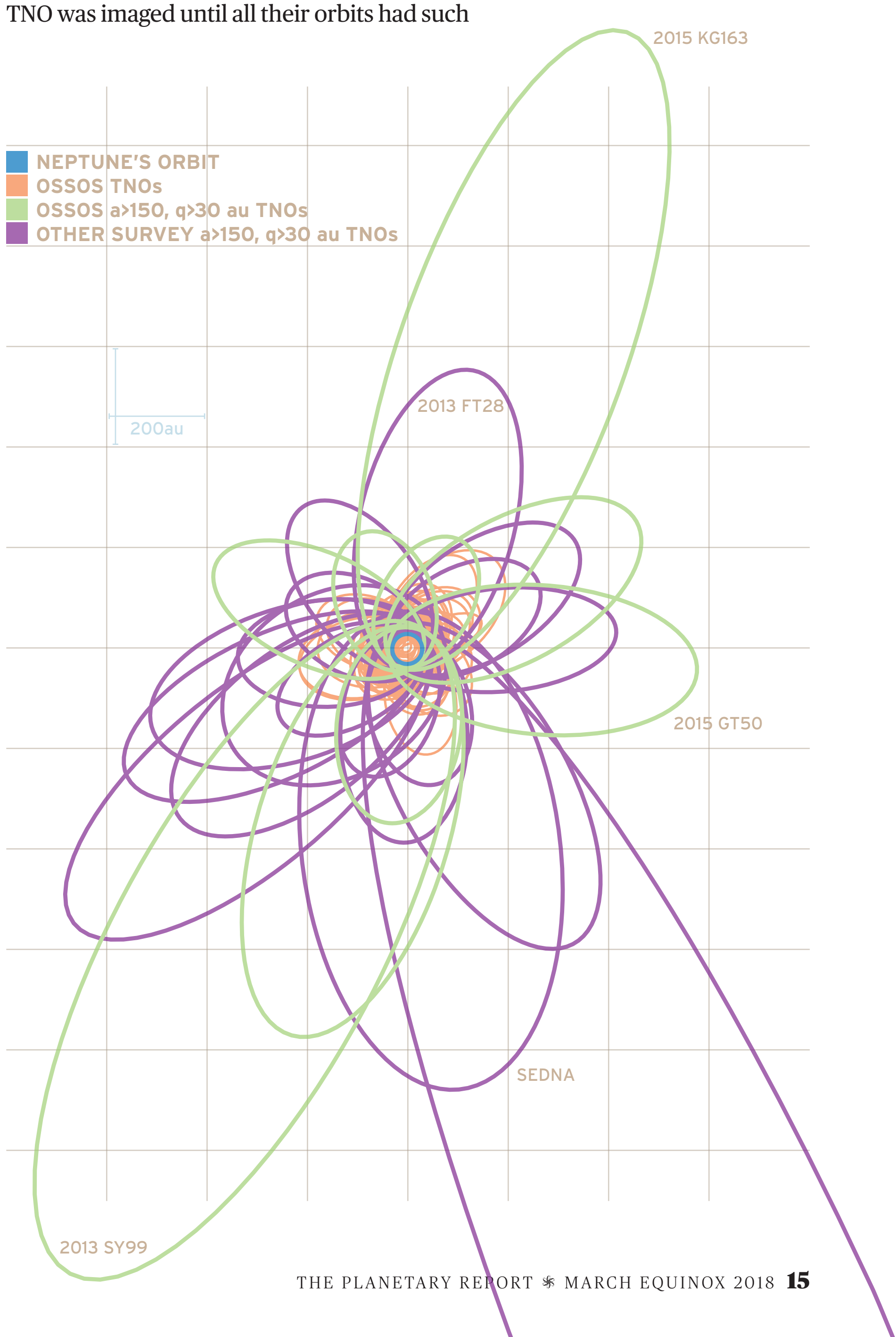


Illustration: Courtesy of the author/Loren A. Roberts/Hearken Creative small uncertainties that their membership in the various orbital populations (such as the TNOs in the thin threads of Neptunian resonance) could be held certain, with numerical simulations of their behavior over millions of years. In total, the whole effort required triple-checked measurements of more than 37,000 points of light.

The 2015 observations brought a new challenge—our best ever visibility. A combination of truly spectacular, crisply stable atmosphere on the discovery nights (with seeing down to 0.4 seconds of arc) and the arrival of a new, deeper camera filter, which let us see fainter TNOs, brought a wave of discoveries. Nearly half of OSSOS's discoveries showed up in 2015's autumn-winter semester. This abundance cranked our tracking efforts to a fever pitch. In retrospect, it's amazing we were able to track every object in our sample above the threshold brightness—at Kuiper Belt distances.

CRACKING THE KERNEL OF THE KUIPER BELT

The 840 detections from OSSOS increased the inventory of trans-Neptunian objects with accurately known orbits by 50 percent. The full data release will be in a special 2018 issue of the *Astrophysical Journal Supplement* series. Ten papers have analyzed the discovery set thus far.

The new TNOs add a lot of detail to our knowledge of the Kuiper Belt. OSSOS detects all objects down to magnitudes as faint as 24.1 to 25.2. OSSOS-defined orbits have exceptionally high quality, with an uncertainty of less than 0.1 percent, which lets us resolve the Kuiper Belt's structure with unprecedented precision. The significance of this structure is best described by the shapes of the TNOs' orbit ellipses. Orbit shapes may be characterized by four measurements: a semimajor axis, which averages how distant an orbit is from the Sun; an eccentricity, or distortion from a circle; an inclination, or tilt; and a distance of closest approach to the Sun, or perihelion. Our 437 non-resonant (or "classical") discoveries show that Kuiper Belt orbits have semimajor axes larger than 37 AU, with a lowest perihelion boundary of 35 AU. The distance from Neptune to the Sun is about 30 AU.

The Kuiper Belt has been known for nearly two decades to have two populations on different distributions of inclination to the ecliptic: there is a near-flat belt, with inclinations less than about 5 degrees, and a more broadly spread population on more tilted and eccentric orbits, with tilts up to about 30 degrees of inclination. We've confirmed that there is a concentrated population in the near-flat, almost perfectly round orbits of the "cold classicals." This population is nestled like a kernel in the midst of the low-inclination TNOs. Fortunately, in 2019 *New Horizons* will be visiting a "kernel" TNO—the little world known as MU69, found by Hubble.

A handful of precious OSSOS discoveries show that the low-inclination belt has an entirely unexpected feature: it continues out beyond the truncating 2:1 resonance with Neptune, with the semimajor axes of its orbits extending to about 50 AU. These orbits may be a stirred-out remnant of Neptune's last swing during its wild migratory days. Or they may hint at the primordial disk, left from the beginning of the solar system.

THOSE DISTANT RESONANT DANCERS

In the filigree regions of resonance with Neptune, OSSOS confirms more than 300 new TNOs, including a staggering 132 plutinos, which orbit in the 3:2 resonance, nearest the Sun. At perihelion, plutinos as small as 40 kilometers in diameter are detectable.

OSSOS discoveries also include TNOs in newly occupied resonances, with mean distances beyond 50 AU. Most distant of all, out at mean distances of 130 AU, two of our discoveries dance securely in the orbital ballet of the 9:1 resonance with Neptune. The precise calibration of OSSOS—telling us not only what is there but what is not—shows that 11,000 unseen worlds must also orbit in

For more information on the Outer Solar System Origins Survey, go to: **ossos-survey.org**

the 9:1. Our computer simulations show these two TNOs have been at their dance a long while: they are stable in the resonance for as long as a billion years. Possibly they have become "stuck" to the narrow resonance, in a flypaper capture from long ago, when their orbits were interacting much more intensely with Neptune.

Rapidly changing orbits characterize a population known as the scattering disk, which is eroding down from much larger numbers, flung out by Neptune since its early days of migration. OSSOS shows the scattering disk must number some 90,000 objects larger than 100 kilometers, based on 68 scattering TNO discoveries.

THE MYSTERY OF 2013 SY99 AND FRIENDS

OSSOS finished its observational duties on December 25, 2017, with CFHT providing a last image of a TNO on one of the strangest orbits among our discoveries. This world is now known as 2013 SY99. It is one of nine such TNOs that OSSOS found; a third of all known TNOs in this unusual population were discovered during our survey. Their orbits have closest approaches to the Sun out beyond 30 AU, and semimajor axes of at least 150 AU. In SY99's case, its orbit has a perihelion of 50 AU and a mean distance of 730 AU, a perihelion exceeded only by those of Sedna and 2012 VP113.

These extreme TNOs take as long as 20,000 years to orbit the Sun, and the splay of their orbits in space has inspired new theories. One idea proposes an unseen large planet in an orbit at hundreds of AU. However, all nine of our extreme TNOs, together with OSSOS's calibrated ability to tell what it did not detect, remain consistent with a population in large orbits that are spread out smooth as butter on bread, rather than in the clumping we might expect from a big planet's shepherding. Formation mechanisms for this distant population are not yet clear, and it remains an area of active investigation.

The OSSOS discoveries form a unique set. It has half as many TNOs as the number of TNOs found in all the 40-plus surveys that went before. Together with perfect tracking efficiency for trans-Neptunian orbits, and a calibration for every survey bias, it will let the true scale of the TNO populations be precisely calculated. We're excited to see how people will use this powerful tool for understanding the inventory and history of our solar system.

ABOVE LEFT *Before being captured as a moon of Saturn, Phoebe was likely a TNO—as evidenced by its retrograde orbit and other characteristics. With a diameter of 213 kilometers (133 miles), Phoebe has the dark color, battered surface, and icy interior thought to be typical of primordial solar system bodies. This image is a mosaic of* Cassini *data collected just before the spacecraft's flyby in 2004.*

Image: NASA/JPL/Space Science Institute

Science is for all
A tool for the universe
To better know us
– KENN SCHUBACH

To live forever,
and see the wonders of space.
In a way, I have.
– J. VASQUEZ

It is a long way
It is very expensive
We still have to go
– JEFFERY KATZ

Star-swept fields above
Winking in welcome greeting
Tempting me to fly
– MARK HICKINBOTHAM

Only in pictures
never truly seen by us
distant icy moons
– CAROL KUCERA

So far from the Sun,
Triton must be a dead world.
But we found geysers!
– SYLVIA MILLER

Looking up at night
If only for a moment
Our crises are quarks
– RODERICK PETERSON

It was not until
My heart flew among the stars
That my soul found peace
– JORDAN ROHRBACK

Our Milky Way glints
The promise of planets, stars
We drown in beauty
– MAGGIE SHARMA

Into the darkness
my mind sees further beyond
the stars call to me
– DARREN VALLANCE

Go because we must
Fulfill our purpose to solve
The puzzles of space
– JEFF KOEPPEL

The Sun went dark in
daytime, behind the Moon's disk.
A total eclipse
– JAY PASACHOFF

Tell me the reason.
Why do the Stars speak to me?
I guess I Breathe it.
– JEFFREY NEWSOME

Sun's eclipse boils black
as the store workers emerge.
Some bosses have hearts.
– BOB LEE

So great the cosmos
So precious intelligence
We must seek others
– BRIAN BURG

Sailing on plasma
across a waterless sea
Dawn comes to Vesta
– RON HANSEN

Fishermen return
as the setting evening star
shimmers on the bay
– JAMES ENGLEBRECHT

Black as night, cold as
ice. Big as, far as, old as
eternity. Space.
– LORRAINE TACOUNI

The solar system
with planets so different
Why are we here now?
– ROB TILLAART

Infinite expanse
Spectral lights beyond our ken
Cosmos of wonder
– EDD ALANESE

Space time connects us
To those from past and future
Beautiful knowledge.
– BAILY EHASZ

Orbit, land, and rove,
our robots explore beyond
where humans can't breathe
– BILL NYE

Farther out than most
Kepler finds new planets and
Gaia maps the stars
– JAMES GREENFIELD

Gems on the curtain
of night. But we know better…
we dare to go there
– TIMOTHY GIBSON

Enceladus waits…
Her geysers call out to us!
When will we answer?
–LARRY FRONZO

As we see the stars
We sail forward with a smile
In a wave of light.
– FRANCISCO DE LA OLIVA

At the stars we look,
we dwell in awe and wonder
on this little speck.
– MARINLINI

Twinkle little star
Now we know just what you are
Bright, fusion bonfire
– TRACY DRAIN

Light sails unfurling
A speck of dust in the void
Sailing on starlight
– ANDREW SWETLAND

My children look up
Let's keep Earth forever safe
It is our one home
– MAYA SODEN

Human spirit soars
Surprising manmade limits
Sailing the frontiers
– KEITH MILHAM

Into the inky
Black, we gaze again upon
Ourselves. Reckless. Wild.
– CALISA LEE

#SpaceHaiku

In late fall, The Planetary Society issued an invitation—to our members and to the public—to share their passion for space exploration in the form of haiku-style poetry. For those who might not know, a haiku is a short Japanese poem comprising three short sentences in five, seven, and five syllables. The response online via Facebook and Twitter, and in e-mail, was amazing! We are honored to share a sampling of your submissions here. Thank you to everyone who contributed their Space Haiku. Your passion and creativity inspire us all!

SOCIETY TRAVEL

Delightful Eclipse and Aurora Adventures Await Planetary Society Members in 2019!

ALASKA AURORA BOREALIS
MARCH 7-13, 2019

We invite you to join our ever-popular trip to view the Aurora Borealis in the clear night skies of Alaska! See Alaskan grizzlies and moose, and ride the train from historic Talkeetna, past 20,310-foot Mt. Denali, to Fairbanks. Astronomer Tyler Nordgren will be our guide as we visit the Poker Flat Rocket Range, learn about sled dogs, and marvel at the extraordinary color and movement of the Aurora Borealis as it dances across the night skies!

TAHITI TOTAL SOLAR ECLIPSE 2019
JUNE 25-JULY 4, 2019
WITH OPTIONAL BORA BORA EXTENSION TO JULY 7TH

Travel to the jewel of the South Pacific, Tahiti, to discover this island paradise! Fly on charter aircraft to remote Gambier Island where we will be hosted by the villagers for an extraordinary glimpse of Polynesian culture and life on one of the most remote islands in the world! Then, board our charter aircraft to fly along the path of the Total Solar Eclipse on July 2, 2019! Fly back to Papeete and enjoy the optional Bora Bora Extension. With leadership by Betchart's Bob Nansen.

Join fellow Planetary Society members on these thrilling adventures! Space is limited, so register early.

To learn more, call Betchart Expeditions at 800-252-4910, or e-mail *info@betchartexpeditions.com*.

WHAT'S UP? *by Bruce Betts*

IN THE SKY

Venus is super bright in the West soon after sunset, getting higher as the weeks progress. Look for the crescent Moon near Venus on April 17 and May 17. Bright Jupiter is rising earlier in the evening East, reaching opposition—the opposite side of Earth from the Sun—on May 9, when it will rise at around sunset and set around sunrise. Reddish Mars is getting farther to the left of yellowish Saturn, with both rising in the middle of the night but rising earlier as the weeks progress.

RANDOM SPACE FACT

Mars' polar ice caps, which are similar to each other in volume, each contain about 6 percent of the water ice volume of Earth's Antarctic ice sheet.

TRIVIA CONTEST

Our June Solstice contest winner is Yale Zussman of Framingham, Massachusetts. Congratulations! **THE QUESTION WAS:** In what year was a solar eclipse first used to test Einstein's theory of general relativity, showing that light from background stars was indeed bent by the gravity of the Sun? **THE ANSWER:** 1919.

Try to win a copy of *The Design and Engineering of* Curiosity by Emily Lakdawalla, and a *Planetary Radio* T-shirt by answering this question:

Which planet in our solar system has the highest average density?

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 May 1, 2018. 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*.

BRUCE BETTS *is chief scientist for The Planetary Society.*

RIGHT *The Morocco Oukaïmeden Sky Survey (MOSS) Observatory scans the sky from Morocco's High Atlas Mountains. Operated from Switzerland and France by NEO Grant winner Michel Ory, this is the first Shoemaker Grant-funded observatory on the African continent.*

Photo: Courtesy of Michel Ory

Defend and Sample!

Protecting Our World and Vacuuming Mars

SHOEMAKER NEO GRANTS

I am happy to announce the latest round of winners in our Shoemaker Near Earth Object Grant program, named after pioneering planetary geologist Gene Shoemaker. Shoemaker Grants mostly support very advanced amateur astronomers around the world in their efforts to find, track, and characterize near-Earth asteroids.

In this round of grants, our largest ever, seven proposals were awarded with a total of $59,300. The winners hail from four to six countries (depending on how you count them) on four continents, including the first Shoemaker-funded observatory in Africa (Morocco). Over the twenty-year history of the program, $382,000 has been awarded through 56 awards in 18 countries on 6 continents. Here is a brief look at the winners and how they will use their grants. For more information, see **planetary.org/neogrants**.

Vladimir Benishek, of Sopot Astronomical Observatory in Serbia, will purchase a CCD camera and a temperature-compensating focuser to create a second observing telescope at his facility. The system will be used primarily for asteroid characterization studies, specifically for taking photometry (brightness) measurements used to determine light curves (brightness with time). These measurements facilitate the determination of the asteroids' spin rates and discovery of binary asteroids (two asteroids rather than just one).

Daniel Coley, at the Center for Solar System Studies (CSSS) in California, will purchase a CCD camera to use with a newly acquired 0.7 meter (28 inch) telescope at their facility in California. The new camera system will be used primarily for photometry to study the physical characteristics of asteroids, including study of the binary nature of some of the asteroids.

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

Coley and his colleagues also collaborate with radar observers to better enable determination of the shapes, spin axes, and rotation periods of near-Earth asteroids.

Robert Holmes, president of the Astronomical Research Institute (ARI) in Illinois, U.S.A., will purchase a CCD camera as well as an adapter for their 0.61 meter telescope. The new camera will replace a camera purchased with a 2008 Shoemaker NEO Grant. The previous camera was used to take more than 52,000 individual measurements of NEO positions (astrometry) to facilitate determination of NEO orbits. The new camera will improve sensitivity and have a much larger memory buffer. *This grant made possible by a gift in memory of Jonathan Masin.*

Gary Hug, representing the Northeast Kansas Amateur Astronomers' League, will purchase several items to enable remote robotic operation of the 0.7 meter Tombaugh Reflector at Farpoint Observatory in Kansas, U.S.A. The Tombaugh reflector was recently upgraded by the group and now can do astrometry (position measurements) of objects with visual magnitude of 22.5 or less. This enables, among other things, follow-up observations used to determine orbits of recently discovered near-Earth asteroids. *This grant made possible by a gift in memory of Jonathan Masin.*

Julian Oey from New South Wales, Australia, will purchase a 0.5 meter telescope to go with an existing mount, camera, and facility at the JBL observatory at a dark, dry location outside Bathurst, Australia. The remote-controlled JBL facility will complement Oey's successful Blue Mountain Observatory: two sites with different weather patterns will facilitate NEO imaging despite cloud cover in one location or the other. The new telescope will be used primarily to provide physical characterization of near-Earth asteroids.

Michel Ory, using the Morocco Oukaïmeden Sky Survey (MOSS) in the High Atlas Mountains of Morocco, will purchase a new CCD camera for its 0.5 meter telescope. Ory and Claudine Rinner operate their MOSS telescope remotely from Switzerland and France, respectively. The new camera will increase their field of view and improve sensitivity. Their focus is on astrometry.

Donald Pray, at the Sugarloaf Observatory in Massachusetts, U.S.A., will purchase a new mount for a 0.5 meter telescope. The mount will improve image quality and overall pointing and tracking capability, and that, in turn, will improve data capture and photometric accuracy. He will sell the old mount and use money received to pay for a new camera for that telescope. In recent years, Pray has discovered the binary nature of more asteroids than any other amateur observer (Benishek was second).

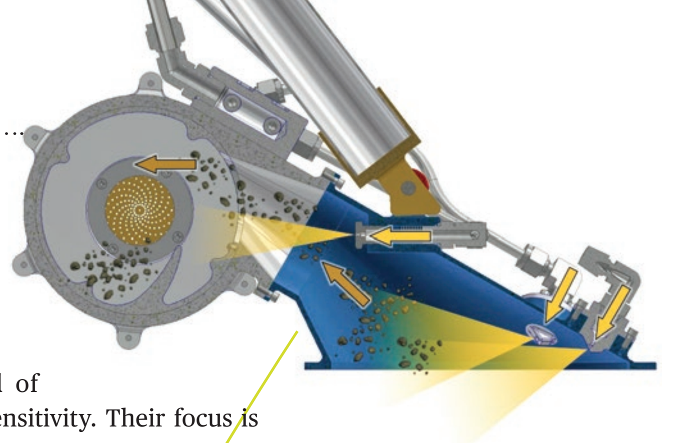
PLANETVAC XODIAC: A SAMPLING TEST ROCKET FLIGHT

It's not easy to pick up dirt and rocks on another world. In fact, it is complex, risky, and expensive. But grabbing a sample and getting that sample into a science instrument, or into a sample return capsule for return to Earth laboratories, has provided some of our most profound discoveries about the solar system.

To test out a new, low-cost, reliable sampling system, we partnered with Honeybee Robotics, makers of a variety of hardware currently working on Mars. In 2013, you helped us sponsor successful tests of their PlanetVac sampling system in a vacuum chamber at Mars atmospheric pressure. PlanetVac uses pressurized gas to push samples into the sampling container.

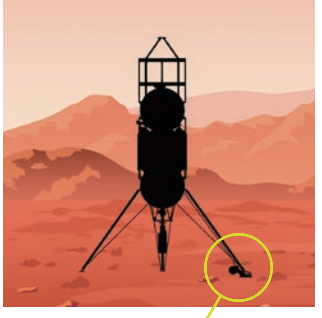
Now, we are providing funding to enable Honeybee to adapt PlanetVac to fly on a NASA-sponsored rocket test flight in the California desert. The Masten Space Systems Xodiac rocket will take off with PlanetVac integrated into a lander leg. The Xodiac will then land and PlanetVac will sample a Mars soil simulant.

This flight will test PlanetVac's ability to operate in a rocket environment and, through that demonstration, get it one step closer to flying on a spaceflight mission. Learn more, support the project, and follow its progress at **planetary.org/PlanetVac**.



ABOVE *Honeybee Robotics' PlanetVac (supported by The Planetary Society) is a solution to the challenges posed by sample return. PlanetVac's nozzles will shoot gas to stir up the Martian surface and then channel the sample into a storage container.*

BELOW *PlanetVac will be tested in California's Mojave Desert on a Masten Xodiac rocket. It will perform its duty from one leg of the lander.*



Illustrations: Honeybee Robotics

REP. JOHN CULBERSON *(R-TX) and*
REP. DEREK KILMER *(D-WA)*

Op Ed: Why We Created the Planetary Science Caucus

A U.S. Bi-partisan Group Committed to Space Exploration

SPACE EXPLORATION BRINGS out the best in us. Since we chose to go to the Moon, space exploration has meant turning the theoretical into the possible, continuing humankind's long history of exploring and questioning what we know about our universe. It's a catalyst for new technologies, and an incubator for new economies and emerging industries. Everything that goes up there is designed and built here on Earth. That means space exploration creates jobs.

When President Dwight Eisenhower signed the National Aeronautics and Space Act in 1958, he solidified an investment that is still paying dividends to this day. Over the past 60 years, NASA has been at the forefront of our country's space science and exploration endeavors. Along that journey, it has been Congress's responsibility to provide funding, stability, and authority. It is in celebration and support of this relationship that we announce the formation of the bicameral, bipartisan Planetary Science Caucus.

Congress's charge to advance space exploration and planetary science comes with a unique set of challenges. For example, to lead the way in space, America needs workers with cutting-edge skills in science, research, technology, and engineering. After all, we're talking about doing things that push humankind's entire understanding of our universe. That reality, coupled with the sheer vastness of space and the enormity of the ambition required to explore it, can easily handicap conversations legislators have when deciding the best path forward on planetary science and exploration.

For these reasons, the new Planetary Science Caucus will endeavor to:

- Advance federal policies that support the search for life in our solar system and beyond;
- Raise awareness of the benefits to the U.S. economy and industrial base resulting from federal investment in space science, technology, exploration, and STEM education;
- Support private industry, academic institutions, and nonprofits that undertake and supplement space science and exploration.

No lone entity could ever accomplish what the entire space science community can accomplish as one. Pushing that envelope will require a holistic approach within the science community.

No one portion of these efforts should ever win out at the expense of another, and it is our hope that this new caucus will contribute to the shared sense of patriotism, purpose, and curiosity that has held us together thus far.

Since our country first set our sights on the Moon, exploring space has meant an America that competes and wins. With the right investments in education and research, and with support for innovative companies and NASA, America will continue exploring and leading the way.

Announcing **Space Advocacy 101**

I'M EXCITED TO ANNOUNCE our new online training course, *Space Advocacy 101*, which is now available for free on our new teaching platform at **courses.planetary.org**. This is the first in what we intend to be a number of online educational courses developed by The Planetary Society.

Space Advocacy 101 is the course I wish I had had when I first began in this field, and it's designed for use by any member of The Planetary Society who has a commitment to becoming a better space advocate. *Space Advocacy 101* provides an overview of how NASA works and how Congress and the White House fund the space program, and it gives tips and tricks on how to effectively communicate with your elected officials as a space advocate. I encourage you to give it a try; I guarantee you will learn something new.

Space Advocacy 101 and the new Planetary Science Caucus are direct results of investments made by members and donors to The Planetary Society. These are unique projects—befitting of our unique organization—among many great successes achieved by our growing Space Policy & Advocacy program this year, and they are only the beginning.

As we aggressively pursue our policy and advocacy program this year, I want to hear from our members. We sent out a special (and brief!) Space Policy Priorities survey in the mail to our U.S. membership. Any of our members can fill it out online. You can provide us feedback and invest in the program yourself at **planetary.org/AdvocacySurvey**. Look for a link to this survey in your electronic mailbox in April.

– Casey Dreier, director of space policy

Mat Kaplan, host

Planetary Radio

WANT MORE SPACE policy and space exploration news? Tune in to *Planetary Radio* every week at **planetary.org/radio**. There you'll find the episode of our Space Policy Edition where we describe our most recent legislative blitz. In February, The Planetary Society enabled 58 members from 21 states to meet with members of Congress and discuss the importance of continued support for space exploration [**planet.ly/2018blitz**]. Keep up-to-date on space and all the ways The Planetary Society, with the support of its powerful members, makes exploration happen. Listen to *Planetary Radio*!

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Twin Grants Challenge Members to Reach Higher

PLANETARY SOCIETY CEO Bill Nye and the M. R. and Evelyn Hudson Foundation have jointly announced two challenge grants, totaling $150,000, to boost The Planetary Society's mission to empower the world's citizens to advance space science and exploration.

With their grants, Bill Nye and the Hudson Foundation want to inspire our members and donors to join them and reach higher with their own philanthropic support of space exploration.

Bill Nye is personally offering a $50,000 challenge. His gift will match, on a 1:1 basis, new and increased unrestricted gifts of any size made in response to the Reach Higher initiative, up to the maximum amount of his pledge. The Hudson Foundation is joining with Bill and offering a $100,000 challenge to inspire gifts of higher amounts. The Foundation will provide an additional 1:1 match on any gift of $1,000 or more, up to the maximum amount of its grant. With matching from both grants, Reach Higher gifts of $1,000 or more will bring in another two dollars for every dollar donated by members. The deadline for meeting these challenges is June 30, 2018.

ABOVE *In a spectacular example of "reaching higher," on February 6, 2018, SpaceX successfully launched the first of its Falcon Heavy rockets.*

Photo: SpaceX

PLANETARY SOCIETY LEADERS SHOW THE WAY

The twin grants behind the Reach Higher initiative are the brainchildren of two key Society leaders, CEO Bill Nye and Board Member Wally Hooser. I invite you to join Bill and Wally and to consider whether you, too, can reach higher to support our movement to connect the world's citizens with the the passion, beauty, and joy of space exploration. For more information, go to **planetary.org/reachhigher**, or call me at 626-793-5100, ext. 214.

The time to Reach Higher is now.

Onward,

Richard

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