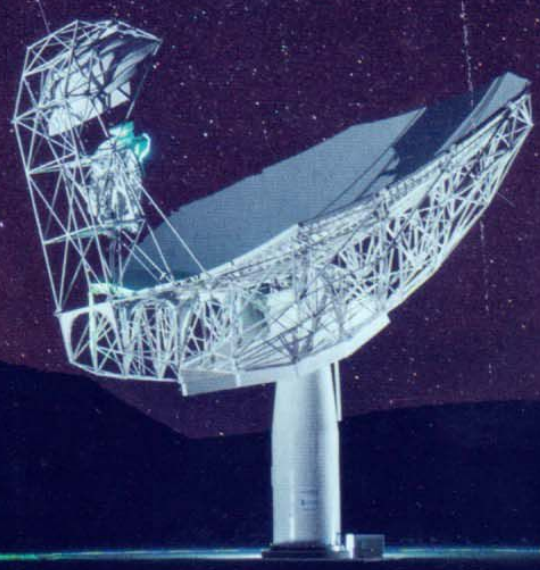
03.2019

NATIONAL GEOGRAPHIC

WE ARE NOT ALONE



"Something great is around those stars."
SARA SEAGER, ASTROPHYSICIST

Scientists say there must be other life in the universe. Here's how they're searching for it.

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The Milky Way glows above one of the 64 antennas of MeerKAT, a supersensitive telescope that scans the sky for radio signals. It's located in South Africa's Northern Cape Province.
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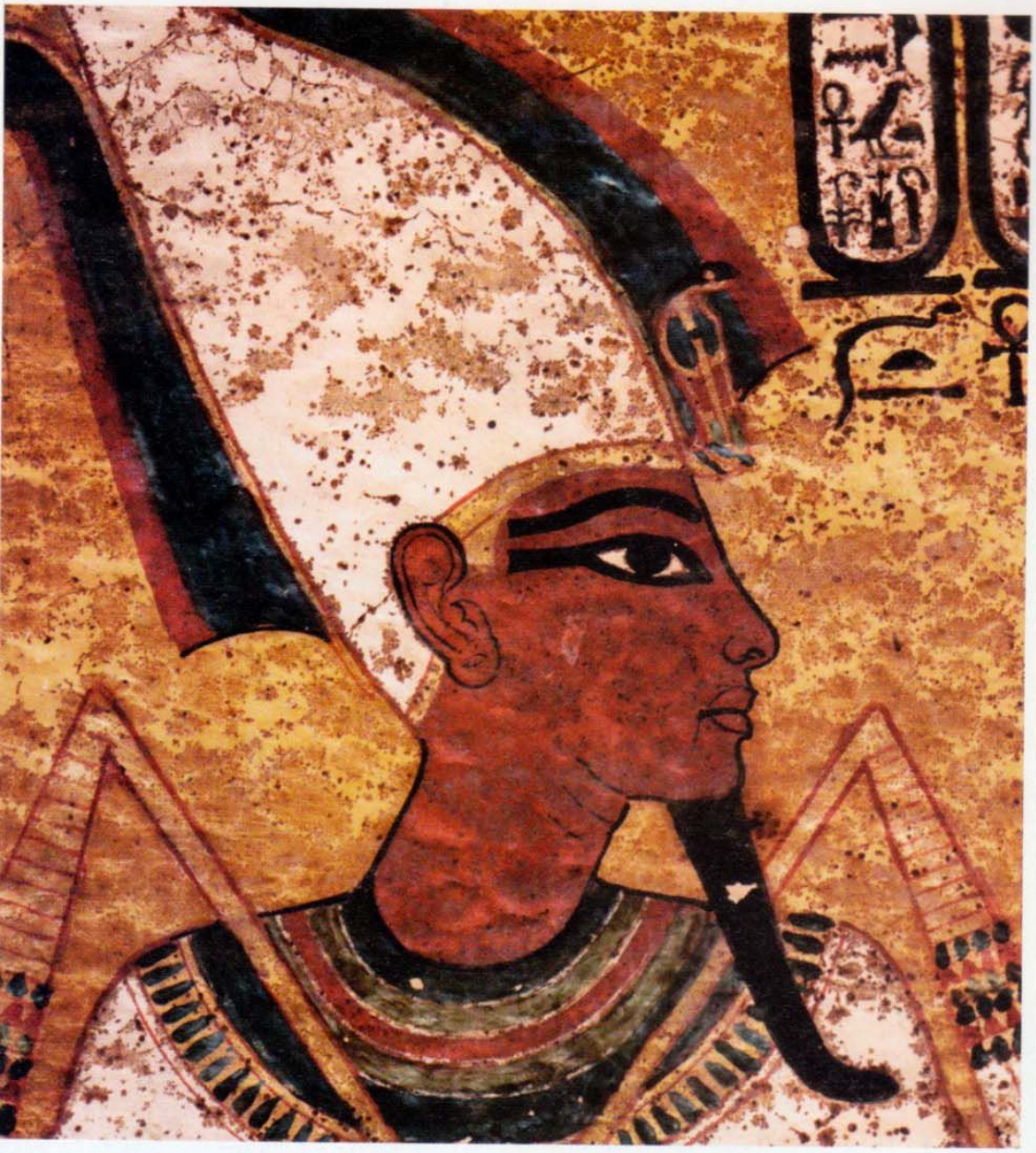
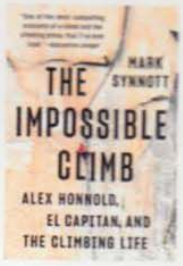


NAT GEO TV

Join the Search for *Lost Treasures of Egypt*

Follow international teams of Egyptologists as they mine the world's richest seam of ancient archaeology: Egypt's Valley of the Kings. See highlights of a full season of excavations as the dig teams use innovative technology to pursue finds such as this wall painting of King Tut. *Lost Treasures of Egypt*'s six episodes air Tuesdays at 10/9c starting March 5 on National Geographic.



BOOKS

Chronicling *The Impossible Climb*

Author Mark Synnott shadowed rock climber Alex Honnold during his secret preparations to free solo Yosemite's El Capitan. The result: a riveting account of Honnold's ropeless climb up the 3,000-foot rock face. *The Impossible Climb* arrives in bookstores March 5.

TELEVISION

More *Story of God*

Morgan Freeman continues his global exploration of the power of religion. New episodes look at the nature of divine visions and at beliefs about the devil. *The Story of God* airs Tuesdays at 9/8c starting March 5 on National Geographic.

BOOKS

Look Up! It's Our Night Sky Guide

National Geographic's *Backyard Guide to the Night Sky* is out in a second edition packed with even more astronomy photos and facts. Available March 19 wherever books are sold and at *shopng.com/books*.

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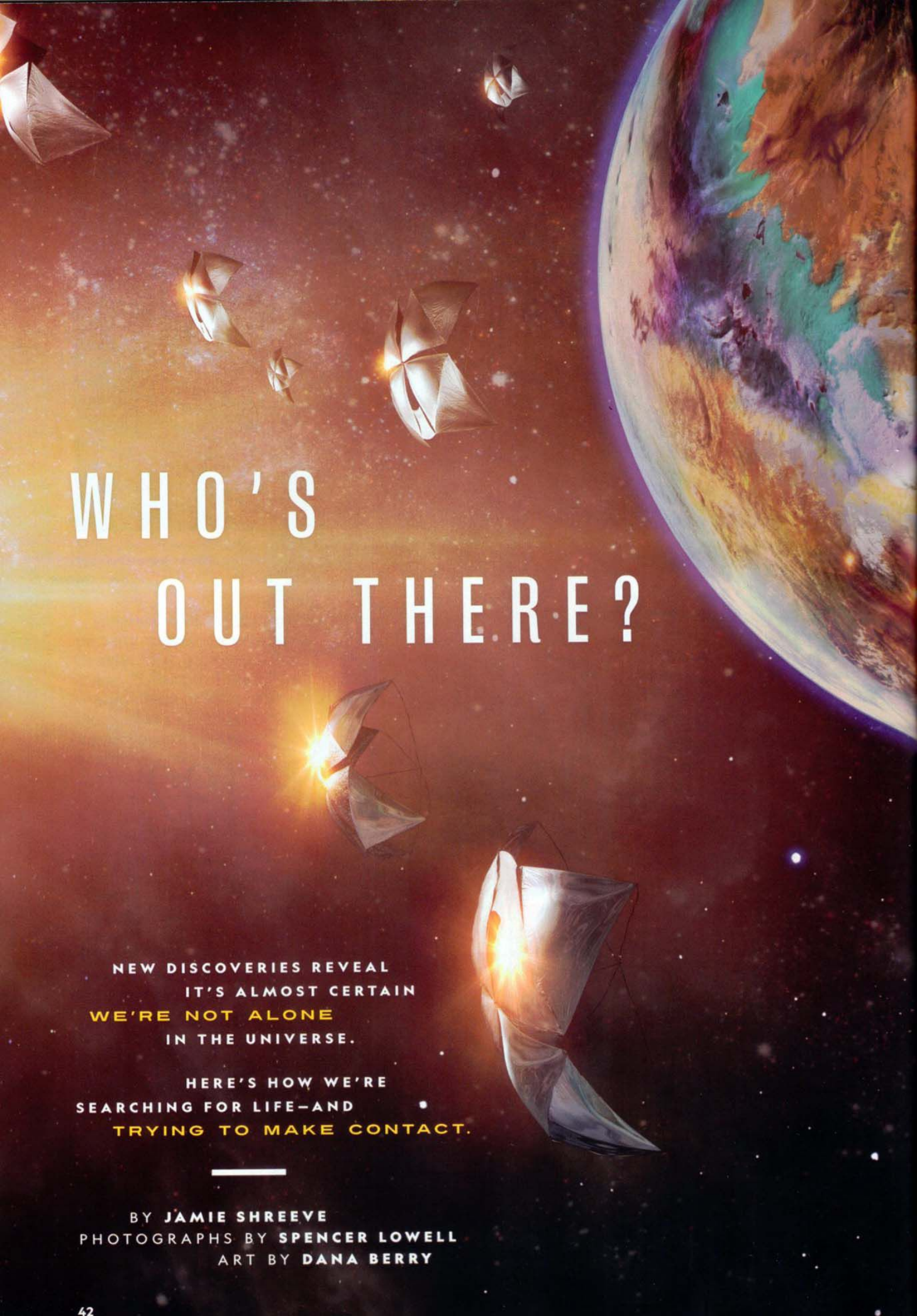


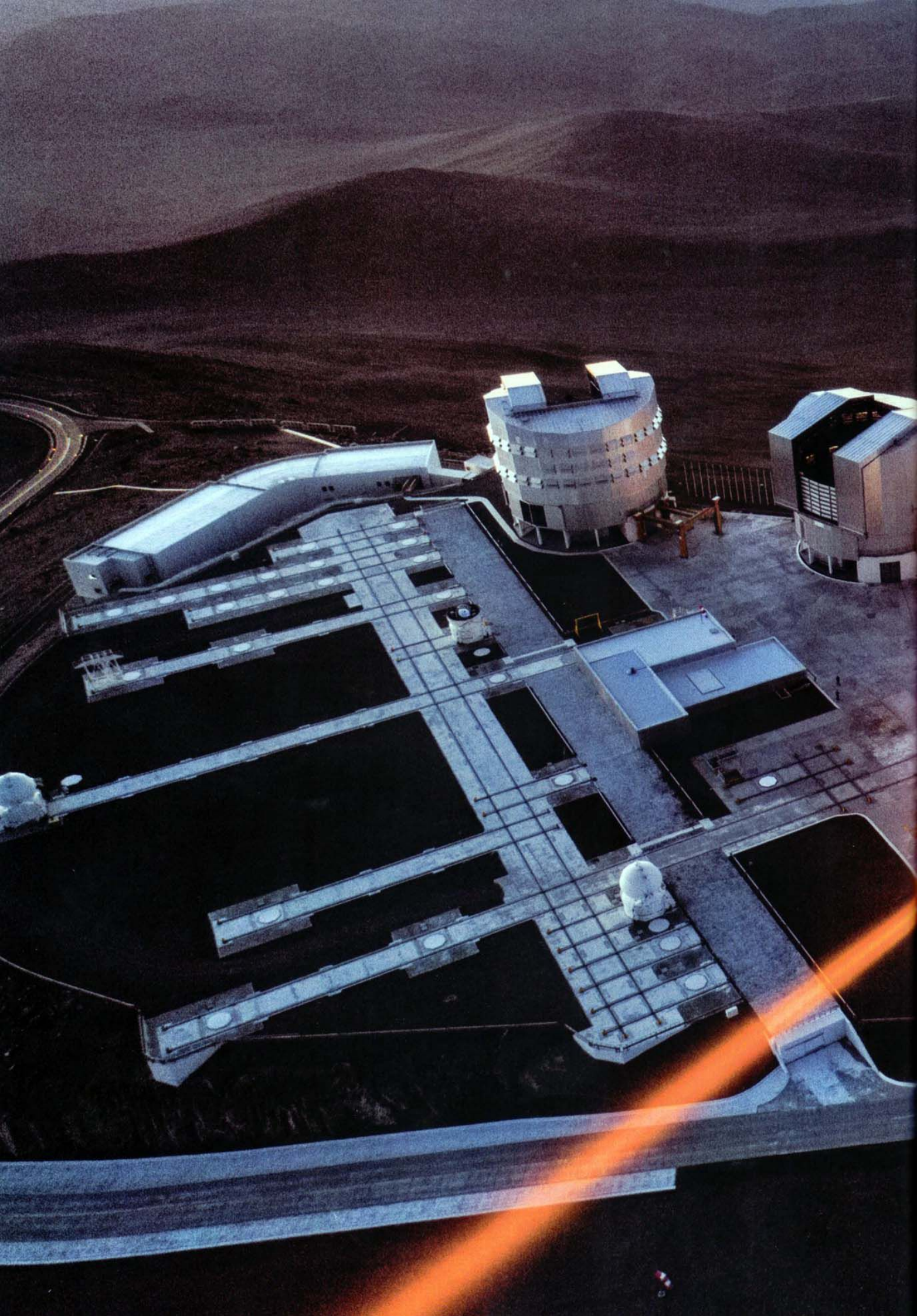
WHO'S OUT THERE?

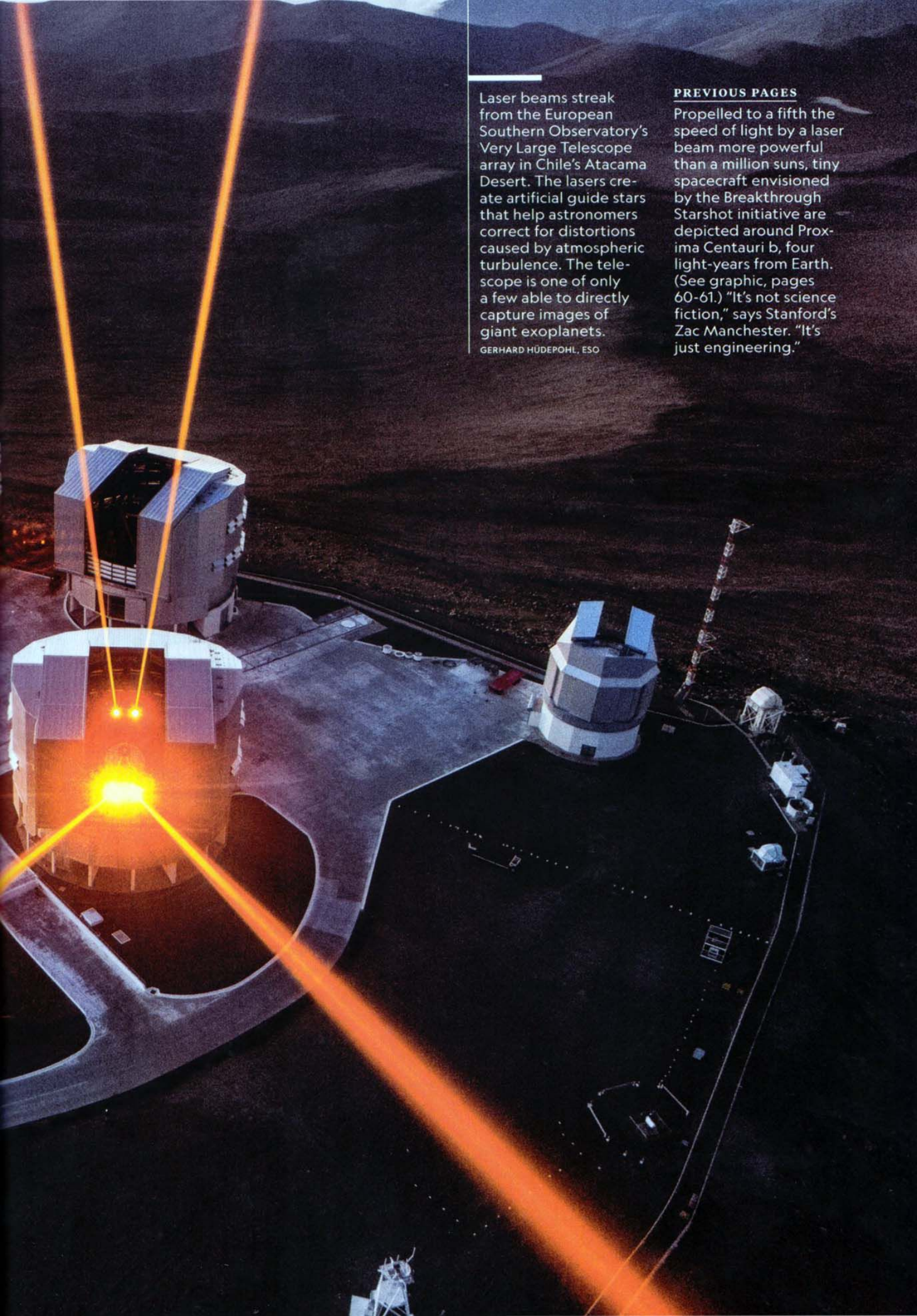
NEW DISCOVERIES REVEAL IT'S ALMOST CERTAIN **WE'RE NOT ALONE** IN THE UNIVERSE.

HERE'S HOW WE'RE SEARCHING FOR LIFE—AND **TRYING TO MAKE CONTACT.**

BY **JAMIE SHREEVE**
PHOTOGRAPHS BY **SPENCER LOWELL**
ART BY **DANA BERRY**

ART DIRECTION: JASON TREAT, NGM STAFF; SEAN McNAUGHTON
SOURCES: BREAKTHROUGH INITIATIVES; ZAC MANCHESTER, STANFORD UNIVERSITY





Laser beams streak from the European Southern Observatory's Very Large Telescope array in Chile's Atacama Desert. The lasers create artificial guide stars that help astronomers correct for distortions caused by atmospheric turbulence. The telescope is one of only a few able to directly capture images of giant exoplanets.
GERHARD HÜDEPOHL, ESO

PREVIOUS PAGES

Propelled to a fifth the speed of light by a laser beam more powerful than a million suns, tiny spacecraft envisioned by the Breakthrough Starshot initiative are depicted around Proxima Centauri b, four light-years from Earth. (See graphic, pages 60-61.) "It's not science fiction," says Stanford's Zac Manchester. "It's just engineering."

In her office on the 17th floor of MIT's Building 54, Sara Seager is about as close to space as you can get in Cambridge, Massachusetts. From her window, she can see across the Charles River to downtown Boston in one direction and past Fenway Park in the other. Inside, her view extends to the Milky Way and beyond.

Seager, 47, is an astrophysicist. Her specialty is exoplanets, namely all the planets in the universe except the ones you already know about revolving around our sun. On a blackboard, she has sketched an equation she thought up to estimate the chances of detecting life on such a planet. Beneath another blackboard filled with more equations is a clutter of memorabilia, including a vial containing some glossy black shards.

"It's a rock that we melted."

Seager speaks in brisk, uninflected phrases, and she has penetrating hazel eyes that hold on to whomever she is talking to. She explains that there are planets known as hot super-Earths whizzing about so close to their stars that a year lasts less than a day. "These planets are so hot, they probably have giant lava lakes," she says. Hence, the melted rock.

"We wanted to test the brightness of lava."

When Seager entered graduate school in the mid-1990s, we didn't know about planets that circle their stars in hours or others that take almost a million years. We didn't know about planets that revolve around two stars, or rogue planets that don't orbit any star but just wander about in space. In fact, we didn't know for sure that any planets at all existed beyond our solar system, and a lot of the assumptions we made about planet-ness have turned out to be wrong. The very first exoplanet found—51 Pegasi b, discovered in 1995—was itself a surprise: A giant planet crammed up against its star, winging around it in just four days.

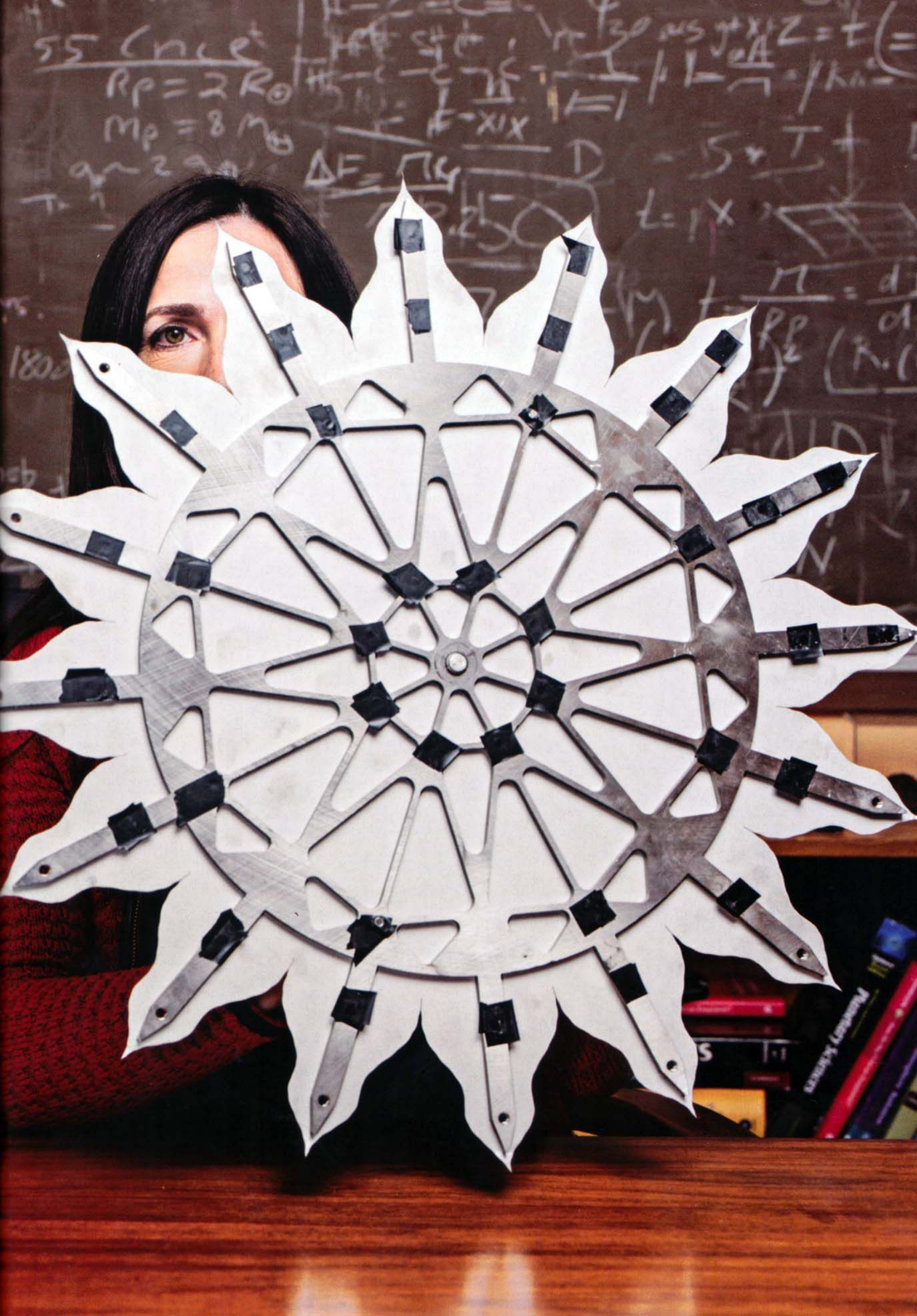
"51 Peg should have let everyone know it was going to be a crazy ride," Seager says. "That planet shouldn't be there."

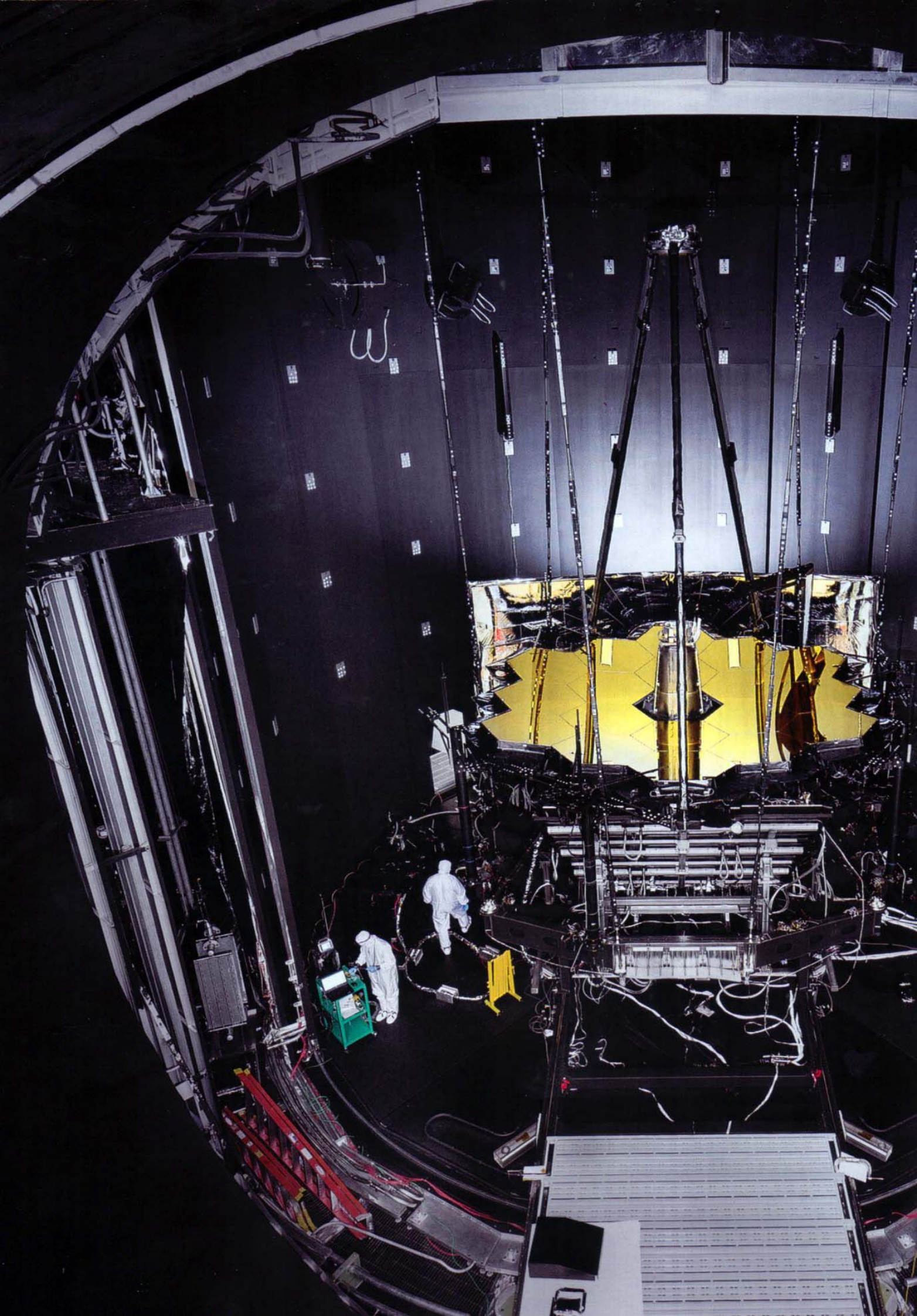
Today we have confirmed about 4,000 exoplanets. The majority were discovered by the Kepler space telescope, launched in 2009. Kepler's mission was to see how many planets it could find orbiting some 150,000 stars in one tiny patch of sky—about as much as you can cover with your hand with your arm outstretched. But its ultimate purpose was to resolve a much more freighted question: Are places where life might evolve common in the universe or vanishingly rare, leaving us effectively without hope of ever knowing whether another living world exists?

Kepler's answer was unequivocal. There are more planets than there are stars, and at least a quarter are Earth-size planets in their star's so-called habitable zone, where conditions are neither too hot nor too cold for life. With a minimum of 100 billion stars in the Milky Way, that means there are at least 25 billion places where life could conceivably take hold in our galaxy alone—and our galaxy is one among trillions.

It's no wonder that Kepler, which ran out of fuel last October, is regarded almost with reverence

Using a model, MIT astrophysicist Sara Seager demonstrates Starshade, under development at NASA's Jet Propulsion Lab in Pasadena, California. Deployed in space, the device, more than 100 feet in diameter, would block the light from a star. A space telescope would capture an image of a planet when it's between Starshade's petals, seeking evidence that life may exist on the planet.





by astronomers. ("Kepler was the greatest step forward in the Copernican revolution since Copernicus," University of California, Berkeley astrophysicist Andrew Siemion told me.) It's changed the way we approach one of the great mysteries of existence. The question is no longer, is there life beyond Earth? It's a pretty sure bet there is. The question now is, how do we find it?

The revelation that the galaxy is teeming with planets has reenergized the search for life. A surge in private funding has created a much more nimble, risk-friendly research agenda. NASA too is intensifying its efforts in astrobiology. Most of the research is focused on finding signs of any sort of life on other worlds. But the prospect of new targets, new money, and ever increasing computational power has also galvanized the decades-long search for intelligent aliens.

TO SEAGER, a MacArthur "genius award" winner, participating on the Kepler team was one more step toward a lifelong goal: to find an Earth-like planet orbiting a sun-like star. Her current focus is the Transiting Exoplanet Survey Satellite (TESS), an MIT-led NASA space telescope launched last year. Like Kepler, TESS looks for a slight dimming in the luminosity of a star when a planet passes—transits—in front of it. TESS is scanning nearly the whole sky, with the goal of identifying about 50 exoplanets with rocky surfaces like Earth's that could be investigated by more powerful telescopes coming on line, beginning with the James Webb Space Telescope, which NASA hopes to launch in 2021.

On her "vision table," which runs along one wall of her office, Seager has collected some objects that express "where I am now and where I'm going, so I can remind myself why I'm working so hard." Among them are some polished stone orbs representing a red dwarf star and its covey of planets, and a model of ASTERIA, a low-cost planet-finding satellite she developed.

"I haven't gotten around to putting this up,"

NASA's James Webb Space Telescope is tested in a giant cryogenic chamber at Johnson Space Center in Houston, Texas, that simulates the frigid conditions of space. Far more powerful than the Hubble Space Telescope, it will probe the formation of stars, galaxies, and solar systems that could support life. CHRIS GUNN, NASA

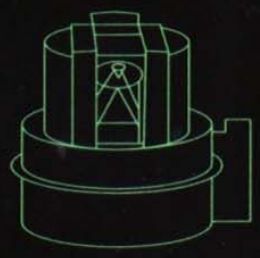
NEW WAYS OF SEEING

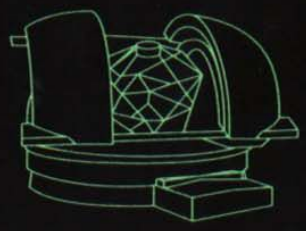
THE NEXT WAVE OF PLANET HUNTERS

The Kepler telescope, which detected thousands of exoplanets, was retired last year when it ran out of fuel, but new telescopes promise dramatic improvements in the hunt. The telescopes shown here are expected to significantly advance our ability to detect signs of habitability thousands of light-years away. In addition to a planet's size and distance from its star, they might be able to study its terrain and check for cloud cover.

TERRESTRIAL INSTRUMENTS

Ground-based scopes can hold heavy, powerful optics that are comparatively easy to maintain. But Earth's atmosphere filters and distorts starlight, limiting what these telescopes can see in outer space.





	SUBARU TELESCOPE	ELT
	Subaru Coronagraphic Extreme Adaptive Optics	*Extremely Large Telescope*
	Removes distant starlight reaching the Subaru telescope, allowing astronomers to directly image exoplanets.	Captures visible and near-infrared spectrum images 16 times as sharp as those of the Hubble Space Telescope.
Aperture	8.2 meters	39.3 meters
Start date	2014	Expected start: 2024

Seager says, unrolling a poster that's a fitting expression of where her career began. It's a chart showing the spectral signatures of the elements, like colored bar codes. Every chemical compound absorbs a unique set of wavelengths of light. (We see leaves as green, for instance, because chlorophyll is a light-hungry molecule that absorbs red and blue, so the only light reflected is green.) While still in her 20s, Seager came up with the idea that compounds in a transiting planet's upper atmosphere might leave their spectral fingerprints in starlight passing through. Theoretically, if there are gases in a planet's atmosphere from living creatures, we could see the evidence in the light that reaches us.

"It's going to be really hard," she tells me. "Think of a rocky planet's atmosphere as the skin of an onion, and the whole thing is in front of, like, an IMAX screen."

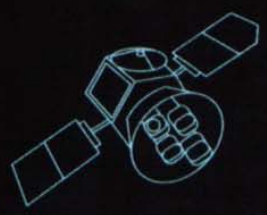
There's an outside chance a rocky planet orbits a star close enough for the Webb telescope to capture sufficient light to investigate it for signs of life. But most scientists, including Seager, think we'll need to wait for the next generation of space telescopes. Covering most of the wall over her vision table is a panel of micro-thin black plastic shaped like the petal of a giant flower. It's a reminder of where she's going: a space mission, still in development, that she believes can lead her to another living Earth.

FROM AN EARLY AGE, Olivier Guyon has had a problem with sleep: namely, that it's supposed to happen at night, when it's so much better to be awake. Guyon grew up in France, in the countryside of Champagne. When he was 11, his parents bought him a small telescope, which he says they later regretted. He spent many nights peering into it, only to fall asleep the next day in class. When he outgrew that telescope, he built a bigger one. But while he could magnify his view of heavenly objects, Guyon could do nothing to enlarge the number of hours in the night. Something had to give, so one day when he was a teenager, he decided to do away with sleep almost entirely. At first he felt great, but after a week or so, he became seriously ill. Recalling it now, he still shudders.

At 43 years old, Guyon today has a very big telescope to work with. The Subaru observatory, along with 12 others, sits atop the summit of

ORBITAL INSTRUMENTS

Away from Earth's atmosphere, telescopes can detect frequencies and wavelengths across the electromagnetic spectrum. But they must be small enough to launch, and they fly too far away to be repaired.



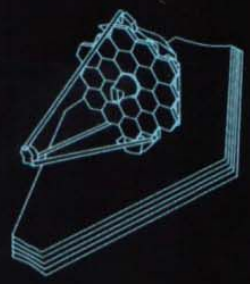
TESS

Transiting Exoplanet Survey Satellite

Detects small planets orbiting bright stars, which could be good candidates for more in-depth habitability studies.

4 cameras, 10.5 cm each

2018



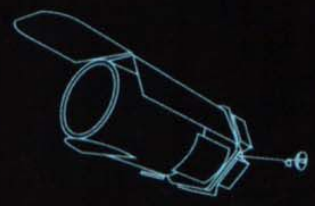
JWST

James Webb Space Telescope

Studies distant stars and exoplanets using four instruments, including infrared cameras and spectrographs.

6.5 meters

Expected start: 2021



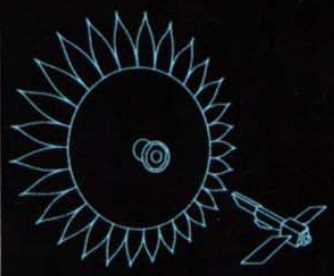
WFIRST

Wide Field Infrared Survey Telescope

Finds exoplanets using light warped by the gravity of distant stars; it could also be paired with Starshade.

2.4 meters

Expected start: 2025



STARSHADE

A flower-shaped light shield more than a hundred feet in diameter, the Starshade will work in tandem with a telescope such as WFIRST. It will block a host star's light, allowing astronomers a direct view of its exoplanets. This mission is still in development.

Mauna Kea, on Hawaii's Big Island. The Subaru's 8.2-meter (27 feet) reflector is among the largest single-piece mirrors in the world. (Operated by the National Astronomical Observatory of Japan, the telescope has no affiliation with the car company—Subaru is the Japanese name for the Pleiades star cluster.) At 13,796 feet above sea level, Mauna Kea affords one of the highest, clearest views of the universe, yet it's only an hour and a half drive from Guyon's home in Hilo. The proximity allows him to make frequent trips to test and improve the instrument he built and attached to the telescope, often working through the night. He carries around a thermos of espresso, and for a while he took to spiking it with shots of liquid caffeine, until a friend pointed out that his daily intake was more than half the lethal dose.

"We can spend a couple weeks up here, and we start to forget about life on Earth," he tells me. "First you forget the day of the week. Then you start forgetting to call your family."

Like Seager, Guyon is a MacArthur winner. His particular genius is in the mastery of light: how to massage and manipulate it to catch a glimpse of things that even the Subaru's huge mirror would be blind to without Guyon's legerdemain.

"The big question is whether there is biological activity up there," he says, pointing at the sky. "If yes, what is it like? Are there continents? Oceans and clouds? All these questions can be answered, if you can extract the light of a planet from the light of its star."

In other words, if you can *see* the planet. Trying to separate the light of a rocky, Earth-size planet from that of its star is like squinting hard enough to make out a fruit fly hovering inches in front of a floodlight. It doesn't seem possible, and with today's telescopes, it isn't. But Guyon has his sights set on what the next generation of ground-based telescopes might be able to do, if they can be fashioned to squint very, very hard.

That is precisely what his instrument is designed to do. The apparatus is called—brace yourself—the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO, pronounced "SKEX-a-o"). Guyon wanted me to see it in action, but a power outage had shut down the Subaru. Instead he offers to give me a tour of the 141-foot dome enclosing the telescope. There is 40 percent less oxygen here than at sea level. Visitors have the option of strapping on *(Continued on page 60)*

SOURCES: NATIONAL ASTRONOMICAL OBSERVATORY OF JAPAN; NASA; EUROPEAN SOUTHERN OBSERVATORY

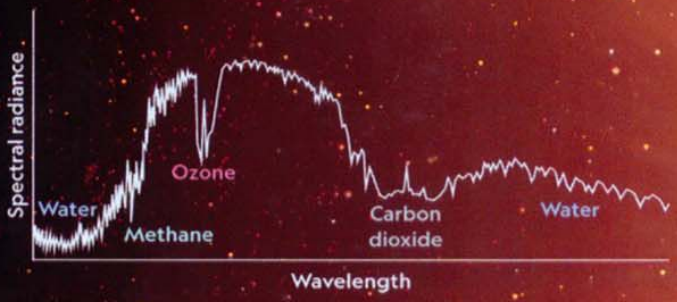
HOW TO FIND LIFE

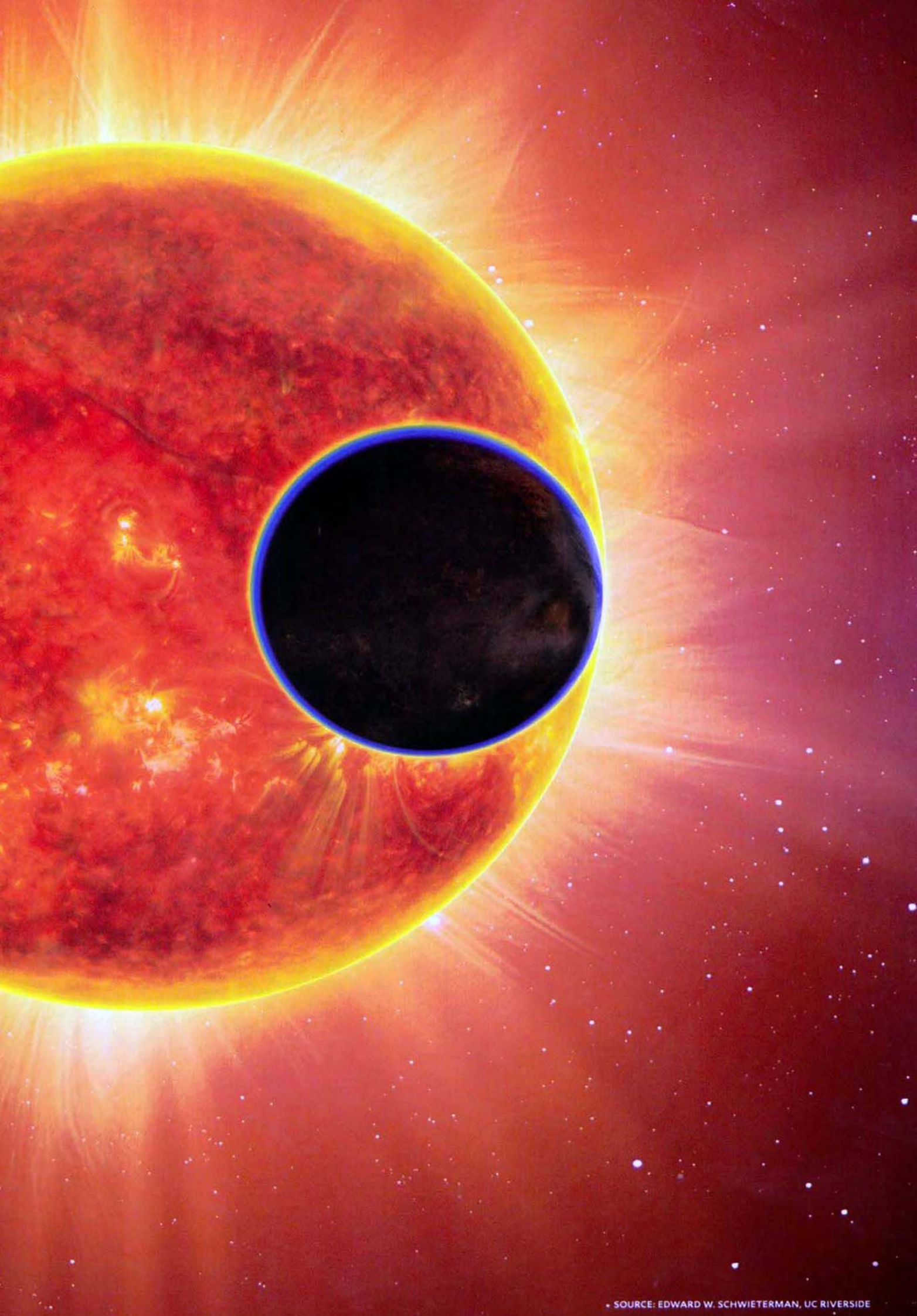
SEEKING THE LIGHT

In this illustration, an exoplanet orbits in front of a star much like the sun. One way to find out if a planet might contain life is to look for telltale signs called biosignatures. As starlight reflects off a planet or passes through its atmosphere, shown here in blue, gases absorb specific wavelengths. The spectrum observed through a telescope could show whether gases associated with life, such as oxygen, carbon dioxide, or methane, are present.

Earth's gaseous signs of life

Electromagnetic energy (light) passing through the atmosphere would create a spectrum like this one, which shows the presence of compounds linked to life.





• SOURCE: EDWARD W. SCHWIETERMAN, UC RIVERSIDE

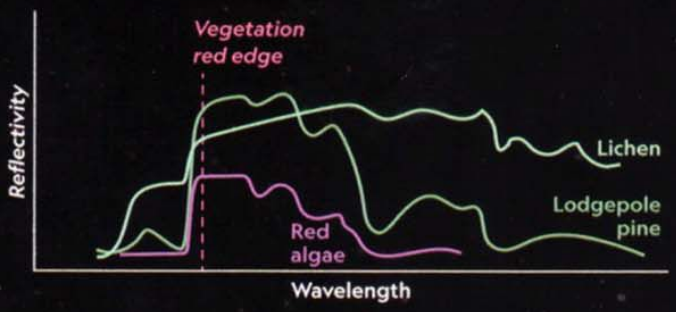
HOW TO FIND LIFE

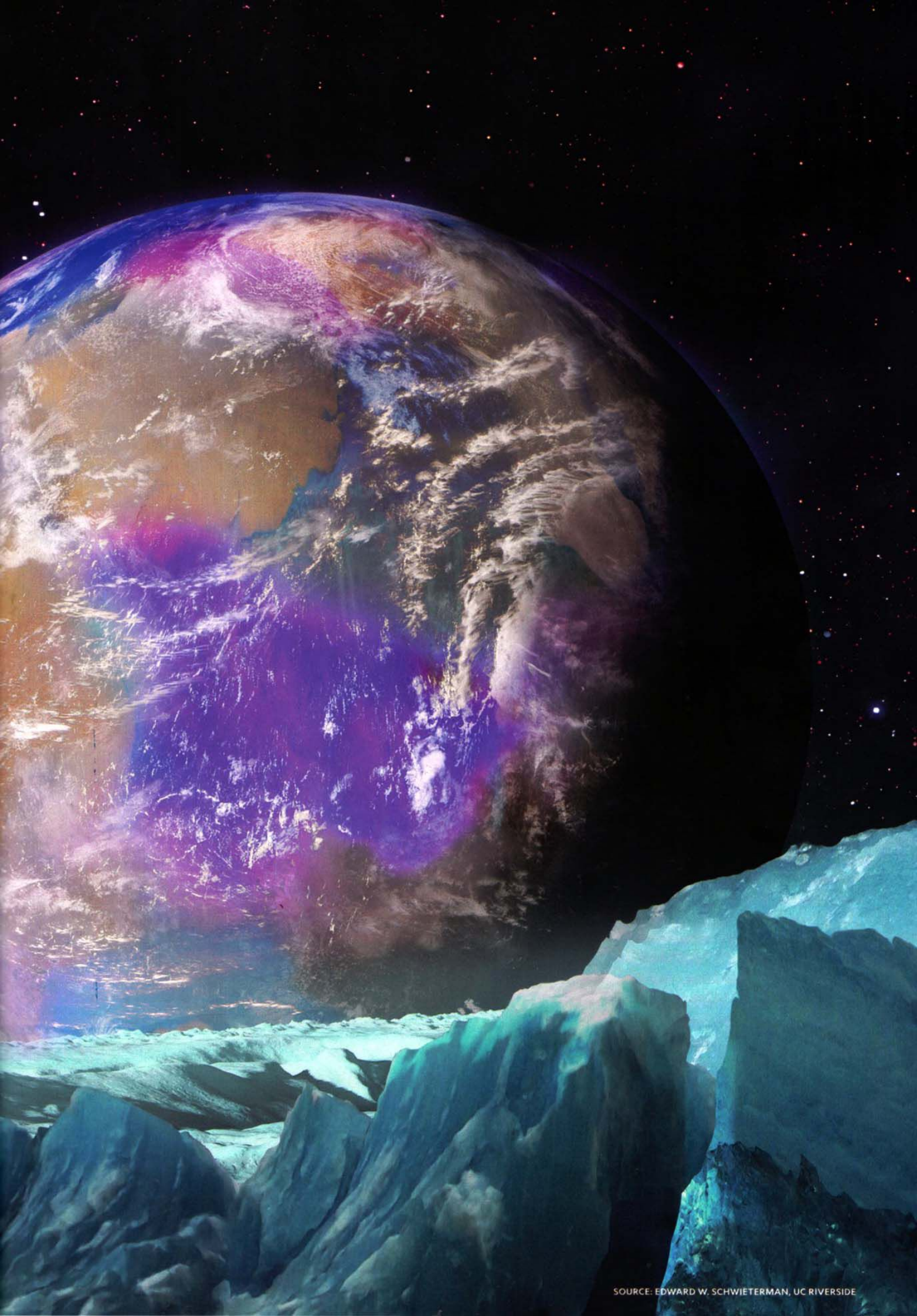
SEEING THE COLORS

On Earth, chlorophyll in photosynthesizing plants absorbs red and blue light, so vegetation appears green. On other living worlds, though, photosynthesis might use a different pigment. The lavender hue of this hypothetical exoplanet, viewed from its icy moon, derives from a pigment called retinal, which is also able to convert light to metabolic energy and may have preceded chlorophyll in Earth's early history.

Earth's chromatic signs of life

A sharp contrast in a spectrum between the absorption of red light and reflection of near-infrared light, known as the vegetation red edge, indicates the presence of plants.





SOURCE: EDWARD W. SCHWIETERMAN, UC RIVERSIDE

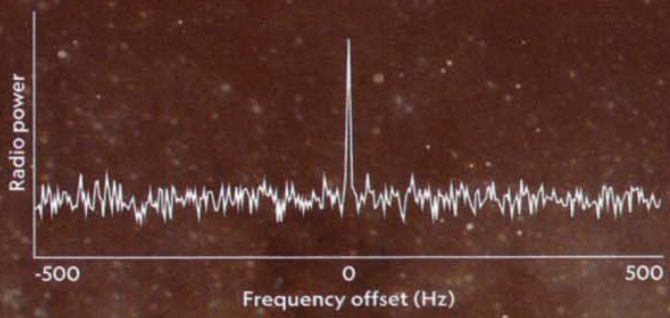
HOW TO FIND LIFE

INTELLIGENT ALIENS

Until now, the search for extraterrestrial intelligence has focused on detecting an incoming radio signal. With increasing computational power and more sensitive telescopes, researchers are expanding the search to optical and infrared emissions, targeting the "technosignatures" of advanced civilizations. These could include laser pulses, polluting gases, or megastructures built around a nearby star to harness its energy.

Transmission spikes from space

This power spectrum from a survey of 14 planetary systems included a signal that looked promising, but no evidence was found that it was created by intelligent life.

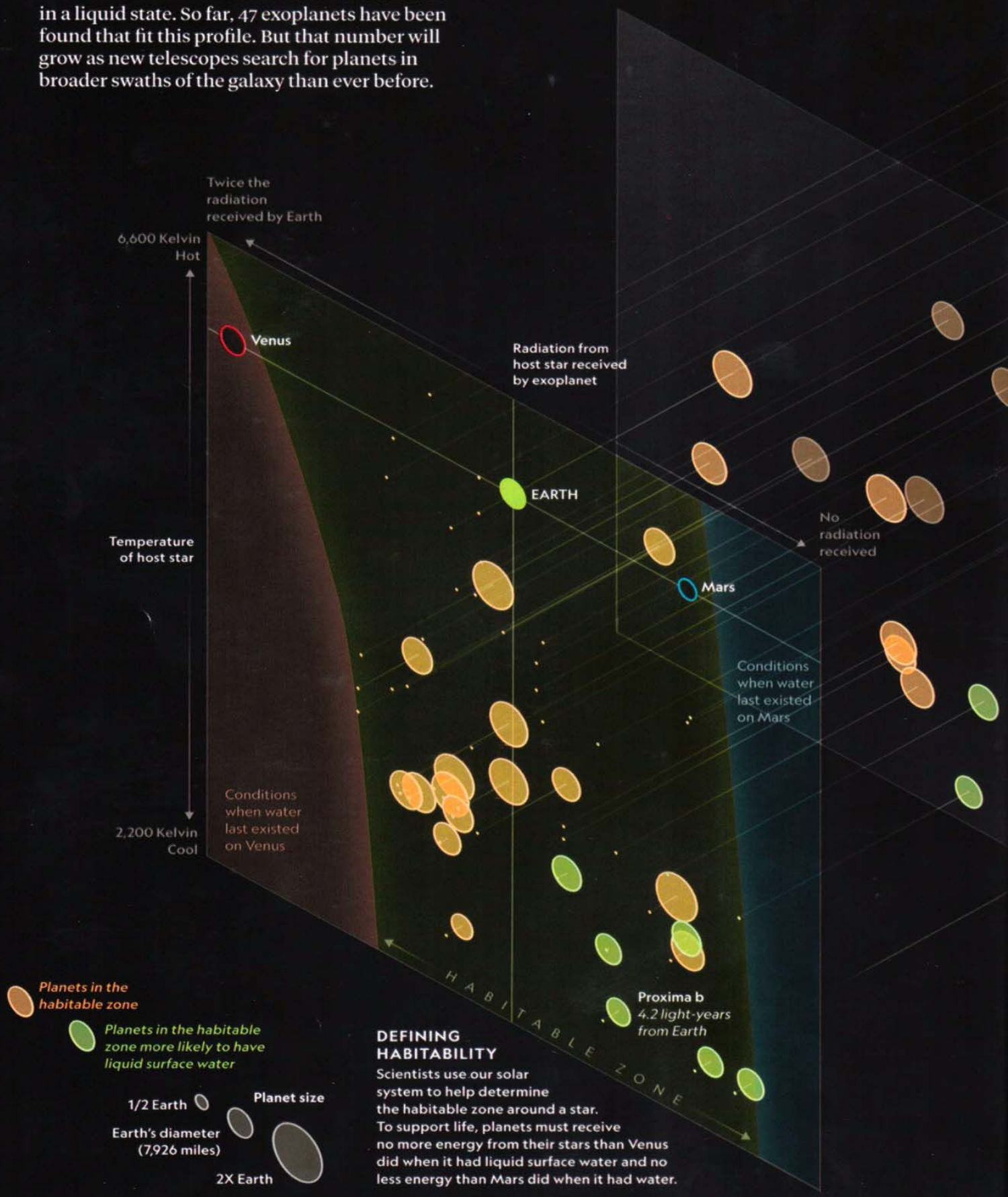


SOURCES: EDWARD W. SCHWIETERMAN, UC RIVERSIDE; BREAKTHROUGH INITIATIVES; SETI INSTITUTE

MAPPING EXOPLANETS

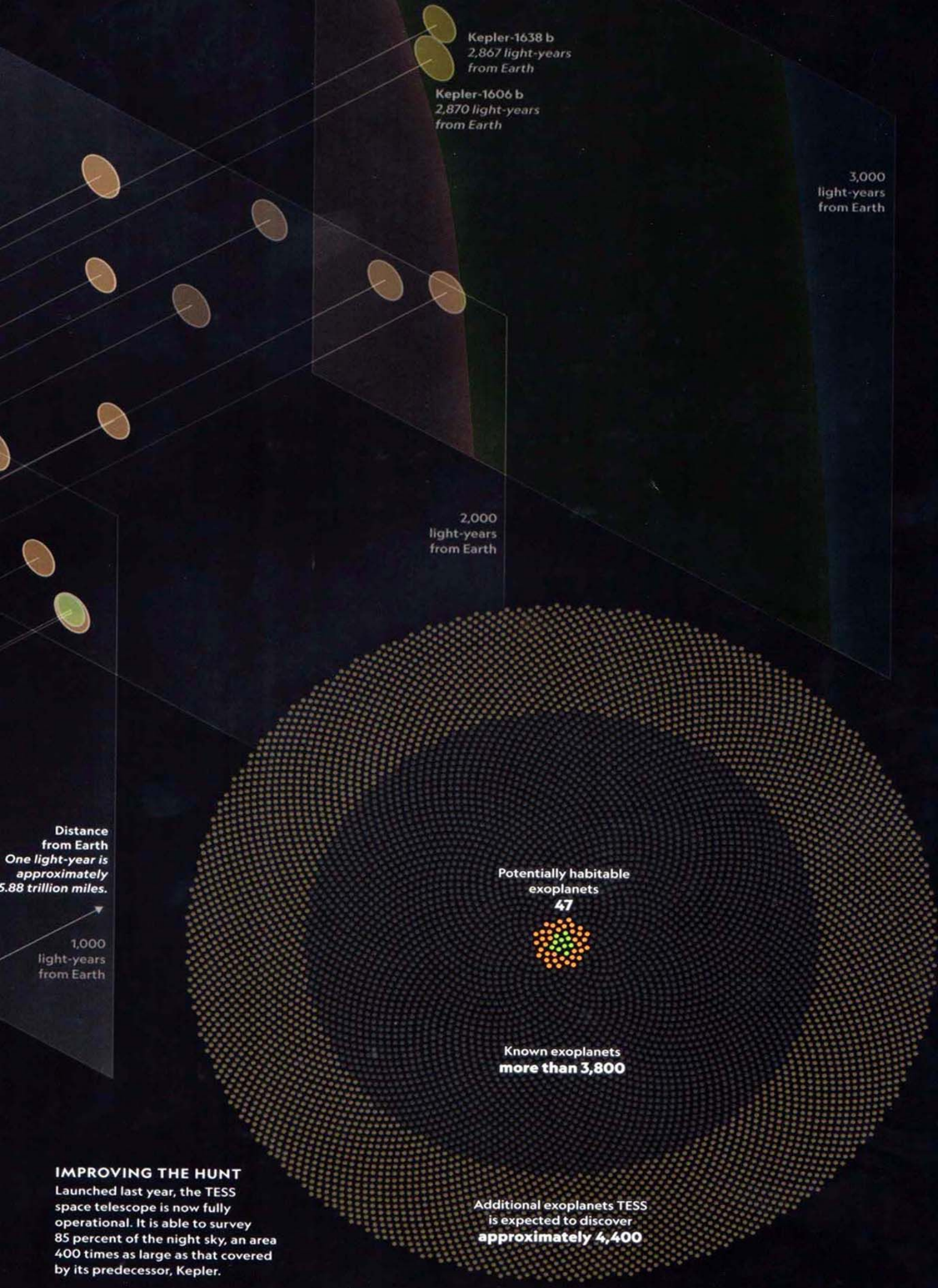
HUNTING FOR HABITABILITY

Earth supports life in part because its terrain is rocky, it doesn't receive too much solar radiation, and its distance from the sun allows water to be in a liquid state. So far, 47 exoplanets have been found that fit this profile. But that number will grow as new telescopes search for planets in broader swaths of the galaxy than ever before.



DEFINING HABITABILITY

Scientists use our solar system to help determine the habitable zone around a star. To support life, planets must receive no more energy from their stars than Venus did when it had liquid surface water and no less energy than Mars did when it had water.



IMPROVING THE HUNT

Launched last year, the TESS space telescope is now fully operational. It is able to survey 85 percent of the night sky, an area 400 times as large as that covered by its predecessor, Kepler.

SOURCES: PLANETARY HABITABILITY LABORATORY; ABEL MÉNDEZ, UNIVERSITY OF PUERTO RICO AT ARECIBO; TOM BARCLAY, NASA

NEW WAYS OF SEEING

PROPELLED BY LIGHT

Breakthrough Starshot is an ambitious plan in development to send tiny probes on a 20-year journey to the exoplanet Proxima Centauri b. But even a featherweight spacecraft needs fuel. The farther it goes, the more it needs. The proposed solution? Forget fuel: Launch it from an orbiting satellite and propel it with Earth-based lasers.

some bottled oxygen, but he decides that I don't need any, and off we go.

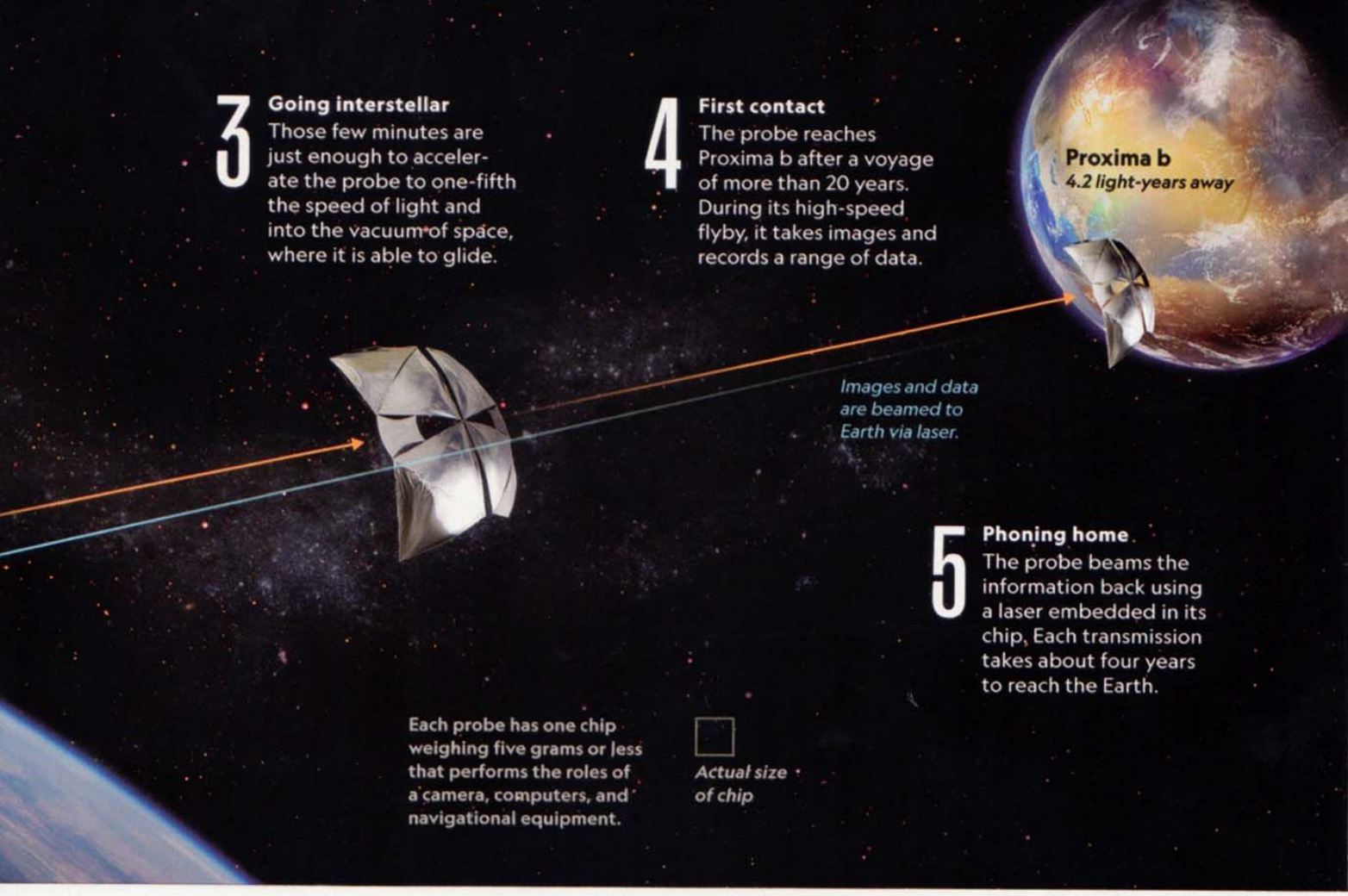
"I was giving a tour the other day to some scientists, and all of a sudden, one of them fainted!" he says, with a mixture of surprise and regret. "I should have known she was not doing well. She had gotten very quiet." I clutch the railings and make sure to keep asking questions.

Ground telescopes like the Subaru are much more powerful light-gatherers than space telescopes like the Hubble, chiefly because nobody has yet figured out how to squeeze a 27-foot mirror into a rocket and blast it into space. But ground telescopes have a serious drawback: They sit under miles of our atmosphere. Fluctuations in the air's temperature cause light to bend erratically—think of a twinkling star, or the wavy air above an asphalt road in the summertime.

The first task of the SCExAO is to iron out those wrinkles. This is accomplished by directing the light from a star onto a shape-shifting mirror, smaller than a quarter, activated by 2,000 tiny motors. Using information from a camera, the motors deform the mirror 3,000 times a second to precisely counter the atmospheric aberrations, and *voilà,* a beam of starlight can be viewed that is as close as possible to what it was before our atmosphere messed it up. Next comes the squinting part. To Guyon, a star's luminosity is "a boiling blob of light that we're trying to get rid of." His instrument includes an intricate system of apertures, mirrors, and masks called a coronagraph, which allows only the light reflected off the planet to slip through.

There's a great deal more to the apparatus; staring at a schematic of the device is enough to cause vertigo, even at sea level. But the eventual result, once the next-gen telescopes are built, will be a visible dot of light that is actually a rocky planet. Shunt this image to a spectrometer, a device that can parse light into its wavelengths, and you can start dusting it for those fingerprints of life, called biosignatures.

There's one biosignature that Seager, Guyon, and just about everyone else agree would be as near a slam dunk for life as scientific caution allows. We already have a planet to prove it. On Earth, plants and certain bacteria produce oxygen as a by-product of photosynthesis. Oxygen is a flagrantly promiscuous molecule—it'll react and bond with just about everything on a planet's surface. So if we can find evidence of it accumulating



in an atmosphere, it will raise some eyebrows. Even more telling would be a biosignature composed of oxygen and other compounds related to life on Earth. Most convincing of all would be to find oxygen along with methane, because those two gases from living organisms destroy each other. Finding them both would mean there must be constant replenishment.

It would be grossly geocentric, however, to limit the search for extraterrestrial life to oxygen and methane. Life could take forms other than photosynthesizing plants, and indeed even here on Earth, anaerobic life existed for billions of years before oxygen began to accumulate in the atmosphere. As long as some basic requirements are met—energy, nutrients, and a liquid medium—life could evolve in ways that would produce any number of different gases. The key is finding gases in excess of what should be there.

There are other sorts of biosignatures we can look for too. The chlorophyll in vegetation reflects near-infrared light—the so-called red edge, invisible to human eyes but easily observable with infrared telescopes. Find it in a planet's biosignature, and you may well have found an extraterrestrial forest. But the vegetation on other planets might absorb different wavelengths of light—there could be planets with Black Forests that are truly black, or planets where roses are red, and so is everything else.

And why stick to plants? Lisa Kaltenegger, who directs the Carl Sagan Institute at Cornell University, and her colleagues have published the spectral characteristics of 137 microorganisms, including ones in extreme Earth environments that, on another planet, might be the norm. It's no wonder the next generation of telescopes is so eagerly anticipated.

"For the first time, we'll be able to collect enough light," says Kaltenegger. "We'll be able to figure things out."

The first and most powerful of the next-gen ground telescopes, the European Southern Observatory's eponymous Extremely Large Telescope (ELT) in the Atacama Desert of Chile, is scheduled to start operation in 2024. The light-gathering capacity of its 39-meter (128 feet) mirror will exceed all existing Subaru-size telescopes combined. Outfitted with a souped-up version of Guyon's instrument, the ELT will be fully capable of imaging rocky planets in the habitable zone of red dwarf stars, the most common

SOURCES: ZAC MANCHESTER, STANFORD UNIVERSITY; BREAKTHROUGH INITIATIVES

SKYJACK
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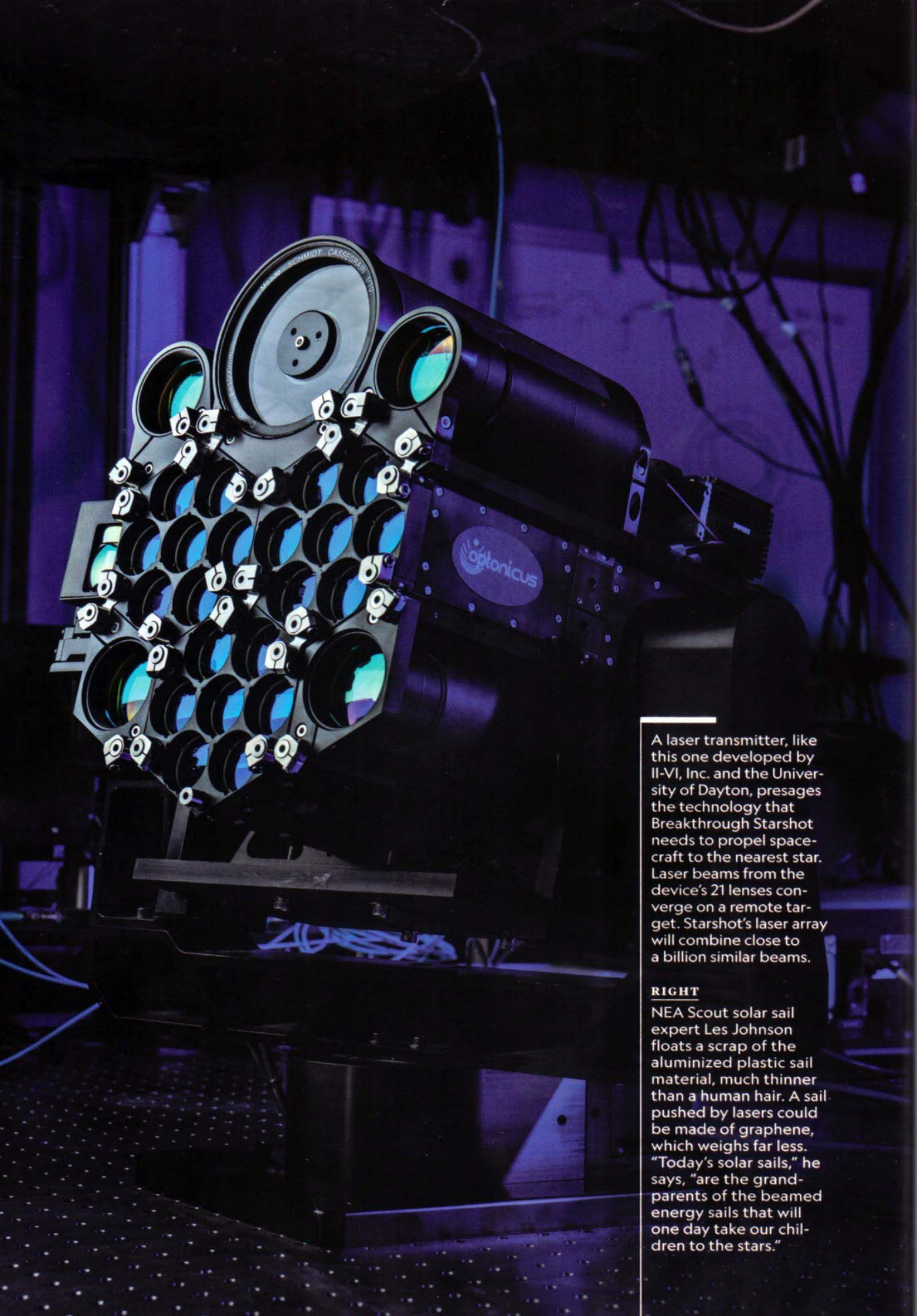
SKYJACK

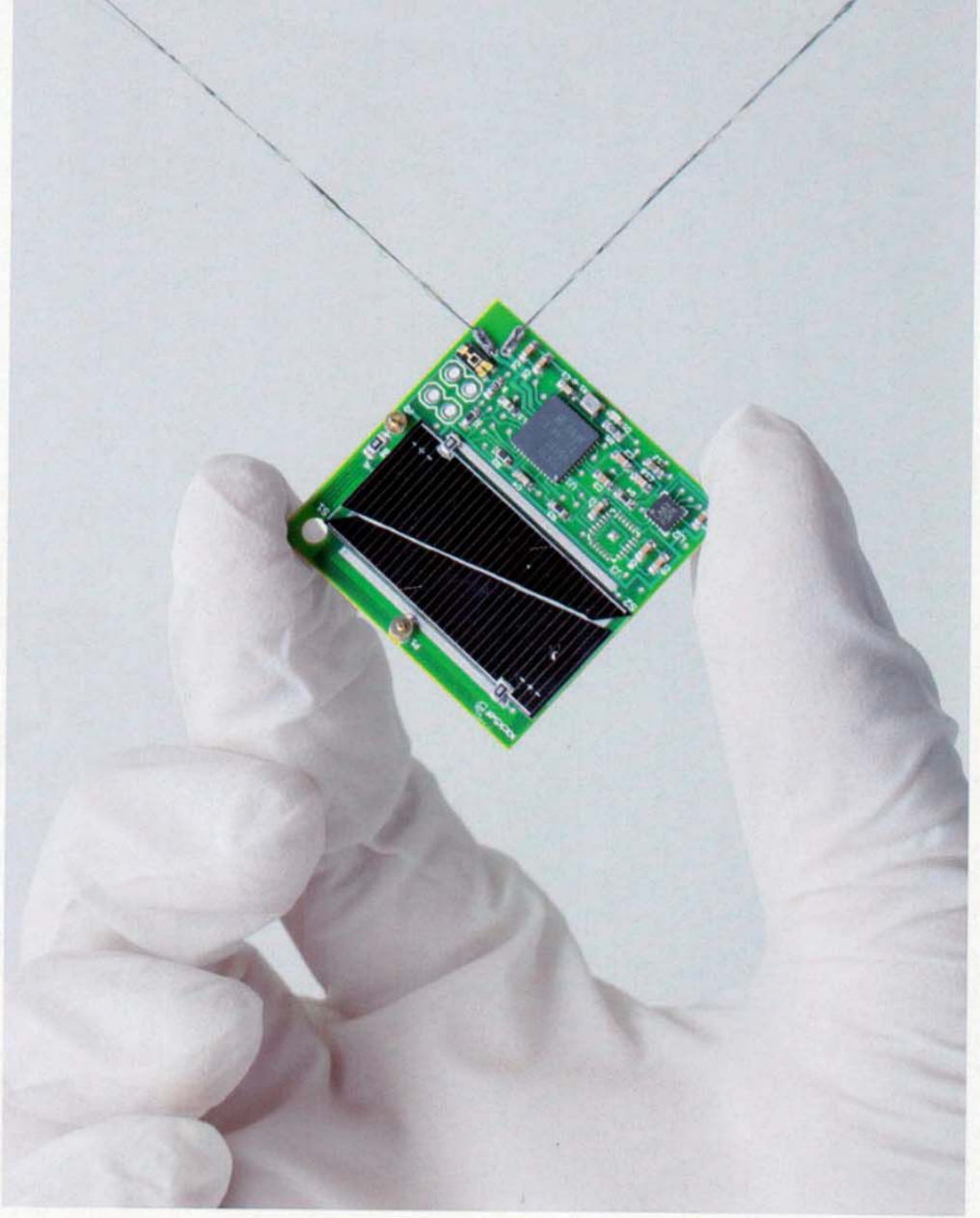
The partially furled solar sail for NASA's Near-Earth Asteroid (NEA) Scout gets a final check before a deployment test at a facility in Huntsville, Alabama. Much as conventional sails catch the wind, solar sails are propelled by pressure from sunlight, minimizing the need for fuel.



A laser transmitter, like this one developed by II-VI, Inc. and the University of Dayton, presages the technology that Breakthrough Starshot needs to propel spacecraft to the nearest star. Laser beams from the device's 21 lenses converge on a remote target. Starshot's laser array will combine close to a billion similar beams.

RIGHT

NEA Scout solar sail expert Les Johnson floats a scrap of the aluminized plastic sail material, much thinner than a human hair. A sail pushed by lasers could be made of graphene, which weighs far less. "Today's solar sails," he says, "are the grandparents of the beamed energy sails that will one day take our children to the stars."



Not much bigger than a postage stamp, a Sprite spacecraft developed at NASA Ames in Mountain View, California, shows that one day it may be possible for the Breakthrough Starshot craft to carry sensors to probe for life in the nearest star system.

stars in the galaxy. They are smaller and dimmer than our sun, a yellow dwarf, so their habitable zones are closer to the star. The nearer a planet is to its star, the more light it reflects.

Alas, the habitable zone of a red dwarf star is not the coziest place in the galaxy. Red dwarfs are highly energetic, frequently hurtling flares out into space as they progress through what Seager calls a period of "very long, bad, teenage behavior." There might be ways an atmosphere could evolve that would protect nascent life from being fried by these solar tantrums. But planets around red dwarfs are also likely to be "tidally locked"—always presenting one side to the star, in the same way our moon shows only one face to the Earth. This would render half the planet too hot for life, the other half too cold. The midline, though, might be temperate enough for life.

As it happens, there's a rocky planet, called Proxima Centauri b, orbiting in the habitable zone of Proxima Centauri, a red dwarf that's the nearest star to our own, about 4.2 light-years, or 25 trillion miles, away. "It's a terribly exciting target," Guyon says. But he agrees with Seager that the best chance of finding life will be on an Earth-like planet orbiting a sunlike star. The ELT and its ilk will be fantastic at gathering light, but even those behemoth ground telescopes won't be able to separate the light of a planet from that of a star 10 billion times brighter.

That's going to take a little more time and even more exotic—one might even say dreamlike—technology. Remember that flower petal–shaped panel on Seager's wall? It's a piece of a space instrument called Starshade. Its design consists of 28 panels arranged around a center hub like a giant sunflower, more than 100 feet across. The petals are precisely shaped and rippled to deflect

the light from a star, leaving a super-dark shadow trailing behind. If a telescope is positioned far back in that tunnel of darkness, it will be able to capture the glimmer from an Earth-like planet visible just beyond the Starshade's edge.

Starshade's earliest likely partner is called the Wide Field Infrared Survey Telescope (WFIRST), scheduled to be finished by the mid-2020s. The two spacecraft will work together in a sort of celestial *pas de deux:* Starshade will amble into position to block the light from a star so WFIRST can detect any planets around it and potentially sample their spectra for signs of life. Then, while WFIRST busies itself with other tasks, Starshade will fly off into position to block the light of the next star on its list of targets. Though the dancers will be tens of thousands of miles apart, they must be aligned to within a single meter for the choreography to work.

Starshade, under development at NASA's Jet Propulsion Laboratory in Pasadena, California, is still a decade or so away, and indeed there's no guarantee that it will be funded. Seager, who hopes to lead the project, is confident. One can only hope. There's something uniquely uplifting about the prospect of a giant flower in space unfurling its petals to parry the light from a distant sun to see if its orbiting worlds are alive.

WHEN JON RICHARDS answered an ad in 2008 on Craigslist for a software programmer, he couldn't have imagined he would spend much of the next 10 years in a remote valley in Northern California, looking for aliens. The search for extraterrestrial intelligence, or SETI, refers to both a research endeavor and a nonprofit organization, the SETI Institute, which employs Richards to run the Allen Telescope Array (ATA), a 340-mile drive from the institute's headquarters in Silicon Valley. The ATA is the only facility on the planet built expressly for detecting signals from alien civilizations. Funded largely by the late Microsoft co-founder Paul Allen, it was envisioned as an assembly of 350 radio telescopes, with dishes six meters (20 feet) in diameter. But owing to funding difficulties—a regrettable leitmotif in SETI history—only 42 have been built. At one time seven scientists helped run the ATA, but due to attrition, Richards is "the last man standing," as he gamely puts it.

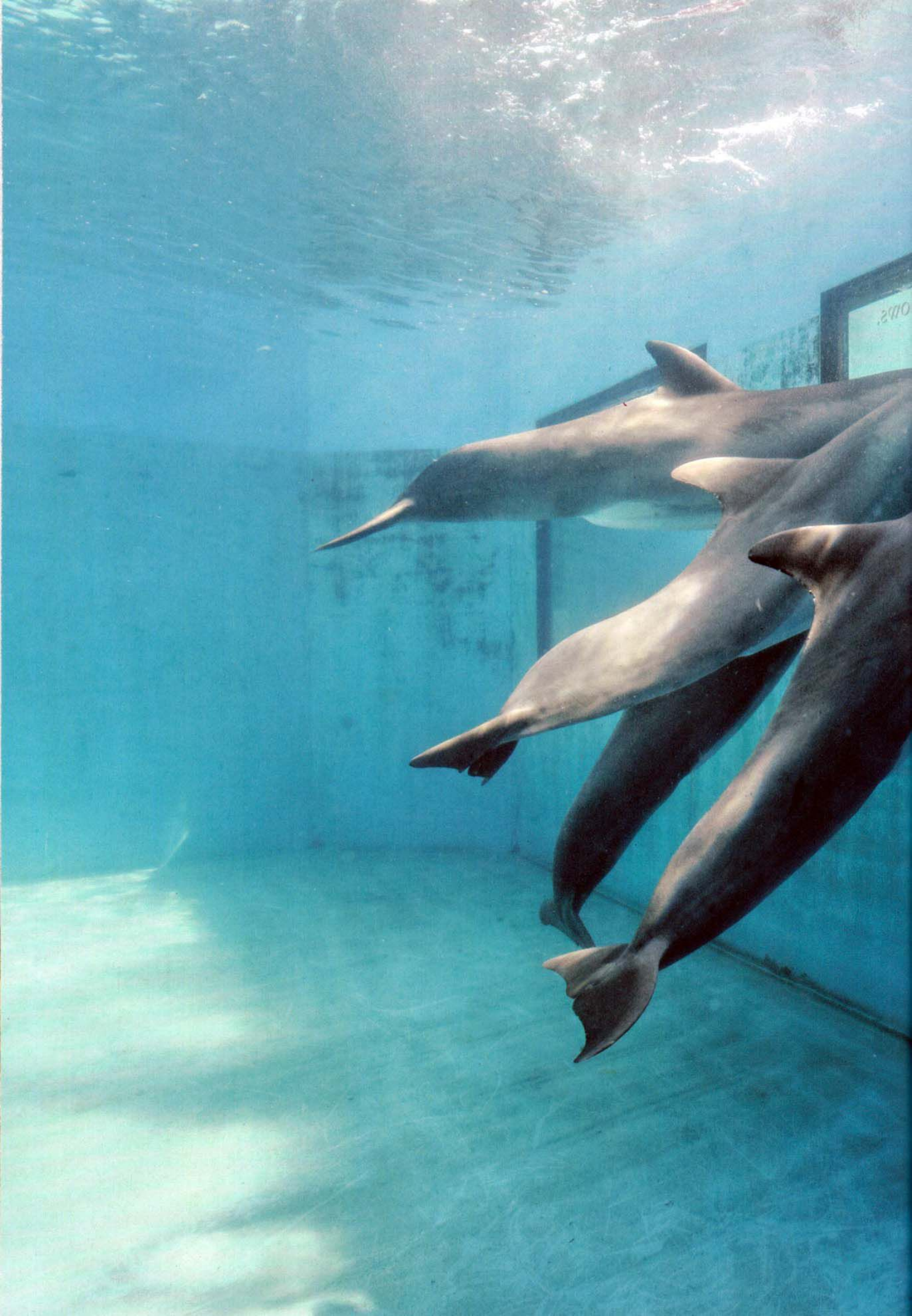
I've come to see Richards on a hot day in August, soon after a rash of wildfires in the area. Smoke veils the view of the surrounding mountains, and in the haze the dishes seem primordially still, like Easter Island statues, each one staring implacably at the same spot in a featureless sky. Richards takes me to one of the dishes, opening the bay doors beneath it to reveal its newly installed antenna feed: a crenellated taper of shiny copper housed in a thick glass cone. "Looks kinda like a death ray," he says.

Richards's job is to manage the hardware and software, including algorithms developed to sift through the several hundred thousand radio signals streaming into the telescopes every night, in search of a "signal of interest." Radio frequencies have been the favored hunting ground of SETI since the search for alien transmissions began 60 years ago, largely because they travel most efficiently through space. SETI scientists have focused in particular on a quiet zone in the radio spectrum, free of background noise from the galaxy. It made sense to search in this relatively undisturbed range of frequencies, since that would be where sensible aliens would be most likely to transmit.

Richards tells me that the ATA is working through a target list of 20,000 red dwarfs. In the evening, he makes sure everything is working properly, and while he sleeps, the dishes point, the antennas rouse, photons scuttle through fiber optic cables, and the radio music of the cosmos streams to enormous processors. If a signal passes tests that suggest it stems from neither a natural source nor some quotidian terrestrial one—a satellite, a plane, somebody's key fob—the computer kicks out an email alert. This being an email he wouldn't want to miss, Richards has set up his cell service to forward the message to his phone. Conceivably, then, our first contact from an alien civilization could come as a text rattling Richards's phone on his night table.

So far, however, all the signals of interest have been false alarms. Unlike other experiments, where progress can be made incrementally, SETI is binary: Either extraterrestrials make contact on your watch, or they don't. Even if they're out there, the chances that you're looking in just the right place at just the right time and at just the right radio frequency are remote. Jill Tarter, the retired head of research at SETI, likens the search to dipping a cup in the ocean: The chance you'll find a fish is exceedingly small, but that doesn't mean the ocean isn't full of fish. Unfortunately,

Research scientist Jon Richards checks on a unit of the SETI Institute's Allen Telescope Array in the Cascade Mountains in Northern California. For 60 years radio telescopes like these have been the primary tools in the search for extraterrestrial intelligence.



Laurance Doyle of Principia College and the SETI Institute communes with some "extraterrestrial" intelligence at Six Flags Discovery Kingdom in Vallejo, California. Doyle's studies of the communication systems of dolphins and whales could help scientists decode patterns in alien languages.

NEXT PHOTO

SETI Institute scientists, funded by NASA, gather data in the Chilean desert that will inform the search for life on Mars. Domes dotting the seemingly lifeless landscape host microbes that thrive in the harsh climate. "It is full of life, absolutely everywhere," says team leader Nathalie Cabrol.

Congress long ago lost interest in dipping the cup, abruptly terminating support in 1993.

THE GOOD NEWS is that SETI the research endeavor, if not SETI the institute, has recently received a remarkable boost in funding, sending ripples of excitement through the field. In 2015 Yuri Milner, a Russian-born venture capitalist, established the Breakthrough Initiatives, committing at least $200 million to look for life in the universe, including $100 million specifically to search for alien civilizations. Milner was an early investor in Facebook, Twitter, and many other internet companies you wish you'd been an early investor in. Before that, he founded a highly successful internet company in Russia. His philanthropic vision might be summed up as, if we agree that finding evidence for alien intelligence is worth $100 million, why shouldn't it be his $100 million? "If you look at it that way, it makes sense," he says, when I meet him in a glitzy watering hole in Silicon Valley. "If it was a billion a year—we should talk."

WHAT WE SHOULD BE LOOKING FOR IS NOT A MESSAGE FROM ET, BUT SIGNS OF ET JUST GOING ABOUT THE BUSINESS OF BEING ET, ALIEN AND INTELLIGENT IN WAYS THAT WE MAY BE ABLE TO PERCEIVE.

Milner is soft-spoken and unobtrusive; I hadn't noticed him arrive until he was standing right next to my chair. He tells me about his background—a degree in physics, a lifelong passion for astronomy, and parents who named him after the cosmonaut Yuri Gagarin, who became the first human in outer space seven months before Milner was born. That was in 1961, which he points out is the same year SETI began. "Everything is interrelated," he says.

Through one of his initiatives, Breakthrough Listen, he intends to spend $100 million over 10 years, most of it through the SETI Research Center at UC Berkeley. Another project, Breakthrough Watch, is underwriting new technology to search for biosignatures with the European Southern Observatory's Very Large Telescope in Chile.

Most far out of all—in both senses—is Milner's Breakthrough Starshot, which is investing $100 million to explore the feasibility of actually going to the nearest star system, Alpha Centauri, which includes the rocky planet Proxima b. Appreciating the magnitude of this challenge requires some perspective. The first Voyager spacecraft, launched in 1977, took 35 years to enter interstellar space. Traveling at that speed, Voyager would need some 75,000 years to reach Alpha Centauri. In the current vision for Starshot, a fleet of pebble-size spaceships hurtling through space at one-fifth the speed of light could reach Alpha Centauri in a mere 20 years. Working from a road map originally proposed by physicist Philip Lubin at UC Santa Barbara, these tiny *Niñas, Pintas,* and *Santa Marías* would be propelled by a ground-based laser array, more powerful than a million suns. It may not be possible. But that's the advantage of private money: Unlike a government program, you're allowed—expected—to take a big gamble.

"Let's see in five or 10 years whether it will work," Milner says, with a shrug. "I'm not an enthusiast in the sense I believe for sure any of this will happen. I'm an enthusiast because it makes sense now to try."

The day after meeting with Milner, I went to the Berkeley campus to meet the beneficiaries of his Breakthrough Listen largesse. Andrew Siemion, the director of the Berkeley SETI Research Center, is ideally positioned to take the search for intelligent aliens to a new level. In addition to his Berkeley appointment, he has been named to head up SETI investigations at the SETI Institute itself, including operations at the ATA.

Siemion, 38, looks the part of a next-gen SETI master; he has a shaved head, a compact build, and a thin gold chain discreetly visible above the buttons of his fitted shirt. While careful to credit the decades of research by Tarter and her colleagues at the SETI Institute, he's keen to distinguish where SETI is going from where it has been. The initial search was inspired by the possibility of a connection—reaching out

in hope of finding someone reaching back. SETI 2.0 is trying to determine whether technological civilization is part of the cosmic landscape, like black holes, gravitational waves, or any other astronomical phenomenon.

"We're not looking for a signal," Siemion says. "We're looking for a property of the universe."

Breakthrough Listen is by no means abandoning the conventional search for radio transmissions, he tells me; on the contrary, it's doubling down on it, dedicating to SETI roughly a quarter of the viewing time on two huge single-dish radio telescopes in West Virginia and Australia. Siemion is even more excited about a partnership with the new MeerKAT telescope in South Africa, an array of 64 radio dishes, each more than twice the size of the ATA's. By piggybacking on observations conducted by other scientists, Breakthrough Listen will conduct a 24/7 stakeout of a million stars, dwarfing previous SETI radio searches. Powerful as it is, MeerKAT is just a precursor to radio astronomy's dream machine: the Square Kilometre Array, which sometime in the next decade will link hundreds of dishes in South Africa with thousands of antennas in Australia, creating the collecting area of a single dish more than a square kilometer, or about 247 acres.

There are other SETI approaches Siemion tells me about—Breakthrough Listen partnerships with telescopes in China, Australia, and the Netherlands, and new technologies in development at Berkeley, the SETI Institute, and elsewhere to look for optical and infrared signals. The gist, echoed by other scientists I talk with, is that SETI is undergoing a transformation from cottage industry to global enterprise.

Most important, empowered and inspired by the accelerating rate of technological development in our own civilization, we are coming to see the target of the quest in a different light. For 60 years we've been waiting for ET to phone Earth. But the stark truth is that ET probably has no compelling reason to try to communicate with us, any more than we feel a heartfelt need to extend a greeting to a colony of ants. We may feel technologically mature compared with our past, but compared with what may be out there in the universe, we're still in diapers. Any civilization that we would be able to detect will likely be millions, perhaps billions, of years ahead of us.

"We're like trilobites, looking for more trilobites," says Seth Shostak, a senior astronomer at the SETI Institute.

What we should be looking for is not a message from ET, but signs of ET just going about the business of being ET, alien and intelligent in ways that we may not yet comprehend but may still be able to perceive, by looking for evidence of technology—so-called technosignatures.

The most obvious technosignatures would be ones we've produced, or can imagine producing, ourselves. Avi Loeb of Harvard University, who chairs the Breakthrough Starshot advisory board, has noted that if another civilization were using similar laser propulsion to sail through space, its Starshot-like beacons would be visible to the edge of the universe. Loeb also has suggested looking for the spectral signatures of chlorofluorocarbons soiling the atmosphere of aliens who failed to live past the technological diaper stage.

"Based on our own behavior, there must be many civilizations that killed themselves by harnessing technologies that led to their own destruction," he tells me when I visit him. "If we find them before we destroy our own planet, that would be very informative, something we could learn from."

On a cheerier note, we could learn a great deal more from civilizations that have solved their energy problem. At a NASA conference on technosignatures (yes, after a quarter century, NASA too is getting back into the SETI game), there was talk about looking for the waste heat from megastructures that we have imagined creating in the future. A Dyson sphere—solar arrays surrounding a star and capturing all of its energy—around our own sun would generate enough power in a second to supply our current demand for a million years. Learning that other civilizations have already accomplished such feats might provide us some hope.

Still, space is vast, and so is time. Even with our ever more powerful computers and telescopes, SETI's expanded agenda, and the gravity assist of a hundred Yuri Milners, we may never encounter an alien intelligence. On the other hand, the first intimation of life from a distant planet feels thrillingly close.

"You never know what's going to happen," Seager says. "But I know that something great is around those stars." □

Contributing writer **Jamie Shreeve** bets we'll find hints of extraterrestrial life before 2030. **Spencer Lowell** has constellations tattooed on one arm. **Dana Berry** has imagined unseen scenes in space for *National Geographic* and other publications.