THE PLANETARY SOCIETY

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THE EXOPLANET ISSUE

THE EXPANDING FRONTIER OF DISCOVERY

AN ABUNDANCE OF WORLDS

Even within a lifetime, so much has changed

by Bill Nye

ANYONE WHO LOOKS up at the night sky wonders if we're alone out here in the Cosmos.

Since childhood, I have had an interest in the stars and our Solar System. My father had survived four years as a prisoner of war in China and Japan, having been captured from Wake Island two weeks after being bombed on what is now called Pearl Harbor Day. With all those years without lights at night, he could glance up and claim to name about 50 Northern Hemisphere constellations. When he came home and had children, we had a telescope. I marveled at Saturn and the Moon. And, like anyone who has ever taken a moment to think about anything, I wondered if we are alone in the Universe.

I remember well the first time I scientifically pondered the possibility of life on other worlds. I was in class in the spring of 1977 when Carl Sagan presented a series of probabilities — the Drake equation. I was a senior mechanical engineering student at Cornell University. I was by no means an astronomy major. But as a senior, they let me into the freshman-level Astro 102. People on campus knew well that Professor Sagan was a big deal in his field because he occasionally appeared on "The Tonight Show" with Johnny Carson — no greater credential could be imagined.

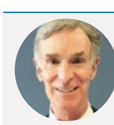
To refresh the memory of those who might not be familiar, the Drake equation is a string of fractions multiplied one after another to reduce the nearly unimaginable number of stars in our galaxy to a much, much smaller number that might be home to intelligent, communicative life. Frank Drake was also a professor at Cornell. He and Sagan naturally collaborated now and then. Back then, planets were presumed to be fairly rare in the Universe. With careful reasoning, Drake conservatively estimated that perhaps one in a hundred stars has a single planet orbiting it.

Some 50 years after it was proposed, the Drake equation is still a very logical way to take a shot at predicting the likelihood that intelligent, technologically advanced aliens are out there in our galaxy. To solve the equation or at least run the numbers, you need to estimate the proportion of life-bearing planets that go on to produce intelligent life that might get in touch with us. You need to estimate the average length of time that advanced civilizations are able to communicate before they crumble. So far, we have only one datum: us and our kin here on Earth. Without any other data, these factors can't be known. Oh, but how they can fascinate.

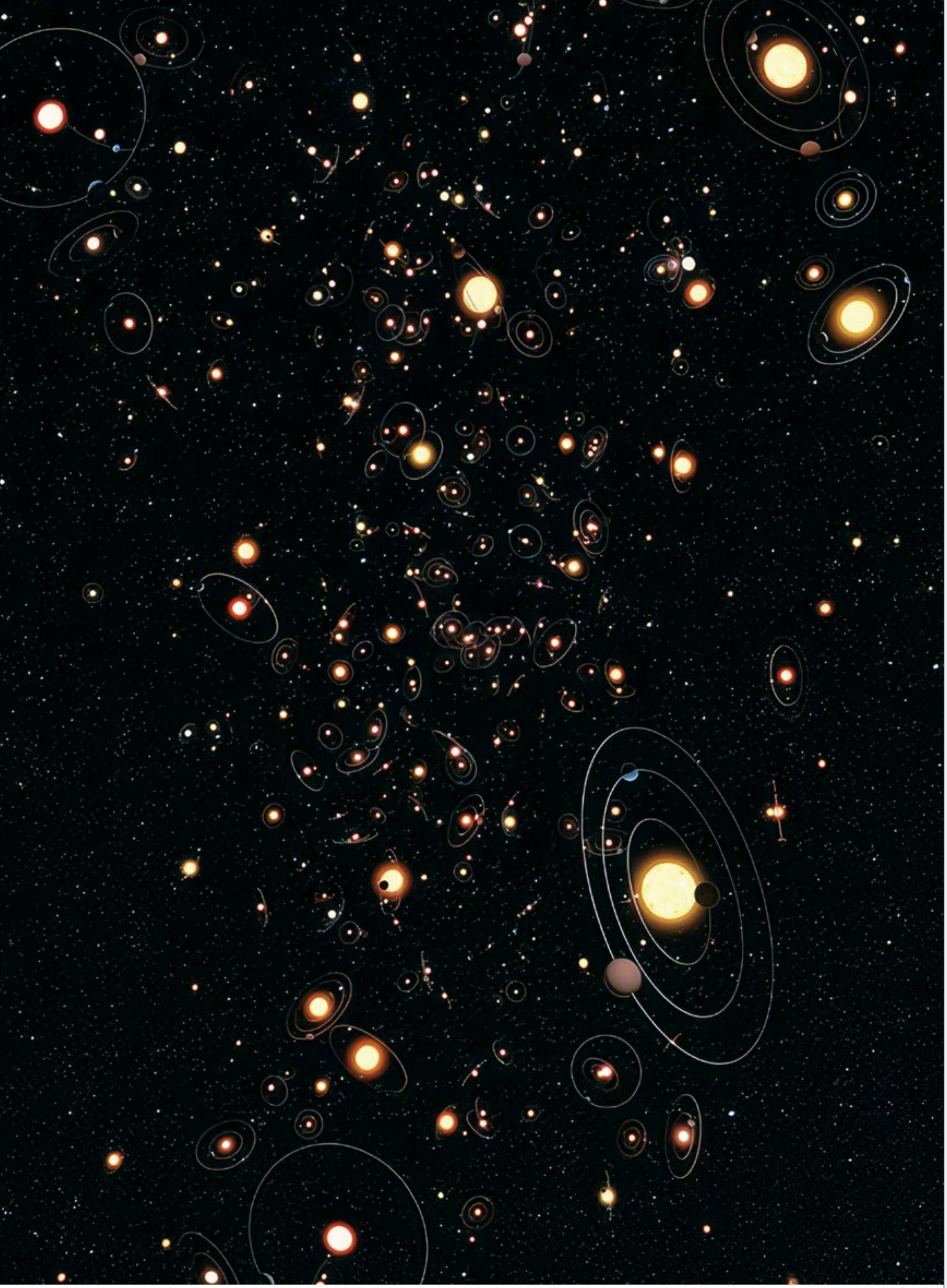
The big thing that's changed since 1977 is our ability to settle on one factor with great confidence, which is the first essential variable in the equation: the fraction of stars that have planets — we call these exoplanets. The number is not, as those folks supposed back then, about one in a hundred. Nowadays, with modern astronomical observations, we presume there may be an average of one to two planets around every star. In other words, the first term of the Drake equation has gotten a hundred times bigger. Planets are far from rare.

Humanity's desire to find life beyond Earth will always be a strong influence in space science and exploration. And the more we learn, the better equipped we will be to solve Drake's famous equation and the others like it that have been developed since his time. In just a few decades, our estimated chances of finding intelligent life out there have increased dramatically. And with projects like those that The Planetary Society supports, those chances are bound to keep increasing.

Bill Nye



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



ABOVE *This artist's depiction of planets orbiting stars in the Milky Way shows how common these planets are. The planets, their orbits, and their host stars are all vastly magnified compared to their real separations.* ESO/M. KORNMESSER

ON THE COVER: Seven known planets orbit the red dwarf star TRAPPIST-1. Because several of those planets lie in the star's habitable zone, they are among the most intriguing exoplanets in the search for life beyond our Solar System. While some characteristics of each planet can be determined using remote observations, the only views we have of the planets themselves come from artists, whose imaginations complement the information we have about each world. *Image: NASA/JPL-Caltech*

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FAR FROM ALONE

How exoplanet discoveries reshape the prospect of alien life

by Kate Howells

ARE WE ALONE in the Universe? This question has been pondered throughout human history. Only in the last century have we begun to systematically try to answer it. As we pointed more powerful telescopes at the planets of our Solar System and sent probes to examine them up close, we found no obvious signs of life. The possibility of large-scale life — even advanced civilizations — was relegated to planets beyond our star's local neighborhood. Exoplanets became our best hope for finding our cosmic kin.

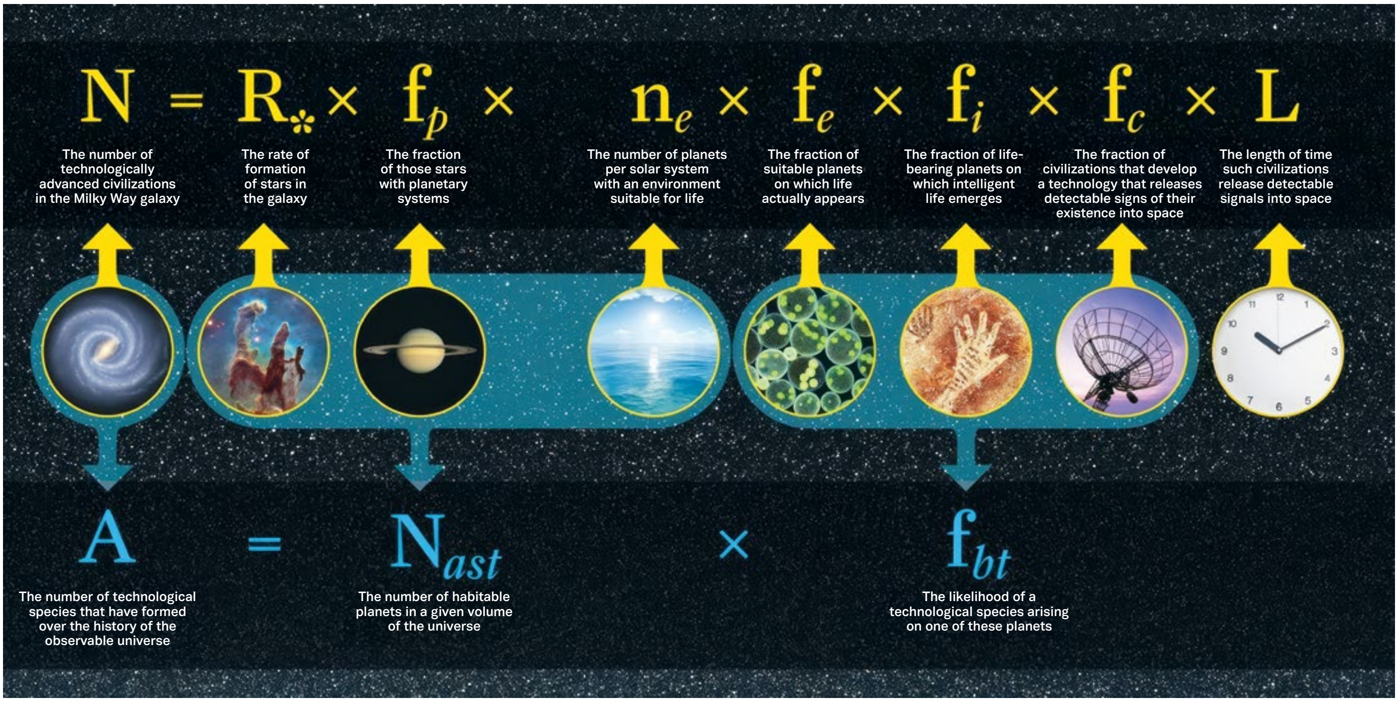
At the first scientific meeting on the search for extraterrestrial intelligence (SETI) in 1961, astrophysicist Frank Drake developed a theoretical equation to estimate the number of active, communicative extraterrestrial civilizations in the Milky Way galaxy. The Drake equation integrates several variables to estimate the number of civilizations in our galaxy with which we might communicate. These variables include:

- The average rate of star formation
- The fraction of stars that have planets
- The average number of planets that could support life per star that has planets
- The fraction of life-supporting planets that develop life
- The fraction of planets with life where life develops intelligence
- The fraction of intelligent civilizations that develop electromagnetic communication
- The length of time such civilizations are able to communicate

When Drake first proposed this equation, it wasn't meant to yield a precise, accurate number, only that the result was greater than zero, meaning that it was worth looking for life beyond Earth. All but the first factor were unknown at the time. With the advent of exoplanet discoveries, that changed.

RIGHT *As we look to the skies, it is useful to see where we came from.* GETTY IMAGES

The first confirmed detection of an exoplanet happened in 1992. Since then, missions like NASA's Kepler and TESS (Transiting Exoplanet Survey Satellite) spacecraft have identified over 5,500 exoplanets. The discovery that planets are common around stars was unexpected. Prior estimates had suggested that most stars didn't have any planets around them at all, let alone numerous planets with an even larger number of moons in most star systems. Exoplanet research has also



ABOVE *The Drake equation is a mathematical formula that helps us think about the probability of finding intelligent life in our galaxy.* UNIVERSITY OF ROCHESTER

expanded our understanding of the habitable zone, the region around a star where liquid water could exist on a planet's surface.

These discoveries have directly impacted the Drake equation, providing much more refined estimates for the equation's second and third variables: the fraction of stars that have planets and the fraction of those planets that have conditions (like liquid surface water) that could support life.

The last four factors of the Drake equation are still completely speculative, of course. But in the same way that new tools allowed us to detect first one and then thousands of exoplanets, advancements in technology may someday introduce us first to one and then to thousands of inhabited worlds, further refining our expectations of the prevalence of intelligent life in the Universe.

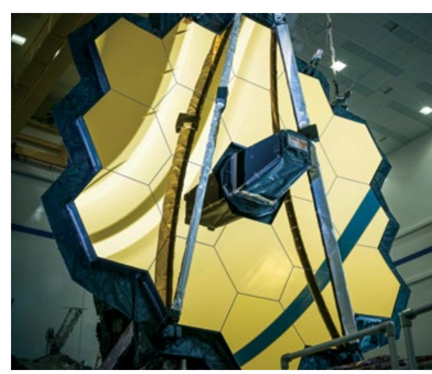
In 2013, exoplanet researcher Sara Seager proposed an adaptation of the Drake equation, focusing on the likelihood of finding alien life more broadly through the detection of biosignatures, such as atmospheric gases that life forms produce. The Seager equation considers factors including the fraction of stars with rocky planets in the habitable zone, another variable that becomes easier and easier to define as exoplanet research advances. And as our ability to study exoplanets and their atmospheres continues to improve with powerful tools like the James Webb Space Telescope, which can analyze the atmospheric compositions of distant planets, so too will our ability to detect biosignatures and refine the Seager equation's parameters.

The Drake equation and the Seager equation are both meant to stimulate scientific thought and discussion and hone our search for signs of life beyond our planet. Although we're still far from solving them, both equations get a lot more optimistic now that we know just how prevalent exoplanets really are.

As we continue to uncover the mysteries of distant worlds, our understanding of life's potential in the Cosmos will evolve. Someday, this may yield one of the most significant discoveries in human history: that we are not alone.

KATE HOWELLS *is the public education specialist for The Planetary Society.*

BELOW *The James Webb Space Telescope after completing its comprehensive systems test in March 2020.* NASA/CHRIS GUNN



EXOPLANET ART

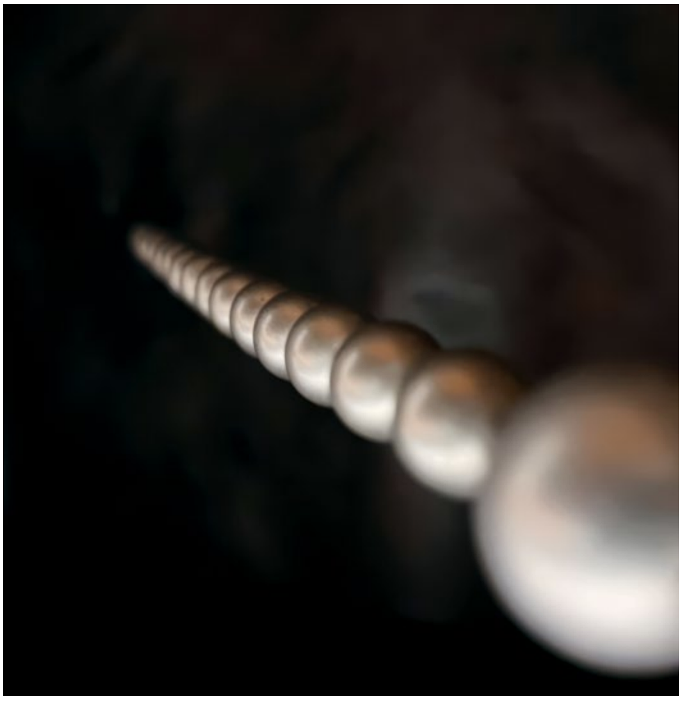
WE ASKED MEMBERS in our online community to share their original creative work depicting exoplanets or exploring ideas related to exoplanets. Here is a selection of our talented members' work. Learn more about these pieces and see other members' artwork at **community.planetary.org**.

Proxima Centauri b
Xakarus Alldredge

Clay Exoplanet Objects
Susan Robinson

Planetary System
Harold Wexler

Exo Syzygy (Système de Silicium)
Gene Lewan

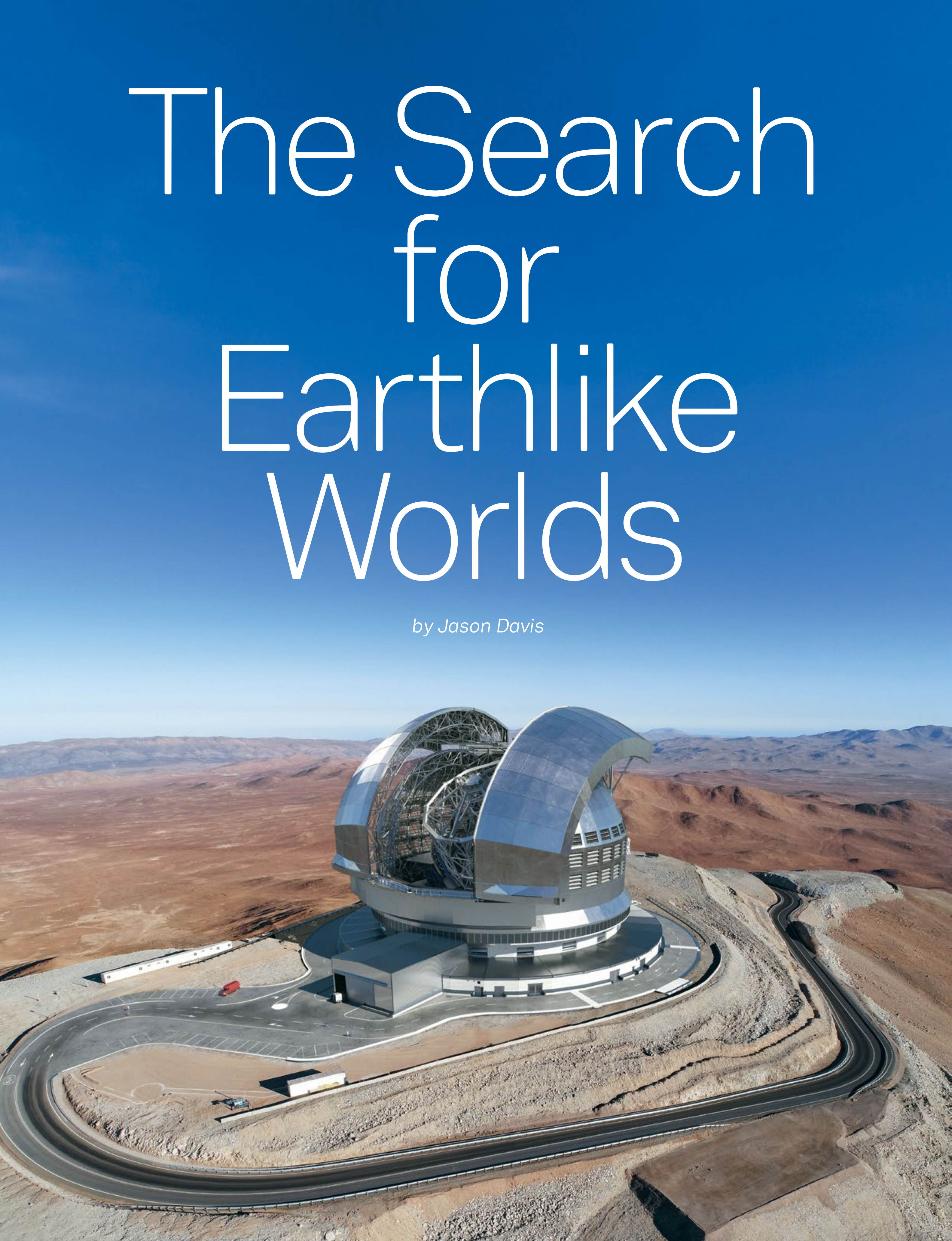


Extrasolar Eclipse
René Mazurkiewicz

Big Blue and Beautiful
Albert Hagi

The Search for Earthlike Worlds

by Jason Davis



IN JULY 2022, just six days after NASA declared that the James Webb Space Telescope was ready for full science operations, the observatory aimed its gold-plated mirrors at a star named TRAPPIST-1.

Located 40 light-years away from Earth, TRAPPIST-1 has seven known planets. At least three are in the star's habitable zone, the not-too-hot, not-too-cold region where liquid water can exist on a body's surface. This makes them prime targets in the search for Earthlike worlds.

TRAPPIST-1 is a red dwarf, a type of star that is small, dim, and cool (by stellar standards). Roughly three-fourths of the stars in the Milky Way are red dwarfs. If TRAPPIST-1 swapped places with our Sun, its habitable zone would fit entirely within the orbit of Mercury. Although planets there would be at the right temperature for liquid water, they could also be bathed in radiation harmful to life as we know it.

"The missing piece is whether the habitable zone of a red dwarf is truly habitable because it's so close to the star," said Jessie Christiansen, a research scientist at the NASA Exoplanet Science Institute.

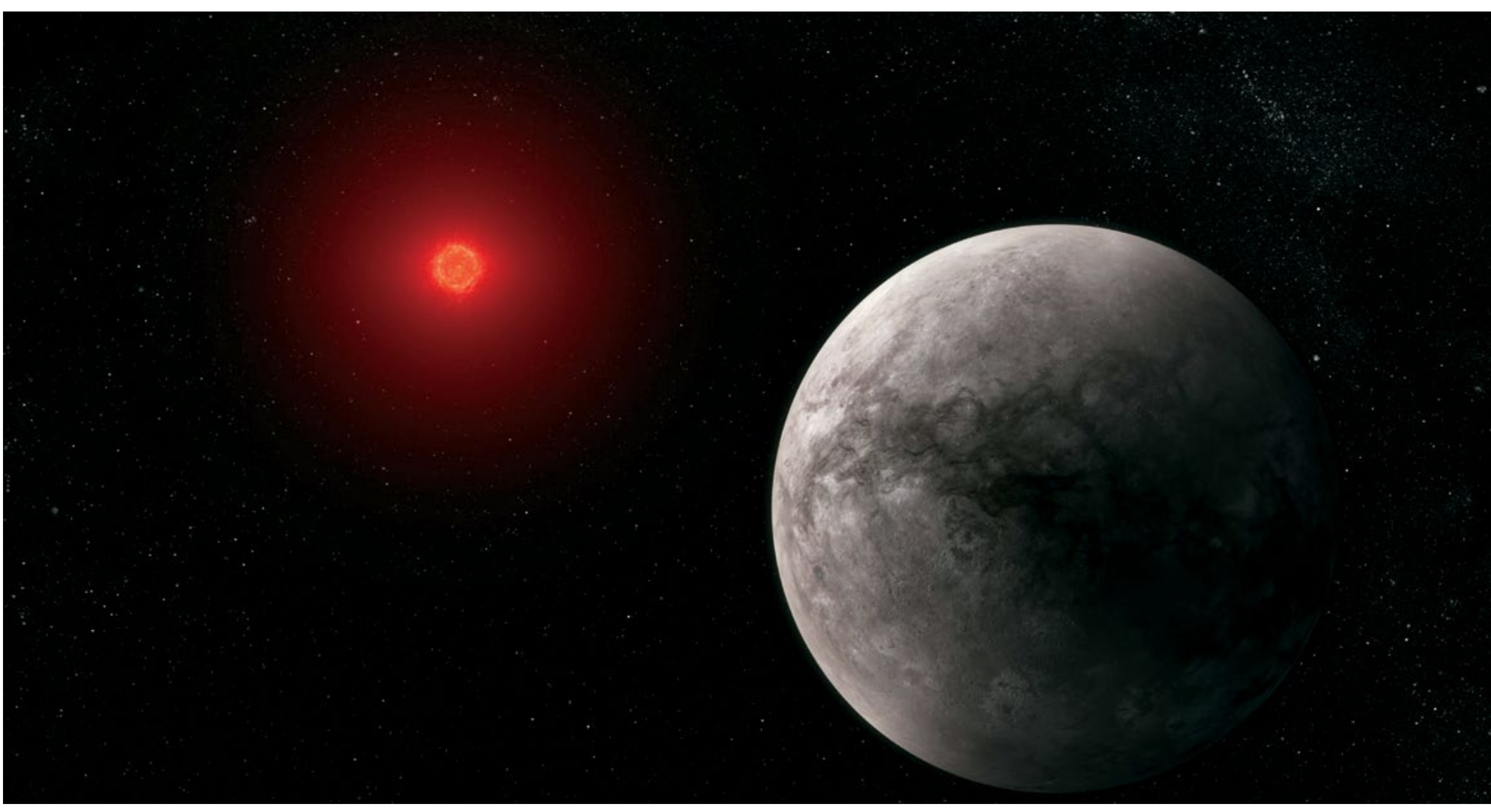
That's where JWST comes in. The space telescope can scan the atmospheres of certain exoplanets as they transit in front of their stars, looking for chemical compounds linked to the presence of life.

JWST could not initially determine whether TRAPPIST-1b, the planet closest to the star, has an atmosphere. Scientists saw intense magnetic activity and solar flares during their observations, which contaminated their data and raised questions on whether life could survive on any worlds near the star.

TRAPPIST-1c sits near the inner edge of the habitable zone and has been theorized to be Venuslike. But JWST

BELOW *This illustration shows the rocky exoplanet TRAPPIST-1b orbiting its red dwarf star. Initial data from JWST indicate that the planet may not have an atmosphere. TRAPPIST-1b is the innermost of seven known planets in the system, at least three of which are in the star's habitable zone.* NASA/ESA/CSA/JOSEPH OLMSTED (STSCI)

OPPOSITE *This 2020 artist's concept of the Extremely Large Telescope (ELT) shows the observatory perched atop Cerro Armazones in Chile at an altitude of about 3,046 meters (9,993 feet). Scheduled to come online in 2028, the ELT will have a mirror 39 meters (128 feet) wide, making it the largest optical telescope in the world.* ESO



ABOVE *This image was captured from a time-lapse video demonstrating what it would look like if NASA's proposed Habitable Worlds Observatory imaged our own Solar System from a distance of 40 light-years. The Sun's light is blocked by a coronagraph. Earth is visible as a faint blue-green smudge to the left of the Sun.*
R. JUANOLA PARRAMON, N. ZIMMERMAN, A. ROBERGE (NASA GSFC)/ LABELS BY THE PLANETARY SOCIETY

observations found little evidence for a thick carbon dioxide atmosphere, leading scientists to hypothesize that the planet formed with very little water. Results are still pending for TRAPPIST-1d, e, and f, the three planets inside the habitable zone, said Christiansen.

"So as of yet, JWST has not unlocked this mystery of whether rocky exoplanets around red dwarf stars can have atmospheres," she said. "I expect this year we will come one step closer to that answer."

JWST is just one instrument in a broad toolkit scientists use to search for and characterize Earthlike exoplanets. New, powerful ground-based observatories are set to come online soon while the scientific community eyes the development of the Habitable Worlds Observatory, a "super Hubble" designed to directly image dozens of Earthlike worlds in their stars' habitable zones.

HIGH-PRECISION WOBBLES

Before we can study Earthlike exoplanets, we have to find them.

NASA's Transiting Exoplanet Survey Satellite, TESS, is the current workhorse of exoplanet discovery. The space telescope stares at the sky, looking for dips in starlight that would indicate an exoplanet passed in front of or behind its host star. Since its launch in 2018, TESS has found 7,000 exoplanet candidates and confirmed more than 400. According to NASA's exoplanet catalog, nine are terrestrial, meaning they are rocky with iron-rich cores similar to Mercury, Venus, Earth, and Mars.

We also find exoplanets using ground-based instruments. One method is the radial velocity technique. As a planet orbits its star, its gravity tugs on the star, making it wobble. By watching a star wobble over long periods, scientists can infer the presence of planets.

The smaller the planet, the less the star wobbles. Earth exerts a pull of just 10 centimeters (4 inches) per second on the Sun. At these fine scales, it's very hard to determine what's an actual wobble amid instrument uncertainties and noise from the uneven surfaces of stars.

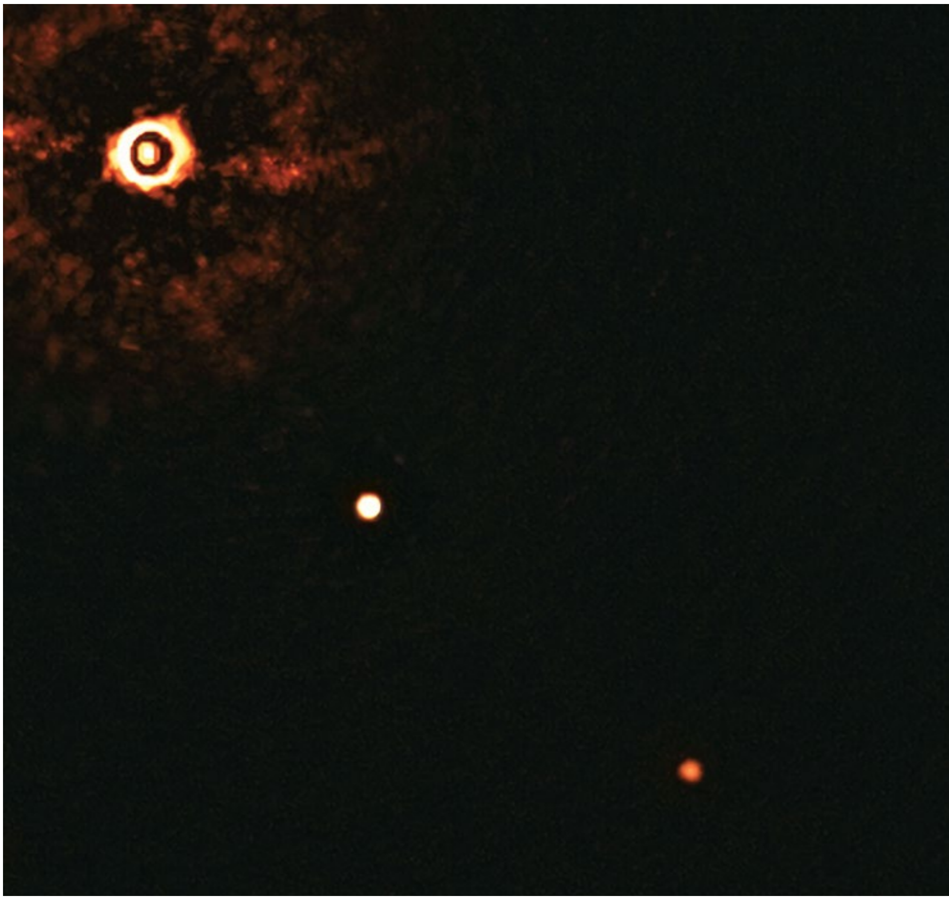
For years, Debra Fischer has been pushing the limits of what the radial velocity technique can do. The Yale University astronomer led the team that built a high-precision spectrograph called EXPRES that scans the sky using the Lowell Discovery Telescope in Happy Jack, Arizona. Similar projects include the NEID spectrograph on the WYN telescope at Kitt Peak in Arizona, the Keck Planet Finder in Hawaii, and ESPRESSO on the Very Large Telescope in Chile's Atacama Desert.

"Every single moment in this field, we're always pushing against the floor of stellar noise or instrumental precision," she said.

Planetary Society members and donors have supported Fischer's work over the years, most recently to repair a laser frequency comb used to calibrate EXPRES. During the day, scientists observe the Sun with EXPRES, collecting data that are used to understand how our own star wobbles and generates noise.

Fischer is now starting to use what she and her colleagues have learned over the years and is applying it to their data. She can now detect star wobbles as small as 30 centimeters (about 12 inches) per second — not quite an Earth-sized planet, but close.

"The quality of our data is amazing," said Fischer. "I feel like there's a whole new standard in radial velocity measurements."



ABOVE *This image shows two planets orbiting a star called TYC 8998-760-1. The star is 300 light-years away from Earth. The planets are gas giants like Jupiter and Saturn, and the star is similar to our own but at an earlier stage of evolution. The image was captured using the European Southern Observatory's Very Large Telescope in Chile.* ESO/BOHN ET AL.

A GROUND-BASED RENAISSANCE

In the next several years, two new, giant ground-based telescopes are expected to come online. Hopes are high that these facilities may be able to equal or exceed JWST's ability to detect the atmospheric compositions of Earthlike exoplanets.

First light for the European Southern Observatory's Extremely Large Telescope is scheduled for 2028. The telescope's main mirror consists of nearly 800 segments and has a diameter of 39 meters (128 feet). Located in Chile's Atacama Desert, it will be the largest optical telescope in the world. The ELT will be able to directly image exoplanets and characterize the atmospheres of Earthlike planets in their stars' habitable zones.

In a study published in The Astronomical Journal, researchers simulated the ability of the ELT to detect oxygen, carbon dioxide, methane, and water on 10 known rocky exoplanets. They found that the ELT and its instruments could indeed detect these potential signs of life.

The Giant Magellan Telescope, also located in the Atacama Desert, is scheduled to begin operations in the early 2030s. The GMT has a seven-segment mirror that measures 25 meters (82 feet) across. The telescope's Large Earth Finder instrument will measure the mass of Earthlike planets and search for biosignatures in their atmosphere.

The Thirty Meter Telescope would have, as its name implies, a mirror 30 meters (98 feet) wide. The TMT would be able to directly detect and characterize exoplanets. Construction of the telescope on the summit of Mauna Kea in Hawaii was suspended following objections from native Hawaiians, who consider the land sacred. It is currently unclear whether a compromise can be made or if the telescope will move to an alternate location.

OBSERVING HABITABLE WORLDS

In addition to the new ground-based observatories coming online, a new fleet of space-based exoplanet explorers is scheduled to launch over the next few years.

First up is Plato, which stands for PLAnetary Transits and Oscillations of stars. Scheduled to launch in 2026, the European Space Agency mission will measure the size of rocky exoplanets in the habitable zone of Sunlike stars.

Next is NASA's Roman Space Telescope, scheduled to launch in 2027. The RST will search for exoplanets using the microlensing technique, which relies on the gravity fields of stars and galaxies to bend and magnify the light of objects behind them. The RST will also test a coronagraph to block the light of stars and directly image exoplanets.

In 2029, ESA plans to launch Ariel, the Atmospheric Remote-sensing Infrared Exoplanet Large-survey mission. Ariel will study the atmospheres of about a thousand exoplanets, including gas giants and rocky worlds.

China also hopes to get in on the space-based exoplanet game around the end of the decade with a set of formation-flying telescopes called Miyin. The mission would directly image and characterize exoplanets in our galactic neighborhood.

While these new missions will place us at the doorway of finding a world like our own, a large space telescope in early development aims to push us through the threshold once and for all.

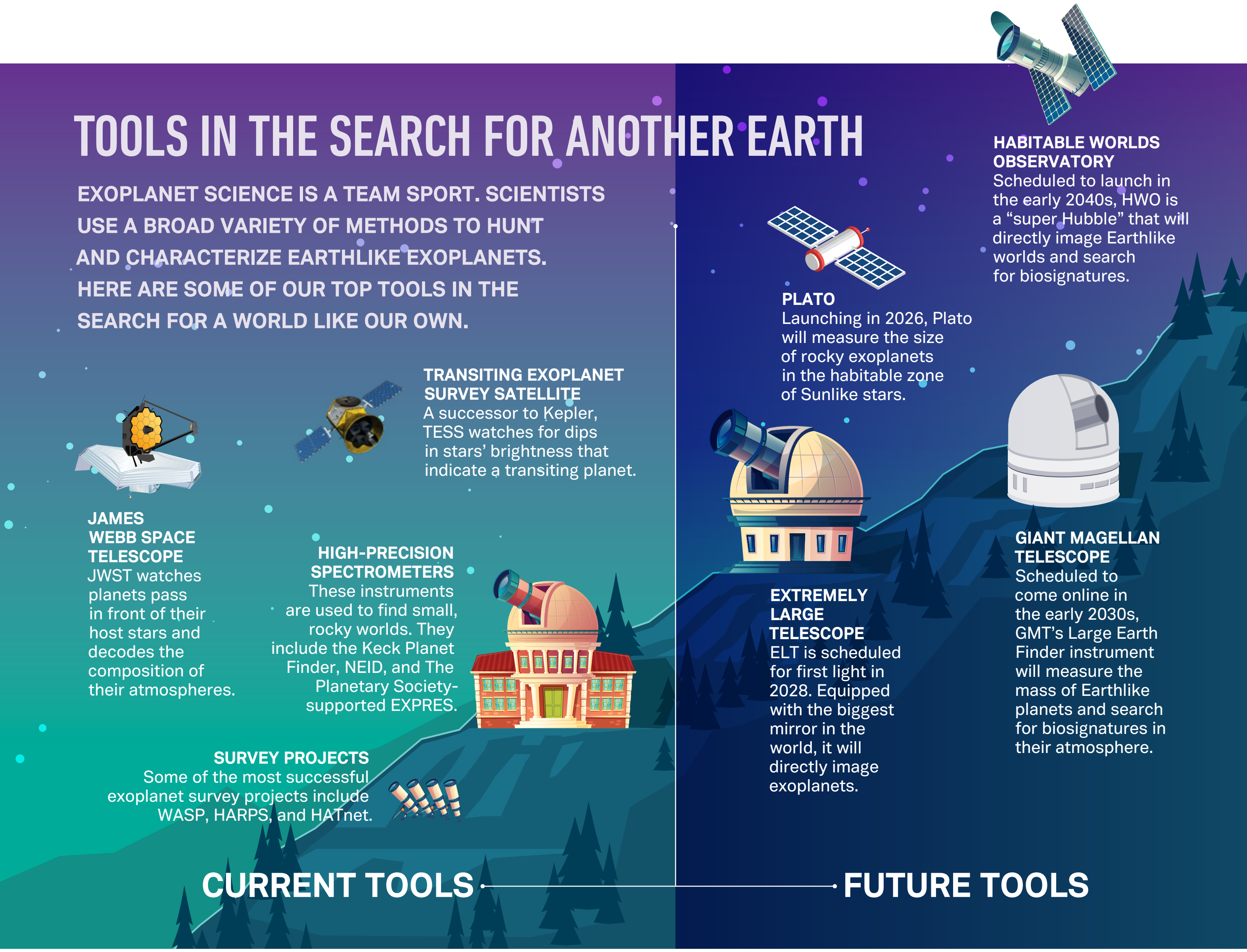
NASA's Habitable Worlds Observatory, or HWO, will be NASA's next flagship telescope mission. HWO would be designed to directly image at least 25 potentially habitable worlds around other stars and search their atmosphere for biosignatures, like oxygen and methane.

Janice Lee is the project scientist for strategic initiatives at the Space Telescope Science Institute in Baltimore, Maryland. Her job is to work with scientists to advance the mission concept as rapidly as possible.

She encourages people to think big: "Think of this telescope as a 'super Hubble.' Let's say the size of Hubble's mirror grew three times or even five times," she said. "Imagine what you could do then."

HWO's main mirror would be about the size of JWST's, but instead of having instruments tuned to infrared light, HWO would be configured for visible and ultraviolet light like Hubble. Certain biosignatures are more pronounced in visible and ultraviolet wavelengths.

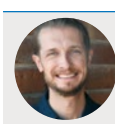
An exciting element of HWO's design is that it would be serviceable like Hubble, so astronauts could repair and upgrade the telescope. Visiting HWO would be a considerable feat since the observatory would orbit the second Lagrange



point like JWST, located 1.5 million kilometers (1 million miles) from Earth.

The HWO project webpage features a time-lapse video showing what it would look like if the telescope imaged our own Solar System for 10 years from a distance of 40 light-years. Venus, Earth, Mars, Jupiter, and Saturn are all visible, slowly orbiting our Sun. A view like this of a star system with habitable exoplanets is a tantalizing prospect, but it's one that will require patience, as HWO would launch no earlier than the early 2040s.

An early 2040s launch date would roughly coincide with the 50th anniversary of the first exoplanet discovery in 1992. In the span of a single human lifetime, exoplanet science has blossomed from its inception to the potential discovery of an Earthlike world. With plenty of exciting discoveries ahead, the best is yet to come.



JASON DAVIS *is the senior editor for The Planetary Society.*

MEET THE SUPERLATIVE EXOPLANETS

Moiya McTier

SCHOOL YEARBOOKS have a tradition of awarding students superlative titles, recognizing those who were the best at something or those who exemplified a quality. In that same spirit, meet our picks for the galaxy's superlative exoplanets.

MOST POPULAR: Kepler-186f

If an exoplanet could be voted prom king or queen, it would be Kepler-186f. It was one of only six exoplanets to be featured on NASA's space tourism poster series because when it was discovered in 2014, it was the most Earthlike exoplanet ever found. Kepler-186f is about 10% larger and 70% more massive than Earth and almost certainly rocky. An orbital period of 130 days also puts Kepler-186f squarely in the habitable zone of its star. That star, however, is only about half the size and mass of the Sun, so the hunt for an Earth twin continued.

ABOVE *This NASA space tourism poster invites people to imagine visiting Kepler-186f.* NASA/JPL

BEST HAIR: YZ Ceti b

YZ Ceti b, the first rocky planet found with a possible magnetic field, is a clear vote for the planet with the best "hair." A few planets with magnetic fields had previously been found, but they were all gas giants whose fields should be bigger and easier to detect. YZ Ceti b is a rocky planet a bit smaller and less dense than Earth, and it orbits its red dwarf host star every two days. YZ joined the exoplanet class when it was discovered in 2017, but we didn't know about its potential magnetic field until astronomers noticed repeated radio signals coming from the planet in 2023. More observations are necessary to confirm the magnetic field, but if true, it could be a big step in the search for a habitable world because we know Earth's magnetic field has been so beneficial to our survival.

MOST ATHLETIC: TOI 4201b

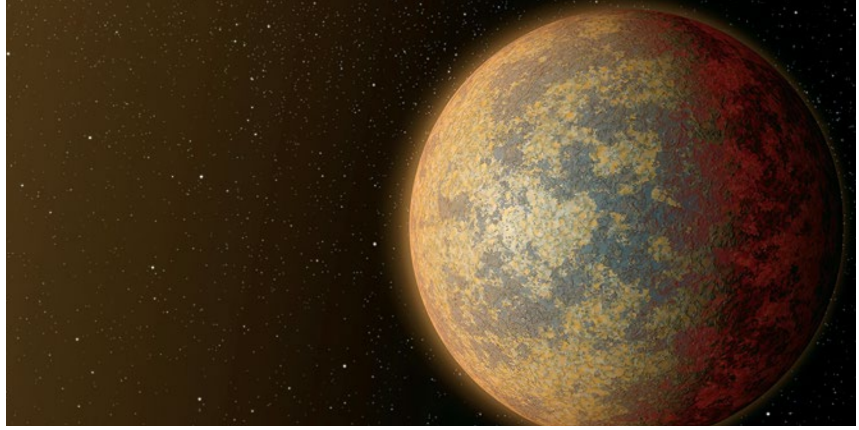
Among exoplanets, the Most Athletic award would surely have to go to the biggest, strongest, fastest one around: TOI 4201b. This planet was a latecomer to the class, just discovered in 2023, but its athletic prowess is impossible to deny. Weighing in at 2 1/2 times the mass of Jupiter, 4201b is one of the biggest planets found orbiting a red dwarf, yet it can still sprint a full lap in just 3 1/2 days. This planet's size is especially impressive because long-lived red dwarf stars have less extra material and typically contain fewer heavy elements than more massive stars, which makes it harder to form big planets.

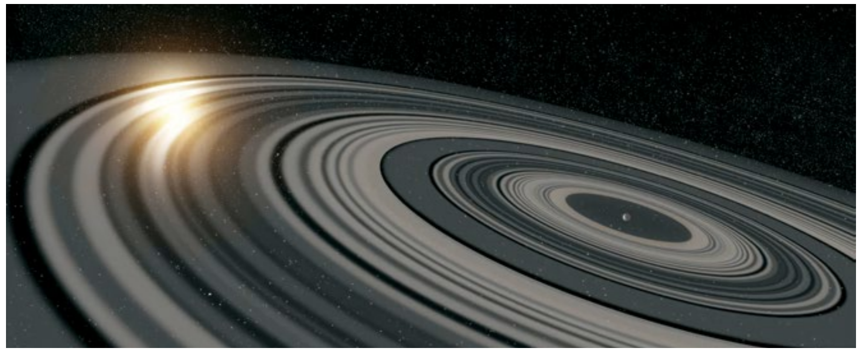
CLASS CLOWN: Proxima Centauri b

The nearest star to our Sun is Proxima Centauri, a small red dwarf about four light-years away that orbits a pair of Sunlike stars every half-million years. Even though it's so close, Proxima is invisible to the unaided eye and wasn't discovered until 1915. It took another century and year to find Proxima's first planet, Proxima Centauri b. Our nearest neighbor planet is practically Earth-size, just a tad bigger and more massive. It orbits its star every 11 days, well inside the habitable zone, where astronomers had unsuccessfully searched for a planet for decades. Proxima b's ability to evade detection (clearly learned from its parent star, so the family is full of tricksters) is the greatest joke a planet has ever played on planet hunters.

BEST DRESSED: Wasp J1407b

Discovered in 2012, Wasp J1407b is so far the only planet — or potentially brown dwarf — beyond our Solar System to be found with rings, and they put Saturn's style to shame. This super Saturn transits





TOP *This artist's impression shows YZ Ceti b, the first rocky exoplanet thought to have a magnetic field.* NASA

BOTTOM *This artist's impression shows the exoplanet Wasp J1407b and its astounding set of rings.* NASA/RON MILLER

a young star slightly less massive than the Sun, and data from the system match a model of 30 different rings, each tens of millions of miles wide — 200 times bigger than Saturn's. J1407b even shows signs of an exomoon that has cleared a path in the rings. The varied accessories made this vote a no-brainer.

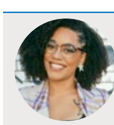
MOST ECCENTRIC: HD 20782b

Most Eccentric may not be the yearbook award you'd want to win, but it's a remarkable feat among planets. Eccentricity is a measure of how not round a planet's orbit is, and most planets' orbits are close to circular — not HD 20782b's, though. It has the most eccentric orbit found to date since its discovery in 2006. The planet itself is bigger than Jupiter and orbits its Sunlike star every 1.6 years. On a scale from zero to one, this planet's eccentricity is 0.95. Throughout its orbit, it can come as close as 105 million kilometers (65 million miles) to its star or as far as 400 million kilometers (250 million miles). This definitely creates drastic temperature and pressure variations on HD 20782b over the course of its eccentric orbit, most likely causing extreme weather in the planet's atmosphere.

MOST LIKELY TO SUCCEED: K2 136b

If success means the potential to host life, there are no obvious winners in this category, but one exoplanet seems to meet more criteria than the rest: K2 136b. It's a dense super Earth that orbits a metal-rich K-type star every eight days. What earns it this title is a combination of its galactic location and host star properties. Planet hunters place a lot of emphasis on the habitable zone around a star, and there are hundreds of planets in their local "Goldilocks zone." To stand out, an exoplanet has to be in the galactic habitable zone as well. This is the region in a galaxy that meets most or all of the large-scale criteria for life. Over the last few decades, the list of conditions has grown to include distance from extremely radiative events, like supernovae; availability of heavy elements; and a stable stellar orbit over billions of years. Recently, studies have suggested that K-type stars might be the best hosts of habitable planets because they're longer-lived and more prevalent than Sunlike stars but often less magnetically active than M dwarfs. Let's just hope K2 136b can live up to its potential.

With over 5,500 planets identified around other stars, you can find plenty of standouts in the exoplanet yearbook. But it's the lessons we astronomers have learned from the class as a whole that really changed our understanding of the Universe. Now we know that most stars have planets and that rocky planets like Earth are common. We know that stellar systems are amazingly diverse and that planets can migrate away from where they formed. Best of all, we know the field of exoplanet research is just getting started.



MOIYA McTIER *is an astrophysicist and folklorist.*

SYMPOSIUM IN PASADENA, CALIFORNIA

ABOVE *Search for Life symposium attendees and staff came to The Planetary Society headquarters in Pasadena, California, in February 2024.* THE PLANETARY SOCIETY

In February, The Planetary Society hosted a two-day symposium bringing together some of the world's leading experts in the search for life, representing fields including astrobiology, SETI, planetary science, and more. This symposium will inform the Society's future efforts to advance the search for life.

CELEBRATING THE APRIL 2024 ECLIPSE

Our Eclipse-O-Rama 2024 event was a great success. Over 800 Planetary Society members from around the world came to Fredericksburg, Texas, to witness the April 8, 2024, total solar eclipse. The two-day festival included educational presentations, fun activities, music, and much more. It was a special opportunity to come together and celebrate our shared passion for space, and there's no doubt that those who attended made memories that will last a lifetime.

TOP *Valerie Sinha won free VIP tickets to Eclipse-O-Rama 2024 through a Prizeo sweepstakes. She is pictured here with her husband, Askok Sinha, and Planetary Society CEO Bill Nye.* THE PLANETARY SOCIETY

BOTTOM *A crowd of Planetary Society members take in the eclipse at our Eclipse-O-Rama 2024 event in Fredericksburg, Texas.* THE PLANETARY SOCIETY

AN APPETITE FOR SPACE SALAD

In 2023, The Planetary Society awarded grants to two projects through our STEP (Science and Technology Empowered by the Public) Grant program. STEP Grants are competitively awarded through an open international process. One of the winning projects, led by Dr. Andrew Palmer of the Florida Institute of Technology in collaboration with several other researchers, aims to test two different methods of producing crops in space and on other worlds using water and using regolith, the surface dirt found on other worlds. Dr. Palmer provided this update on his project.

The team kicked off our project in 2023 by visiting Professor Rafael Loureiro's lab at Winston-Salem State University (WSSU), where most of the plant growth was set to occur. Finally meeting face to face was such an amazing opportunity for some of us who had been working together for nearly two years but had never met in person. Over the next two days, we spent six to seven hours laying out the finer details of the project. Along the way, we also settled on an acronym for the project: CHRGE (Comparing Hydroponic and Regolith Growth and Evolution).

We also exchanged emails with Professor Travis Hunsucker, our systems engineering analyst, and established what information he'd need to make his first-generation models for comparing these two different growth systems. Then, we were off to work in the lab, preparing our first generation of plant samples for transfer into lunar regolith or hydroponic systems.

Later that year, we presented the project at a meeting of the American Society of Gravitational and Space Research, thanking all the members of The Planetary Society for their support. The presentation sparked good discussion and a lot of interest from space biologists familiar with the challenge. It was great to get so much feedback and validation of the significance of this project.

Several months later, we have now completed at least one generation of both lettuce and tomato growth in lunar regolith as well as by hydroponics. Those samples have been frozen and are in storage at WSSU, waiting to be shipped to the Jet Propulsion Laboratory and Florida Tech for the analysis of their metabolites as well as their microbiome (bacterial partners). The regolith simulants from these studies are being used as substrates for a new generation of crops, and we are starting to characterize the chemical and physical changes to these simulants as a result of them having already been used once to grow plants.

At the Palmer Lab at Florida Tech, we've been doing practice runs with lettuce and tomatoes that we are growing in our own lab, optimizing our sampling methods and analysis so we are ready to run once we get our samples back from WSSU. Similarly, Dr. Laura Fackrell has been working on methods for isolating and characterizing the microbiomes of the regolith simulants as well as the plant tissue. Professor Travis Hunsucker is working toward a first-generation model to compare these two systems.

We also took three students to the regional meeting of the American Society of Plant Biology this March to present on some of their work on this project, and we hope to submit the first paper from this project by August of this year.

None of this would have been possible without the support of The Planetary Society. Thank you!

"Tiny Tim" the tomato plant is shown growing in a lunar regolith simulant under LED grow lights. ANDREW PALMER

LEFT *This hydroponically grown romaine lettuce is the same variety grown on the International Space Station.* ANDREW PALMER

BELOW *NASA's Michoud Assembly Facility in New Orleans.*
NASA

SPACE POLICY AND ADVOCACY IN ACTION

POLICY PRINCIPLES FOR MARS SAMPLE RETURN In February, with extensive input from our board of directors, The Planetary Society released a set of principles to guide the future of Mars Sample Return, which at the time of writing was under revaluation by NASA due to unexpected cost growth and mismanagement.

The science provided by Mars Sample Return remains extraordinarily compelling. Given the perilous state of the program and the possible temptation to cut the science return to save money, The Planetary Society proposed a set of principles for how NASA should approach a restructured Mars Sample Return campaign:

- Return the full suite of samples collected by the Perseverance rover; don't leave precious samples on the surface to shave proverbial pennies off the project's cost.
- Don't delay. Pursue the project now while we have samples on the surface of Mars; an experienced Mars workforce; and buy-in from our European allies, who have made a billion-euro-plus commitment to the effort.
- And do it with balance; we can't let MSR consume NASA's entire science directorate. There are other missions, such as the Habitable Worlds Observatory, that are important priorities in their own right that will advance our search for life in the Cosmos.

On April 15, NASA Administrator Bill Nelson announced that the agency would solicit ideas from industry and from other NASA institutions for a cheaper and faster version of Mars Sample Return and would consider returning only a fraction of the samples already collected. NASA leadership was not satisfied with the results of their internal study, which would have delayed the project to 2040 at a cost of $11 billion. NASA will evaluate proposals and make a program decision in the fall.

ADVOCACY ACTIONS IN SUPPORT OF NASA'S BUDGET In February, the Jet Propulsion Laboratory (JPL) announced layoffs of 530 people, roughly 8% of the lab's full-time workforce. This dramatic action was caused by a congressional fight over Mars Sample Return. The U.S. Senate had proposed to slash MSR's budget by $522 million; the House of Representatives, on the other hand, had strongly supported the project and proposed an increase to $949 million, the amount originally requested by the White House. Due to unrelated politics delaying final 2024 appropriations by more than five months, NASA restricted the rate of spending on MSR to match the lowest possible budget scenario from the Senate.

In response to this, The Planetary Society called on our U.S. members to write to their representatives in Congress and urge them to pass a budget supporting NASA's science portfolio, including MSR and other high-priority missions. Within a matter of days, over 1,800 people from every state had taken action online, speaking up for the importance of space.

Ultimately, Congress passed a budget preserving most science programs, though funding did decrease. MSR was reinforced as NASA's top planetary priority, and though its budget was not restored, NASA was granted flexibility during its restructuring period.

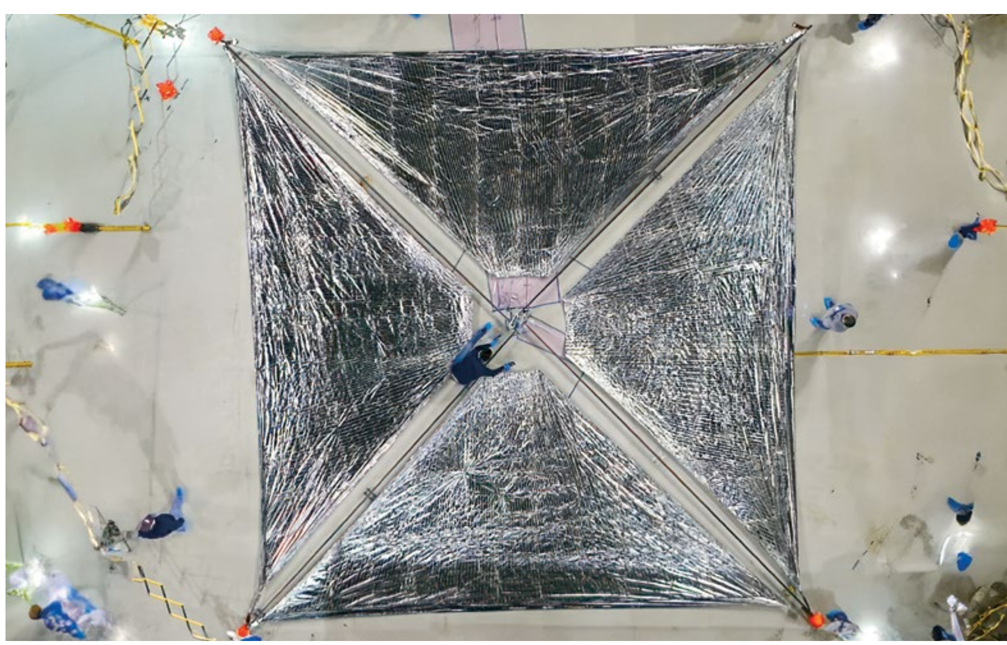
THE DAY OF ACTION On April 29, we held our Day of Action, bringing nearly 100 advocates from across the United States to Washington, D.C., to meet with their representatives in Congress and speak about the importance of investing in space science and exploration. Research has shown that in-person constituent meetings like these are the most effective way to engage elected officials on topics like space exploration. Participants in this year's Day of Action advocated for funding for NASA's overall science portfolio, including Mars Sample Return, Habitable Worlds Observatory, planetary defense, and the search for life beyond Earth. You can read more about the Day of Action at **planetary.org/dayofaction**.

TOP *Planetary Society members convened for a group photo on the roof of the Johns Hopkins University Bloomberg Center during their training for the 2024 Day of Action.*
THE PLANETARY SOCIETY

BOTTOM *As part of the 2024 Day of Action, Planetary Society CEO Bill Nye met with NASA Administrator Bill Nelson before a hearing of the House Science, Space, and Technology Committee on the NASA Budget.*
THE PLANETARY SOCIETY

LIGHTSAIL CONTINUES TO ADVANCE SOLAR SAILING

Five years after The Planetary Society's LightSail 2 spacecraft launched, the mission continues to contribute to the field of solar sailing. NASA's ACS3 solar sail mission, which aims to deploy a sail similar in shape to that of LightSail 2 but with a little more than twice the surface area and different boom material, is making progress. The Planetary Society continues to work with NASA, sharing what we learned about solar sailing from our LightSail program. Planetary Society Chief Scientist Bruce Betts also served on the ACS3 mission's review panel. ACS3 successfully launched into Earth orbit on April 23. Learn more at **planetary.org/space-missions/acs3**.



BELOW *Engineers at NASA's Langley Research Center test deployment of the Advanced Composite Solar Sail System's solar sail. The unfurled solar sail is approximately 9 meters (30 feet) on a side.*
NASA

MAKE YOUR OWN CRATERS

In this activity, you'll make your own small impact craters like the big ones on Mercury! You should do this activity with an adult helper.

YOU'LL NEED:

- Simulated dark colored planet surface dirt/rock, like cocoa powder or cinnamon.
- Simulated light colored planet dirt/rock, like flour.
- Broad, shallow box or pan, e.g., pie tin, pizza box. (Smaller boxes or pans use less dirt material. Larger ones have room for more craters and less chance of spillage)
- Simulated asteroid impactors, e.g. marbles, ball bearings, or even small rocks.
- Something to sprinkle the dark material out, like a large spoon, or a container with small holes.
- Drop cloth or towel (optional)
- Cardboard or any flat edged item smaller than the box/pan width to level the material.

PROCEDURE:

1. Optionally, spread a drop cloth or towel out on the ground or floor.

2. Place the box or pan on the ground or floor.

3. Pour the simulated light colored planet dirt/rock into the box/pan and smooth the surface using the cardboard. Depth should be about 2 to 5 cm (about 1 to 2 inches).

4. Sprinkle a thin layer of dark planetary surface material so that it completely covers the light colored material.

5. Stand next to the box/pan and drop an "asteroid" (marble, rock, other) into the box/pan.

6. Did it make a crater?

7. If you can see the "asteroid" you dropped, carefully remove it from the box/pan without disturbing the surface. Real asteroids are going so fast when they hit Mercury or another planet that they break apart.

8. Drop more "asteroids" from the same height. Try dropping different sizes. Do not repair the planetary surface between impacts.

9. Write in your log book: What do the craters look like? Do bigger asteroids make bigger craters? What happened to the layers? Do the craters look like Mercury craters?

10. Optionally, draw the final surface or take a picture of it and put that in your log book.

DEFEND OUR PLANET

June 30 is Asteroid Day, an international day to celebrate the science of asteroids and to promote awareness of the threat they can pose to our planet. Check out asteroidday.org to find public events around the world that combine education and celebration.

You can also support The Planetary Society's efforts to defend Earth from impacts. Through public education, crowdfunded projects, international competed grants, advocacy, and more, we engage our members to help advance the efforts to find, track, characterize, and deflect potentially dangerous asteroids. You can help by going to **planetary.org/defendearth**.

CHECK OUT YOUR MEMBER COMMUNITY

The Planetary Society's online community now has more than 11,000 members from around the world. These are people who share a passion for space and want to learn and work together to advance science and exploration. One of the most popular activities in the community is our monthly book club. Each virtual book club meeting includes a live video Q&A with the author of that month's book. Another great offering in the member community is a series of online courses. The newest course is all about the search for life and how you can help advance research, exploration, and even the discovery of life in our Solar System or beyond. Go to **community.planetary.org** to sign in!

KIDS CAN GET INVOLVED TOO!

If there's a kid in your life who loves space, Planetary Academy is for them! Each Planetary Academy member receives an educational adventure pack in their mailbox every three months. Each pack has been thoughtfully developed by the educational experts of The Planetary Society to delight kids age 5-9 who love space. They include activities like this one [at left] from our package all about the planet Mercury!

CALENDAR OF EVENTS

JUNE
20
June solstice

AUGUST
11-12
Perseid meteor shower

AUGUST
14
Conjunction of Mars and Jupiter

SEPTEMBER
8
Saturn at opposition

SEPTEMBER
17-18
Partial lunar eclipse

SEPTEMBER
18
Super harvest Moon

SEPTEMBER
22
September equinox

METEOR CRATER FROM AN IMPACT 50,000 YEARS AGO

YOU CAN HELP DEFEND EARTH TODAY

With the support of members like you, we're advancing the global endeavor to protect Earth from an asteroid impact. It's the only large-scale natural disaster we can prevent … but only if we try.

That's why we need your help to power our critical work as a planetary defender. Will you join us?

There is no better time than now to make a difference. A major asteroid impact could be devastating, but your investment today advances our work on a global level to protect humankind.

Visit **planetary.org/defendearth**
to make a gift today and learn more!

THE PLANETARY SOCIETY FIND YOUR PLACE IN SPACE

LEFT
NASA's Mars Perseverance rover acquired this image of the Ingenuity helicopter using its left Mastcam-Z camera.
NASA/JPL-CALTECH/ASU/MSSS

IN THE SKY
Yellowish Saturn comes up in the middle of the night in the east in June and near sunset by September. Very bright Jupiter and reddish Mars are in the predawn east. Jupiter approaches Mars from below and passes it in the sky when they are extremely close together on Aug. 14. They are very near the crescent Moon on Aug. 22. A partial lunar eclipse occurs overnight on Sept. 17-18, but less than 4% of the Moon will be in the darker (umbral) part of the eclipse. The Perseid meteor shower, usually one of the top meteor showers of the year, peaks Aug. 11-12, with increased activity several days before and after. Viewing will be best after the setting of the nearly quarter Moon around 1:00 a.m. (depending on your time zone). From a very dark site, there are typically 50 to 75 meteors per hour at the peak. For more night sky tips, you can always check out **planetary.org/night-sky**.

RANDOM SPACE FACT
If Pluto and Charon were each centered on opposite goal lines of an American football field, Pluto would extend to about the 6-yard line and Charon to about the opposite 3-yard line, and they would revolve around the system center of mass at the 11-yard line near Pluto. They revolve around that point that is outside Pluto.

TRIVIA CONTEST
Our September equinox contest winner is David Lee Summers of Las Cruces, New Mexico, USA. Congratulations! The question was: ***What did NASA name the Mars helicopter Ingenuity's first takeoff and landing airfield on Mars?*** The answer: ***Wright Brothers Field.***

Try to win a copy of the new book "Casting Shadows: Solar and Lunar Eclipses with The Planetary Society" by Bruce Betts and a Planetary Radio T-shirt by answering this question:
What was the first exoplanet discovered around a Sunlike 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 Sept. 1, 2024. One entry per person. The winner will be chosen in a random drawing from among all the correct entries received.

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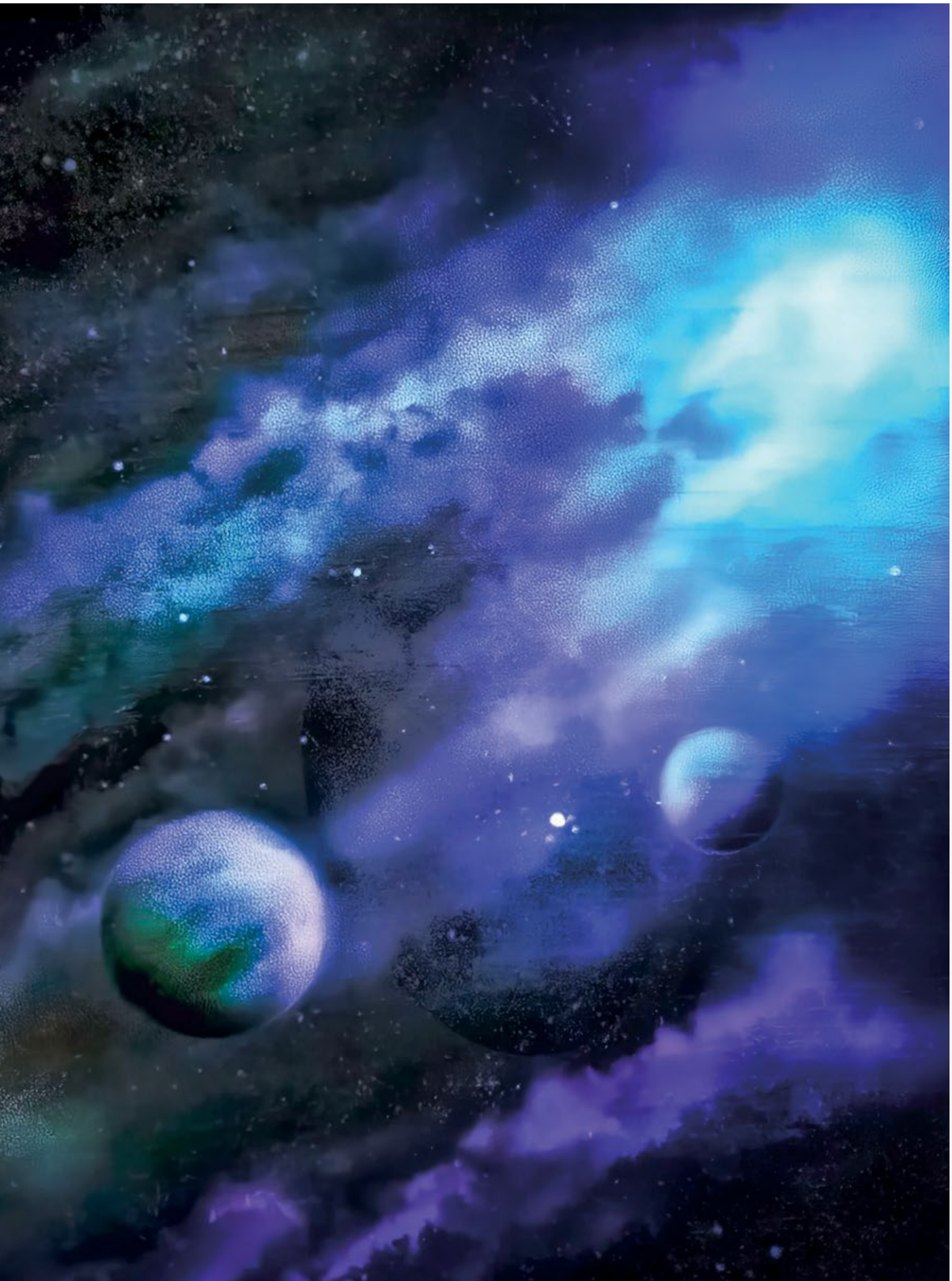

Binary Worlds
Raven Stihl

Planetary Society member Raven Stihl created this depiction of a pair of exoplanets with their home galaxy shown in the background in swaths of blue and purple. The number and diversity of worlds beyond our Solar System is staggering and provides ample inspiration for artists and scientists alike.

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*.