



THE PLANETARY REPORT

DECEMBER
SOLSTICE **2020**

VOLUME 40, NUMBER 4

planetary.org



THE YEAR IN PICTURES

FINDING PERSEVERANCE AND HOPE
THROUGH SPACE EXPLORATION



CALIBRATING MARS ✨ BEPICOLOMBO MEETS VENUS ✨ PLANETFEST RETURNS



NASA/CHRIS GUNN

Countdown to Liftoff

WHEN NASA ANNOUNCED the name of the James Webb Space Telescope in 2002, the observatory was scheduled to launch in 2010. While it's common for one-of-a-kind space projects involving new technologies to run over budget and fall behind schedule, not many people would have predicted that Webb would still be on the ground at the end of 2020 with a price tag that has grown to almost \$9 billion, not including operations costs.

If all goes well, 2021 will be Webb's year. The flagship observatory is currently scheduled to blast off on 31 October 2021 after its latest delay of 7 months caused in part by COVID-19. This image shows technicians folding the telescope for launch configuration prior to sound and vibration tests. To learn more about the telescope, visit planetary.org/webb. 🚀



ESA/BEPICOLOMBO/MTM

THREE MONTHS AGO, scientists using Earth-based telescopes announced they had found phosphine in Venus' clouds. Phosphine is a molecule strongly associated with life that has few nonlife methods of production, particularly on a rocky planet like Venus. Some regions of Venus' upper atmosphere are remarkably temperate and Earthlike, and for decades, scientists have hypothesized that there could be microbial life-forms floating around the planet. As of early November, other scientists have not been able to replicate the results or detect the phosphine using other instruments. Extraordinary claims require extraordinary evidence—evidence that future Venus missions could collect.

This picture of Venus comes from Europe and Japan's BepiColombo spacecraft, which is on its way to Mercury. On 16 October 2020, BepiColombo performed the first of 2 Venus flybys using the planet's gravity to bend its trajectory toward Mercury. Venus appears here as a featureless bright orb, much as it would look to a human peering out a spacecraft window. 🚀

READ OUR COVERAGE OF THE PHOSPHINE DISCOVERY: [PLANETARY.ORG/PHOSPHINE-DISCOVERY](https://planetary.org/phosphine-discovery)

FIND OUT WHAT BEPICOLOMBO WILL STUDY AT MERCURY: [PLANETARY.ORG/BEPICOLOMBO](https://planetary.org/bepicolombo)

SEE MORE BEAUTIFUL SPACE IMAGES: [PLANETARY.ORG/SPACE-IMAGES](https://planetary.org/space-images)

ON THE COVER: A SpaceX Crew Dragon capsule carrying astronauts Robert Behnken and Douglas Hurley nears splashdown in the Gulf of Mexico off the coast of Pensacola, Florida on 2 August 2020. Behnken and Hurley spent 64 days in space as part of the first crewed commercial flight to the International Space Station. Credit: NASA/Bill Ingalls * *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. * Viewpoints expressed in articles and editorials are those of the authors and do not necessarily represent positions of The Planetary Society, its officers, or its advisers. ©2020 by The Planetary Society. All Rights Reserved. The Planetary Society and *The Planetary Report*: Registered Trademarks © The Planetary Society. Planetfest™ The Planetary Society.

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

A Picture Is Worth a Thousand Words

Seeing for Ourselves What's Out There and What's Right Here

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AS I HOPE YOU know, it's family lore here at The Planetary Society that a big reason humankind has images from interplanetary spacecraft is because our cofounder Bruce Murray insisted that the fleet of Mariner spacecraft that flew to Mercury, Venus, and Mars have cameras on board. By all accounts, there were a great many scientists in the 1960s who insisted that images would be a luxury, a publicity ploy, and of limited scientific value. Can you imagine a planetary exploration program without pictures?

This issue of *The Planetary Report* looks at some of the most impactful space images from the past year. Along with everything that we learn about the worlds in our cosmic neighborhood, pictures can make the story come to life. When we look at a photo of Venus shrouded in thick clouds, it makes the excitement of possible biosignatures in that atmosphere all the more real.

I bring this up, of course, because along with a great many of you, I live with the hope that we will find evidence of life—or even something alive—right here in our own solar system. Well, my friends, diligent researchers have discovered what may be phosphine gas in the atmosphere of Venus. Other scientists have already examined and questioned those results, and we'll have to be patient while the scientific process examines these extraordinary findings. But no matter what happens, consider the possibility: right now, unless you have an environment with Jovian gas-giant pressures, we don't know of any way to produce a measurable abundance of phosphine without something like anaerobic (no-oxygen) bacteria metabolizing away, replenishing this gas as it breaks down in sunlight. If you haven't stopped to think this over, please do so now. Although the surface

of Venus is inhospitable—I mean hellish in the literal sense—55 kilometers (34 miles) above the surface, the nominally toxic gasses of the atmosphere are a temperate 30 degrees Celsius (86 degrees Fahrenheit). Could something live up there? Could it be that Venus had liquid water oceans and more Earthlike air in primordial times, which led to life, and because of a runaway greenhouse effect, all that's detectable there today are the exhalations of some kind of aeroplankton—very small anaerobes drifting high in the Venusian sky? That would be ... well, that would be amazing. It would change the course of human history. It might quickly lead to an answer to the deep question “how did life begin?” or perhaps “how does life begin there, here, or anywhere?”

While you're thinking about all that, please take some time to look at the pictures we've chosen for this issue. They're from space—and so are we. The more we learn about the cosmos and our place within it, the more we realize the significance of our own world and how perfectly suited our species is to this place. Astronauts often speak of the overview effect. By their accounts, once you see Earth from space, you're never the same. Carl Sagan brought this sentiment home with his powerful few paragraphs about the pale blue dot. Seeing our home world in an image snapped from the cold emptiness of space reminds us to treasure what we have right here beneath our feet. It seems as though there's a great deal of trouble for our species these days, but with the powerful understanding of our place among the stars, we can work together to make our world wonderful while we explore what else must be out there. 🌟



Congress Congratulates The Planetary Society on 40 Years

IN SEPTEMBER, representatives of the United States Congress acknowledged the importance of The Planetary Society by introducing a formal resolution recognizing our 40th anniversary. Congresswoman Judy Chu, who introduced the resolution, explained the important role that our organization has played in Congress over the years:

“Few things can capture the human imagination quite like space exploration. And thanks to their decades of outreach and advocacy, The Planetary Society has put outer space in reach for so many people. I am privileged to represent some of the greatest minds in science who have taken us to Mars and beyond. But these accomplishments would not have been possible without the amazing people at The Planetary Society who have helped Americans and people around the world understand the importance of space and space exploration. That includes the federal government.

As a member of Congress, I have counted on The Planetary Society’s voice on Capitol Hill to advocate for the funding and resources that are necessary to advance this work. But they’re not only helping us to understand the accomplishments of today. Through education, The Planetary Society is helping to inspire the next generation of leaders who will take us even further. We are so fortunate to have an organization like The Planetary Society working to encourage science and exploration, and I congratulate them on an incredible 40 years of success.”

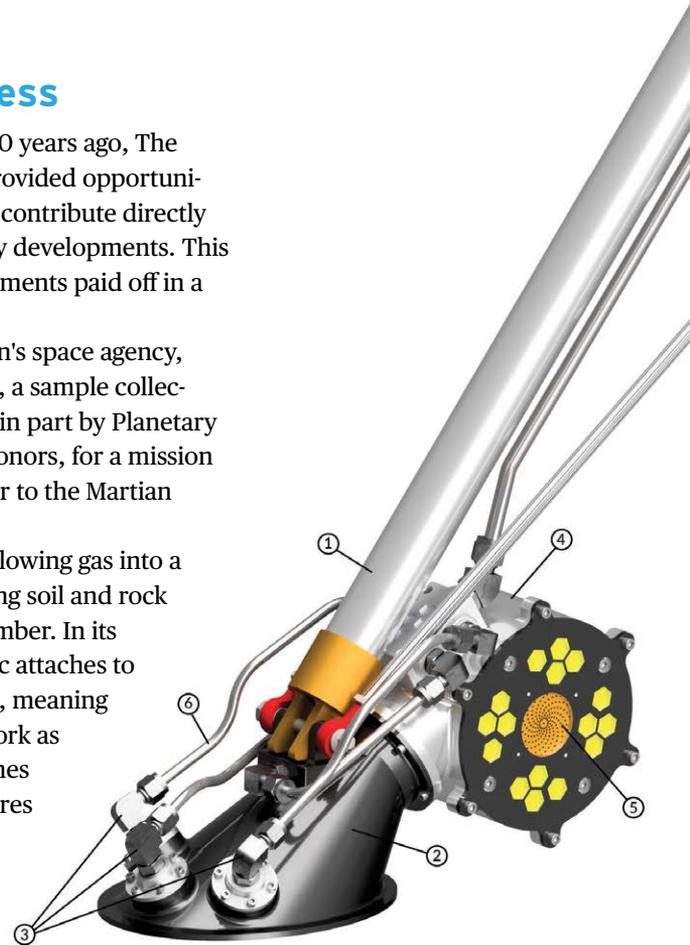
Sci-Tech Success

SINCE OUR FOUNDING 40 years ago, The Planetary Society has provided opportunities for our members to contribute directly to innovative technology developments. This year, one of these investments paid off in a big way.

NASA and JAXA, Japan’s space agency, have selected PlanetVac, a sample collection technology funded in part by Planetary Society members and donors, for a mission to the Moon and another to the Martian moon Phobos.

PlanetVac works by blowing gas into a planetary surface, stirring soil and rock up into a collection chamber. In its simplest form, PlanetVac attaches to a spacecraft’s lander leg, meaning the device is ready to work as soon as the lander touches down. The system requires as little as one moving part: a valve that opens to release the gas. This makes it the ideal technology for low-cost, reliable sample collection.

The lunar version of PlanetVac will launch in 2023 aboard a yet-to-be-selected lander under NASA’s Commercial Lunar Payload Services program, which supports the agency’s plans to return humans to the lunar surface. Japan’s MMX spacecraft will launch to Phobos in 2024 and return samples from the Martian moon to Earth in 2029 using PlanetVac as one of its 2 sampling mechanisms. Learn more at planetary.org/planetvac.



ABOVE This image shows the PlanetVac sampler as it would look installed on a lander leg ①. You can see the sampler cone ②, air nozzles ③, a sample container ④, a filter ⑤, and pneumatic tubing ⑥.

HONEYBEE ROBOTICS

LEARN MORE ABOUT YOUR IMPACT

The Planetary Society’s year-end impact report is now available on our website. Go to planetary.org/impact2020 to learn more about how your support is making a difference to the future of space science and exploration.



EXPLORE WORLDS

Increase discoveries about the worlds of our solar system and beyond.



FIND LIFE

Elevate the search for life as a space exploration priority.

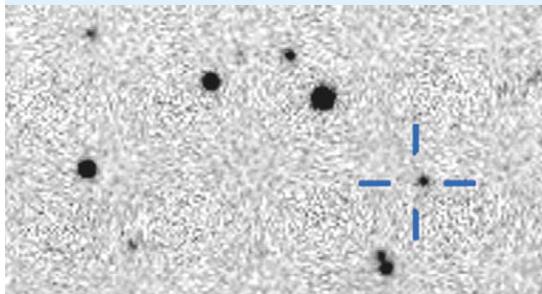


DEFEND EARTH

Decrease the risk of Earth being hit by an asteroid or comet.

CORE ENTERPRISE HIGHLIGHT: DEFEND EARTH

Recently, Planetary Society members have enabled major advances in our work to defend our planet from dangerous asteroids and comets.



LEFT This may look like random static to you, but the fuzzy dot indicated by the blue crosshairs is asteroid 2020 QU6, seen here in amateur astronomer Leonardo Amaral's discovery images. Finding the signal in the noise is difficult, and that's why it's crucial that we continue to fund the people looking for it.

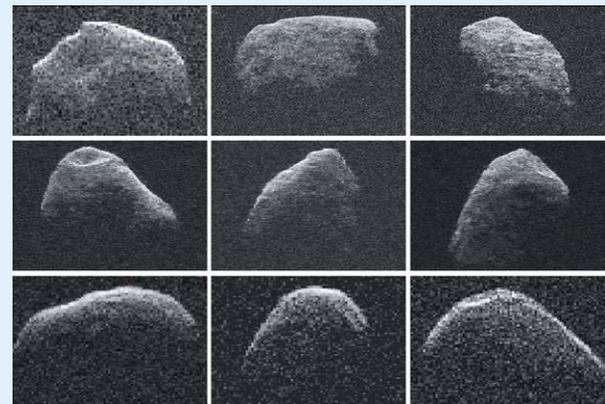
LEONARDO AMARAL

BELOW These images of asteroid Apophis were captured by radar in 2012.

NASA/JPL-CALTECH

Finding the Threats

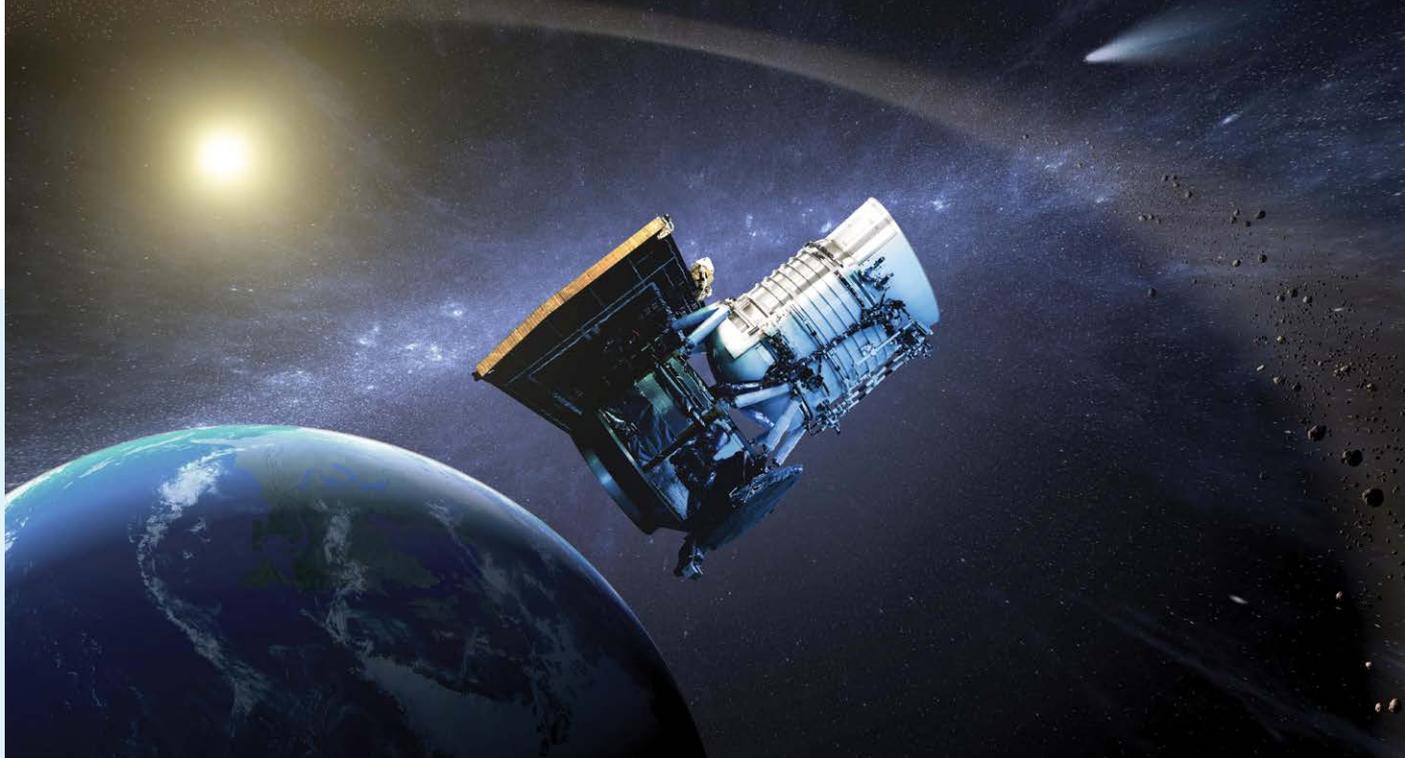
THIS YEAR, you enabled the discovery of NEO 2020 QU6, a kilometer-wide asteroid that would create global devastation if it were to hit Earth (fortunately, its orbit is such that it won't). Amateur astronomer Leonardo Amaral discovered the large near-Earth object (NEO) with the help of a Planetary Society grant of \$8,500 in 2019 to purchase a more stable telescope mount for better tracking and longer camera exposures. The Society's Shoemaker NEO Grant program funds advanced amateur astronomers around the world who find, track, and characterize potentially dangerous space rocks like NEO 2020 QU6. That it wasn't detected until now should serve as a reminder that there's much work to be done when it comes to defending our planet from dangerous asteroids. Amaral's location in Brazil allows him to monitor the far southern skies not currently covered by the large professional surveys.



November 2020, The Planetary Society participated in a virtual international conference that brought together experts from many fields to plan for this event. This once-per-thousand-years occurrence provides unique opportunities for science as well as public education and advocacy. This near pass will likely capture the attention of the public and the media, creating a unique opportunity to educate the public and policymakers about asteroid science, the actual nature of the broader asteroid threat, what is being done to reduce the threat, and pathways for improving future detection and deflection capabilities. With 9 years to prepare, we are making sure

Preparing for Apophis

IN 2029, a 370-meter-wide asteroid named Apophis will fly by Earth, coming as close as 31,300 kilometers (19,400 miles)—closer than most communications satellites. In



that the Apophis flyby will be a turning point in humanity's perspective on planetary defense.

Spreading the Word

PUBLIC OUTREACH and education are a critical part of our planetary defense work. Recently, we hosted a live webinar about the NEO threat and what people can do to help, featuring *Planetary Radio* host Mat Kaplan, chief scientist Bruce Betts, chief advocate and senior space policy adviser Casey Dreier, and special guest professor Amy Mainzer of the University of Arizona, principal investigator for the NEOWISE mission. If you missed this free webinar, you can still find it along with recordings of other past live events at planetary.org/live.

Advocating for Defense

ALTHOUGH WE'RE PROUD that our members around the world are helping to defend the planet from impacts, it's important that the world's governments do their part as well. This year, The Planetary Society partnered with the University of Arizona and the office of Senator Kyrsten Sinema (D-AZ) in a virtual congressional briefing on the importance

of planetary defense. Chief advocate Casey Dreier made the case for why we need the NEO Surveillance Mission, a space telescope dedicated to finding and characterizing potentially threatening asteroids and comets. Our ongoing advocacy on this front has proven effective; in the last 10 years, NASA's funding for planetary defense has increased substantially, though it still accounts for less than 1% of the agency's expenditures. More increases are needed to better defend the planet.

Ensuring the Future of Our Work

THE EFFORT to defend Earth from asteroid and comet impacts is complex and ongoing. Thanks to the support of members like you, we can keep working to keep our planet safe. This year, we embarked on a fundraising campaign and raised more than \$76,000 to support our ongoing planetary defense work, and in our recent membership drive, 504 new members joined The Planetary Society to help us continue fighting for the security of our home world. Because of this support, we can keep working to defend our home from the dangers of space rocks. 🚀



TOP An artist's concept of NEOWISE, the asteroid-hunting mission led by Amy Mainzer.

NASA

ABOVE Earth has been struck by asteroids before, like the one that created this crater in Arizona, USA 50,000 years ago. Let's prevent it from happening again.

EDUPIC GRAPHIC RESOURCES

Planetary Society members like you make this work possible. *Thank you!*



GET INVOLVED

New 2021 Member Directory

The Planetary Society is partnering with Publishing Concepts, Inc. to offer members—that's you!—the opportunity to reserve a digital or hardbound 2021 Planetary Society Member Directory. Starting in early 2021, postcards and emails will be sent out to give you the chance to opt in for this opportunity, update your contact information, and reserve your copy.

This special-edition directory will document our organization's 40-year history and be filled with photos and stories from over the years. Plus, it will contain a listing that will help you stay connected with fellow members. We hope you'll participate and reserve your copy!

Important Tax Deadlines

For U.S. tax purposes, gifts must be received on or before the last day of the year. Here are some common methods of making a gift and their associated deadlines.

ONLINE CREDIT CARD GIFTS: transaction completed by 11:59 p.m. EST (8:59 p.m. PST), 31 Dec

CHECKS SENT VIA U.S. MAIL: postmarked on or before 31 Dec

CHECKS SENT VIA THIRD-PARTY SHIPPING (SUCH AS FEDEX OR UPS): delivered on or before 31 Dec

CREDIT CARD GIFTS VIA U.S. MAIL: received and processed on or before 31 Dec

STOCK TRANSFER: broker-to-broker instructions issued in time for completed transfer on or before 31 Dec

TOP OF PAGE, CLOCKWISE FROM TOP LEFT *Planetary Society cofounder Carl Sagan and musician Chuck Berry at Planetfest '89, which celebrated Voyager 2's flyby of Neptune; Hope, Tianwen-1, and Perseverance are all arriving at the Red Planet this year.*

THE PLANETARY SOCIETY, ESA/MBRSC/CNSA/WEIBO/NASA

LEFT *This mosaic of 100 Viking orbiter images acquired in 1980 shows Mars in fantastic detail. The Red Planet is ready to be explored.*

NASA/JPL/USGS

The Return of Planetfest

In February 2021, the next generation of Mars exploration will begin. With the United States of America's Perseverance rover, China's Tianwen-1 lander, and the United Arab Emirates' Hope orbiter all arriving at the Red Planet, this calls for a global celebration.

Planetfest '21 will continue The Planetary Society's long-standing tradition of ringing in a major exploration milestone by hosting a festival to bring together the people who love exploration and the ones who make it happen. The festivities will culminate with a worldwide virtual landing party marking Perseverance's arrival on the Red Planet.

This time, with the coronavirus pandemic still preventing in-person gatherings, we will get together virtually. The silver lining, of course, is that people from around the world can join the festivities. So, wherever you are, we invite you to join us in February to usher in this exciting new age of Mars exploration.

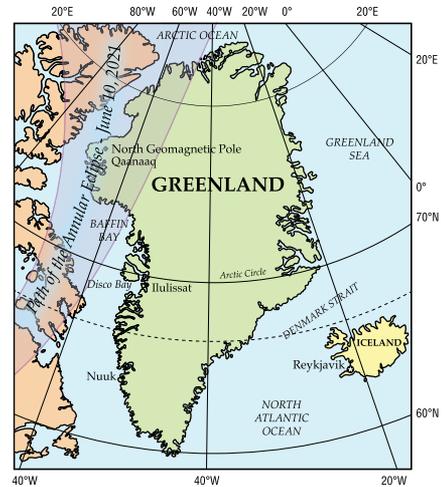
Keep an eye on your email inbox for announcements from us about this exciting virtual event and go to planetary.org/planetfest21 to learn more.

YOU'RE CORDIALLY INVITED...

Members, save the date for a virtual gala like no other. During Planetfest '21, we invite you to join us for an exclusive virtual dinner event with our CEO Bill Nye, members of our board of directors, and other space luminaries. We look forward to celebrating our 40 years of shared achievement with you.

CELEBRATE MARS WITH US!

Travel Adventures for You!



We invite you to travel with The Planetary Society to see wonderful eclipses or the aurora borealis in 2021!

As we go to press, travel restrictions during the COVID-19 pandemic are evolving, and countries are starting to open. For updated information, contact Betchart Expeditions Inc. at 800-252-4910 or go to betchartexpeditions.com.

ALASKA AURORA BOREALIS 11-17 MARCH 2021

See the greatest light show on Earth on this ever-popular adventure!

DISCOVER THE GEOMAGNETIC NORTH POLE & WEST GREENLAND ANNULAR ECLIPSE 3-13 JUNE 2021

See extraordinary landscapes, sled dogs, glaciers, and the annular eclipse in this land of the midnight sun!

BAFFIN ISLAND, CANADA ANNULAR ECLIPSE 6-11 JUNE 2021

Discover the "ring of fire" in the remote Canadian High Arctic!

ANTARCTICA TOTAL SOLAR ECLIPSE 2021 23 NOVEMBER - 15 DECEMBER 2021

See the total eclipse in one of the most remote places on Earth, plus South Georgia and the Falkland Islands.



ADVOCATE FOR SPACE WITH US!

ABOVE The Planetary Society's 2020 Day of Action in Washington, D.C. drew 115 members from 28 states to advocate for space exploration.

THE PLANETARY SOCIETY

Join the 2021 Day of Action

The Day of Action is an annual event that brings together Planetary Society members and their representatives in Congress. In-person congressional meetings are not possible at present, so we're organizing our first-ever virtual Day of Action for the spring of 2021. We'll arrange virtual meetings with your congressional representatives and their staff so you can safely and effectively share your passion for space science and exploration. Non-U.S. residents will have ways to participate as well. Learn more and register at planetary.org/dayofaction.

"Until my first Day of Action, I always thought of the government as Them. Now I think of it as Us."

—LAUREL B., 2019 DAY OF ACTION PARTICIPANT, UNITED STATES

Keep Looking Up! You Make This Work Possible

This has been a year like no other. We have been challenged, we have changed, and we have grown. Space science and exploration—and the benefits they provide to humankind—are even more vital to our dream of a positive future. As 2020 comes to an end, your support will ensure that we can continue to advance space science and exploration in 2021 and beyond. You can fuel our advocacy, education, and science and technology work while going through whatever challenges our world faces in the coming years. Go to planetary.org/planetaryfund to do your part to support the future of exploration and discovery and to help spread the cosmic perspective to people all around Earth.



WIKIMEDIA COMMONS

IN THE SKY

On 21 December 2020, very bright Jupiter and yellowish Saturn will be closer in the sky than they have appeared in almost 400 years. Low in the west in the early evening, they will be 7 arcminutes apart, or less than one-fourth the width of a full Moon. They will remain relatively close as they drop out of view below the horizon over the following weeks. They will reappear in the predawn east by March. Reddish Mars is in the evening south. Super-bright Venus is visible in the predawn east in January but then moves out of the night sky. Mercury is low in the west in the evening in late January and is then close to Jupiter and Saturn very low in the predawn east at the beginning of March. The Quadrantids meteor shower peaks the night of 2-3 January. The Quadrantids is an above-average shower, but the Moon will interfere some with visibility this year.

RANDOM SPACE FACT

The atmospheric surface pressure on Venus is higher than the bite pressure of a grizzly bear.

TRIVIA CONTEST

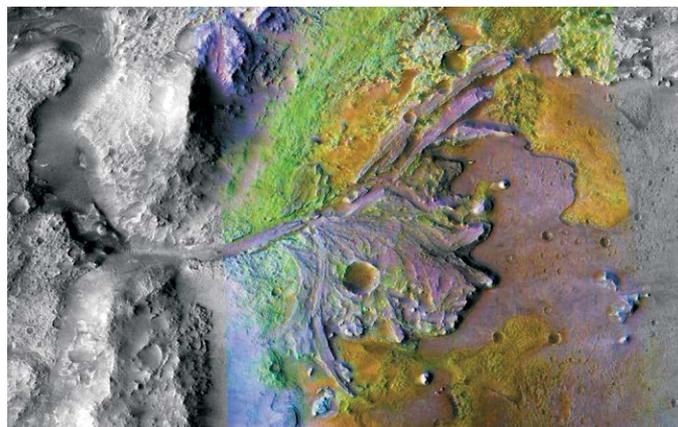
Our June solstice contest winner is Guy Horanberg of Santa Clarita, California, USA. Congratulations! The question was: **What was the first successful robotic mission to return samples from beyond Earth?** The answer: **The robotic Soviet Luna 16 mission (shown in the 1970 Russian postage stamps above) returned 101 grams (3.6 ounces) of samples from the Moon in 1970.**

Try to win a copy of *Space Exploration for Kids* by Bruce Betts and a *Planetary Radio* T-shirt by answering this question:

What was the only Apollo spacecraft call sign named after a single star?

Email 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 email 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 1 March 2021. The winner will be chosen in 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.



NASA/JPL/JHUAPL/MSSS/BROWN UNIVERSITY

ABOVE NASA's Perseverance rover will touch down in Jezero crater, the site of an ancient river delta where life may have once flourished.

Where We Are

An At-a-Glance Spacecraft Locator

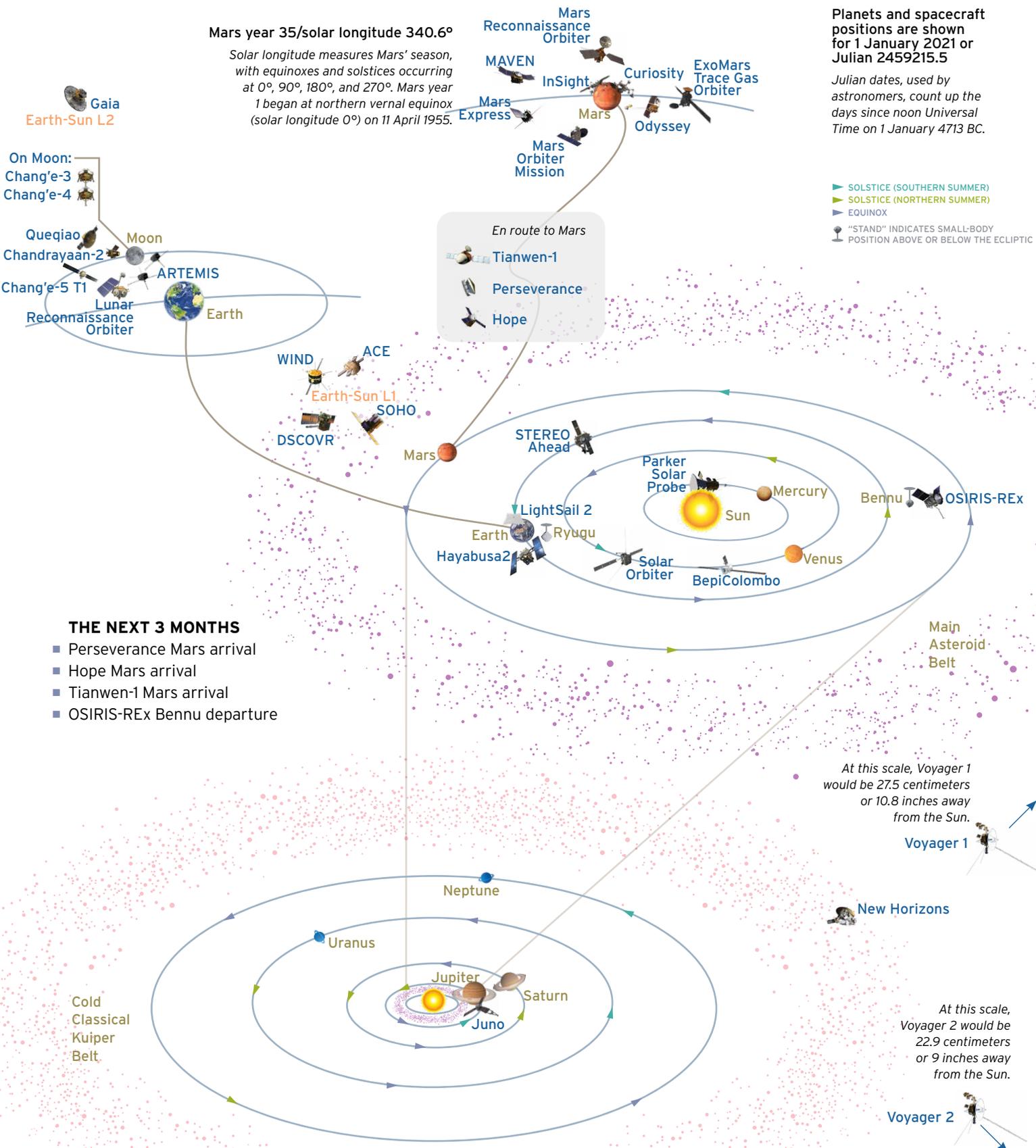
THE FLOTILLA OF SPACECRAFT launched to Mars in July has almost arrived. On 18 February 2021, NASA's Perseverance rover will plunge through the Martian atmosphere in a dramatic repeat of the 2012 Curiosity landing. Also in February, the United Arab Emirates' Hope mission will aerobrake into Martian orbit to begin studying the planet's climate, while China's Tianwen-1 orbiter and rover will enter orbit before the rover descends to the surface around May.

Japan's Hayabusa2 spacecraft should have delivered its precious samples of asteroid Ryugu to Earth on 6 December 2020 and is now starting its extended mission to visit 2 more asteroids. Europe and Japan's BepiColombo spacecraft flew past Venus on 16 October and will make a second flyby in August 2021. NASA's OSIRIS-REx, fresh off its successful sample collection at asteroid Bennu, is expected to depart for Earth in March 2021. 🚀

LEARN ABOUT ALL 3 NEW MARS MISSIONS AT
[PLANETARY.ORG/MARS2020](https://planetary.org/mars2020)

TO STAY UP TO DATE ON THESE AND OTHER MISSIONS, VISIT
[PLANETARY.ORG/SPACE-MISSIONS](https://planetary.org/space-missions)

TO GET WEEKLY MISSION NEWS IN YOUR EMAIL INBOX, VISIT
[PLANETARY.ORG/CONNECT](https://planetary.org/connect)



Mars year 35/solar longitude 340.6°

Solar longitude measures Mars' season, with equinoxes and solstices occurring at 0°, 90°, 180°, and 270°. Mars year 1 began at northern vernal equinox (solar longitude 0°) on 11 April 1955.

Planets and spacecraft positions are shown for 1 January 2021 or Julian 2459215.5

Julian dates, used by astronomers, count up the days since noon Universal Time on 1 January 4713 BC.

- ▶ SOLSTICE (SOUTHERN SUMMER)
- ▶ SOLSTICE (NORTHERN SUMMER)
- ▶ EQUINOX
- “STAND” INDICATES SMALL-BODY POSITION ABOVE OR BELOW THE ECLIPTIC

En route to Mars

- Tianwen-1
- Perseverance
- Hope

THE NEXT 3 MONTHS

- Perseverance Mars arrival
- Hope Mars arrival
- Tianwen-1 Mars arrival
- OSIRIS-REx Benu departure

At this scale, Voyager 1 would be 27.5 centimeters or 10.8 inches away from the Sun.

Voyager 1

New Horizons

At this scale, Voyager 2 would be 22.9 centimeters or 9 inches away from the Sun.

Voyager 2



THE YEAR IN

Perseverance and Hope Amidst Turmoil

IT WAS A TOUGH YEAR on planet Earth. The COVID-19 pandemic ravaged the globe while protesters around the world rallied to end systemic racism. Space exploration is an inherently optimistic endeavor. Amidst the year's turmoil, we saw some truly awe-inspiring cosmic moments. In May, astronauts Bob Behnken and Doug Hurley flew a SpaceX Crew Dragon to the International Space Station and back, completing the first-ever commercial, crewed, orbital spaceflight. The mission rejuvenated our appreciation for the beauty and drama of human spaceflight.

We were also inspired by the launch of 3 new Mars missions. Although the pandemic significantly slowed most space activities, technicians in multiple countries managed to meet a brief launch window that only comes around every 2 years when Mars and Earth are optimally aligned. The name of 2 missions, Perseverance and Hope, took on a whole new significance.

High above Earth, The Planetary Society's LightSail 2 spacecraft continued to demonstrate solar sailing technologies while capturing beautiful pictures of our planet. Elsewhere in the solar system, NASA's OSIRIS-REx successfully collected a sample from asteroid Bennu while Hayabusa2 flew back to Earth carrying dust and rock from asteroid Ryugu. In September, scientists using Earth-based telescopes announced that they had found phosphine on Venus, raising the prospect for life existing there. With these accomplishments came the reminder that we humans can do incredible things when we work together, and there is hope for better days ahead. 🪐



PICTURES



ABOVE This image, cropped from a 116-frame panorama captured by NASA's Curiosity rover in January 2020, shows Mount Sharp on Mars. The scene looks remarkably similar to the landscape found in some parts of the southwestern United States.

NASA/JPL-CALTECH/MSSS

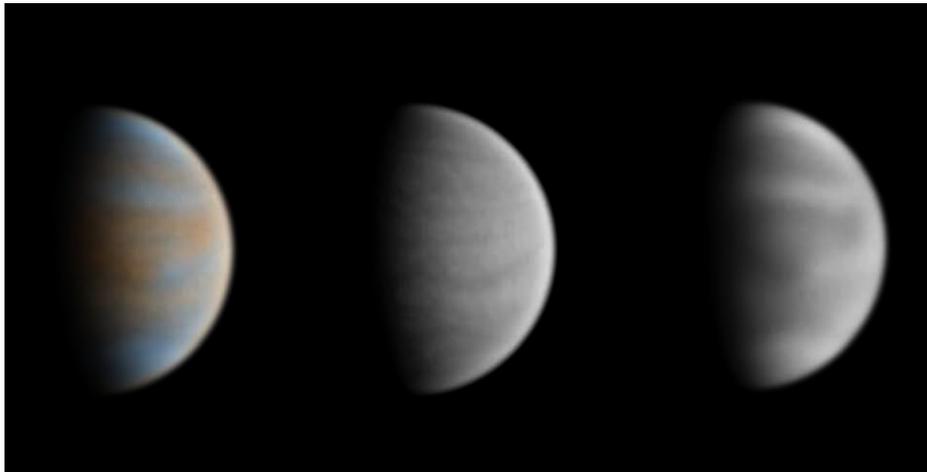
LEFT NASA astronauts Bob Behnken (left) and Doug Hurley are all smiles after safely returning to Earth aboard a SpaceX Crew Dragon on 2 August 2020. The mission, Demo-2, was the first crewed flight of NASA's Commercial Crew program.

NASA/BILL INGALLS



LEFT *In mid-2020, many stargazers around the world were able to see comet NEOWISE with the naked eye. This image of the comet was captured from Gila Bend, Arizona on 18 July 2020 by astrophotographer Adam Block.*

ADAM BLOCK



ABOVE *These 3 views of Venus were captured by the Chilescope Observatory in Chile on 15 February 2020. Visible-light views of Venus show a nearly featureless surface, so scientists use filters such as infrared (left, center) and ultraviolet (right) to capture atmospheric details unseen by the human eye.*

S. TRATTNIG/D. PEACH/CHILESCOPE

BELOW *NASA's Juno spacecraft captured this view of Jupiter's swirling clouds during its 29th close pass over the giant planet in September 2020.*

NASA/JPL-CALTECH/SwRI/MSSS/KEVIN M. GILL





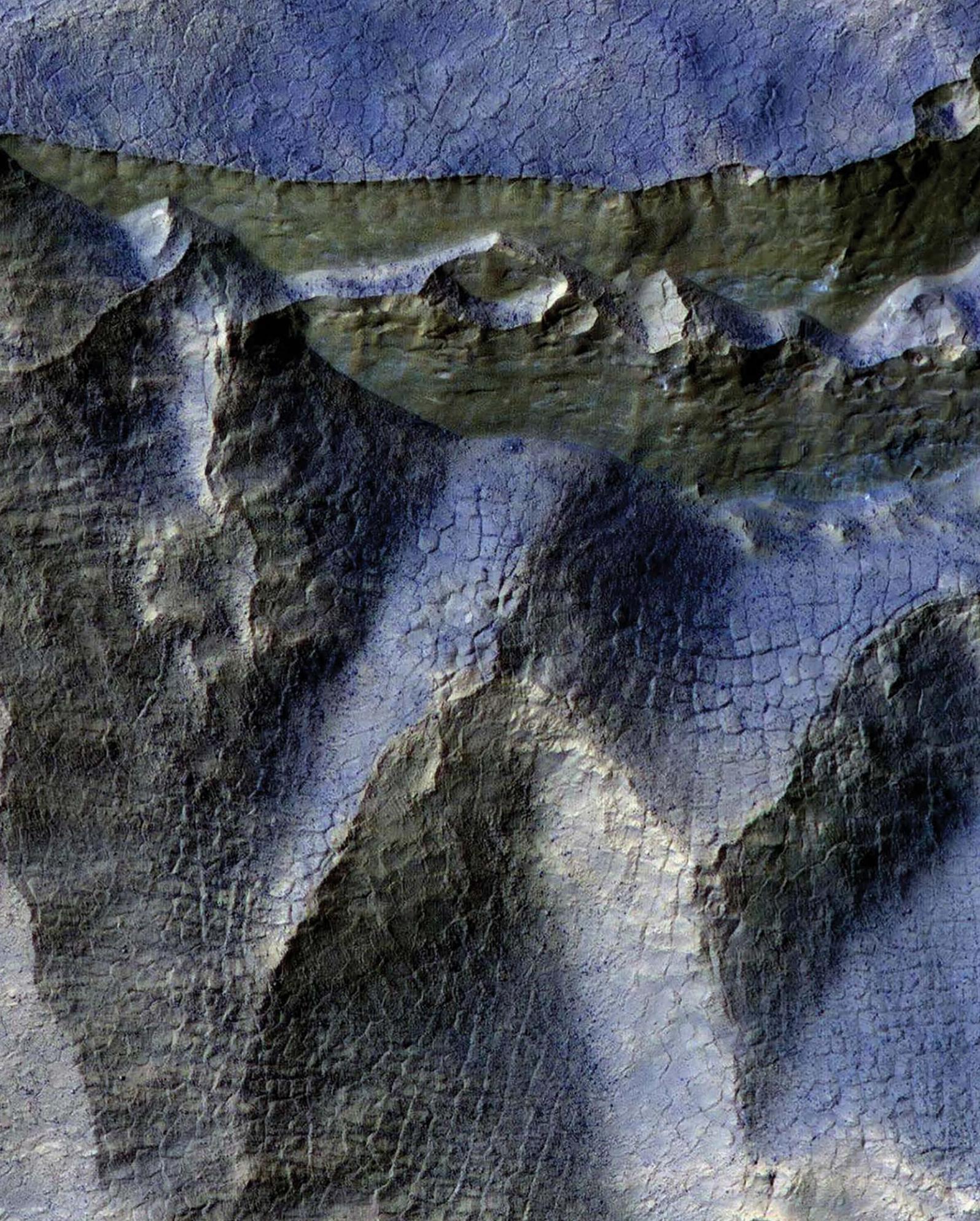
ABOVE LEFT *This image, taken by The Planetary Society's LightSail 2 spacecraft on 19 May 2020, shows the Arabian Peninsula with the Red Sea and Nile River at left and the Persian Gulf at right. North is approximately at top right. A material similar to a piece of fishing line, called Spectraline, held the spacecraft's solar panels closed prior to sail deployment and can be seen at upper left. This image has been color-adjusted, and some distortion from the camera's 180-degree fisheye lens has been removed.*

THE PLANETARY SOCIETY

LEFT *A Japanese H-IIA rocket blasts off carrying Hope, the United Arab Emirates' Mars mission, on 19 July 2020.*

MITSUBISHI HEAVY INDUSTRIES

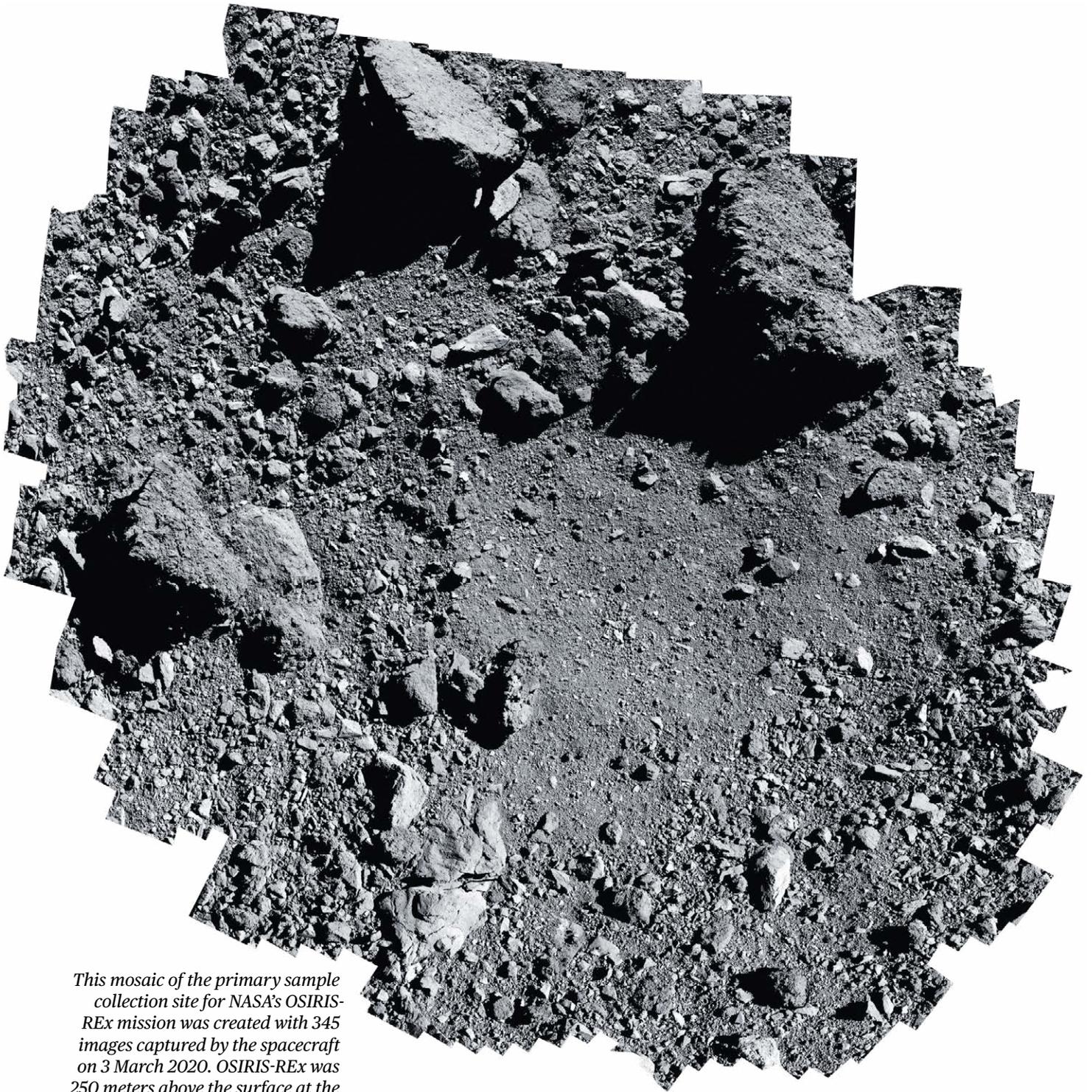






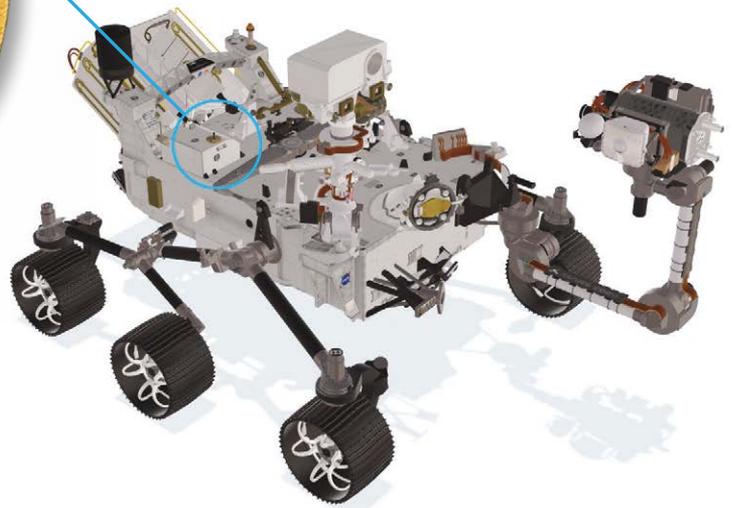
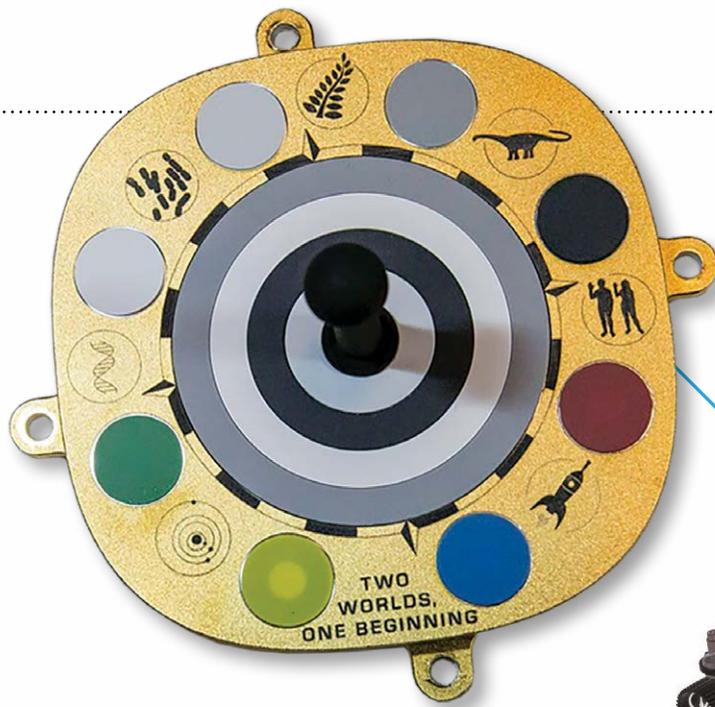
About one-third of Mars has ice just beneath the surface. Scientists study the ice to learn what early Mars was like and whether it was warm and wet long enough for life to take hold. In this false-color image from NASA's Mars Reconnaissance Orbiter, layers of bluish ice can be seen layered inside an exposed brownish cliff face. MRO takes repeat images of scenes like this, occasionally revealing ice boulders that have tumbled down slopes.

NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA



This mosaic of the primary sample collection site for NASA's OSIRIS-REx mission was created with 345 images captured by the spacecraft on 3 March 2020. OSIRIS-REx was 250 meters above the surface at the time. The specific collection site is the relatively rock-free area in the middle. The boulder in the upper right is 13 meters wide on its longest axis.

NASA/GODDARD/UNIVERSITY OF ARIZONA



Calibrating Mars

Two Colorful Calibration Targets Will Help Scientists Measure Martian Scenes

by Kjartan Kinch, Mark Hilverda, Morten Bo Madsen, and Jim Bell

IN JULY, NASA's Perseverance rover launched from Kennedy Space Center in Florida, carrying to Mars the hopes, dreams, and efforts of thousands of engineers and scientists. The 1-ton rover will land in Jezero crater this February. Sometime around 3 to 4 billion years ago, Jezero was filled with a lake fed by 2 rivers on the northwest side. Mars likely had an environment at the time that could have supported life. Perseverance will explore Jezero's river delta for signs of ancient life, attempting to answer one of the biggest questions in science: are we alone?

As the rover travels the delta, it will collect samples with a robotic coring drill and seal them into small tubes. Later this decade, NASA and the European Space Agency are planning missions that will bring the samples back to Earth. Perseverance's onboard cameras help rover drivers plan the route and avoid dangerous hazards. Two scientific cameras on the rover's mast also help scientists study the composition of nearby rocks and soil, providing critical context for when

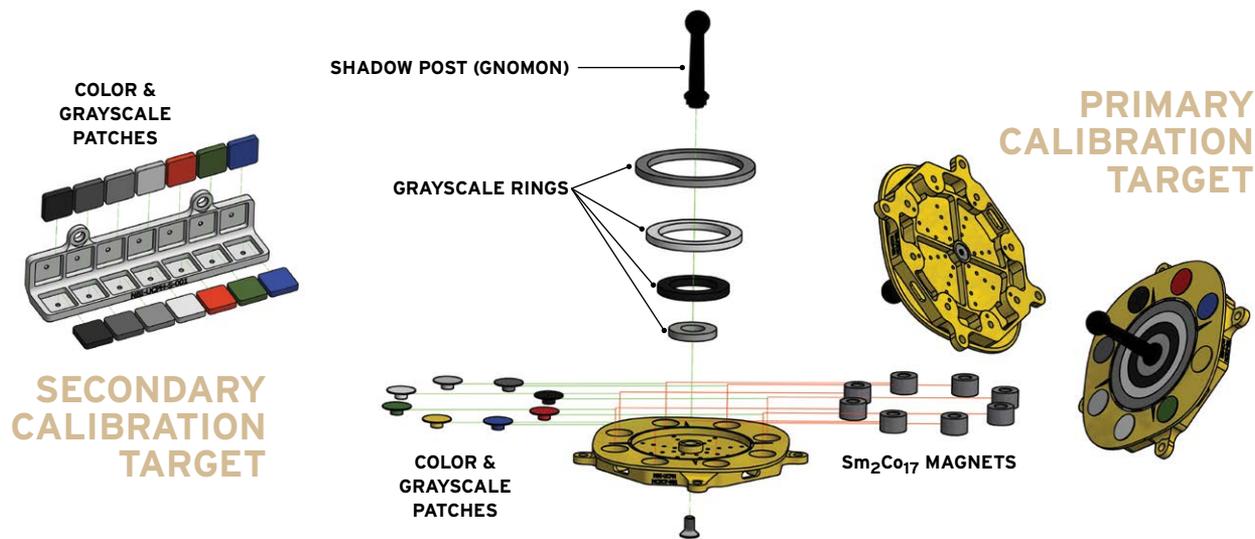
the samples are studied in Earth laboratories many years from now.

Those 2 scientific cameras are known as Mastcam-Z. They sit about 2 meters off the surface—about eye level for a professional basketball player—and are based on the Mastcam cameras aboard NASA's highly successful Curiosity rover. They are upgraded with zoom capabilities (hence the "Z").

The cameras have filters that allow them to see how bright rocks and soils and other features of interest look across different wavelengths of light, including some in the infrared and ultraviolet that human eyes can't see. Scientists can tell a lot about a scene based on how bright it is at different wavelengths. However, there's a problem: just like on Earth, the brightness of scenes on Mars varies depending on the time of day, the time of year, and how much dust is in the atmosphere. How can we account for those changing conditions? We use calibration targets—objects of known brightness and color that will tell us how the Sun and dust are affecting our measurements.

ABOVE This image shows the primary calibration target for the Mastcam-Z cameras on NASA's Perseverance rover, containing a motto, graphics, and a sundial. The blue circle on the rover model indicates the primary and secondary targets' location.

NASA/JPL-CALTECH/ASU/UNIV. COPENHAGEN



HOW CALIBRATION WORKS

The primary and secondary Mastcam-Z calibration targets are mounted behind the rover's mast atop a small box that houses the electronics for the rover's pyro firing systems. Both are small enough to fit in the palm of your hand and collectively weigh just 118 grams (4.2 ounces). Whenever Mastcam-Z takes an image of the Martian terrain, we can tell it to image the calibration targets too. Since we already measured how these targets reflect various wavelengths of light on Earth, imaging them on Mars will tell us how to adjust our readings.

We'll use the primary target the most, but since the secondary is located nearby but in a different spot that gets shadowed about half the time, we can use images of it to understand how Sun exposure and dust accumulation are affecting the primary target. That's right—our calibration target has a calibration target!

Every NASA surface mission ever sent to Mars has had a calibration target. Since scientists image these targets many times during a mission, a little extra thought gets put into their appearance. The Planetary Society helped design the calibration targets for the Spirit and Opportunity rovers, and since it is an official education and outreach partner for the Mastcam-Z instrument, it helped with Perseverance's design too.

THE PRIMARY TARGET

The primary target measures 10 centimeters (4 inches) across. It has an aluminum base with thin silver and gold coatings on top to give it an artistic appearance and to enable laser etching of additional embellishments. Along the outside of the target are 8 circular patches with colors that span the range of sensitivity of the Mastcam-Z cameras. Underneath each is a strong magnet that

ABOVE This diagram shows the primary and secondary calibration targets for the Mastcam-Z cameras aboard NASA's Perseverance rover.

UNIV. COPENHAGEN/ASU

ABOUT THE AUTHORS: **KJARTAN KINCH** is a Mastcam-Z coinvestigator based at the Niels Bohr Institute of the University of Copenhagen in Copenhagen, Denmark. He led the design, manufacture, and testing of the Mastcam-Z calibration targets. He loves maps. **MARK HILVERDA** is a digital specialist for The Planetary Society. He is a designer and geoscientist who loves space, art, and web development. Working with the Mastcam-Z team, he created the art for the vignettes on the calibration target. **MORTEN BO MADSEN** is a Mastcam-Z coinvestigator based at the Niels Bohr Institute of the University of Copenhagen in Copenhagen, Denmark. He has participated in all of NASA's rover missions and led the design, manufacture, and testing of camera calibration targets for NASA's Phoenix lander. He loves music, Mars landscapes, and working with science. **JIM BELL** is the Mastcam-Z principal investigator, and he served as president of The Planetary Society's board of directors from 2008 to 2020. He teaches at Arizona State University and has been having fun using and designing Mars calibration targets since NASA's 1997 Pathfinder mission.

should repel most of the Martian dust from its center. This is based on similar magnets used on the Spirit, Opportunity, Phoenix, and Curiosity missions.

Inside that are 4 gray-to-black rings that match 4 of the circles on the periphery. These rings, like the grayscales on a photographer's test chart, provide the main calibration information used by the camera team.

In the middle of the rings is a post called a "gnomon," which is the name for the part of a sundial that casts a shadow. The grayscale rings surround the gnomon so that brightness can be measured in both sunlit parts of the rings and parts of the rings that are shadowed by the gnomon. The shadows on Mars are not black but reddish because of sunlight scattered by the dusty atmosphere. (Similarly, shadows on Earth are distinctly blueish because of sunlight scattered in our blue sky.) Surrounding the middle rings is a compass rose with points aligned along the rover's X and Y directional axes. Using the gnomon's shadow on the compass rose, you can determine either the direction the rover is pointing or the local time as long as you know the other!

The target also contains laser-engraved graphics, a motto, and an inspirational message. NASA calls these embellishments "festooning"; they don't serve a direct engineering or scientific purpose, but they're meaningful nonetheless. They have artistic value, they help communicate Perseverance's goals and historical context to the public, and they offer a fun and educational way to connect to the mission.

THE MOTTO

Like Spirit, Opportunity, and Curiosity, Perseverance's primary calibration target has a motto. The original inspiration for Spirit and Opportunity was the gnomon since sundials often have mottos associated with beginnings, endings, or the passage of time.

The Spirit and Opportunity motto was "Two Worlds, One Sun," and you can learn



more about the calibration target for those missions in the January/February 2004 issue of *The Planetary Report*. Curiosity's motto is "To Mars To Explore." Perseverance's motto, "Two Worlds, One Beginning," echoes the Spirit and Opportunity motto and evokes the idea of Earth and Mars growing out of the same initial cloud of gas and dust that formed our solar system. Both planets had similar starting conditions but evolved into very different worlds.

We chose the Eurostile font for its clean forms that are free of sharp points and excessive detail. This also serves as a nod to science-fiction fans like many of us on the team since Eurostile appears in movies like *2001: A Space Odyssey* as well as the *Star Trek* TV and movie series.

THE GRAPHICS

Seven icons, which the Mastcam-Z team calls "vignettes," fill the space between the colored calibration circles and depict the evolution of life, from the formation of our solar system to spaceflight. (See sidebar for descriptions.)

ABOVE The calibration target's outer edge contains an inspirational message for future explorers.

UNIV. COPENHAGEN

Target Vignettes:



MERCURY, VENUS, EARTH, AND MARS ORBITING THE SUN: This symbolizes the formation of the solar system and the steady revolutions of our planets. The positions of Mercury, Venus, and Earth are shown for the time of the launch window in July 2020, while Mars is at its approximate position for the time of the landing in February 2021.



DNA STRAND: This symbolizes the emergence of life on Earth. Perhaps Perseverance will help us learn that life formed on Mars around the same time.



CYANOBACTERIA: This symbolizes the early proliferation of microorganisms on Earth and possibly Mars.



FERN: This symbolizes green plants spreading across Earth.



DINOSAUR: An apatosaurus symbolizes the great diversity of life on Earth.



HUMANS: This vignette echoes the image of humans placed on plaques aboard the Pioneer spacecraft in the 1970s, which will eventually reach interstellar space. A similar image is encoded on the Voyager golden records, which are already in interstellar space. On Pioneer, only the man is waving, and on Voyager, the woman is waving. We decided to make both people wave.



ROCKET: The rocket is traveling from Earth (the blue dot) to Mars (the red dot). We chose a stylistic rocket because the realistic version looked a little too much like a missile. Additionally, the stylized version is linked to science fiction that was popular at the dawn of the Space Age, which inspired many early scientists and engineers to pursue the exploration of other worlds.

CALIBRATING MARS

INSPIRATIONAL MESSAGE

The Spirit, Opportunity, and Curiosity calibration targets carried inspirational messages printed on the edges of the target that were not visible from onboard cameras. These messages were meant to be read by future astronauts or other travelers to Mars. Perseverance's target has a message, but it's shorter since our target base is thinner to save weight. It reads: *"Are we alone? We came here to look for signs of life, and to collect samples of Mars for study on Earth. To those who follow, we wish a safe journey and the joy of discovery."*

The phrase "joy of discovery" then repeats in Mandarin, Hindi, Spanish, and Arabic. Together with English, these are the 5 most-spoken languages on Earth. "Joy of discovery" was also the final phrase on the Spirit, Opportunity, and Curiosity targets, connecting Perseverance to its predecessors.

SECONDARY TARGET

The secondary calibration target is smaller and simpler, measuring just 8 centimeters (3 inches) long. It repeats the color patterns from the primary target with the exception of yellow because of limitations on the size of the target. The patterns are repeated both horizontally and vertically; the vertical patterns will accumulate less dust and give us yet another measure of how the Martian environment is affecting the calibration targets.

EYES OPEN ON MARS

When Mastcam-Z first opens its eyes on Mars, one of the first things we'll do is image the targets while they are as dust-free as possible, giving us a baseline from which we can monitor changes. Later, as the rover explores Jezero crater, pictures of the targets will beam back to Earth alongside gorgeous panoramas of the Martian landscape; close-up images of rocks, soils, layers, and other features that formed in an ancient river; and more.

Did life once exist on Mars? This is a big question that can only be answered with countless small steps spanning decades. Perseverance, the next step, relies on thousands of parts, processes, and people to do its job. We're honored to be part of the group that made these calibration targets possible and by the role we're playing in answering that ultimate question posed on the rover for future Martian visitors: are we alone? 🚀

Learn More:

LEARN ABOUT THE PERSEVERANCE MISSION

[PLANETARY.ORG/PERSEVERANCE](https://planetary.org/perseverance)

VISIT THE MASTCAM-Z PUBLIC WEBSITE

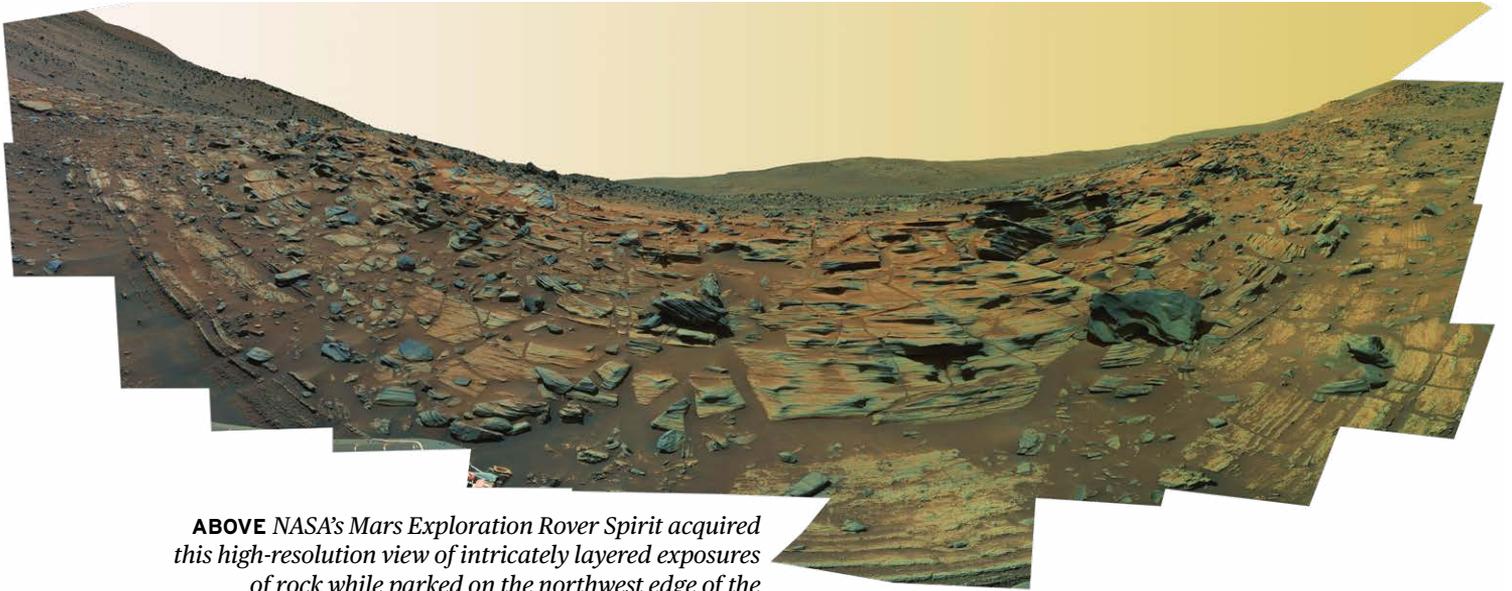
[MASTCAMZ.ASU.EDU](https://mastcamz.asu.edu)

READ STORIES FROM THE MASTCAM-Z TEAM

[PLANETARY.ORG/MASTCAM-Z](https://planetary.org/mastcam-z)

SEE HOW PERSEVERANCE'S SAMPLES WILL GET BACK TO EARTH

[PLANETARY.ORG/MARS-SAMPLE-RETURN](https://planetary.org/mars-sample-return)



ABOVE NASA's Mars Exploration Rover Spirit acquired this high-resolution view of intricately layered exposures of rock while parked on the northwest edge of the bright, semicircular feature known as "Home Plate."

NASA

The Inspiring Artistry of Space

I WAS SITTING in Dr. Ray Arvidson's clean white computer lab, staring at a wall-sized panoramic image of Home Plate, a rough whitish outcrop in Mars' Columbia Hills. At the time, I was an art student, and my latest assignment was to draw a 6-by-4-foot charcoal self-portrait with a focus on chiaroscuro—light and shadow. For reference, my art professor showed us paintings by Caravaggio and stills from Orson Welles' *Touch of Evil*, but I never thought that I would find such an interesting example here in Ray's *Land Use and the Environment* class. The bright, reflective rock faces contrasted with the inky shadows underneath the jutting rock layers, all nestled in gently sloping hills against a dim orange sky—a portrait of stark beauty. My jaw dropped in complete awe; I was astounded by the incredible power of one image.

After that first class, I discovered that pictures—like an outcrop at Home Plate or a

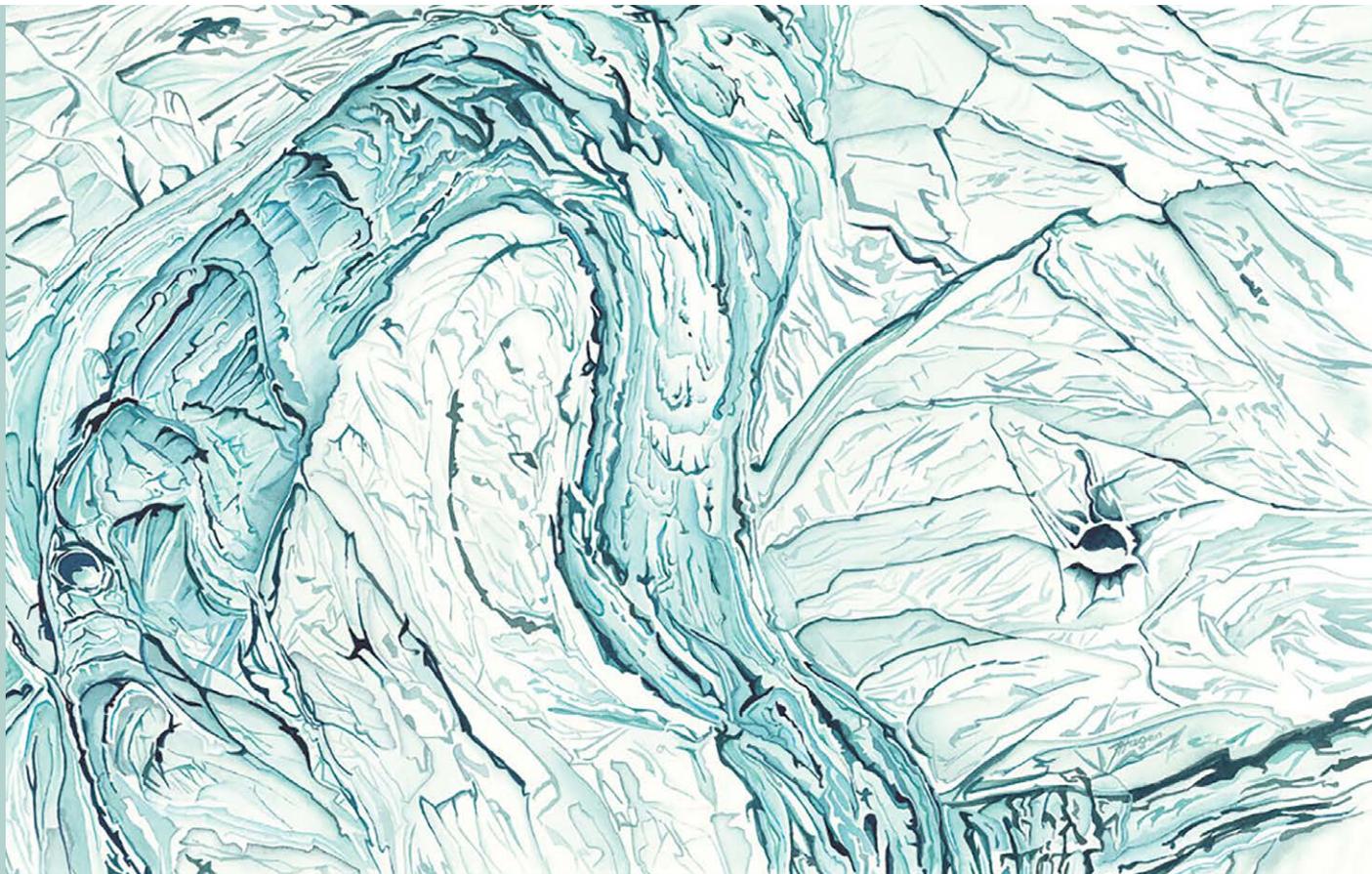
CRISM image colored by different spectral bands—could lead to questions. Of what is this made? How do clays form on Mars? My undergraduate research thesis tackled the latter question, tying together multispectral imagery of Nilli Fossae from CRISM with visible/near infrared spectroscopy and analytical chemistry techniques. The artistry of Mars and, during my graduate studies, the eerie beauty of Titan never failed to astonish me, and every downlinked image started a new round of “what is this, and how can we figure it out?”

As we eagerly await the arrival of 3 new Mars missions, a massive space telescope, and a quadcopter on Titan, I wonder what our pictures will inspire. What questions will we ask, and how will we solve them? When we're left grasping for answers, what will we explore next? 🚀



BRYNÉ HADNOTT is a Planetary Society member, researcher, and writer currently based in Seattle, Washington. When she's not coding image-processing algorithms in Python, she's writing creative nonfiction essays in her terrible handwriting or finding secret places to paddleboard. She likes coffee, loves dogs, and isn't a fan of cilantro.

WHY I EXPLORE Planetary Society members are explorers. We share this common passion, although we have different stories that drive our passion. We're curious to know your story. If you'd like to share, we've set up a form at planetary.org/whyexplore, where you will also be able to read other “Why I Explore” stories. We'll also continue to share stories in future issues of The Planetary Report.



Fraser Hagan, *Enceladus Ice Fields*

Saturn's moon Enceladus is an icy world whose surface is ever-changing. A subsurface ocean of liquid water creates tectonic activity on its surface, causing water to spew from geysers and marking the surface with a mosaic of fractures, ridges, and valleys. When Enceladus was named in 1789, its tectonic qualities were not yet known; it simply appeared as a point of light orbiting the planet Saturn. The moon's name turned out to be surprisingly fitting. Enceladus is named after a giant from Greek mythology. The giant Enceladus was said to cause earthquakes and

volcanic eruptions on Earth as he shifted beneath the ground. We now know that these phenomena are caused by Earth's own tectonic activity. Although the great icy fissures of Enceladus are not caused by the movements of a giant beneath its surface, what lies beneath the ice is no less intriguing. Enceladus' subsurface oceans are one of the places in our solar system most likely to hold some form of life.

Fraser Hagan is a graphic designer from Vancouver, Canada and a member of The Planetary Society.

Do you want to see your artwork here? We love to feature our members throughout this magazine. Send your original, space-related artwork to connect@planetary.org.