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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HEALTHY HAIR
by HERBAL ESSENCES

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On the Cover
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.

SAREL VAN STADEN AND MARYNA COTTON; PANORAMA COMPOSED OF THREE IMAGES

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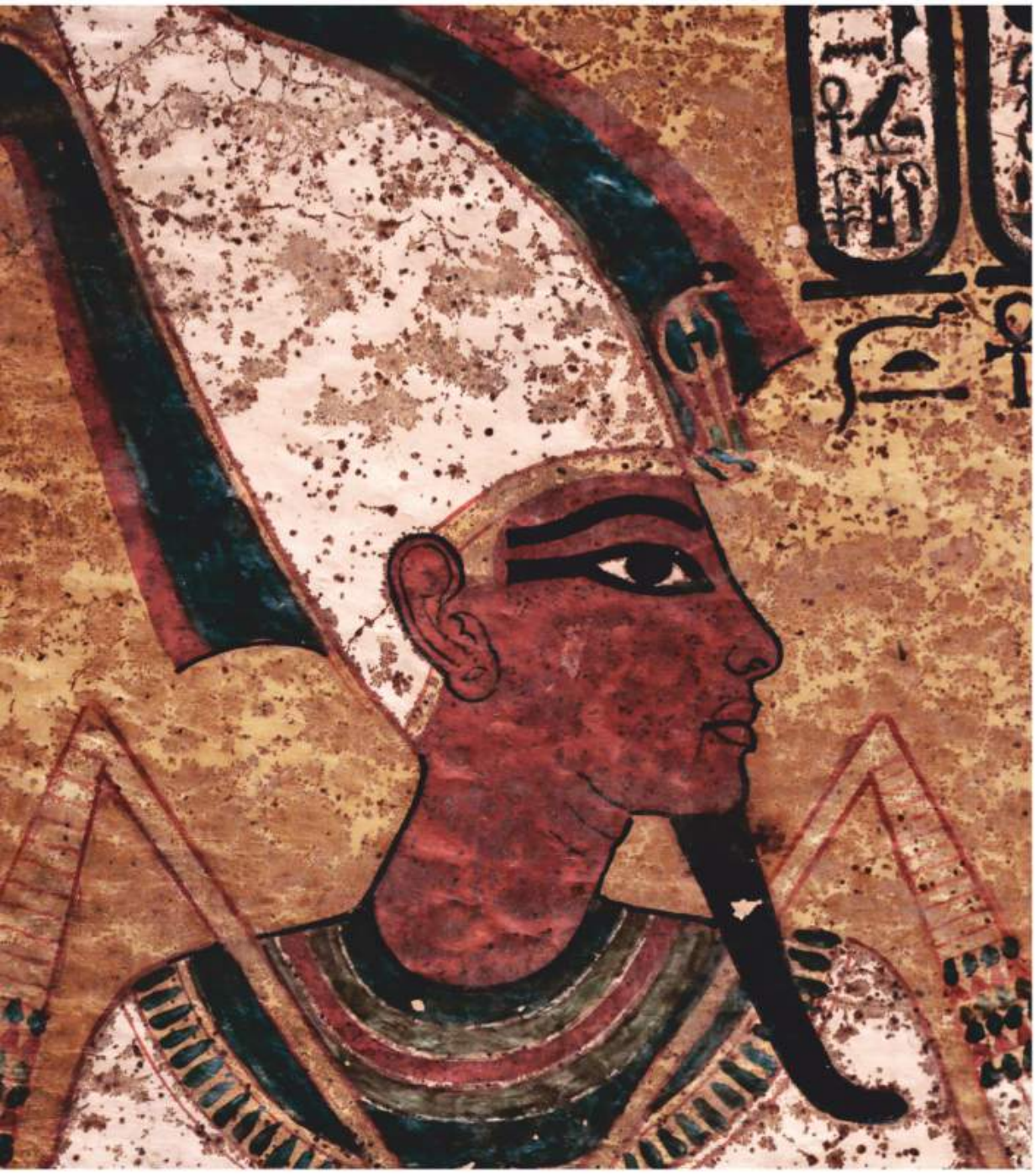

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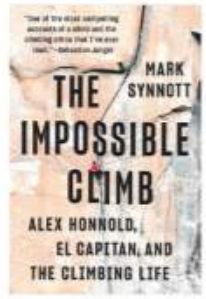

BOOKS

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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PHOTO: WINDFALL FILMS

GOING HIGHER

TO DIG DEEPER

In 2019 NASA Earth Science will launch five new science campaigns to investigate some of Earth's most pressing research questions, such as the cause of intense East Coast snow storms and the impact of ocean currents on global climate. For one of these projects, they're calling on the expertise of the researchers at Texas A&M University.

Texas A&M and Harvard University are teaming up to collect important atmospheric data from a high-altitude NASA aircraft to study the impact of strong storms on the stratosphere. "Dynamics and Chemistry of the Summer Stratosphere" will investigate how storms can carry chemical pollutants into the lower atmospheric layer, potentially affecting the ozone. As storms become stronger and more destructive, this kind of information is invaluable for keeping the earth and its inhabitants safe. It's another way that the Aggies at Texas A&M are

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SALVADORANS

Uncertain Future

BY **SUSAN GOLDBERG** PHOTOGRAPH BY **ADAM FERGUSON**

Cecilia Martínez (seated), a native of El Salvador, lives in the United States under the immigration classification known as temporary protected status. She poses in front of her Long Island, New York, home with her son, Andrew, and her daughter, Gracie, who were born in the United States and are U.S. citizens.

CECILIA MARTÍNEZ WAS 15 in 1998 when she slipped into Arizona from Mexico. She came with no family and arrived to none, striking out on her own, scraping by on babysitting and bagging groceries. It was hard but preferable to her native El Salvador: "I came to work. Everyone said you could make a better life here."

Indeed she has. Three years after she arrived, Martínez received temporary protected status (TPS), an immigration classification given to people from countries where conditions—such as armed conflict or natural disaster—would make returning unsafe. El Salvador qualifies: In 2001 two catastrophic earthquakes struck, and since then escalating warfare among gangs, police, and the military has made the nation one of the world's deadliest outside of war zones.

Martínez is among the 200,000 Salvadorans who currently have TPS, meaning they can legally live and work in the United States. She has a business cleaning homes and construction sites on Long Island, New York. And she has two children, ages 17 and 12, who are U.S. citizens.

Today her life feels as uncertain as when she first arrived. In early 2018 the Trump administration declared that Salvadorans would lose TPS and should leave the country by September 2019. A court temporarily blocked the order, but there's no final decision on Salvadorans' fate, and it's uncertain when one will be made.

To Martínez and many Salvadorans who have long made the United States their home, returning to El Salvador is unthinkable. She has become an activist, journeying to Washington, D.C., to tell lawmakers what will happen to families like hers if TPS is revoked. "When you have been living in the U.S.A. for so many years, they think you are rich, and the gangs come after you," she says. "They ask for 'rent'—that's what they call it. They will go after my son, who is 17. They will hurt us if we don't give them what they ask for." In the coming year "our son planned to go to college," Martínez says. "But now our life has stopped."

We asked writer Jason Motlagh and photographers Moises Saman and Adam Ferguson to document the lives of Salvadorans in their homeland and in the United States. What plagues El Salvador—poverty, violence, lack of opportunity—exists also in Guatemala and Honduras. It explains why so many people are making a treacherous and probably fruitless walk north: They are looking, as Martínez did, to build a life with safety, dignity, and a future.

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NATIONAL GEOGRAPHIC

With water misters and smoke machines, Dutch artist

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

Berndnaut Smilde creates clouds to photograph in odd places—here, in China's Shanghai Himalayas Museum—using smoke and mist machines. (He retouches the images so the tools aren't seen.)

PHOTO: NINA CHEN

CONJURING CLOUDS

Berndnaut Smilde creates the vaporous puffs—and poses them.

VOL. 235 NO. 3

The artist's creations in gallery spaces include a sky-grazing cloud at the De Groen Fine Art Collection in Arnhem, the Netherlands (top), and a low-hanging cloud in the Visual arts center in Carlow, Ireland.

PHOTOS, FROM TOP: CASSANDER EEFTINCK SCHATTENKERK; MICHAEL HOLLY

Smilde's settings range from the ornate—the Green Room in the San Francisco War Memorial & Performing Arts Center (top)—to the spare: the Hotel Maria Kapel exhibition space in Hoorn, the Netherlands.

PHOTOS, FROM TOP: R.J. MUNA; CASSANDER EEFTINCK SCHATTENKERK

In Cologne, Germany, a cloud hovers in the Sankt Peter Köln, a late Gothic church that's also used as a center for spirituality, art, and music.

PHOTO: CASSANDER EEFTINCK SCHATTENKERK

THE BACKSTORY

CLOUDS ARE AN ORDINARY SIGHT. BUT THIS ARTIST MAKES HIS OWN—SPARKING APPRECIATION OF THEIR FLEETING BEAUTY.

BERNDNAUT SMILDE CREATES fluffy clouds in locations where nature never would place them. The Dutch artist's sculptures last five seconds—10 seconds tops—before they disappear.

Smilde's ongoing project, called "Nimbus," explores the visual effects of clouds. A church or museum interior looks different behind a cloud, and an everyday cloud is peculiar in a castle or a canyon. Each scene is made more intense by lasting only moments.

The ingredients for Smilde's clouds: just smoke and water vapor. He requires a cold and damp space with no air circulation, lest the clouds never form or fall straight to the ground. He mists an area with a spray bottle to put water vapor into the air. Then he turns on fog machines that spout tiny particles, and the vapor condenses around them.

Smilde runs around the forming cloud, coaxing it into a shape about 10 feet across and six feet tall. Then he steps back long enough for a photographer to snap several images. Once the air clears, he'll start over, repeating the process dozens of times until he's happy with the results. Later, he'll retouch the photos to remove his tools.

The artist regularly fields invitations to create clouds on command, like a tropospheric party trick. Often he declines. He says he only attempts new images when the setting offers him something fresh as an artist. To him, the crucial takeaway is not the wonder of a fabricated cloud but its transience—that it exists for a moment and then is gone forever.

Each creation is "about being at the right place at the right time," Smilde says. "If you're seeing a photo, you already missed it." **—DANIEL STONE**

Photographer Cassander Eeftinck Schattenkerk captures an image of a cloud that Smilde created in the Baths of Diocletian, part of the National Roman Museum.

PHOTO: ANNEGRET KELLNER

THE DISCOVERIES OF TODAY THAT WILL DEFINE THE WORLD OF TOMORROW

NATIONAL GEOGRAPHIC | VOL. 235 NO. 3

A Wake-Up Call on Water Quality

ONE-FOURTH OF AMERICANS DRINK WATER FROM SYSTEMS THAT DON'T MEET SAFETY LAWS. ALL OF US, TOGETHER, CAN CHANGE THAT.

BY **RHEA SUH**

WHEN MY YOUNG DAUGHTER says she's thirsty, I take for granted that the water from our kitchen tap is clean and safe. In fact, that's what most Americans assume. But should we?

As we mark World Water Day on March 22, the disturbing truth is that roughly a quarter of Americans drink from water systems that violate the Safe Drinking Water Act. Violations range from failing to properly test water to allowing dangerous levels of lead or arsenic—and occur everywhere: in rural communities and big cities, in red states and blue ones.

The lead contamination crisis in Flint, Michigan, was extreme—and shocking because of the role that race played. However, it was not an isolated case, and we need to consider it a national wake-up call.

Across the country, water systems are old, badly maintained, and in dire need of modernizing—from lead service lines in Milwaukee, Wisconsin, and Newark, New Jersey, to silt and debris in drinking

EVERYONE HAS A RIGHT TO CLEAN WATER, NO MATTER WHAT YOU LOOK LIKE, HOW MUCH MONEY YOU MAKE, OR WHICH POLITICAL PARTY YOU FAVOR. IN AMERICA, THAT RIGHT IS ENSHRINED IN LAW.

water after heavy rain in Austin, Texas, to fecal contamination in Penn Township, Pennsylvania. Worse, some are managed by dysfunctional agencies where incompetence and socioeconomic and racial bias may determine whether a community is made sick by its drinking water. The reality is that we can no longer assume that our water is safe to drink.

How unsafe is it? Depending on the source of contamination and the exposure, health effects include neurological problems and developmental disabilities in children (lead), interference with hormones (perchlorates), and increased risk of cancers of the skin, bladder, and kidney (arsenic). The Environmental Protection Agency regulates more than 90 contaminants—but a hundred more that are tracked are so far unregulated.

EVERYONE HAS A RIGHT to clean water, no matter what you look like, how much money you make, or which political party you favor. In America, that right is enshrined in the Clean Water Act of 1972, which defines how the EPA regulates pollutants in U.S. waters, and the Safe Drinking Water Act of 1974, which establishes maximum amounts of pollutants in all public water systems. Those federal laws were passed at the peak of environmental degradation in our country—a time when smog choked our cities and rivers were so contaminated they regularly caught fire.

Those laws and many other regulations at state and city levels have made great progress toward reducing pollution and addressing public health. Some of us now don't worry about the toxicity of the air for our children's afternoon soccer games or the flammability of the local river, primarily because our environmental protections have worked. But in far too many places around the country, those basic laws are not being upheld or enforced, and people are suffering the consequences.

Look at Puerto Rico. The water situation there was unacceptable—the worst in the nation—even before Hurricane Maria in 2017. An analysis by my organization, the Natural Resources Defense Council (NRDC), showed that almost all of Puerto Rico's residents in 2015 got their water from systems that violated the Safe Drinking Water Act and nearly 70 percent of them got their tap water from sources contaminated with coliform bacteria, disinfection by-products, and more.

PFAS: Chemicals Most of Us Carry

What are perfluoroalkyl substances? Generally known as PFAS, they're a class of human-made chemicals found in everything from nonstick pans to raincoats and firefighting foam. They're also known to harm human health.

Two of these chemicals, PFOS and PFOA, are present at unsafe levels in the drinking water of six million Americans and found in the bodies of 98 percent of Americans. They enter water supplies when manufacturers dispose of PFAS or, in the case of firefighting foam, when used at places such as airports and naval bases.

The world around us is full of PFOS and PFOA. They don't break down in the environment or degrade easily when they enter the human body. Even at low levels, PFAS are linked to a range of serious illnesses, including cancer of the kidneys and testicles, thyroid and liver disease, lower fertility in women, and birth defects.

Ask your local representatives what they're doing about PFAS and safe drinking water. **–RS**

ILLUSTRATION: DADU SHIN

Maria created a full-blown humanitarian crisis. People had no choice but to get their drinking water from toxic sources, and scores ended up in emergency rooms with gastrointestinal illnesses. Even now, more than a year after the storm, Puerto Ricans are still warned to boil water before drinking it.

As climate change increases the intensity and duration of hurricane season, Puerto Rico will likely find itself in even more dire circumstances. That means we need to invest significant resources now in the island's water and power infrastructure, which remains fragile at best.

So far, U.S. leaders have approved only a small fraction of what Puerto Rico needs to protect itself. By shortchanging this American island, we are condemning it to more climate-related destruction and an ongoing water crisis. And many other vulnerable communities are in the same fix.

ACROSS AMERICA, the first step in securing clean drinking water is better information. In 2016, New York became the first state in the country to require school districts to test drinking water sources for lead, something the Safe Drinking Water Act fails to do.

NRDC looked at the data on drinking water from New York State's public schools. Our analysis showed that 82 percent of public schools in New York had one or more taps that exceeded the state's lead action level—and as you might expect, the problem was worse in lower-income schools.

New York already is one of 10 states (along with the District of Columbia) that require universal blood tests for lead before age three. Now, newly armed with data on lead sources, the state has an opportunity to protect the 2.7 million children in public schools (including my daughter) and to become an example for other states.

Lead makes headlines, but it's not the half of it. The more we look for pollution, the more we'll find, and the list of contaminants is long: Coliform bacteria near dairy farms in Wisconsin. Nitrates from fertilizers in Iowa's rivers. Lead, mercury, and uranium in fracking fluid in places like Ohio, Oklahoma, Pennsylvania, and North Dakota. Toxic chemicals such as those in Teflon that are so ubiquitous they're found in the blood of 98 percent of people in the United States and nearly every country in the world. (For more on this topic, see "PFAS: Chemicals Most of Us Carry" on the previous page, and visit *thedevilweknow.com*.)

LEAD MAKES HEADLINES, BUT IT'S NOT THE HALF OF IT. THE MORE WE LOOK FOR POLLUTION, THE MORE WE'LL FIND, AND THE LIST OF CONTAMINANTS IS LONG.

The problem may feel overwhelming, but together we can solve it. We need to start with the basics, like replacing lead pipes and fixing deteriorating mains. Then we can modernize our aging water infrastructure with more filtration or treatment processes to better purify wastewater before it enters the drinking water system. We need to better regulate pollutants, strengthen protections for drinking water, and improve testing. A bonus: We can do all of these things *and* create good-paying new jobs in communities throughout the country.

IT ALL BEGINS BY insisting that clean water not be treated as a partisan issue. No matter how you voted in the past two elections, you didn't vote for contaminated drinking water. So, together we need to hold government officials to account at all levels. We can start with leaders in Washington who, in my estimation, are trying to shrink government's role in protecting public health.

In 1970 millions of Americans rose up and demanded stronger environmental and public health protections—and won them. Nearly 50 years later we need to rise up again.

This is where you come in. You can join the many people taking to the streets to march for a clean environment. You can read up on water issues in your community, then attend town hall or water department hearings. You can call your representatives and tell them that water quality matters to you and your family. Your voice is exactly what's required now to defend and make real our right to clean water. □

Rhea Suh is president of the Natural Resources Defense Council, an environmental action organization with some two million members. Before joining NRDC in 2015, she was an assistant secretary at the U.S. Department of the Interior, where she led initiatives on land conservation, climate change, and other environmental issues.

2.1 billion

people worldwide lack access to safe drinking water systems, according to the United Nations organization UN-Water.

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MANY PEOPLE, SCARCE WATER

STORY AND PHOTOGRAPH
BY **PAUL SALOPEK**

NORTHERN INDIA embraces a sprawling network of waters, from the muddy tributaries of the Indus in the west to the banks of the sacred Ganges coiling along its central plains and the miles-wide currents of the Brahmaputra in the east. Creeks, canals, wetlands, dams, and swollen torrents help irrigate the most populous democracy on Earth. Yet this river-etched heartland is the scene of one of the most dire water crises today.

Last year, a government study revealed that nearly half India's population—some 600 million people—ekes by on scarce or polluted supplies of water. As many as 200,000 Indians die annually from the effects of water contamination. And it's been projected that more than 20 major cities—Delhi, Bangalore, and Hyderabad among them—will zero out their groundwater stores in less than two years.

I witnessed this slow-motion environmental calamity while walking

The Out of Eden Walk

In 2013 Paul Salopek began what he calls "an experiment in slow journalism," a 21,000-mile storytelling walk along the pathways of the humans who first explored Earth in the Stone Age. As he travels, he's covering the major stories of our time by giving voice to the people who inhabit them every day. Look for the account of his foot traverse across water-stressed northern India in an upcoming issue of *National Geographic*, and follow his odyssey online at *outofedenwalk.org*.

hundreds of miles across rural landscapes visited by few outsiders. In the state of Madhya Pradesh, for example, I met a 12-year-old shepherd, Shailendra (above), watering his goats on the Chambal, one of several rivers the government hopes to "interlink" with other waterways in a drastic water redistribution plan.

In the lush Punjab, the pumps and pesticides of the green revolution have depleted precious reserves of groundwater and spawned hot spots of infertility and cancer. In the states of Rajasthan and Madhya Pradesh, villagers complained that fluoride—a mineral tainting new wells drilled for growing human populations—was discoloring their teeth and causing bone deformities.

"It's hard not to feel overwhelmed," said Arati Kumar-Rao, a renowned Indian nature photographer and one of my walking partners. "Our denial is a form of mass blindness."

NGM MAPS

CLEAR AND STRONG

Glasswing butterflies are called *espejitos*—little mirrors—in their native South America. Wings that are transparent (because they have no colored scales) give them both camouflage and a delicate look. But that's deceiving: Some glasswings can carry nearly 40 times their own weight.
–PATRICIA EDMONDS

PHOTO: MICHAEL AND PATRICIA FOGDEN, MINDEN PICTURES

HOW CAN WE MAKE OUR BODIES BETTER?

As you sit down to breakfast, your cereal declares itself "fortified with vitamins and iron," your milk is "rich in calcium," and your orange juice is "packed with vitamin C." Such labeling is the result of a century of worry that we are not getting the vitamins and minerals we need—and as many as 90 percent of Americans are not. Unchecked, these deficiencies can be dangerous.

Vitamins and minerals facilitate vital functions in our bodies. For example, B vitamins help convert nutrients into energy, while minerals support functions ranging from muscle contraction to maintaining blood pressure. Although

vitamin D can be synthesized from sunlight, almost all our vitamins and minerals come exclusively from what we eat. And that can be a problem.

At the start of the 20th century, scientists suggested cleansing foods to rid them of impurities. Though well-intentioned, processing grain removed essential B vitamins while sterilizing milk destroyed vitamin C. People got worse, not better. As the early 1900s progressed and revealed the existence and role of vitamins and minerals, supplements quickly became a popular way to compensate for a poor diet. The United States first issued nutrient intake recommendations to the public in 1941, and later introduced the Recommended Daily Allowance (RDA), also known as the Recommended Dietary Allowance. Today, we know that a balanced diet will usually provide all the vitamins and minerals we need.

DEFICIENCIES CONTINUE, HOWEVER, BECAUSE FOR MANY REASONS PEOPLE ACROSS THE DEVELOPED AND DEVELOPING WORLD ARE UNABLE TO ACCESS THE RIGHT QUANTITY, QUALITY, AND VARIETY OF FOODS.

Similarly, modern life sees us spend less time outdoors in the sun, making it difficult to get enough vitamin D. This is where the judicious use of supplements can help.

Most deficiencies can be remedied simply by bringing our intake of vitamins and minerals up to their RDA, and one easy way to do this is through taking supplements. As the global population grows and it becomes even harder to ensure that everyone has the foods they need, supplements could play a crucial role in maintaining world health. So long as supplements remain a supplement and not a substitute for the goal of a healthy, balanced diet, they can be a welcome addition to the breakfast table.

DISPATCHES
FROM THE FRONT LINES
OF SCIENCE
AND INNOVATION

Roaches Kick Away Zombie Stings

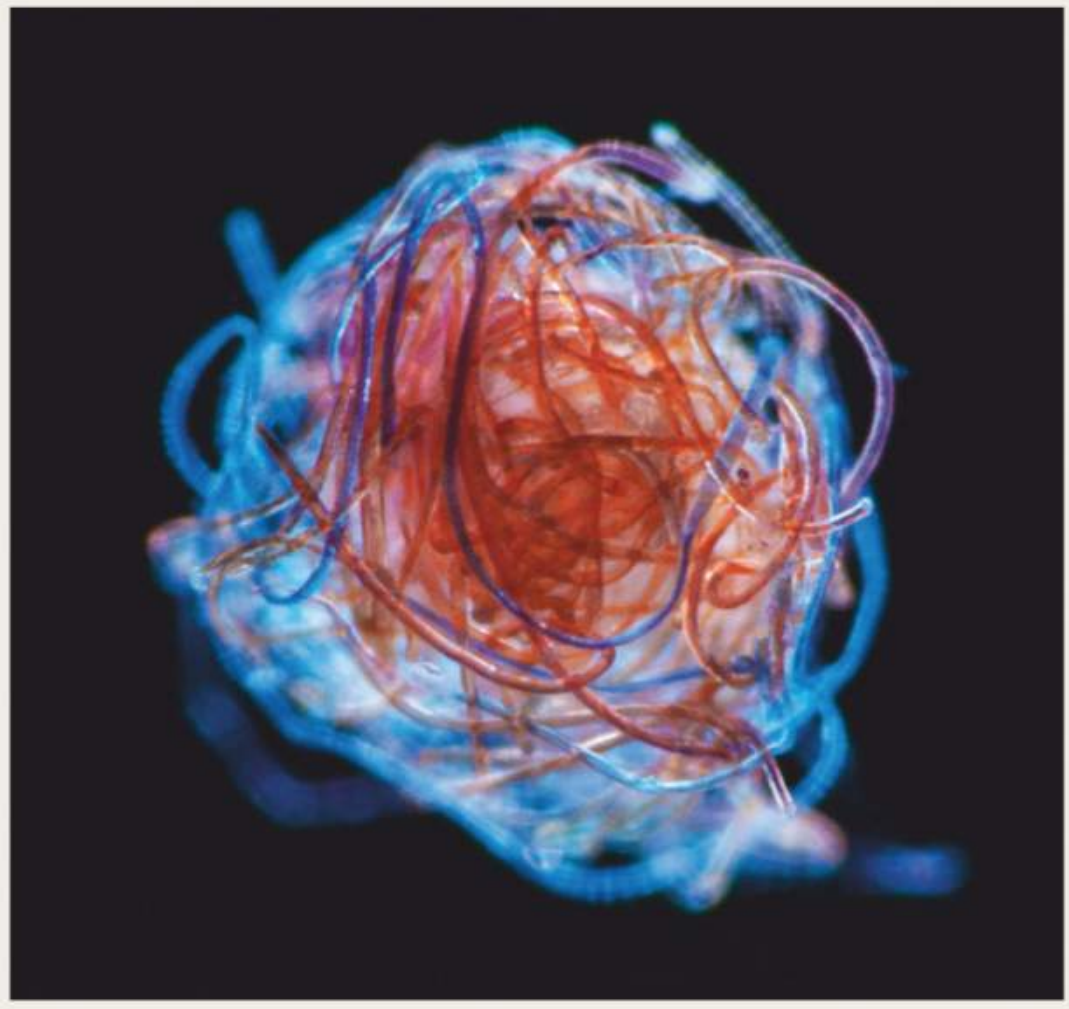
"How Not to Be Turned Into a Zombie"—that's what biologist Kenneth Catania titled his report on the parasitism of American cockroaches by emerald jewel wasps. If stung in the brain, the roach will follow the wasp into a hole where the wasp lays an egg, then seals the hole, leaving the roach to be food for the larva. But in Catania's study, roaches that vigorously kicked and parried with their legs evaded the stings 63 percent of the time.

GENETICS

How Poppies Got Power

Humans have long derived morphine and codeine from opium poppies. But how did the flowers evolve to have pain-killing powers? Messily. The poppy's DNA shows that over more than 110 million years, most of its genome duplicated twice and two extra genes fused into one that's crucial for narcotic formation. The find may contribute to advances in opiates, which remain vital despite their addictiveness.

—MICHAEL GRESHKO



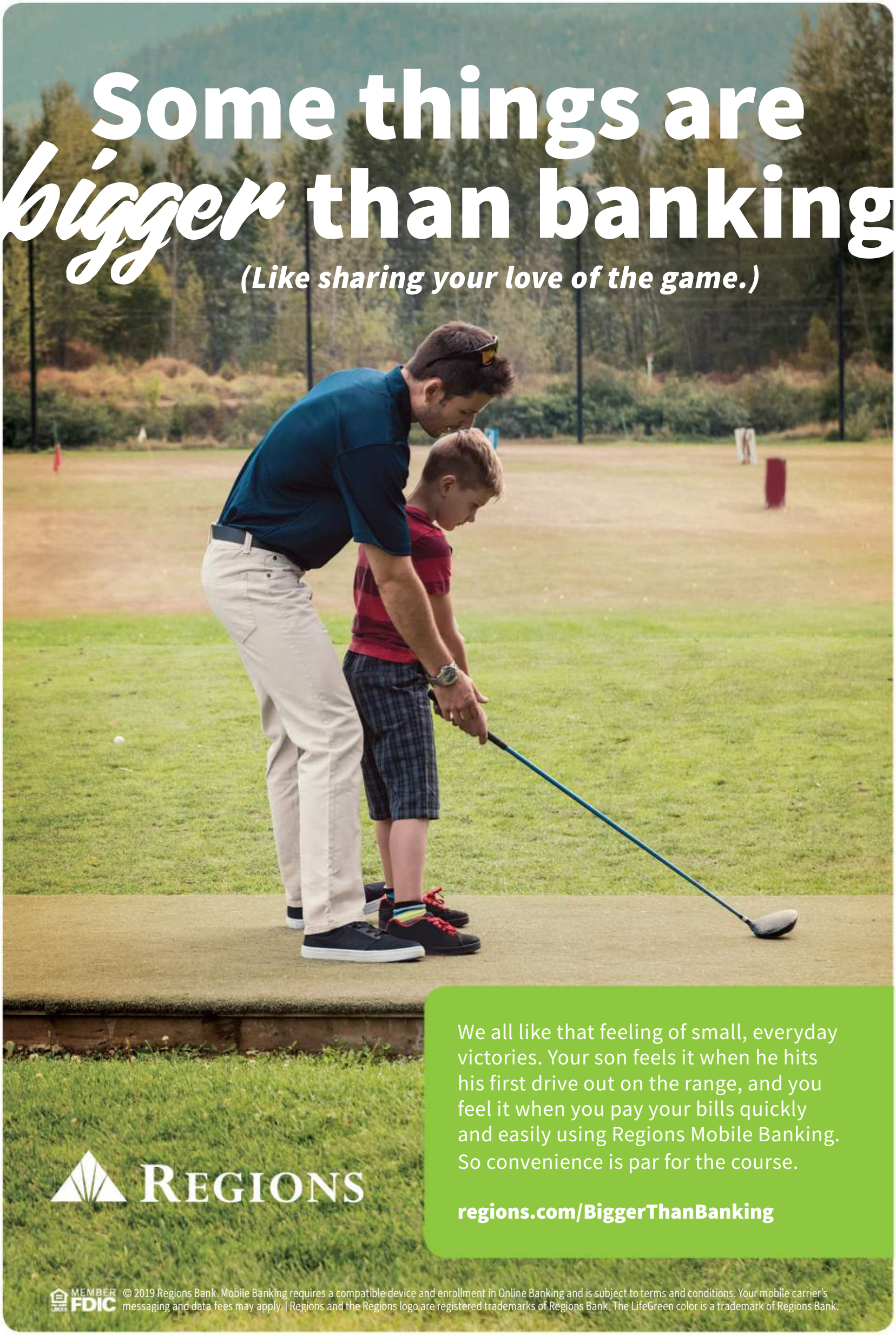
PLASTICS

POLLUTION COMES IN TINY, TOXIC PACKAGES

THE OCEAN IS GETTING OVERWHELMED BY PLASTIC MICROFIBERS—AND PLANKTON ARE EATING THEM.

The knot of microfibers above is less than four millimeters across, roughly the size of tiny aquatic organisms known as plankton. Every week scientist Richard Kirby sets sail from the coast of Plymouth, England, trailing a net behind his yellow boat to gather plankton—but lately he finds nearly as much plastic in his catch. More than 600,000 tons of plastic microfibers are estimated to enter the ocean each year, shed from fleece, polyester, and other synthetic fabrics during washing. Plankton may eat them or get tangled in them, and the ecological impacts are under study. "Our pollution has extended right down to the bottom of the marine food chain," Kirby says. "We've changed the plankton for the foreseeable future, for hundreds of years or possibly thousands." —ALEJANDRA BORUNDA

PHOTOS (FROM TOP): ANTAGAIN, GETTY IMAGES/ISTOCKPHOTO; RICHARD KIRBY; JOE PETERSBURGER, NATIONAL GEOGRAPHIC CREATIVE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A NEW DINO REVEALED

Meet the mighty *Zuul crurivastator,* a recently discovered Cretaceous dinosaur with a sledgehammer tail that could topple tyrannosaurs.

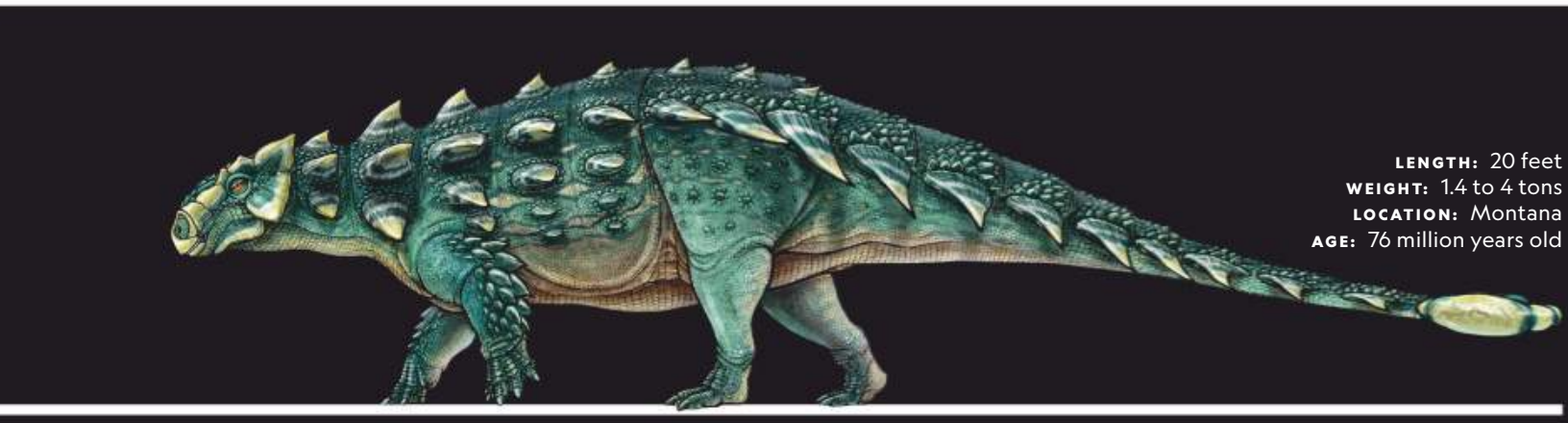
BY **MICHAEL GRESHKO**

IN THE 1984 FILM *GHOSTBUSTERS,* a ragtag crew of parapsychologists does battle with Zuul, a hellhound with a gargoyle's face. Minions possessed by the fictional beast proclaim, "There is only Zuul!" But in real life, scientists have discovered a doppelgänger: *Zuul crurivastator,* a new genus and species of dinosaur with movie-monster looks.

The creature is the most complete ankylosaurid—a type of club-tailed armored dinosaur—ever found in North America. It's also amazingly preserved. *Zuul*'s armor fossilized in place, down to the furrowed soft tissues sheathing it. Preserved damage on *Zuul*'s flank may even chronicle its battles with other ankylosaurids. "It's beyond our wildest dreams," says David Evans, the Royal Ontario Museum paleontologist who is leading the study of *Zuul*.

The tanklike herbivore died 76 million years ago in what's now northern Montana, near an estuary fringing an ancient sea. Its bloated carcass somehow ended up in a river, where it got caught in a logjam and was quickly buried in sand. The animal stayed entombed until 2014, when private fossil excavators stumbled across the remains. The Royal Ontario Museum acquired the fossil in 2016, and in May 2017, museum researchers declared it a new type of dinosaur. While research on the fossil continues, *Zuul* has made its red-carpet premiere—as the focus of a new museum exhibit.

PERFECTLY PRESERVED
A team of technicians has labored for years to remove excess rock from *Zuul*. Among them: **Amelia Madill,** a fossil preparator with the exhibits firm Research Casting International.



LENGTH: 20 feet
WEIGHT: 1.4 to 4 tons
LOCATION: Montana
AGE: 76 million years old

MILD MANNERED

As seen in the artist's rendering (top) and fossil (above), large horns jut from around *Zuul*'s eyes, inspiring its demonic name. But *Zuul* thirsted for buds, not blood: It used its **shovel-like jaw** to eat soft plants.

WELL PROTECTED

Osteoderms**—bony armor plates—**cover *Zuul*'s skin. Their thorny shapes are exaggerated by brownish sheaths once made of keratin, the same type of protein in human hair and fingernails.

PHOTOS: MARK THIESSEN. ILLUSTRATION: DANIELLE DUFAULT © ROYAL ONTARIO MUSEUM

'DESTROYER OF SHINS'

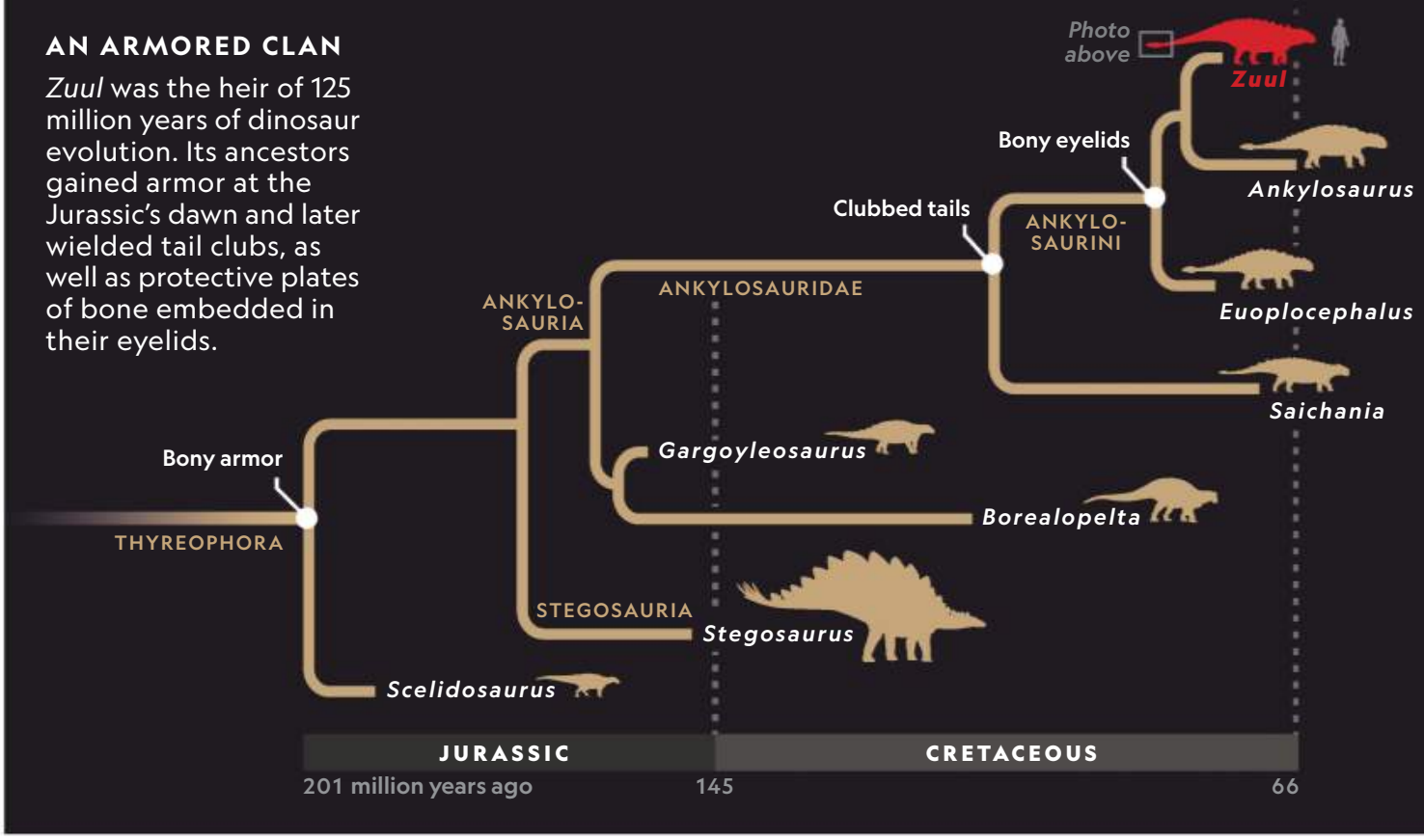
Ankylosaurids such as *Zuul* are best known for their tails, which by 100 million to 90 million years ago had evolved into stiff sledgehammers each capped with a bony knob that in some later species grew to two feet wide. *Zuul*'s formidably **spiky tail, seen here,** stretched nearly seven feet long and may have helped it fend off tyrannosaurs such as *Gorgosaurus* or other members of its own species. To honor *Zuul*'s weaponized posterior, Evans and his colleague Victoria Arbour gave the dinosaur the species name *crurivastator*—Latin for "destroyer of shins."

'IT'S OUTSTANDINGLY PRESERVED ... IT'S JAW-DROPPING. IT'S HARD TO FATHOM JUST HOW LONG THE TAIL IS OR JUST HOW SHARP THOSE SPIKES ARE.'

VICTORIA ARBOUR, CURATOR OF PALEONTOLOGY, ROYAL BC MUSEUM

AN ARMORED CLAN

Zuul was the heir of 125 million years of dinosaur evolution. Its ancestors gained armor at the Jurassic's dawn and later wielded tail clubs, as well as protective plates of bone embedded in their eyelids.

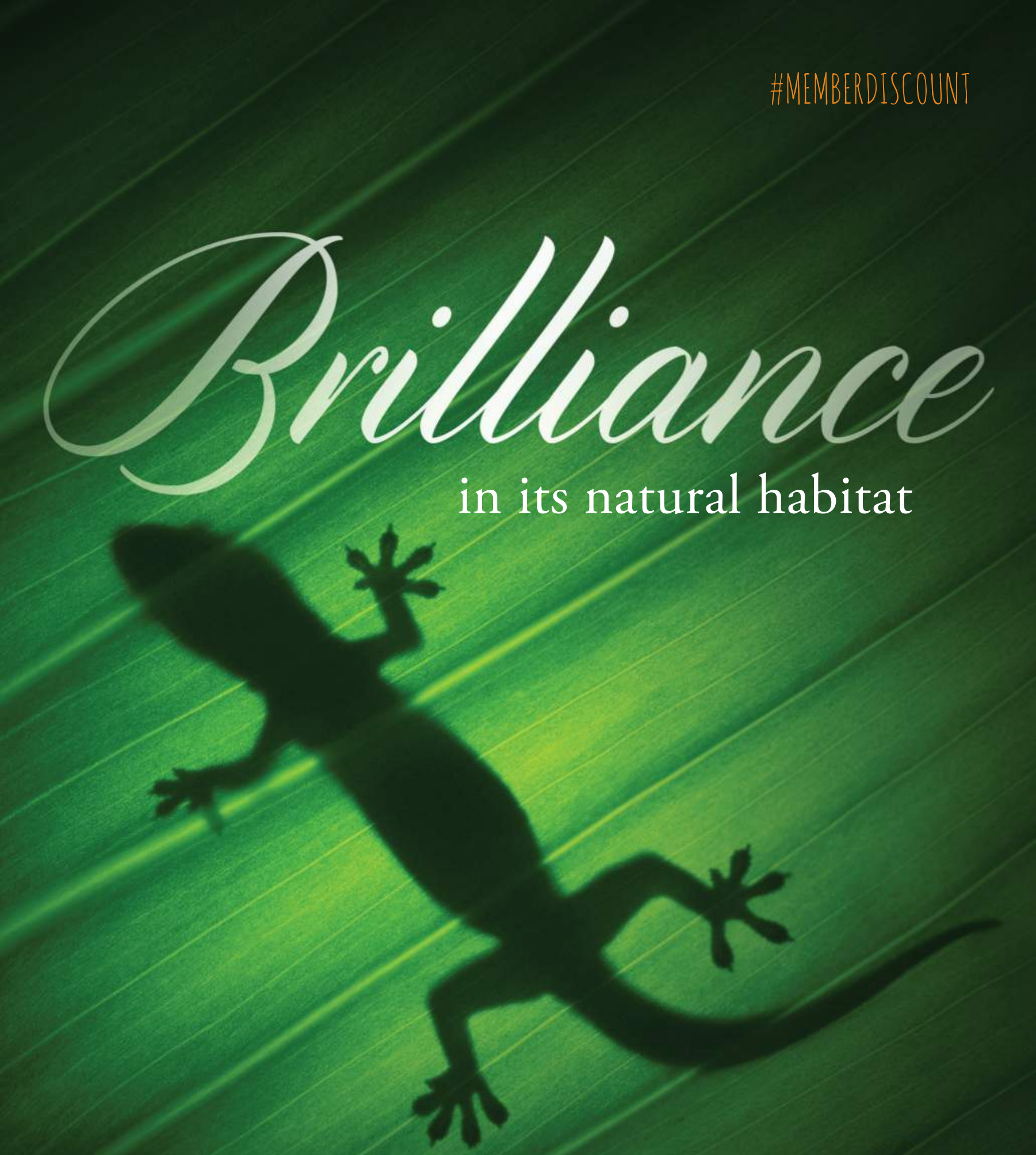


TAYLOR MAGGIACOMO AND DAISY CHUNG, NGM STAFF. SOURCES: VICTORIA ARBOUR, ROYAL BC MUSEUM; DAVID EVANS, ROYAL ONTARIO MUSEUM

#MEMBERDISCOUNT

Brilliance

in its natural habitat



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GENIUS

LESLIE DEWAN

BY **RACHEL HARTIGAN SHEA** PHOTOGRAPH BY **REBECCA HALE**

Safer. Cheaper. Greener. That's her vision for nuclear energy.

Leslie Dewan, 34, is looking to the early days of nuclear power to combat climate change today. A National Geographic emerging explorer with a Ph.D. in nuclear engineering, she wants to resurrect the molten-salt reactor, a 1960s-era design that she hopes will revive nuclear energy as a powerful environmental tool—generating electricity that's both carbon free and cheaper than coal. "There's this driving sense of urgency," she says.

Before the accidents at Three Mile Island and Chernobyl, molten-salt reactors seemed too expensive and safer than necessary. Dewan, with fellow MIT graduate Mark Massie, updated the design with modern technologies and materials that keep the safety features and lower the cost.

Unlike today's models, a molten-salt reactor uses a liquid uranium salt as fuel, allowing for easier extraction of fission by-products. It has a containment system that kicks in when the plant loses electricity, so it's less vulnerable to an accident. If one does occur, it's less likely to blast out radiation, because the reactor operates at atmospheric pressure. It also uses half the fuel and produces less than half the waste.

Dewan and Massie hoped to build the reactor themselves but recently realized that the small company they founded didn't have the capacity. Instead they've open-sourced the design. "We wanted to bring it out into the world," she says, "so that everyone could use it."

The hidden gems helping a remote African community to shine

National Geographic photographer, Shannon Wild, travels to Mozambique and discovers how sustainably mined gemstones have helped transform a remote rural community

All images: Shannon Wild

"I feel a real connection with Mozambique," says Shannon. "It reminds me of home - there's a lot of similarities to the Australian Outback, with its beautiful red dirt and dust, highlighted against the blue sky."

Northeastern Mozambique's sanguine earth has concealed a precious secret for millennia: the world's biggest deposit of rubies; natural gemstones that formed here over five hundred million years ago.

Today, Gemfields' Montepuez Ruby Mine (MRM) produces over half of the global ruby supply, employs 1,110 local people, and funds health, education and agricultural projects that are helping to transform lives in this rural community.

"Here, like so many remote regions across Africa, access to schooling, healthcare and basic facilities have been very limited," explains Shannon. "The new MRM mobile health clinic has made high-quality care accessible to 20,000 people from ten surrounding villages - it's literally a life-saver."

Committed to building lasting, sustainable livelihoods for the communities around their mines, Gemfields has been helping local women to develop their skills and generate income since the Montepuez operation opened in 2012.

"MRM's farming facility offers local women the opportunity to grow and sell their crops which is incredibly empowering, especially in rural villages where there can be very limited options for women," says Shannon.

Gemfields has also improved the region's infrastructure, including roads, electricity and communication networks, while new schools have ensured that 2,000 children now have a primary education.

"There's a real pride in the school facilities and a determination to do well from both teachers and pupils," says Shannon. "It's been a real eye-opener for me to see how Gemfields is trying to give back to the local community: it's making a world of difference."

Gemfields is the world's leading supplier of responsibly sourced coloured gemstones. The company works with community partners to improve infrastructure, build schools, develop agricultural projects and provide healthcare for people living in the remote rural region surrounding the Montepuez Ruby Mine in Mozambique. **gemfields.com**

You can’t wish the flu away.

Indication

XOFLUZA is a prescription medicine used to treat the flu (influenza) in people 12 years of age and older who have had flu symptoms for no more than 48 hours.

It is not known if XOFLUZA is safe and effective in children younger than 12 years of age or weighing less than 88 pounds (40 kg).

Important Safety Information

Do not take XOFLUZA if you are allergic to baloxavir marboxil or any of the ingredients in XOFLUZA.

Before you take XOFLUZA, tell your healthcare provider about all of your medical conditions, including if you:

- are pregnant or plan to become pregnant. It is not known if XOFLUZA can harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if XOFLUZA passes into your breast milk

Tell your healthcare provider about all the medicines you take, including prescription and over-the-counter medicines, vitamins, and herbal supplements.

Brief Summary
XOFLUZA™ (zoh-FLEW-zuh)
(baloxavir marboxil) tablets

What is XOFLUZA?
XOFLUZA is a prescription medicine used to treat the flu (influenza) in people 12 years of age and older who have had flu symptoms for no more than 48 hours.

It is not known if XOFLUZA is safe and effective in children less than 12 years of age or weighing less than 88 pounds (40 kg).

Do not take XOFLUZA if you are allergic to baloxavir marboxil or any of the ingredients in XOFLUZA. See the end of this leaflet for a complete list of ingredients in XOFLUZA.

Before you take XOFLUZA, tell your healthcare provider about all of your medical conditions, including if you:

- are pregnant or plan to become pregnant. It is not known if XOFLUZA can harm your unborn baby.
- are breastfeeding or plan to breastfeed. It is not known if XOFLUZA passes into your breast milk.

Tell your healthcare provider about all the medicines you take, including prescription and over-the-counter medicines, vitamins, and herbal supplements.

Talk to your healthcare provider before you receive a live flu vaccine after taking XOFLUZA.

How should I take XOFLUZA?

- Take XOFLUZA exactly as your healthcare provider tells you to.
- Your healthcare provider will prescribe a single dose of XOFLUZA (which may be more than one tablet).
- Take XOFLUZA with or without food.
- Do not take XOFLUZA with dairy products, calcium-fortified beverages, laxatives, antacids or oral supplements containing iron, zinc, selenium, calcium or magnesium.
- If you take too much XOFLUZA, go to the nearest emergency room right away.

xofluza™
(baloxavir marboxil) tablets 20mg 40mg

But now you can attack it with new, one-dose XOFLUZA.

The flu is serious. And it needs to be treated that way. Over-the-counter remedies treat flu symptoms. One-dose XOFLUZA attacks the flu virus at its source and helps you feel better in just over two days.*

Why wait? Prescription XOFLUZA is most effective within the first 48 hours of symptoms. Talk to your doctor as soon as you feel signs of the flu.

Visit XOFLUZA.com/save to see if you're eligible to pay as little as $30 for your XOFLUZA prescription.**

*On average patients recovered from flu symptoms in 2.3 days (54 hours versus 80 hours with placebo).

**Terms and conditions apply (see XOFLUZA.com/save for full list of terms and conditions).

Talk to your healthcare provider before you receive a live flu vaccine after taking XOFLUZA.

Take XOFLUZA with or without food. Do not take XOFLUZA with dairy products, calcium-fortified beverages, laxatives, antacids, or oral supplements containing iron, zinc, selenium, calcium, or magnesium.

The most common side effects are diarrhea, bronchitis, nausea, common cold symptoms (nasopharyngitis), and headache.

XOFLUZA is not effective in treating infections other than influenza. Other kinds of infections can have symptoms like those of the flu or occur along with flu and may need different kinds of treatment.
Tell your healthcare provider if you feel worse or develop new symptoms during or after treatment with XOFLUZA or if your flu symptoms do not start to get better.

Please see brief summary on this page.

You are encouraged to report side effects to Genentech by calling 1-888-835-2555 or to the FDA by visiting www.fda.gov/medwatch or calling 1-800-FDA-1088.

What are the possible side effects of XOFLUZA?
The most common side effects of XOFLUZA in adults and adolescents include:

- diarrhea
- bronchitis
- common cold symptoms (nasopharyngitis)
- headache
- nausea

XOFLUZA is not effective in treating infections other than influenza. Other kinds of infections can appear like flu or occur along with flu and may need different kinds of treatment. Tell your healthcare provider if you feel worse or develop new symptoms during or after treatment with XOFLUZA or if your flu symptoms do not start to get better.
These are not all the possible side effects of XOFLUZA.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

How should I store XOFLUZA?

- Store XOFLUZA at room temperature between 68°F to 77°F (20°C to 25°C).
- Store XOFLUZA in the blister package that it comes in.

Keep XOFLUZA and all medicines out of the reach of children.
General information about the safe and effective use of XOFLUZA.
Medicines are sometimes prescribed for purposes other than those listed in a Patient Information leaflet. Do not use XOFLUZA for a condition for which it was not prescribed. Do not give XOFLUZA to other people, even if they have the same symptoms that you have. It may harm them. You can ask for information about XOFLUZA that is written for health professionals.

What are the ingredients in XOFLUZA?
Active ingredient: baloxavir marboxil
Inactive ingredients: croscarmellose sodium, hypromellose, lactose monohydrate, microcrystalline cellulose, povidone, sodium stearyl fumarate, talc, and titanium dioxide.

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For more information, go to www.XOFLUZA.com or call 1-855-XOFLUZA (1-855-963-5892).

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ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY

NATIONAL GEOGRAPHIC | VOL. 235 NO. 3

EVOLVED TO CRACK

THE INTRICATE WEB OF CRACKS and crevices that gives African elephants their distinctive look is, in fact, an essential adaptation. The millions of micrometer-wide fractures in elephants' skin retain mud and water after mud baths, helping the animals stay hydrated between trips to the water hole. Evaporation from the mud and water also aids temperature regulation—vital because elephants, unlike many mammals, don't sweat. How the crevices develop has long been a mystery, but Michel Milinkovitch and his colleagues may have solved it. Their research suggests that fractures form when the growth of new skin puts stress on the brittle, outermost skin layer. The findings offer fresh insights into how elephants beat the heat.

Finding water
With five times as many olfactory receptor genes as humans, elephants can find water miles away, even inside a tree or belowground.

BAOBAB TREE

AFRICAN BUSH ELEPHANT

2 in
50 mm
AREA ENLARGED

Digging for water

1

NEWBORN SKIN

Epidermis

Papilla

Dermis

A smoother start
Elephants are born with an uncracked skin surface and an uneven sublayer (dermis) with protrusions known as papillae. When skin cells die, instead of sloughing off, they accumulate.

ADULT SKIN

Stratum corneum

1 mm

AGING

Building up layers
As elephants age, the layers of accumulated skin cells (stratum corneum) over the dermis become thicker.

Bowing to pressure
Bending of the accumulated layers causes cracks to form in the troughs between the protruding papillae.

Crack

Skin layers

SPECIES The African elephant genus includes two species: the bush elephant *Loxodonta africana* and the forest elephant *Loxodonta cyclotis*.

RANGE African bush elephants primarily inhabit the dry, grassy plains of East Africa, where temperatures often exceed 85° Fahrenheit.

DECODER

BY **MONICA SERRANO**

Bathing
To coat their bodies in water and mud, elephants collect liquid in their trunks and spray it onto their heads and backs.

An elephant can hold up to three gallons of water in its trunk.

Dusting
When water is scarce, an elephant will cover itself in dust, which, like mud, can shield its skin from parasites and sunburn.

Because an elephant doesn't shed skin, its epidermis is about 50 times as thick as a human's.

DUST

Young elephants develop their bathing skills by playing in the mud.

STRATUM CORNEUM THICKNESS

Human 0.018 mm

Elephant 0.9 mm

Evaporation Sun

2

SKIN SURFACE

Papillae Cracks

Water flow

Stratum corneum

3

Supersoaked
The buildup of cracked layers creates a network of channels in which water moves by capillary action. Skin like this can retain up to 10 times as much water as a smooth surface.

Mud shield against parasites
The pattern of cracks helps keep mud and water from sliding off the elephants' skin, affording more lasting protection against parasites, sunburn, and heat.

ART: MONICA SERRANO AND CLARE TRAINOR, NGM STAFF. ANNIE ROTH; ALEXANDER STEGMAIER. SOURCES: MICHEL C. MILINKOVITCH AND OTHERS, *NATURE*, 2018; PAUL MANGER, UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG; IUCN/SSC AFRICAN ELEPHANT SPECIALIST GROUP

Strange Reflections

STORY AND PHOTOGRAPHS BY **JODI COBB**

IN VENICE A PHOTOGRAPHER DISCOVERS BIZARRE CREATURES—AND SOLACE FOR HER GRIEF—IN DISTORTED IMAGES OF THE CITY IN THE WATER.

WHEN CONFRONTED WITH THE LIMITS of the known world, a 16th-century European cartographer inscribed the warning "Here Be Dragons" on a small copper globe. Beware: What lies beyond is unexplored—and perilous.

I have spent my life photographing unknown worlds: the secret life of the geisha in Japan, the tragic landscape of human trafficking. Danger often lurked nearby. My assignment on Venice for *National Geographic* was the exception. Nothing about Venice is unexplored. Every brick, every doorway, and every one of its 400 bridges has been mapped and painted. Every photographer since the invention of the camera has lingered on those bridges and photographed gondolas and reflections on the canal water underneath. Venice posed no danger to me beyond the curse of the cliché.

My mission was to document the city's vulnerability to water—the threat of flooding and how the Venetians were trying to prevent it. I made a few photographs of the reflections, but I was there to investigate the only unknown: Would Venice vanish underwater? Those reflections held no clues.

Late one night the phone rang in my hotel room. It was my brother: My mother had been hospitalized, and I should return home immediately. I caught the next flight out but didn't make it in time. My mother was a pioneer of her generation of women, escaping her small coal-mining hometown in Wyoming to travel the world with my dad, my two brothers, and me. Fearless and restless, she thought it only natural that I would want to become a pioneer in my own way, and stoked those flames through my entire life. Mom created and supported my wanderlust. "No great chasm was ever leaped in two small jumps," she would say. "Go for it. Don't look down."

During Venice's seasonal floods, facades in Piazza San Marco appear as shifting reflections—some more clear than others. The mirror image above ran in the magazine. Until recently, Cobb kept abstractions like the one on the previous page to herself.

I returned to Venice, but waves of grief would unexpectedly overtake me at the sight of lighted candles in a church or a funeral boat moving through the canals. The sound of a choir would bring me to tears.

The reflections in the canals inexplicably enticed me. I often stopped to photograph them, confounding my young Italian assistant who knew the magazine did not publish abstract images and thought I was just wasting time. But the more he questioned, the more I resisted. I was often shooting through tears and wanted to avoid his eyes.

When I went back to Washington, D.C., to show the work in progress to the editors, several other events happened in my personal and professional lives that left me awash in confusion and dislocation. I had reached the limits of my known world.

And yet I still had one last trip to make in the fall—to photograph the *acqua alta,* the seasonal floods when water periodically spills into the streets, squares, and shops of Venice. Reflections would appear where there hadn't been any, and once again I strangely found solace in them. Everything else vanished as I lost myself in the shifting movement of the dark water that, stirred by a breeze or passing boat, suddenly shattered into colors and patterns.

When the assignment was over, I didn't show those reflection pictures to anyone. They had nothing to do with the kind of photographs I loved to make, ones that tried to explore hidden worlds, social issues, and the human condition. I forgot about them.

Five years later I found them deep in my computer files. As I began to edit, strange creatures emerged from the depths of the images: bizarre mythical beasts, cartoon characters, carnival masks, snakes, and gargoyles. They had been there all along, waiting for my imagination to bring them to life. And maybe daring me to find the courage to chart my own course in photography and life, to take time away from searching out what lies in the hearts of others to explore the depths of what lies in my own.

But beware: Here be dragons.

Jodi Cobb has photographed stories for *National Geographic* for more than three decades and has worked in more than 65 countries.

I lost myself in the shifting movement of the dark water that, stirred by a breeze or passing boat, suddenly shattered into colors and patterns.

FEATURES

PHOTO: CHARLES FRÉGER

132

'WITH THEIR IDENTITIES DISGUISED BEHIND ORNATE MASKS, REVELERS TELL STORIES, RELEASE FRUSTRATIONS, AND AGITATE FOR POLITICAL AND SOCIAL CHANGE.'

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.

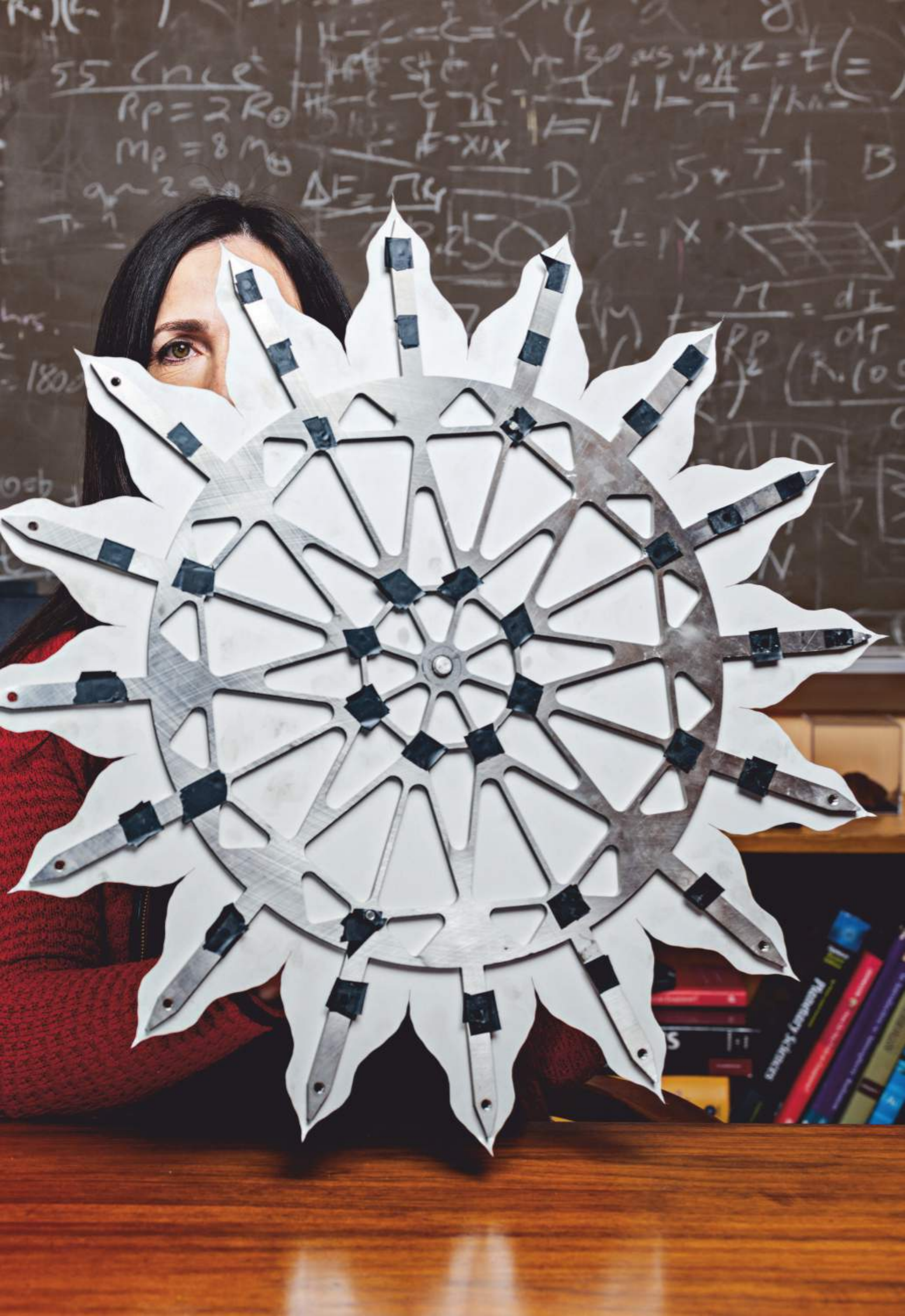
"51 Peg should have let everyone know it was going to be a crazy ride," Seager says. "That planet shouldn't be there."

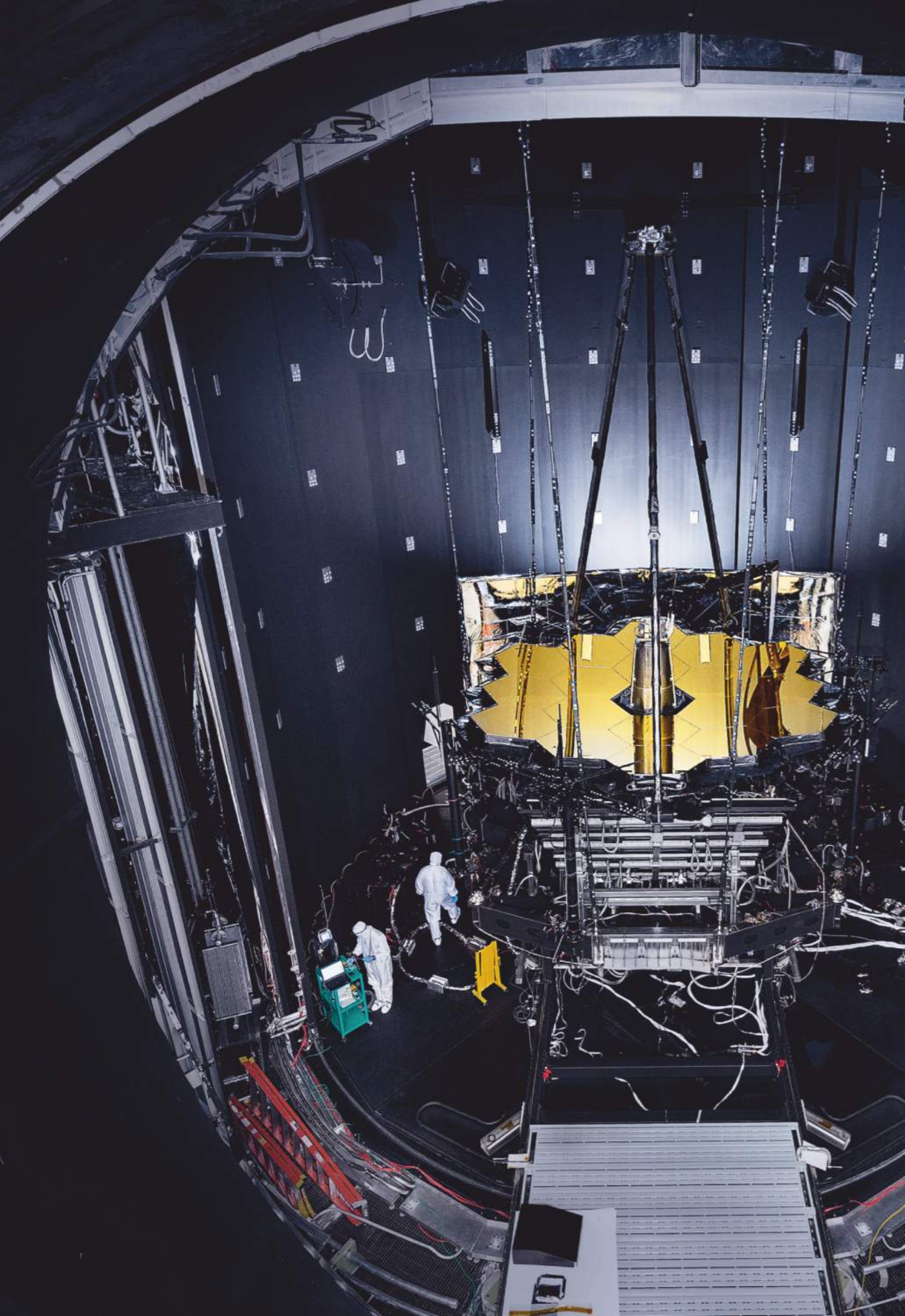
Today we have confirmed about 4,000 exoplanets. The majority were discovered by the Kepler space telescope, launched in 2009. Kepler's mission was to see how many planets it could find orbiting some 150,000 stars in one tiny patch of sky—about as much as you can cover with your hand with your arm outstretched. 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

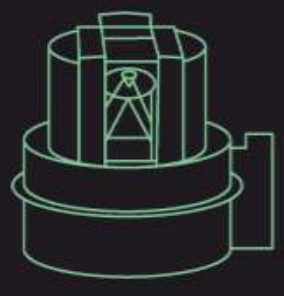
NEW WAYS OF SEEING

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

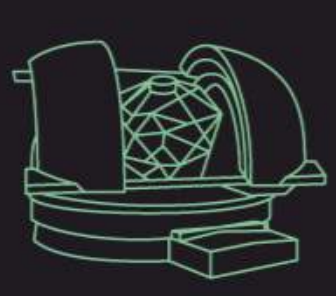
Ground-based scopes can hold heavy, powerful optics that are comparatively easy to maintain. But Earth's atmosphere filters and distorts starlight, limiting what these telescopes can see in outer space.



SUBARU TELESCOPE

Subaru Coronagraphic Extreme Adaptive Optics

Removes distant starlight reaching the Subaru telescope, allowing astronomers to directly image exoplanets.



ELT

Extremely Large Telescope

Captures visible and near-infrared spectrum images 16 times as sharp as those of the Hubble Space Telescope.

	Subaru	ELT
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."

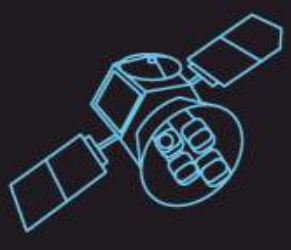
There's an outside chance a rocky planet orbits a star close enough for the Webb telescope to capture sufficient light to investigate it for signs of life. But most scientists, including Seager, think we'll need to wait for the next generation of space telescopes. Covering most of the wall over her vision 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.



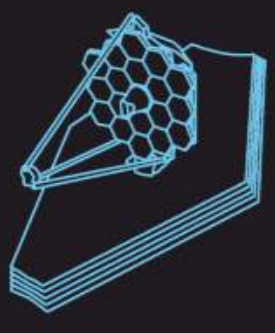
TESS

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



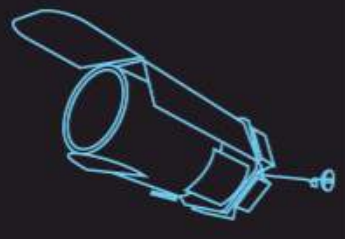
JWST

James Webb Space Telescope

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

6.5 meters

Expected start: 2021



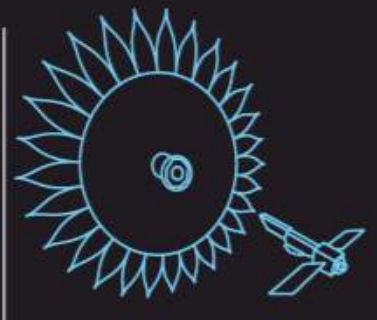
WFIRST

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

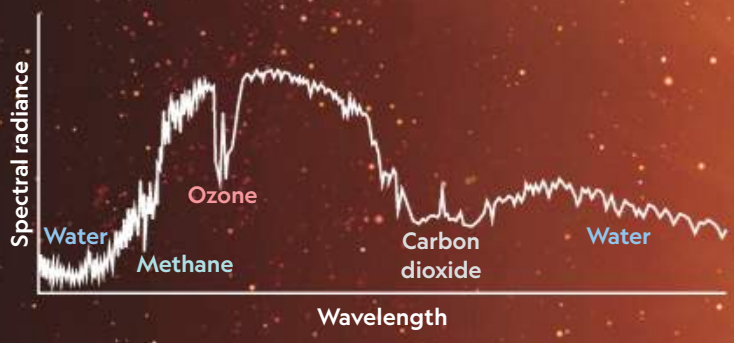
HOW TO FIND LIFE

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

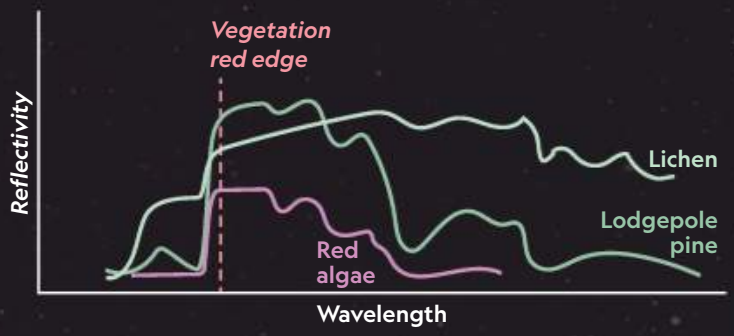
HOW TO FIND LIFE

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

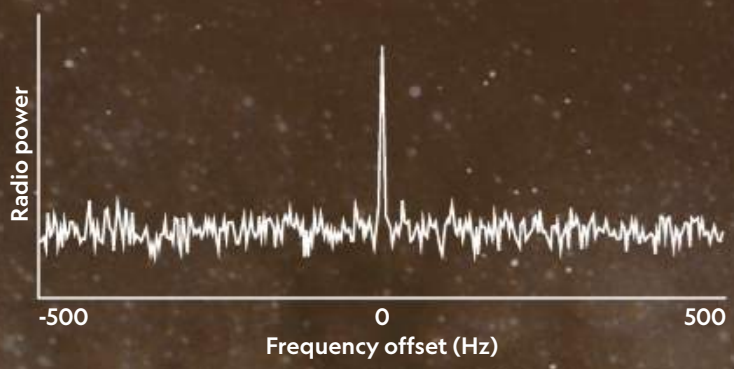
HOW TO FIND LIFE

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.

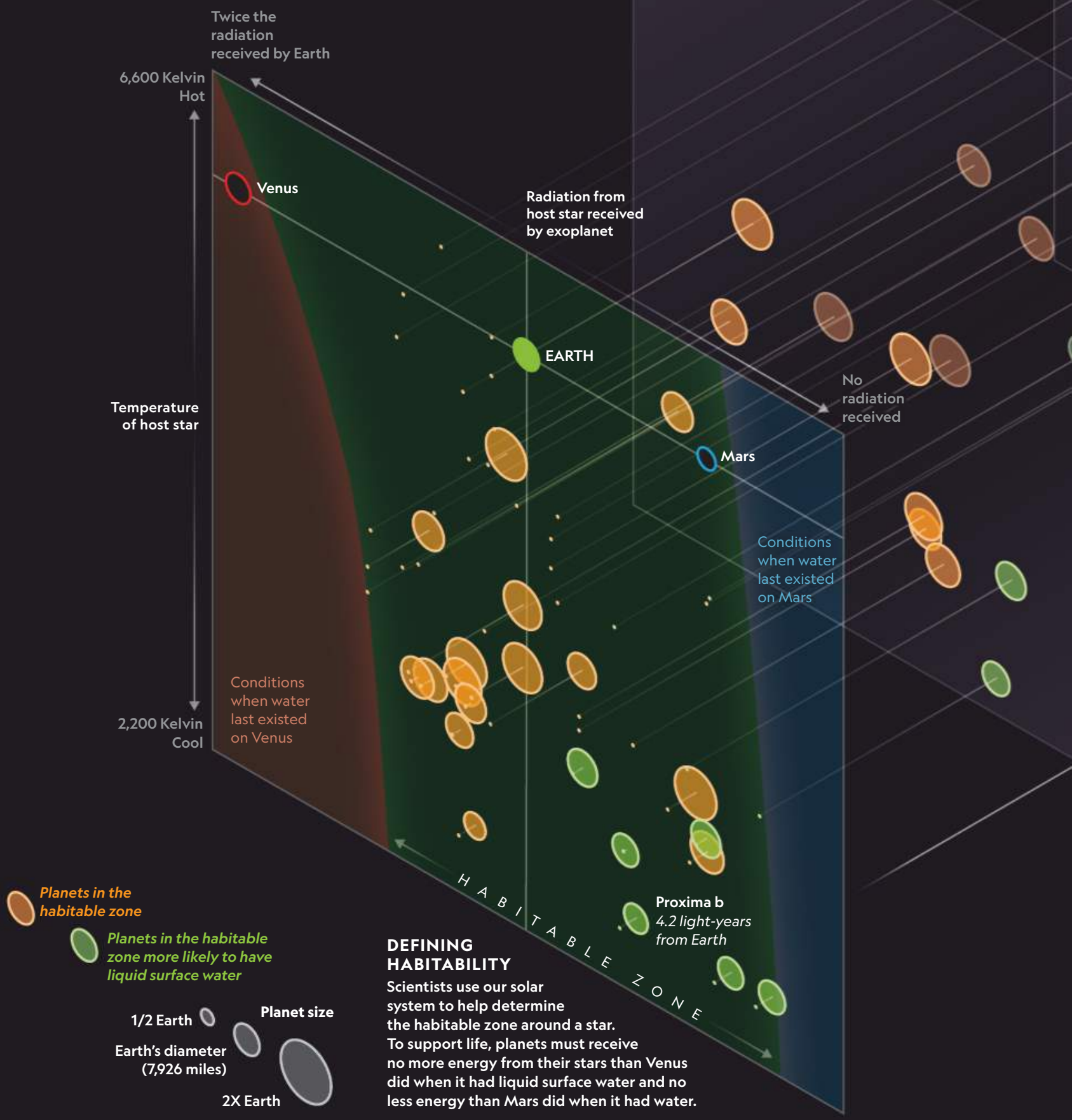


SOURCES: EDWARD W. SCHWIETERMAN, UC RIVERSIDE; BREAKTHROUGH INITIATIVES; SETI INSTITUTE

MAPPING EXOPLANETS

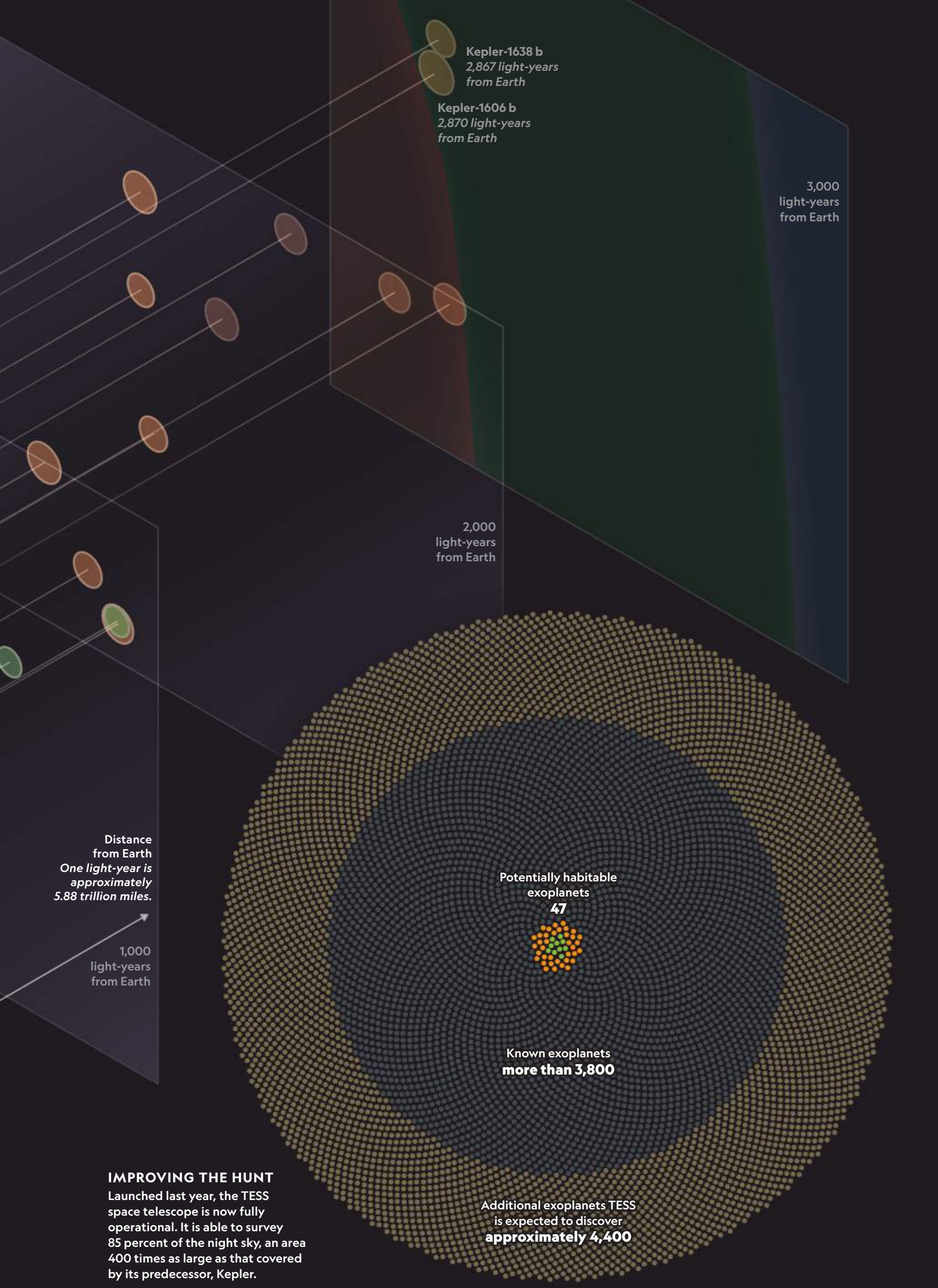
HUNTING FOR HABITABILITY

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

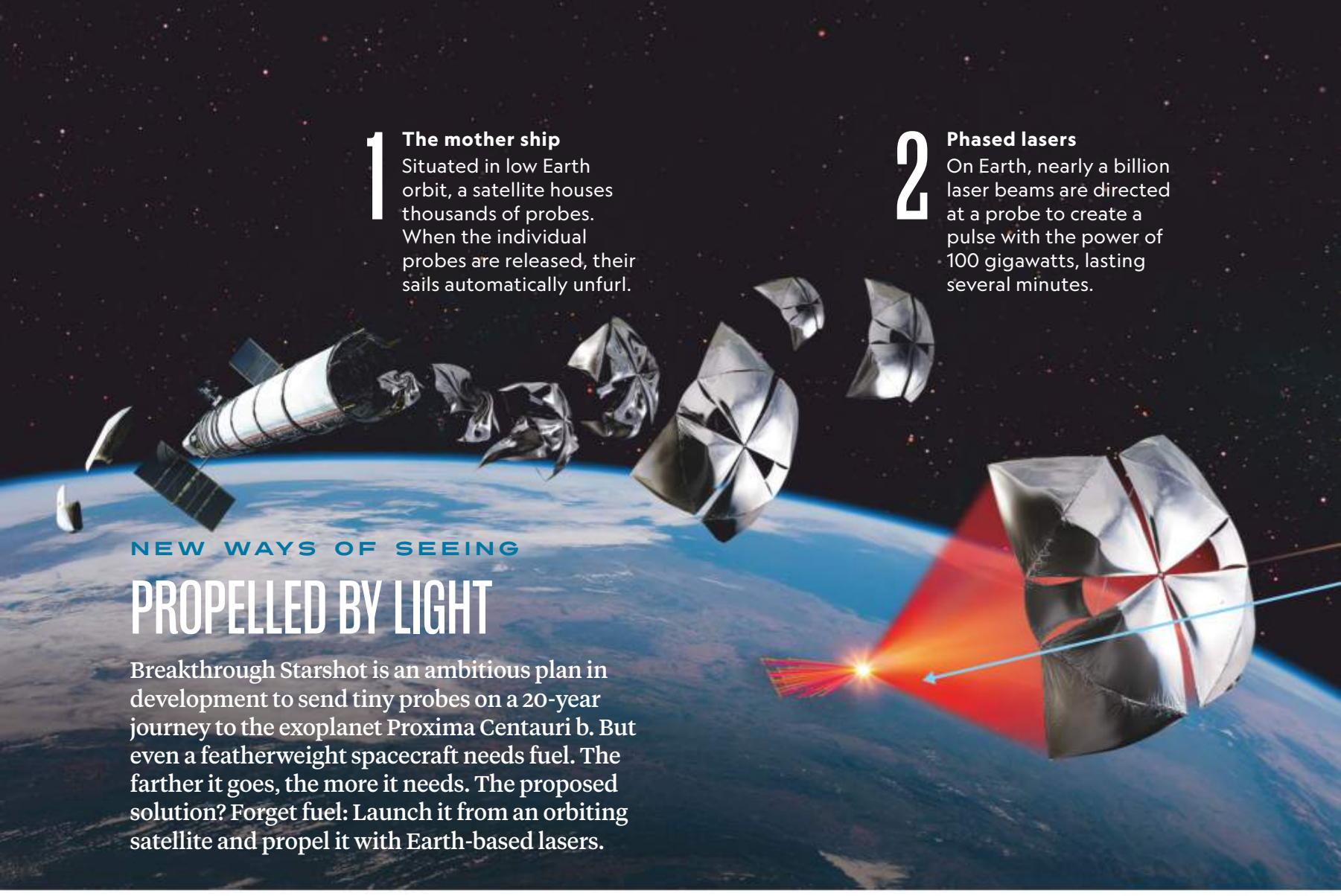
Scientists use our solar system to help determine the habitable zone around a star. To support life, planets must receive no more energy from their stars than Venus did when it had liquid surface water and no less energy than Mars did when it had water.



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.

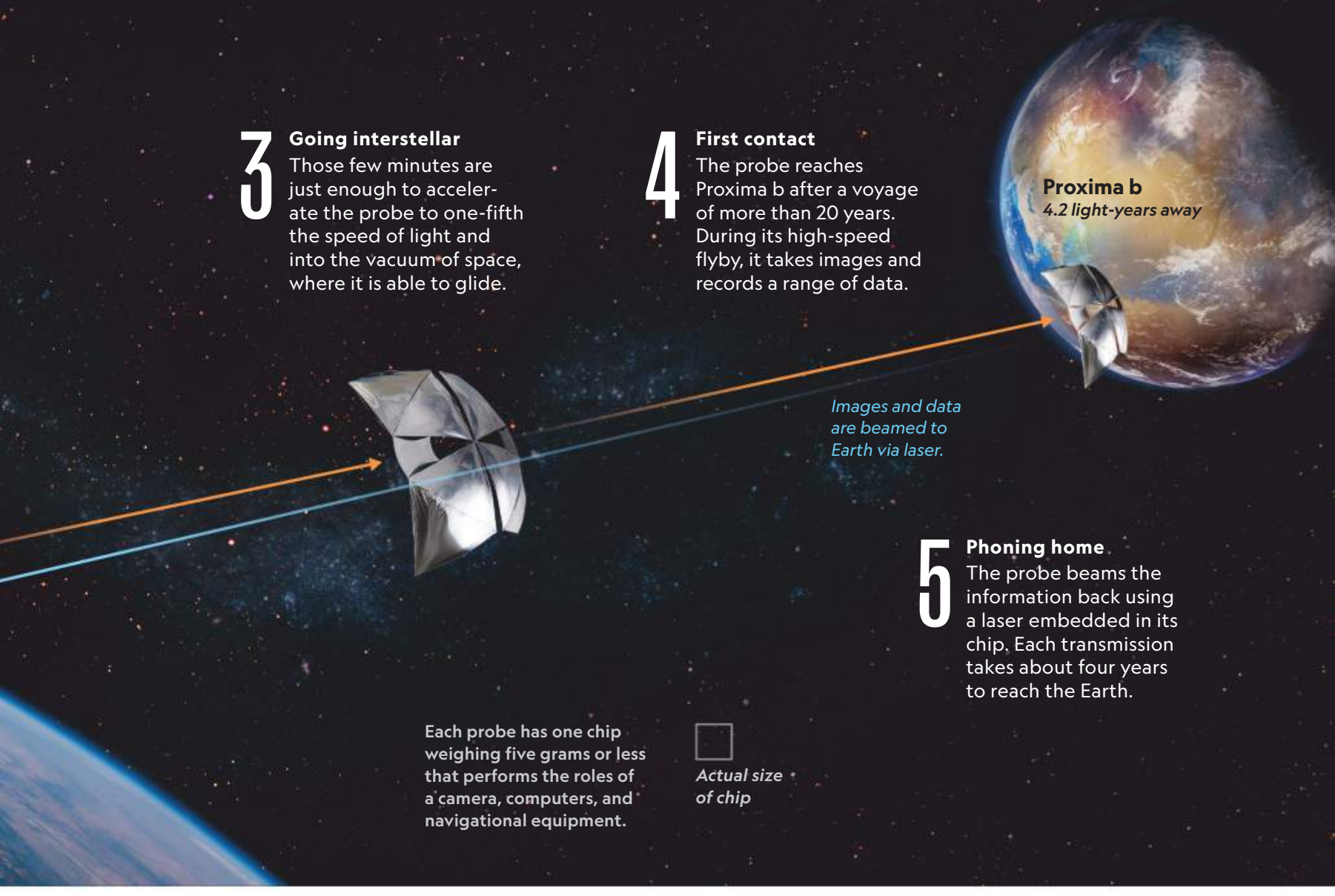
"I was giving a tour the other day to some scientists, and all of a sudden, one of them fainted!" he says, with a mixture of surprise and regret. "I should have known she was not doing well. She had gotten very quiet." I clutch the railings and make sure to keep asking questions.

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

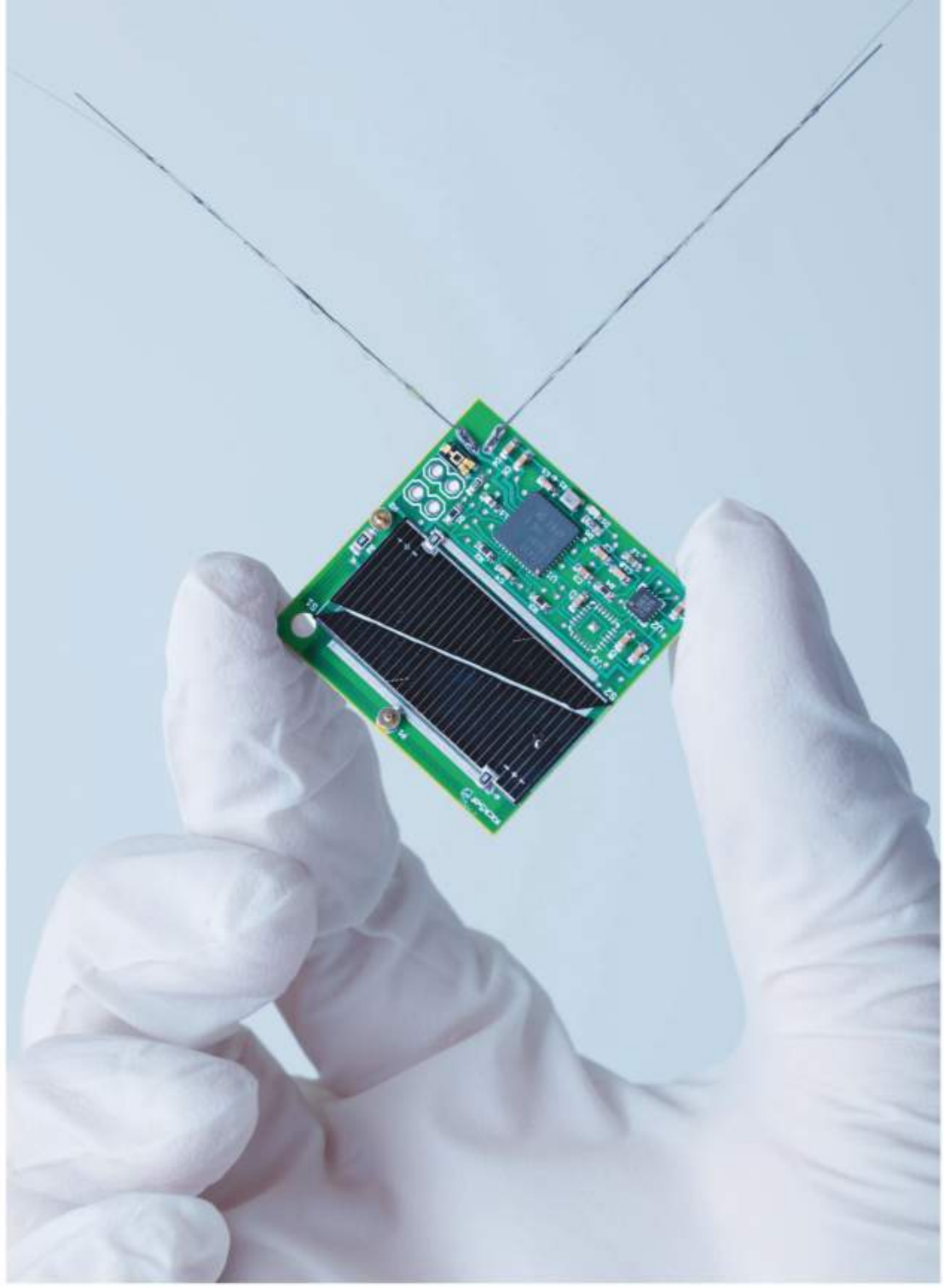

SKYJACK
SJIII 3219

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.

BY **JASON MOTLAGH**

PHOTOGRAPHS BY **MOISES SAMAN**

NO WAY OUT

GANG WARFARE AND POVERTY ARE DECIMATING EL SALVADOR. MANY MIGRANTS HAVE FLED TOWARD THE UNITED STATES, BUT CHANGES IN U.S. POLICY COULD SEND THOUSANDS BACK INTO THE CHAOS.

Onlookers gather at the scene of a homicide in downtown San Salvador, El Salvador's capital. Violence has driven hundreds of Salvadorans to leave each day for the United States, where they make up the fourth largest Latino community, after Mexicans, Puerto Ricans, and Cubans.

Criminal gangs in El Salvador command tens of thousands of members, and their battle for supremacy has fractured this tiny country.

Members of the MS-13 gang crowd into their cramped cell inside Chalatenango prison, in northern El Salvador. Authorities house rival gangs in separate prisons to avoid deadly riots, but extreme crowding has stretched the prison system beyond its limits.

Generations of migrants have carved out lives for their families in the U.S., far from the violence that continues to plague their homelands.

Juan and Yesenia Valle and their U.S.-born daughters pose outside their home in New York State. Juan came to the United States almost 20 years ago to help support his mother and brother, who were already here. He is now the co-owner of a thriving sign and awning business. Juan hopes he and his wife can stay in the U.S. permanently: "I consider the U.S. my country. There is nothing in El Salvador for me now. If I go back, I die over there."

PHOTO: ADAM FERGUSON; LOCATION INFORMATION IN PHOTO HAS BEEN REMOVED.

The deportees from the United States file out of the buses with their heads down, stripped of belts and shoelaces like criminals.

Rounded up from immigration detention centers around the country, they'd been boarded onto an unmarked jet near the Texas-Mexico border early in the morning and flown more than 1,100 miles to an airport outside El Salvador's capital, San Salvador. In just four hours a perilous journey north that had taken many of the migrants years to prepare for and weeks to complete was undone.

"Welcome," a Salvadoran migration officer greets them in a new reception center built with help from the U.S. government. "You are family here." A hundred and nineteen blank faces stare back. One by one, names are called out, and the men and women come forward to receive their belongings, undergo health screenings, and collect bus fare to get them home.

A 24-year-old man with a strong build and easy smile sits in the back wearing a white T-shirt hand-scrawled with the words "Faith Hope Love." Like many in El Salvador, he doesn't want to reveal his name. As a teenager in rural Usulután, one of the country's 14 departments, he'd been pressured to join Mara Salvatrucha, the largest gang in El Salvador, also known as MS-13. He signed up for the police academy instead, and when the gang found out, death threats followed.

He fled south to Colombia, where he found work as a truck driver and fell in love. His girlfriend

Salvadoran migrants cross the border from Guatemala into Mexico in November 2018. From here they would trek another 2,400 miles to reach the U.S. At that time, to deter migrants, President Donald Trump ordered more than 5,000 U.S. troops to the border with Mexico.

NGM MAPS

got a visa to the U.S. and took a plane to join relatives. He paid a coyote, or people smuggler, $8,000 and spent the next month running a seven-border gantlet up the Central American isthmus, finally slipping into Texas and heading east to Atlanta. There, a relative who's a permanent U.S. resident gave him a job installing sprinklers that paid $3,000 a month, more than five times the average monthly household income in El Salvador. He sent $500 back to El Salvador each month to help his mother and grandmother.

For five years in Georgia he kept a low profile. Work on weekdays, parks and malls on weekends, church on Sundays. No traffic tickets or run-ins with the law. Until an unlucky morning in September 2017, when he was stopped at a random police checkpoint and arrested for driving without a license. Georgia police handed him over to Immigration and Customs Enforcement authorities, who locked him up.

The man's name is called out. He picks up his wallet and Bible and laces up his boots. "I'm really scared," he confides. News reports about El Salvador that he's watched in the U.S. have given him the impression that gangs have "taken over the whole country." Of one thing he is sure: "I will go back to the U.S.A. as soon as I can."

His next ordeal starts the moment he steps into the street in San Salvador. The reception center is located in an MS-13 stronghold, as graffiti on the opposite corner attests. The nearest cash machine is two blocks away on the turf

By the time El Salvador's civil war ended in a stalemate in 1992, 75,000 people were dead and more than a million were displaced.

Ana Machado, 53, and her daughter, Kenia Gaitan, 29, sit with Gaitan's three children, Jakob, three, Bridget, six, and Aviela, nine, in their Virginia apartment. Machado came to the U.S. in 1991 as a civil war refugee and was only recently granted political asylum. She works as an office cleaner. Gaitan, who arrived in 2006 after threats from MS-13, is undocumented, but her children are U.S. citizens.

PHOTO: ADAM FERGUSON

of MS-13's archenemy, the 18th Street gang.

El Salvador's government says that criminal gangs command an estimated 60,000 active members, and their battle for supremacy has fractured this tiny country of 6.4 million people along an expanding web of invisible fault lines that run red. In 2017 the homicide rate was 61 per 100,000 people, making El Salvador the second deadliest of any country not at war, after Venezuela.

El Salvador is locked in the latest phase of a social conflict that exploded during the 1980-1992 civil war, in which leftist guerrillas rose up against a wealthy elite and the military state that had long dispossessed the rural underclass of land. With the stated aim of stopping communism in its backyard, the U.S. supported El Salvador's right-wing dictatorships with billions of dollars of economic and military aid that prolonged the bloodshed. By the time the war ended, in a stalemate, 75,000 people were dead and more than a million were displaced, hundreds of thousands of whom fled to the U.S. From Los Angeles to Washington, D.C., Salvadoran refugees found employment and community, and they sent money home.

The children who came with them, displaced youths craving identity in a foreign land, created MS-13 on the streets of Los Angeles and swelled the ranks of a rival, 18th Street—a Hispanic gang that formed around 18th Street in the Pico-Union neighborhood of Los Angeles and absorbed wayward refugees from Central America. As gang wars, and the war on gangs, intensified, laws were enacted that made it easier to deport immigrants with criminal records. In the late 1990s the U.S. began exporting thousands of convicts back to Central America each year. In the vacuum of weak governance and poverty in their home country, gang members reproduced their social structures and tactics and multiplied exponentially.

"We knew how to use weapons, make bombs," says Ricardo, a former barrio leader of 18th Street who was deported after a conviction for stealing cars. The returnees spawned "a social monster—and we're still dealing with that monster," he adds. In the teeming slums of San Salvador, a metro area of a million people, competition for turf and status bred a kill-or-be-killed strain of nihilism far more extreme than anything he'd known on the streets of Los Angeles.

A hell of hyperviolence and economic despair has since engulfed the country and its neighbors, driving tens of thousands of Central Americans north to the U.S., where generations of migrants have carved out safe, dignified, and law-abiding lives for their families. As the exodus continues, the U.S. is threatening to deport legions of Salvadorans back to the horrors they fled.

Today some 200,000 Salvadorans in the U.S. have temporary protected status (TPS), a designation that allows undocumented migrants deemed at risk because of armed conflict or environmental disasters in their home countries to stay in the U.S. People like Abel, in his 50s, a soft-spoken maintenance worker in the Washington, D.C., area who sends money back home every month. He says he came to the U.S. for "the dream": honest work, security, a better life. The reality is bittersweet. He's seen his children just once in 18 years, and his wife died in his absence. "Life is cold here," he says matter-of-factly. "But there is opportunity, and so we must endure."

In January 2018, President Donald Trump's administration ordered an end to TPS for Salvadorans. It was set to expire in September 2019, but a U.S. district court halted that plan, allowing Salvadorans to continue to live and work in the U.S. until a final decision is made. The about-face has been accompanied by a surge of federal immigration raids and the forced separation of newly arriving migrant families at the U.S.-Mexico border. Like every TPS holder I spoke with, Abel plans to stay in the U.S. illegally if TPS ends, rather than return to El Salvador voluntarily. "I've sacrificed too much to give up," he says.

Despite Trump's "zero tolerance" policy that resulted in separation of families and increased detentions at the southwest border of the U.S., the seemingly endless cycle of revenge between rival gangs and between gangs and authorities—not only in El Salvador but also in Guatemala and Honduras—keeps pushing people north. Last fall a caravan of more than 5,000 Central American migrants began walking toward the U.S., drawing renewed global attention to the crisis.

HIGH IN MORAZÁN DEPARTMENT, in northeastern El Salvador, the legacy of U.S. involvement still smolders. Driving past lush farms and volcanoes that thrust into the clouds, I reach the village of El Mozote. It was here in 1981 that Salvadoran soldiers armed and trained by the U.S. massacred more than 1,000 civilians, mostly children. According to a cable sent from the U.S. Embassy in San Salvador to the State Department, the U.S. government went to great

lengths to bury the truth of the massacre.

Morazán is one of the most economically depressed regions of El Salvador, having never recovered from the war's devastation. It is also one of the least violent. Some ascribe this to the vigilance of the local people, many of whom are ex-rebel combatants. The simpler explanation is economic. Gangs, though present in nearly all the country's municipalities, gravitate toward urban areas where commerce concentrates and extortion opportunities are greater.

In a sunburned cornfield outside town, Bernaldino Vigil, a farmer who says his father was executed by government troops during the war, says droughts and fickle weather have wiped out successive crops. Debts have mounted, preventing him from leaving and forcing his two daughters still at home to drop out of school and work alongside him. "Sure, we have peace," he says, "but it's getting harder to survive."

José María Guevara, a convenience store owner in El Mozote, lost 30 relatives in the massacre but survived because he left during the war and returned later. He has sent two of his children to New York City. One cleans houses; the other works as a gardener. His youngest daughter, Rosa, is eager to follow in their footsteps because it's too expensive to continue her university studies in the city two hours away. "I'll take any job in America," she says. Most of her friends have left for the U.S. or moved to cities such as San Miguel and San Salvador, but Trump's election put Rosa's travel plans on hold. Guevara says he would have had to take out a loan to pay a coyote's $10,000 fee, a gamble that could have cost him his shop. "If she got caught and sent back, we'd all be screwed," he says.

Distrito Italia, a barrio north of San Salvador, was built with Italian-government funding through the World Bank after a magnitude 7.6 earthquake in 1986 left 300,000 homeless. The barrio boasts wide brick lanes and graffiti-free walls thanks to a cleanup effort led by my guide, Pastor Mario Hernández. But MS-13 has no need to advertise its presence here—the gang's control is total.

Gangs are known to help transport drugs and guns and even shake down transnational companies operating in El Salvador, but most of their money comes from what are called micro-extortions. Almost everyone with a business in Distrito Italia, from the bus driver to the *pupusa* vendor, pays something to MS-13—five dollars, $10, $50 a month. An estimate by the digital newspaper *El Faro,* based on the government operation investigating MS-13 finances, says it all adds up to annual revenue of more than $30 million for the gang nationwide. Overall, violence costs the national economy four billion dollars a year.

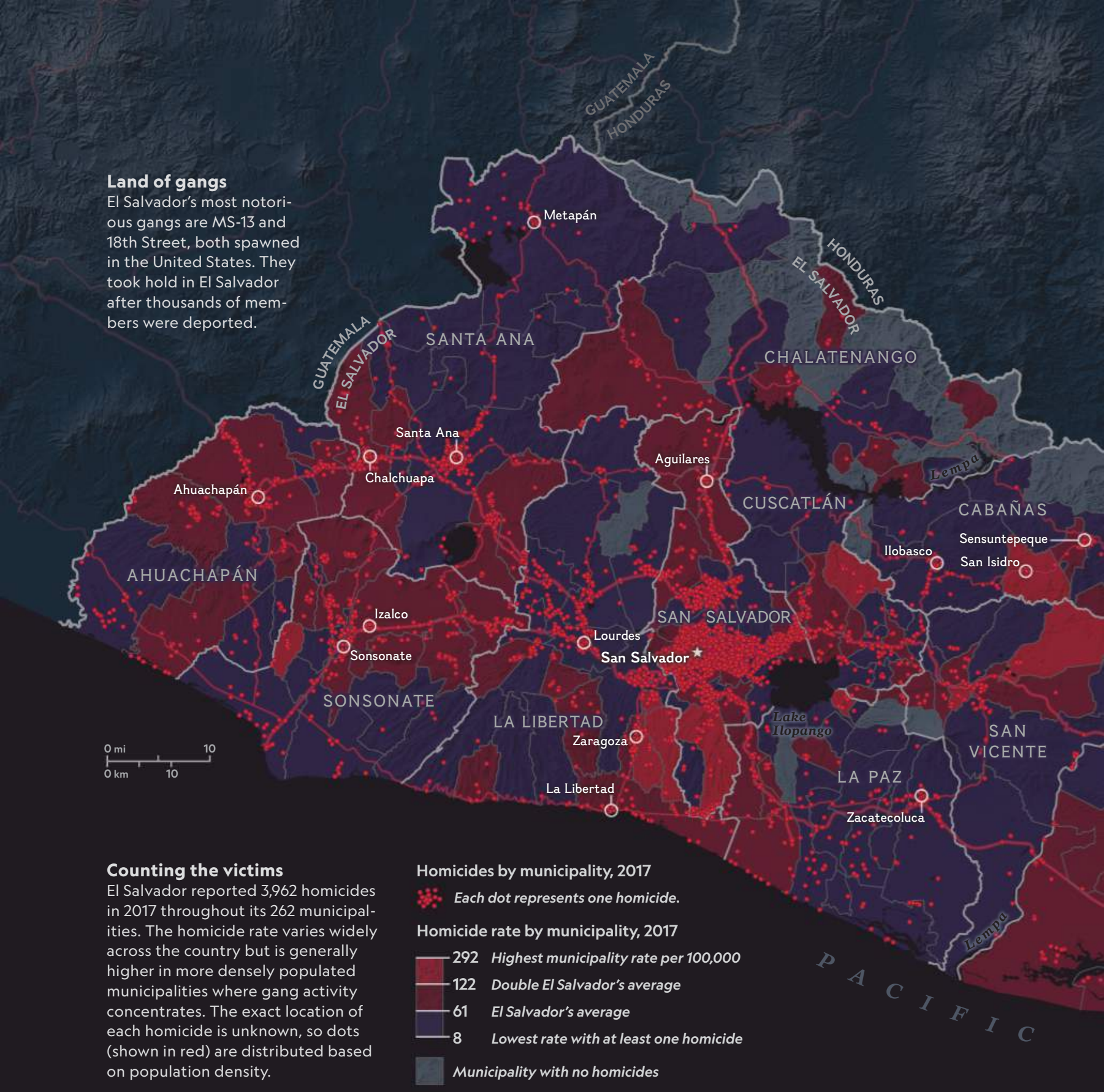
Hernández introduces me to Aaron, a lean 20-year-old in a sports jersey and gold hoop earrings. He's never been jumped into the gang—beaten by a group for the symbolic 13 seconds—but he is "associated," which means he's ordered to run the odd package, collect money here and there, keep watch. Aaron tells the pastor that overnight a gang member was gunned down by rivals, the 10th friend he's lost, he says, counting out with his fingers.

We walk deeper into the barrio, and Aaron nods to the "antennas" posted on every other corner. Lanky teens thumbing cell phones with seeming indifference, they're poised at the push of a button to relay word of any intruder. Where the sidewalk peters into dirt, we find Julio, 30, a veteran gang member dressed in all blue with a Los Angeles Dodgers cap—classic MS-13 dress code. He scans over our shoulders, uneasy. A text message says police are patrolling the area. "They could be over there," he says, pointing across a small field, "and just start shooting."

After a state-brokered truce between MS-13 and 18th Street began to fall apart in 2013, the

A truck full of police officers in tactical fatigues and black ski masks slows down to size us up, assault rifles at the ready.

Land of gangs
El Salvador's most notorious gangs are MS-13 and 18th Street, both spawned in the United States. They took hold in El Salvador after thousands of members were deported.



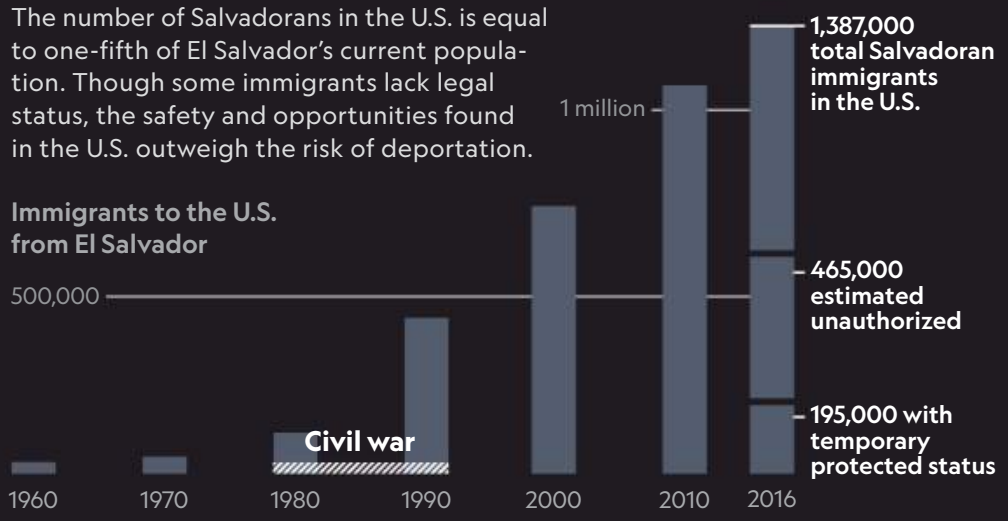
Counting the victims
El Salvador reported 3,962 homicides in 2017 throughout its 262 municipalities. The homicide rate varies widely across the country but is generally higher in more densely populated municipalities where gang activity concentrates. The exact location of each homicide is unknown, so dots (shown in red) are distributed based on population density.

Homicides by municipality, 2017
Each dot represents one homicide.

Homicide rate by municipality, 2017
- 292 *Highest municipality rate per 100,000*
- 122 *Double El Salvador's average*
- 61 *El Salvador's average*
- 8 *Lowest rate with at least one homicide*
- *Municipality with no homicides*

Fleeing to the U.S.

The number of Salvadorans in the U.S. is equal to one-fifth of El Salvador's current population. Though some immigrants lack legal status, the safety and opportunities found in the U.S. outweigh the risk of deportation.



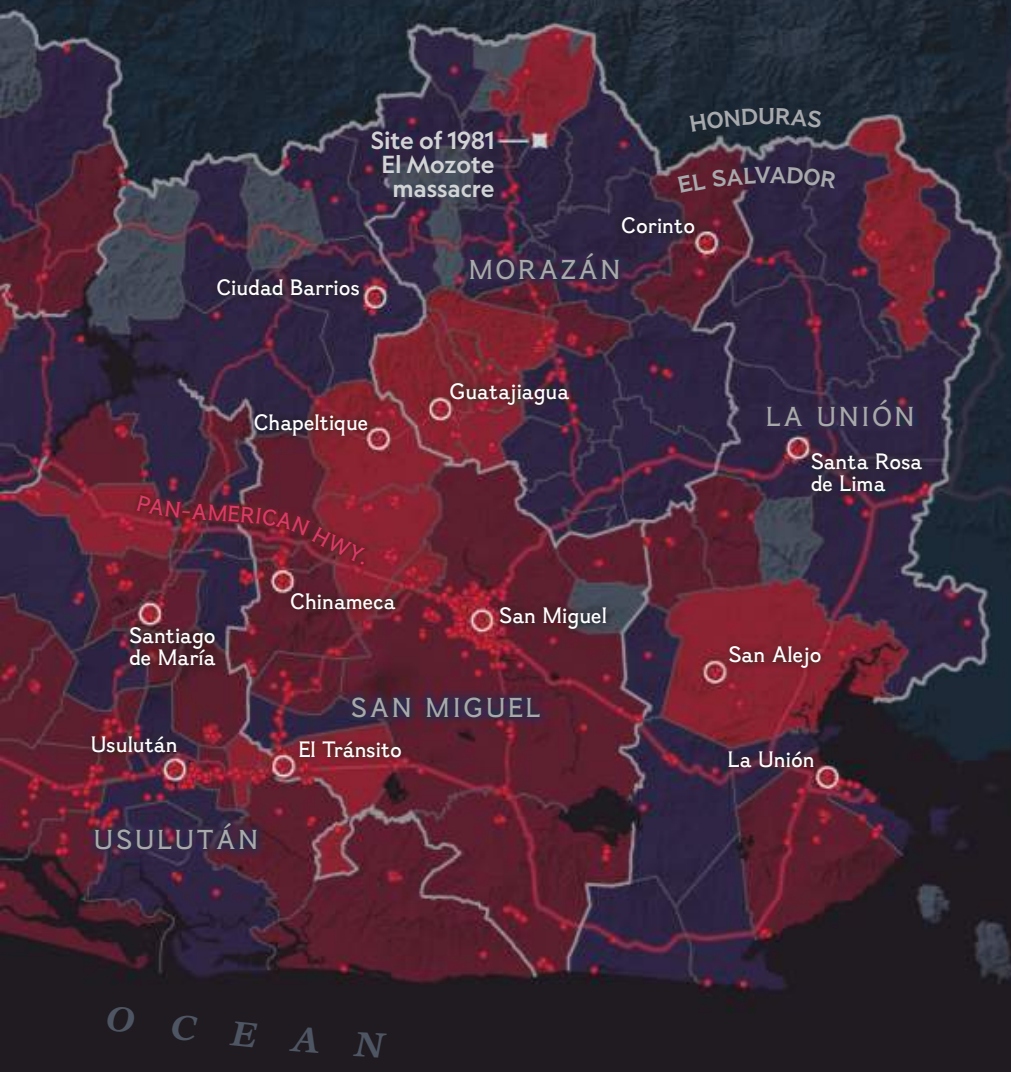
Uncertain future
Temporary protected status (TPS) legalizes U.S. residency for a limited time, until it's safe to return home. If TPS is ended, many could face deportation.

Cash flow at risk
The five billion dollars Salvadorans sent home in 2017 amounted to 18 percent of their country's GDP. That flow will diminish if deportations increase.

SOURCES: GOVERNMENT OF EL SALVADOR; INSIGHT CRIME; MIGRATION POLICY INSTITUTE; U.S. CENSUS BUREAU; UN OFFICE ON DRUGS AND CRIME; ASTER GDEM (A PRODUCT OF METI AND NASA); ROAD DATA © OPENSTREETMAP CONTRIBUTORS, AVAILABLE UNDER OPEN DATABASE LICENSE: *OPENSTREETMAP.ORG/COPYRIGHT*

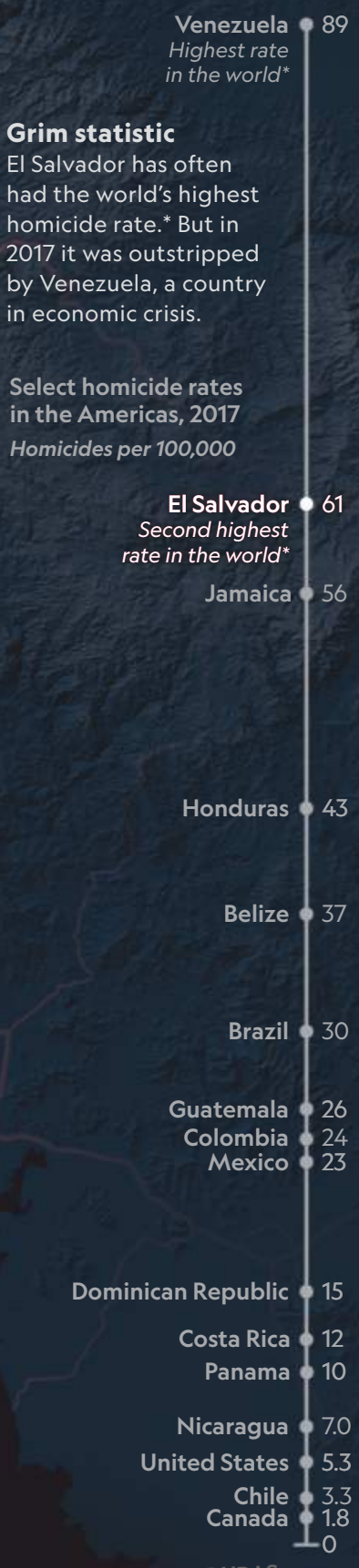
State of Fear

El Salvador may be Central America's smallest country, but it's also the most densely populated and one of the deadliest—long past the end of its 1980-1992 civil war. In August 2015 there was a homicide every hour. The following years have offered little reprieve, with nearly 4,000 homicides in 2017. The high count has multiple causes, including gang activity, drug trafficking, and extrajudicial killings by police and military forces.



Grim statistic
El Salvador has often had the world's highest homicide rate.* But in 2017 it was outstripped by Venezuela, a country in economic crisis.

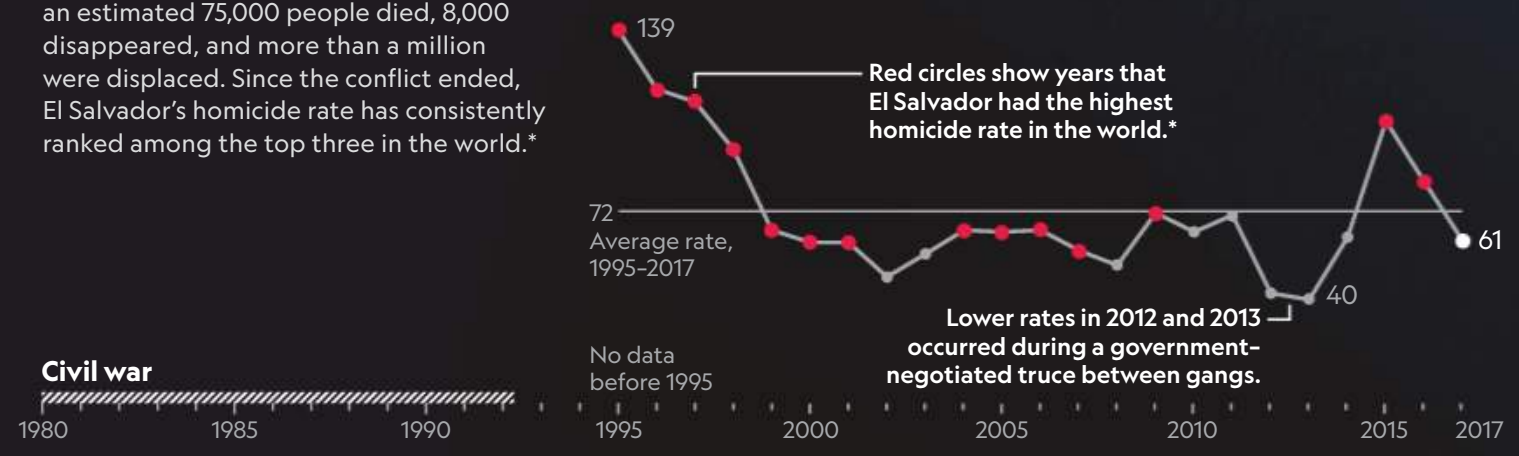
Select homicide rates in the Americas, 2017
Homicides per 100,000



A History of Violence

The U.S. supported the Salvadoran government in a civil war during which an estimated 75,000 people died, 8,000 disappeared, and more than a million were displaced. Since the conflict ended, El Salvador's homicide rate has consistently ranked among the top three in the world.*

El Salvador's homicide rate, 1995–2017
Homicides per 100,000



RILEY D. CHAMPINE, NGM STAFF; NAT CASE, INCASE, LLC
*EXCLUDES COUNTRIES IN AN ARMED CONFLICT

The homicide rate in the capital, San Salvador, is almost four times higher than in the country as a whole.

An alleged thief lies dead in a bus after a passenger, in self-defense, shot him and another assailant (who lived) during an attempted robbery in downtown San Salvador. The shooter fled the scene.


37


19
LUNES / Monday
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Programmer
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After a gang truce began to fall apart in 2013, the homicide rate in El Salvador reached 104 per 100,000 people in 2015, one of the world's highest.

The diaries of forensic criminologist Israel Ticas, with photos here showing two mass gravesites, document his relentless efforts to find the hidden victims of gang violence. Ticas has exhumed hundreds of bodies from clandestine graves across the country. Beheadings, dismemberments, and signs of torture are commonplace.

national homicide rate reached 104 per 100,000 people in 2015. Authorities have responded with a campaign of "extraordinary measures." They include the creation of elite police units, use of the army troops in security efforts, and near-free rein to conduct searches and seizures. In January 2015 the government gave officers a green light to shoot at criminals "without fearing consequences for their actions," heralding a shift toward shoot-to-kill tactics borne out by mounting reports of extrajudicial killings and torture that hark back to 1980s-era brutality.

Julio rocks back and forth. Another text comes through, and he takes off.

On our way back to the pastor's church, Aaron tells me he's several months from graduating from high school and wants to pursue a degree in physical education to support his mother, who sells secondhand clothes from the U.S. Trouble is, he can't leave the barrio. A couple of months back, he had to decline a spot with a soccer club because if he played on 18th Street turf, his neighborhood affiliation could get him killed.

"I try to keep my distance from the homeboys and stay on the right path," he says, "but it's like prison." Hernández says many young men like Aaron end up wasting away and getting girls pregnant, adding to the socioeconomic pressure that fuels *la delincuencia*, or criminal activity.

The last time Aaron asked his older brother in Houston to send money so he could travel north, his brother urged him to stay put because life in the U.S. was getting harder. "What's left?" Aaron sighs. "Join the gang? I don't want to do that because I know my fate—I'll end up dead."

At that moment a truck full of police officers in tactical fatigues and black ski masks whips around the corner, then slows down to size us up, assault rifles at the ready. Aaron throws them a wary glance; the truck moves on. A couple of blocks farther down the street, Julio pops out from a back alley, sweating and short of breath.

ON A HOT SUNDAY MORNING in the Dina neighborhood, an 18th Street stronghold in south San Salvador, Pastor Nelson Moz stands before a packed house at the Eben-Ezer Baptist Missionary Church. He opens his sermon with a call for divine protection in a time of darkness. The front line with MS-13 is less than 50 yards up the street, and tit-for-tat killings have spiked recently. Out front, latecomers stride past a derelict car with a blown-out rear window.

The pastor's words resonate with Sara, a lifelong resident whose grandson Alex was gunned down three years ago around the corner from her family home. She says he was killed by police officers after he refused to talk to them and kept walking. "He was a good boy," she affirms. Afraid to pursue justice for fear of reprisals from the police, the family raised money to hire a coyote to guide one of her daughters and a granddaughter to Indio, California, where two of Sara's other children lived. They send money home every month, but all are undocumented and the rise in immigration raids has her on edge. "Their fate," Sara says, "is in God's hands."

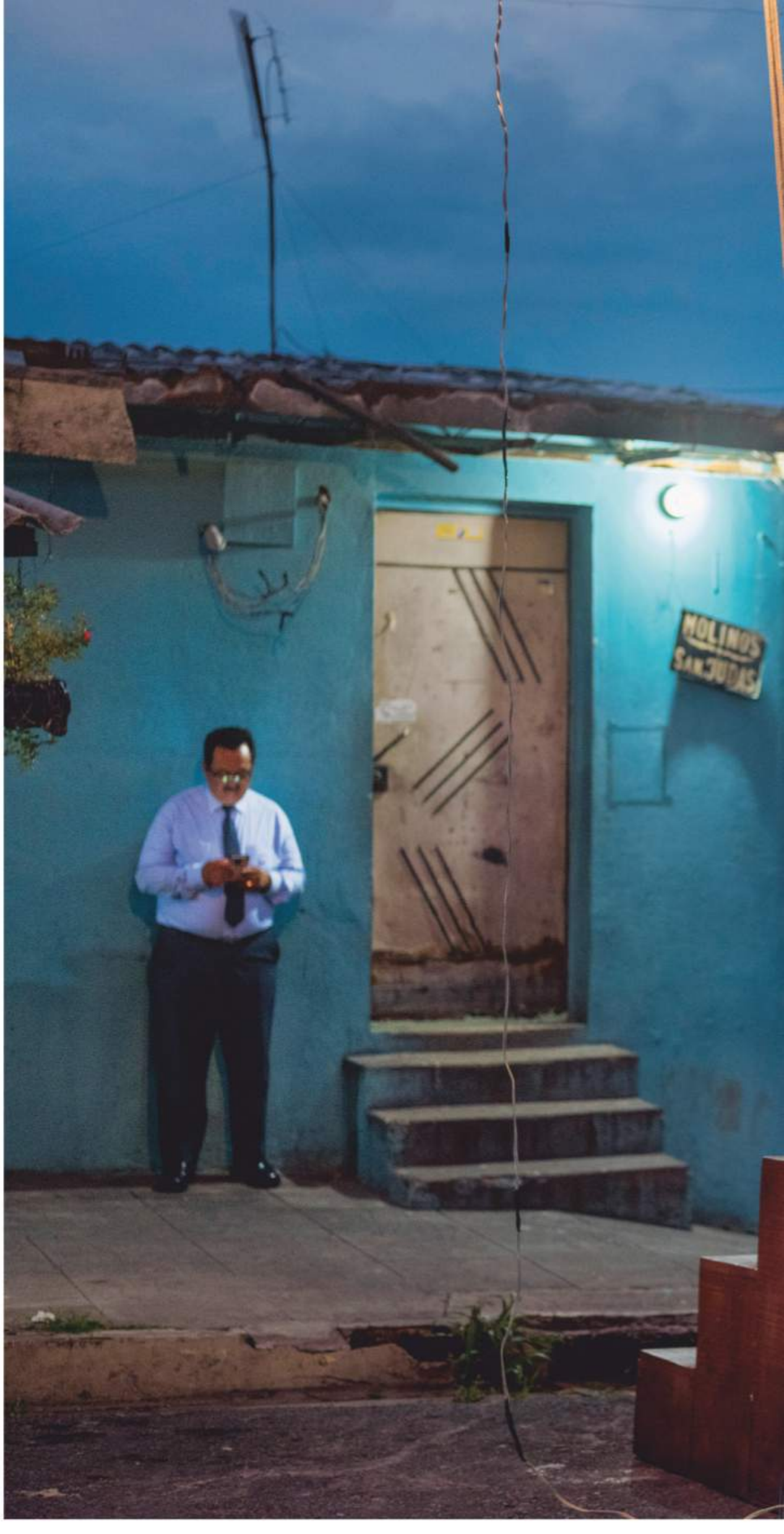
Gang markings carry a heavy social stigma and make members an easier target for rivals and police.

The sermon segues into a parable about sin and redemption, a theme important to the dozen or so former gang members in the crowd who have found their way to Moz's rehabilitation program. Some have covered their facial tattoos with makeup. Gang markings carry a heavy social stigma in El Salvador and make members an easier target for rivals and police. Eyes closed, palms raised to the sky, the men shed tears and offer up pleas for forgiveness.

Moz's charges live on the church premises, under strict conditions. To stay, they must

A net protects María Agustina Márquez from mosquitoes in the home she shares with her husband and granddaughter near Intipucá. Many there rely on remittances from those in the U.S. Both her sons are in the U.S. but barely manage to send money home.

Religion is one of few pathways for Salvadorans who want to renounce gang life and make a fresh start.



Wilfredo Gómez, a former 18th Street gang member turned preacher, speaks at a memorial service in San Salvador's Dina neighborhood. The service honored a parishioner and ex-gang member killed by rivals after his release from prison. "You walk with God or the devil, but you can't serve both," another former gang member said.


EBEN-EZER

renounce the gang and study the Bible. They sleep in cramped bunks, rise at dawn to bake bread, which they sell to support themselves, and pledge to get their ink removed.

It's life on a razor's edge. "The state knows nothing but pressure and violence, which creates more violence," Moz explains. "And the gang forgives nothing." He shows me a picture on his phone of a 19-year-old who strayed from the program, lying facedown in a pool of blood, one of five young men he's lost.

A memorial service is held that afternoon for another of his flock: an 18th Street member who joined Moz's church after seven years in prison, only to be gunned down in front of a corner store two blocks away. An evangelical rock band warms up next to the spot, and Ricardo, the former barrio gang leader, is rigging up the speakers.

In 1983 Ricardo, then 18, fled Dina for the U.S. He arrived in Los Angeles as the gang culture there was metastasizing from street brawls into gun battles over the booming trade in crack cocaine. He gravitated toward 18th Street, which was becoming one of the city's largest and most violent gangs. He rose to lead its notorious Shatto Park Locos clique before landing in prison in Southern California and signing his own deportation papers back to El Salvador. Ricardo has been shot five times. "I know I have to pay for the things I've done," he says.

In 2007, Ricardo says, he heard God's call and told the gang he was walking away. As an example for his sons and grandsons, he lasered off the giant 18th Street tattoo that covered his chest and stomach. Now in his 50s, he drives a delivery truck to pay the rent, goes home early, and tries to keep his distance from the active members, who are always watching. "You walk with God or the devil," he says, "but you can't serve both."

Salvadoran fisherman Arnovis Guidos Portillo watches his daughter and son in their home in Usulután department. After reaching the U.S. together in May 2018, father and daughter were detained by immigration authorities and kept in different facilities for more than a month before being deported separately to El Salvador, where they reunited.

ISRAEL TICAS IS AN EXPERT on the devil's work. One of the few forensic criminologists working for El Salvador's attorney general, he's tasked with digging up the casualties of gang mayhem and calls himself "lawyer for the dead." Prosecutors need bodies to convict the killers they catch, so gangs have gone to great lengths to dispose of victims—and anyone who would dare unearth them. Ticas, who has survived attempts on his life, says he carries a pistol wherever he goes and expects that one day he too will be killed.

At the end of a long, tree-shaded dirt road that runs into a coffee plantation outside San Salvador, Ticas is searching for his 66th body of the year, accompanied by a squad of armed police and a slight young man in baggy jeans and balaclava: the informant, a defector from 18th Street. The victim he's helping Ticas locate was a fellow 18th Street member whose arrest and swift release brought suspicion that he was a rat. According to Ticas, the gang lured him to the plantation on the pretext that they'd be killing an MS-13 rival, then strangled him with a wire, chopped up the corpse with a machete, and buried the remains at the base of a tree.

Three years have passed since then, and the informant's guidance yields nothing. "This dirt here is too dark and uniform," Ticas explains. "If this were the right spot, the colors would be mixed"—a sign the ground had been disturbed. "Like this," Ticas says. He starts a series of fresh

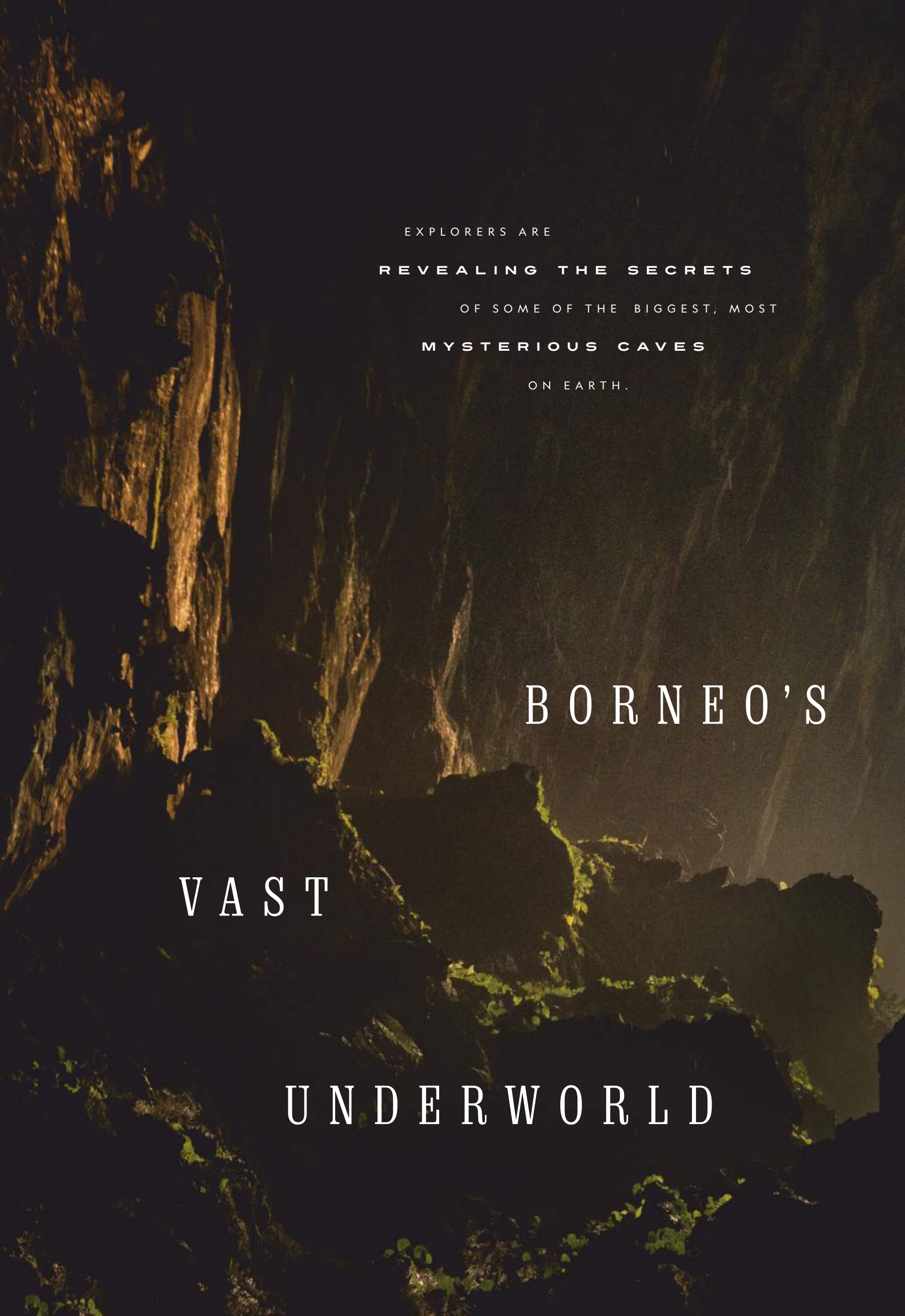
holes and tells the informant to keep digging.

The last time I followed Ticas to a crime scene, he smashed through the floor of an abandoned house to exhume a man who'd been hog-tied and stabbed. In a country where murder has become mundane, Ticas keeps exhaustive records and chilling mementos in his office "museum": skulls, homemade weapons tainted with blood, snapshots of beheadings, flayed bodies, and other torture killings too obscene to describe.

Most victims Ticas unearths are women and girls—used, abused, and targeted in revenge killings. In 2017, 468 women were killed, one every 19 hours. Countless others are missing. One survey found that only six out of every hundred women would even report a rape, reflecting an overwhelming fear of gangs and the systemic betrayal by authorities, says Silvia Juárez of Ormusa, a group that works to stop violence against women. The state is "failing" to address an epidemic of femicide and sexual violence, she says, "and this is what's causing so many women to flee."

At a safe house in the capital, a transgender woman who says she was gang-raped and then threatened by police after reporting the crime says it's too dangerous for her to try to leave. Her only option is to lie low and hope her asylum request is granted by a European country. In the past the destination of choice was reliably the United States, a haven for the oppressed. These days it's looking more like a dead end. □

Jason Motlagh has reported on migration issues from Bangladesh to the Darién Gap. He lives in Mexico. Documentary photographer **Moises Saman**'s work has focused on the wars in Iraq and Afghanistan and the Arab Spring and its aftermath.


EXPLORERS ARE
REVEALING THE SECRETS
OF SOME OF THE BIGGEST, MOST
MYSTERIOUS CAVES
ON EARTH.
BORNEO'S
VAST
UNDERWORLD

BY **NEIL SHEA**

PHOTOGRAPHS BY **CARSTEN PETER**

Limestone pinnacles pierce dense vegetation near the center of Malaysia's Gunung Mulu National Park. Eroded from the thick limestone bedrock over hundreds of thousands of years, these karst features hint at the otherworldly caverns belowground.

PREVIOUS PHOTO

At dusk, a swarm of bats disperses to hunt in the rainforest surrounding Deer Cave. One of the planet's largest underground passages, it holds more than two million bats.

Sarawak Chamber, briefly illuminated by dozens of flashbulbs, is the largest cave chamber yet discovered on Earth—more than twice the size of Britain's Wembley Stadium—and home to thousands of small birds called swiftlets.

PANORAMA COMPOSED OF FIVE IMAGES

Waterfalls roughly 400 feet high pour through the roof of Deer Cave after a rainstorm. A few of Gunung Mulu's caves contain large rivers, which swell into wild torrents during heavy rains.

Late on a sweltering morning in April, two slim British cavers named Frank and Cookie lowered themselves into a slick, humid pit deep below Borneo's rainforest.

CLIMBING DOWN PAST AN ANCIENT HEAP of bird guano and pushing through a gallery of gleaming pillars the color of old bone, the pair were hoping to make history. They had crawled into Cave of the Winds, deep inside a cave system known as Clearwater, where they would search for a passage to Racer Cave, part of the Racer-Easter system.

Connecting the two would create a "super system," one of the longest subterranean labyrinths on the planet. As the men wormed down, drilling and hammering bolts into the slick rock to hold their climbing ropes, their odds of success seemed good.

Already they knew Clearwater stretched for 140 miles and that some of the caverns were lined with turbulent rivers, while the Racer-Easter system contained chambers so enormous that a jetliner could fit easily within its walls with plenty of room to spare. In other words, the limestone underlying this region, beneath Malaysia's Gunung Mulu National Park, is riddled with some of the biggest holes, widest tunnels, and most mind-blowing voids anywhere on Earth.

If you are the kind of explorer who enjoys crawling down into wet, hot darkness in order to find more wet, hot darkness, Borneo is a dreamland, a Disneyland, and a Neverland, all in one.

Now imagine them down there, Frank and Cookie, mud smeared and grinning, on the verge of joining two cave systems into a single, immense whole. Not your thing? Well, for cavers, it's *the* thing. And it's rare that such superlative connections are made. In the often obscure world of underground exploration, which is governed by international bodies with names such as the "Longest, Largest, and Deepest Committee," such a feat would be a very big deal.

Elsewhere far below the Earth's surface, in the entrails of Racer Cave, another team was slithering into place. They too carried hammers and a drill, and soon the two teams would begin banging on the cave walls and drilling into the rock, listening for each other, hoping noise would lead them to a connection and a spot in the record books.

Not far above them, I sat in a large gallery, listening for their drills. The gallery was pristine; it had been discovered only days before, and I was one of the first ever to enter it. But where I sat, surrounded by towering stalagmites and colossal

mushrooms of stone, the cavern was alive with other sounds. At my elbow, water tinkled into limpid basins, while overhead, thousands of swiftlets—tiny black birds that spend much of their lives in the pitch-black chambers—twittered and clicked and echolocated toward nests made of saliva, moss, and mud.

If Frank and Cookie were making history somewhere below my feet, I wasn't going to hear it. But that was fine. More than any other sport, caving is about secrets and the things we endure to find them out. Sometimes all you can do is wait to see what the darkness reveals. So I lay back, turned out my light, and listened as the swifts swooped low, coming so close I could feel wingbeats on my cheeks.

CLARE TRAINOR, NGM STAFF

Thick stands of stalagmites rise from moon-pale banks of sediment in the Drunken Forest—a cave named for formations that tilt at unusual angles.

PANORAMA COMPOSED OF FOUR IMAGES

"THIS IS A VERY EXCITING PLACE. Where else on Earth can you find so much unexplored territory?"

A huge grin lit Andy Eavis's face. Then the expedition leader frowned.

"Well, I suppose there are a few spots," he said, considering his own question. "Papua New Guinea comes to mind. And of course, there's the bottom of the sea. But anyway, no. So far as cave exploration is concerned, Borneo is singular. There's no place like it under the earth."

Eavis, stout and hale at 70, felt comfortable staking the claim. He has spent more than 50 years exploring some of the world's most remote and fantastic subterranean systems and has served on nearly every one of his sport's governing bodies, helping decide how caving records are kept and how titles such as "biggest" and "deepest" are bestowed. Less formally, he's spent years working to protect caves and ensure they remain open to the cavers who love them. Eavis is, by any measure, an ambassador of the underworld.

It was morning in the rainforest, and Eavis stood on the porch of a research station near park headquarters, preparing to go underground. A sweltering breeze fell through the canopy, silencing the whir of innumerable insects.

Along the walking trails, snails and frogs scurried back into the shadows while birds shrieked and booed at the rising heat. Eavis pulled on black running tights—standard wear

A spelunker appears as a small speck in Deer Cave's gaping mouth—nearly 500 feet high. Sunlight penetrates deep inside, allowing mosses, ferns, and algae to flourish near the entrance. On the floor, crabs, insects, and bacteria feed on bird and bat guano.

Originally carved by subterranean rivers, Credence cave system was slowly pushed upward by tectonic forces, which lifted it away from water and helped dry it out.

for explorers in "hot" caves like those in Borneo, where temperatures can reach 80 degrees F.

"Of course, when I got started, we didn't have kit like this," Eavis said, waving at the tights. "Or this." He held up a battered red helmet to which he'd fastened a lamp big as a teacup.

"Back then, we were basically stumbling around in the dark. We had no idea the immensity of the things we'd discovered."

IN 1979, EAVIS ARRIVED in Borneo as part of a British expedition designed to study the rainforest and help the recently independent Malaysia understand the newly established Gunung Mulu National Park. Caving was still a relatively young sport, and Eavis and a team of four others were brought on only after expedition leaders realized that there were huge caves among the forest's many treasures.

Eavis and his friends had honed their skills back home, in Britain, where caves were commonly small and cold. Borneo's caves, opposite in almost every way, pushed Eavis and his companions into another dimension.

With their first discovery they set their record for size: It was called Deer Cave, or Gua Rusa, and its entrance was so enormous—nearly 500 feet high—that the sun reached deep inside and fresh air followed, creating a strange and wonderful habitat in the seam between daylight and darkness. A mammoth colony of bats clung to the cavern's roof, while on the floor thick piles of guano teemed with cockroaches, crabs, worms, and hosts of specialized microbes.

The British team found that Deer Cave stretched for nearly two miles, and for a decade afterward it stood as the world's largest known cave passage. In 1991 a cave discovered in Vietnam, called Hang Son Doong, surpassed it, but the drop in rank did not dull Deer Cave's allure. Today it's a major attraction for tourists, who wander its length on a boardwalk and gather at dusk at its mouth, drinks in hand, clapping and sighing as millions of bats stream like smoke into the sky.

Ostentatious, obvious, oversize—Deer Cave hinted at what more awaited underground. Over three months in Mulu, with the help of guides from the nearby Penan and Berawan tribes, the cavers came upon a score of entrances leading deeper into the region's ancient limestone.

Some of the caves began as obscure cracks in rock faces, covered with brush and branches. These, usually at higher elevations, were older, relatively dry caves that bored through the heart of Mulu's mountains.

Other caves, at lower elevations, were like giant storm drains—massive holes in the bedrock that channeled rainfall into subterranean rivers. These river caves were younger, formed hundreds of thousands of years ago, lined with beautiful limestone formations, and home to fish, birds, snakes, ghost-white crabs, and a galaxy of insects and spiders.

During their time belowground in 1979, Eavis and his fellow cavers explored some 30 miles of passages—an unprecedented feat. Nearly 40 years later, wearing black tights in the hot syrup of morning, Eavis smiled at the memory.

"There's no expedition that's ever explored that much at one time," he said. "We did most of it standing up, you see."

Eavis paused, stared down at his tights, and bent at the waist. He picked a leech from his bootlace and flicked it into the jungle.

"Up to that point we were all just simple English cavers," he said. "Mulu transformed us."

THE 1979 ADVENTURE set the stage for exploration in Borneo. Several caving teams have since made the long journey to Mulu, and Eavis himself has led many of them. For his 13th trip, in 2017, he organized a team of 30 cavers, including his son Robert and many Mulu veterans. In late March I reached him by phone in Kuching, a city on Borneo's west coast, as he traveled north to meet them.

"We will probably find somewhere near 30 miles of new cave passage," he said confidently. "And nobody ever does that. Except for me, I suppose."

Two weeks later, when I joined him in Mulu, that faith had been tempered. The expedition was divided into three main teams. Two of them searched for new passages in a remote area of the rainforest while the third, called the "connection team," pored over maps, looking for spots where different cave systems might be linked.

So far, Eavis said, the pace of discovery had been slow and the holy grail of connections—the one Frank and Cookie would later probe for—had eluded them. Eavis acknowledged disappointment, but his teams still had found more than seven miles of fresh passage, and more lay ahead.

The morning after my arrival I joined Eavis and a small crew headed for a cave called Gua

Nasib Bagus—the Good Luck Cave—which holds the otherworldly Sarawak Chamber. Eavis, with other British explorers, had discovered the cave and the chamber in 1981, by following a river into the side of a mountain.

After climbing, pulling, and crawling upstream for hours, the cavers arrived at a still, calm place where the river vanished into the earth. The men unfurled measuring tapes and began surveying into the gloom, expecting to reach the rear wall soon.

But no wall appeared. So they tried a different tactic, veering sharply, figuring they'd bump into a side wall. They heard swiftlets calling overhead, the river roaring somewhere beneath their feet. Still no wall. Their headlamp beams simply dissolved into the darkness.

After 17 hours of exploring, the men tumbled out of Good Luck Cave, soaked and confused. Either they'd just spent hours walking in circles, or they'd made an astounding find.

down—natural caves are nonlinear and expand and contract according to the movement of rocks, the meandering of water, the work of chaos.

Concepts of "up" and "down" assume subtler meanings underground, where directions can be utterly inverted over a few million years. If someone is exploring the down part of the cave, another caver might try looking up. And up was Mad Phil's specialty.

His nickname apparently had come from a canoeing stunt during his university years, but Mad Phil was known for climbing cave walls that no one else would even attempt. He and Eavis planned to ascend into the roof of Sarawak Chamber, searching for tunnels that ran through it like hidden passages in the ceiling of a mansion.

RAIN FELL as we wound through the forest. Gradually it came down harder and faster, the noise

THE MEN EMERGED SOAKED AND CONFUSED. EITHER THEY'D SPENT 17 HOURS WALKING IN CIRCLES, OR THEY'D MADE AN ASTOUNDING FIND.

Later teams proved that Sarawak Chamber is the largest known enclosed space on Earth, at 2,000 feet long, 1,400 feet wide, and almost 500 feet tall. It's more than twice as big as the United Kingdom's most celebrated sports arena, Wembley Stadium.

AS WE TREKKED toward Good Luck through thick rainforest, I asked a caver named Philip Rowsell, known as "Mad Phil," why an ambitious explorer would return to this storied terrain if so many records had been set here. He told me that caves never reveal everything during a first visit.

"You often find things earlier guys missed. Especially if it's so frickin' massive that they're sort of stunned."

Sarawak Chamber was so big, Mad Phil explained, that it almost certainly contained new passages—particularly in the roof, where no one had ever searched. Although it's tempting to think of caves as similar to mine shafts—tunnels that slope relatively straightforwardly drowning all sound and talk. Soon the forest itself blurred, fading in the deluge until all life seemed separated by only the sheerest of membranes.

An hour later we arrived at the mouth of Good Luck Cave, where a river emerged from a tall cleft in a wall of limestone. We waded in and pushed ahead, the clear warm water reaching first to our calves, then swelling over our hips, then shoving into our chests.

The passage widened and grew, opening like a train tunnel above us. Bats and birds commuted through it, occasionally dipping into our headlamp beams, and soon the river became whitewater, blasting through sharp channels of limestone, forcing us onto boulders slick with spray and guano.

The route was so treacherous that in certain places previous cavers had bolted ropes to the walls so they could drag themselves forward against the current.

After a wild and sodden mile, the river disappeared into the earth, and Sarawak

Chamber swallowed us into its vastness.

Even when every lamp focused upward, we could see only the dim suggestion of its massive dome. And if we turned our lamps toward the back of the cave, we saw nothing at all. It was easy to imagine Eavis and his friends lost, years before, in the void.

"If you look around, you might find our old boot prints," Eavis said, laughing. "Stumbling around like blind mice we were."

THE WEIRD THING about caves is that you remember them brightly. Dim in certain corners, but otherwise the walls and rocks and spiders are pretty well illuminated. Photographs only enhance this illusion. What's true is that except for the instant when a photographer's flash dumps light through a cavern, most everything is invisible.

With no sunlight to measure time, we marked it with meals, tea, and chocolate bars.

a dozen of them, passing from a pile of loose, muddy boulders into a maze of limestone with walls sharp as the face of a cheese grater, to an eerily quiet niche carpeted with feathers and deep drifts of guano that seemed a place where cave creatures—birds, spiders, crickets, centipedes—went to die.

Beyond that lay a hushed nursery where the cave was so warm, so still, the swifts felt safe laying their eggs on bare ground. We never found another entrance, though surely there was one—the sound of water and swarms of birds told us that. But we'd have to leave it to future cavers.

IN THE END, Eavis's team did not rack up more record-setting discoveries. Frank and Cookie—the mud-covered pair, drilling and banging at the bottom of a cave—never connected the Clearwater cave system to its neighbor that seemed so tantalizingly close. But the

BEYOND THE EDGES OF CAMP A CONSTELLATION OF

LITTLE JEWELS GLINTED IN THE LAMPLIGHT—

THE EYES OF SPIDERS, SOME AS BIG AS MY HAND.

Near the chamber's entrance, Mad Phil began drilling bolts into the wall, working his way around an overhanging ledge to the roof. The rest of us explored below, pressing forward, sounding the planet's largest known enclosed space.

Overhead the swifts chattered and bickered and called without rest, occasionally dropping down to land on our chests, where they would sit and allow themselves to be petted.

At "night" we set our bedrolls on flat rock and strung up lines to air out our socks. The chamber was humid and warm, as though the darkness itself were wet, and beyond the edges of camp a constellation of little jewels glinted in the lamplight—the eyes of countless spiders, some as big as my hand.

One "day," with Mad Phil and a young caver named Ben, I explored along the left side of the chamber, searching for another entrance. Sarawak is so large that it contains many distinct precincts, and we climbed through at least half

expedition succeeded in finding and mapping a respectable 14 miles of new passages.

A few weeks after I left Borneo, I spoke with Eavis, who had returned to Britain. He told me he was already planning a return trip to Gunung Mulu National Park to connect the caves himself.

"We were extremely close," he said.

He assured me it was not the pursuit of records, or the odd celebrity his sport sometimes bestows, that continued to drive him. He thought about the caves every day. His children knew well his stories from under the jungle.

"My guess is that only 50 percent of the passages have been discovered," he said. "Wouldn't you just want to know? Mulu is this incredible place, and I want to know what's down there and see how all the pieces all fit together."

It was, he said, the labyrinth of a lifetime. ▯

Neil Shea wrote about Kurdish forces battling ISIS in northern Iraq for the February 2016 *National Geographic*. **Carsten Peter**'s images of China's largest caves appeared in the July 2014 issue.

An expedition team member climbing toward the roof of Deer Cave dangles above a silhouette that looks like Abraham Lincoln. The sharp presidential profile is a natural feature of the limestone and one of the cave system's many curiosities.

TREE

THE MINI-MONSTERS OF THE RAINFOREST ARE MASTERS OF DISGUISE—AND FULL OF SURPRISES.

BY **DOUGLAS MAIN**

HOPPERS

PHOTOGRAPHS BY
JAVIER AZNAR GONZÁLEZ DE RUEDA

Known for their devoted parental care, treehopper mothers of the species *Alchisme tridentata* watch over their progeny until the young hoppers are old enough to fly away. The nymphs have barbs and bright red and yellow accents, probably warning that they're unpalatable.

PREVIOUS PHOTO

A treehopper of the genus *Bocydium* sports overhead orbs that may resemble a fungus that's deadly to insects.

If there were a competition for the world's weirdest insect, treehoppers would have a clear shot at first place. See one for the first time and you're sure to wonder, What *are* those strange protrusions sprouting from its body?

Many treehoppers flaunt outlandish outcroppings, such as the helicopter-like orbs of *Bocydium* sp. (above). Others play it coy, mimicking thorns, leaves, or insect droppings. Still others impersonate ants or wasps. Forty-plus named species, as well as another 700 or so awaiting scientific description, resemble drops of rainwater.

Those singular shapes, insect anatomists explain, stem from the treehopper's specially modified pronotum—a section of the thorax that in other insects resembles a small, shield-like plate. But treehoppers are the creative kids in their class, with their pronota arching into grotesque spires or globes, veritable billboards of their individuality.

As their common name suggests, these tiny insects—none are longer than a dime is wide—live on trees and plants worldwide, with nearly half the 3,200 or so described species inhabiting the New World tropics. One leaf in the Ecuadorian rainforest where this story was photographed could easily harbor more treehopper species than found in all of Europe.

Treehoppers are members of a huge and varied order of insects known as the Hemiptera, which include leafhoppers and cicadas. Like others of their kind, they're equipped with mouthparts for piercing plant stems and slurping the juices inside. A bit like mosquitoes, they have two interlocking, needlelike feeding tubes, one for siphoning fluids, the other for secreting saliva that prevents the juices from coagulating.

Because they're often content to feast on one plant's bounty their entire life, most treehoppers pose little threat to economically important crops (though they may spread at least one botanical disease). Partly for this reason, treehoppers haven't been studied as extensively as their close relatives. This lack of scientific attention has left significant gaps in our knowledge of these bugs, including the purpose of their mystifying body modifications.

It's a good bet that those pronounced pronota help protect treehoppers from predators. Spines and barbs warn that they might be tough to swallow, and bright colors advertise toxins within. Mimicry—the art of appearing to be something else—also plays a defensive role. The strange globes crowning *Bocydium*'s body resemble globs of *Cordyceps,* an insect-killing fungus common in rainforests.

Though the pronota are large, they're also hollow and lightweight, allowing the insects to fly with surprising ease. Intriguingly, their

pronota are wired with nerves and hairlike structures known as setae that receive unknown stimuli and may help the bugs sense their environment, says Stuart McKamey, a researcher with the U.S. Department of Agriculture's Systematic Entomology Laboratory.

While it's tantalizing to imagine what information treehoppers may glean with these receptors, their main mode of communication involves plant-borne vibrations. In contrast to their cicada cousins, which communicate by rubbing body parts together to produce shrill songs, treehoppers shake and jerk their bodies to send signals through plants, says Rex Cocroft, a researcher at the University of Missouri. Cocroft and other researchers record these vibrations with microphone-like devices that reveal a chorus of calls, clicks, chirps, and songs—none of which are audible to the human ear.

This ability to communicate with each other helps treehoppers defend their young. Unlike most insect mothers, which desert their eggs soon after laying them, many treehopper mothers remain present and vigilant, guarding their offspring until the nymphs grow up and fly away. When predators such as stinkbugs approach, the nearest nymph sounds the alarm by swinging its body and producing a vibrational "chirp." Siblings pick up the vibe and join in, amplifying the signal. Springing into action, the mother confronts the invader, furiously buzzing her wings or punching with her club-shaped back legs.

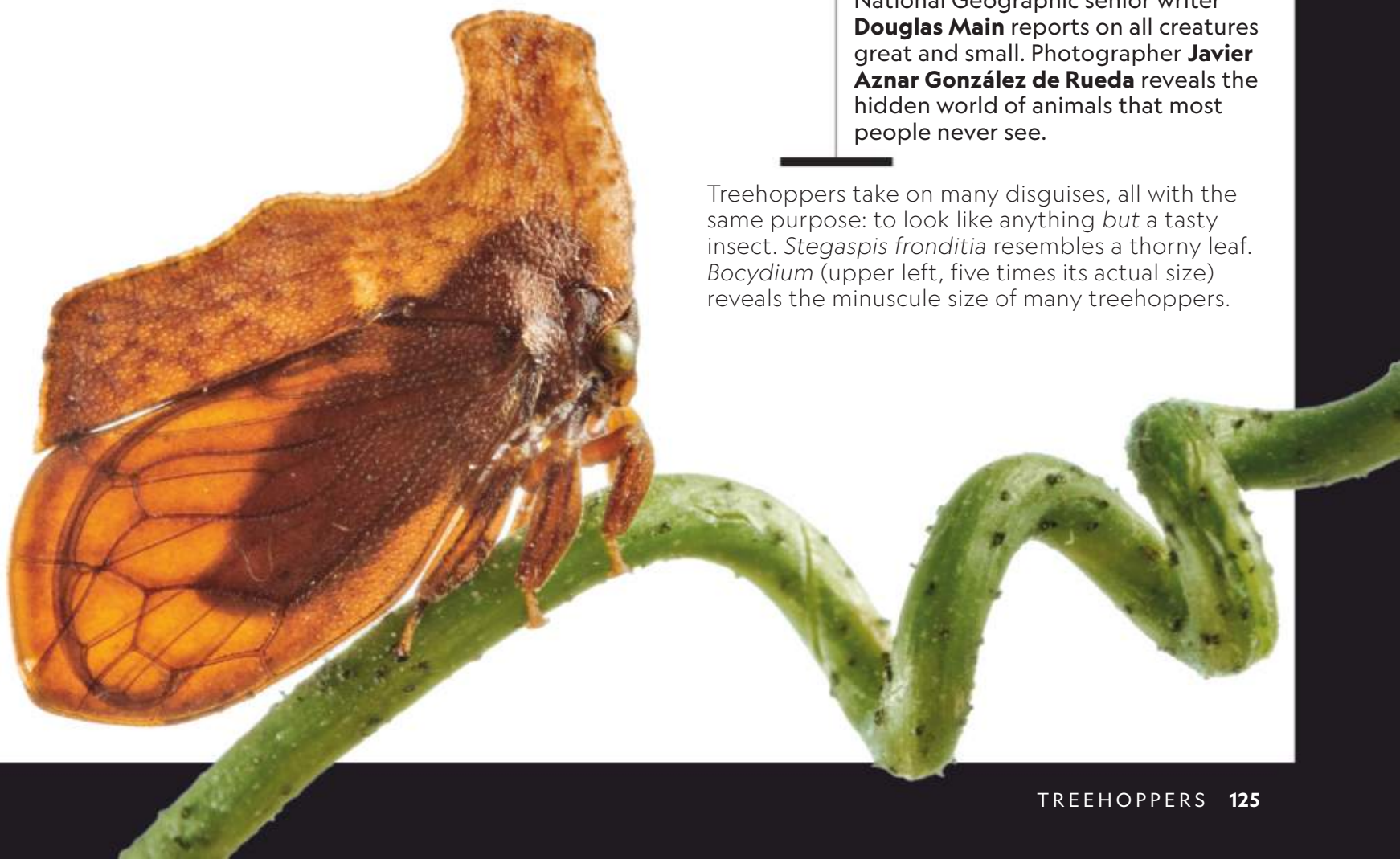
Many treehoppers flaunt outlandish outcroppings. Others play it coy, mimicking thorns, leaves, or insect droppings.

Sometimes treehoppers get help from ants and other insects that provide protection in exchange for honeydew, a sweet liquid treehoppers secrete as a product of constantly drawing plant sap.

Collecting treehoppers that have ant allies can be painful: "You'll get dozens of stings on your hands," says Chris Dietrich, curator of insects at the Illinois Natural History Survey. But the astonishing variety of these bizarre bugs makes for endless surprises.

"When you work with insects," McKamey says, "it's like Christmas every day." ▯

National Geographic senior writer **Douglas Main** reports on all creatures great and small. Photographer **Javier Aznar González de Rueda** reveals the hidden world of animals that most people never see.



Treehoppers take on many disguises, all with the same purpose: to look like anything *but* a tasty insect. *Stegaspis fronditia* resembles a thorny leaf. *Bocydium* (upper left, five times its actual size) reveals the minuscule size of many treehoppers.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Spiky, thorny, tricky, sci-fi weird: Treehoppers come in countless shapes and colors.

1, 5, 14, 18: Treehoppers of the genus *Heteronotus* mimic ants and/or wasps.
2. An *Aetalion reticulatum* female cares for a mass of newly laid eggs.
3. *Phormophora maura*.
4. *Membracis* nymphs have spikes to dissuade predators.
6. *Membracis elevata*.
7. *Chelyoidea* sp. mimics the texture and color of turtle ants.
8. A treehopper of the *Cladonota* genus looks like a bird dropping.
9. *Gelastogonia* sp.
10. A thornlike *Enchenopa* sp.
11. *Adippe histrio*.
12. *Hypsoprora* sp., another poo mimic.
13. *Membracis bucktoni*.
15. *Tropidolomia auriculata*, a species attended by ants.
16. Ceresini sp.
17. The devil treehopper, *Hemikyptha marginata*, the world's largest known treehopper species.
19. *Stegaspis fronditia*.
20. *Stylocentrus rubrinigris*, possibly mimicking insect-killing fungi.
21. A stingless bee eager to drink honeydew from two *Aetalion reticulatum* females.
22. *Anchistrotus* sp. can lose its "helmet" and still survive.
23. *Nassunia* sp.
24. Bird-dropping mimic *Notocera* sp.
25. *Amastris subangulata*.

A prickly *Cladonota biclavata* patrols a tree near Ecuador's Napo River. Found from Mexico to Argentina, some treehoppers in this genus have among the largest pronota (their modified thoraxes). "It's pretty amazing that these things can even hop or fly with this big thing they're lugging around with them," says Chris Dietrich, curator of insects at the Illinois Natural History Survey. And yet most seem to do both with ease.

'Nature does nothing uselessly,' wrote Aristotle. Yet it's hard to glean the purpose of such tiny grandiosity.

A spiky mouthful, *Alchisme grossa* has thornlike barbs that may dissuade would-be predators. This perturbed bug perched on a red leaf after flying away from photographer Javier Aznar González de Rueda. But members of this species are more commonly found on foliage matching their own hue. They may appear unappetizing, but there's no need to tempt fate by sticking out.

BY **JACQUELINE CHARLES**

PHOTOGRAPHS BY **CHARLES FRÉGER**

RITUALS OF SPIRITED REBELLION

IN THE AMERICAS, CARNIVALS AND OTHER MASQUERADE CELEBRATIONS USE MYTHICAL ANIMALS AND MISCHIEVOUS DEVILS TO HONOR THEIR CULTURES' AFRICAN, INDIGENOUS, AND EUROPEAN ROOTS—AND TAKE A FEW JABS AT THEIR FORMER OPPRESSORS.

GUADELOUPE Seen as incarnations of spirits, Guadeloupean Carnival participants beat drums called *boulas* before Ash Wednesday in spontaneous marches meant to awaken the public. The painted halves of these young men represent their indigenous ancestry on one side and their Maroon ancestry on the other. They're standing in the sea near Baie-Mahault to symbolize the more than 12 million Africans enslaved by Europeans and transported to the Americas across the Atlantic from the 16th to the 19th centuries.

During a trip to Haiti a few years ago, I traveled off the beaten path and visited the southeastern port city of Jacmel, where Kanaval—the Haitian Creole name for Carnival—is celebrated the week before the National Carnival in Port-au-Prince.

Unlike festivities centered around *méringues,* as Carnival tunes are called in the French-speaking nation, Jacmel offers a more homespun experience. From boys caked in black soot to the sound of *rara*—the Vodou rhythms that are a mainstay of Carnival celebrations in Haiti—to musicians beating drums or blowing trumpets made from recycled metal and bamboo horns, each rhythm tells its own story as it sends you dancing. I was awestruck by the wild artistry that floods the town's narrow streets. There were frighteningly beautiful interpretations of the devil, large mythical animals, and grotesque-looking masks made from papier-mâché.

For some, Carnival season, especially Mardi Gras in New Orleans, means body-baring excess, bead throwing, and a raucous free-for-all where debauchery and excessive drinking are encouraged. But in parts of the Caribbean, Carnival—known as Carnaval in Brazil—is more than the revelry that has turned such festivities into a glittery tourist draw. It's an artistic space, a public bullhorn, an unapologetic expression of cultural identity and empowerment by descendants of enslaved Africans. Forbidden from worshipping their deities or participating in the 18th-century pre-Lenten masquerade balls of their French and British masters, slaves merged African traditions and folklore with colonial rituals to create their own fete.

Today celebrations like Corpus Christi, Three Kings' Day, and Day of the Dead take different forms across the African diaspora and may be hosted at other times of the year, but the festivities have common elements. Colorfully and wildly dressed characters blend Christianity, folklore,

ANTIGUA AND BARBUDA At Fort James on the island of Antigua, the pink masks worn by troupes of clowns during Carnival may represent European colonizers. (During the 18th century, the British Royal Navy maintained and sheltered its Caribbean fleet at a well-protected dockyard on the island.) Carnival outfits worn throughout the Americas have roots in African, European, and indigenous traditions but constantly evolve in response to contemporary culture.

ST. CROIX Carnival in St. Croix is celebrated as it is in much of the British-colonized Caribbean, with a character called John Bull, which symbolizes the prosperity and gluttony of the empire. Before some of the Virgin Islands were sold to the United States, the representation often was made of natural fibers such as raffia but now typically is made of shredded plastic bags. Other variations of bull portrayals in the Caribbean include Red Bull in Saint Kitts and Nevis and Jonkonnu in Jamaica.

DOMINICAN REPUBLIC The devil is a key character of the Dominican Carnival, and his portrayal varies from village to village. The mask of this particular devil, Tifuá, can be made from an ox, horse, or cow skull, among other things. Tifuás take to the streets of San Juan de la Maguana, scaring children for their bad behavior. In the past, anything that did not reflect the Roman Catholic traditions of the time was labeled as "devil," forcing many African and indigenous traditions to be molded to Catholic beliefs.

PANAMA Commonly celebrated in mid-June in Chepo, the Corpus Christi tradition—which honors the body and blood of Jesus Christ—was used by the Catholic Church in the Americas to convert native people and African descendants to Christianity through street theater. Chepo's history includes the legacy of Bayano, a cimarron king who led one of the biggest slave uprisings in the Americas in the 1550s. These teenagers' outfits include papier-mâché masks—and mirrors, something also seen in West African culture.

UNITED STATES Mardi Gras Indians dress in ceremonial attire to honor the Native Americans who helped blacks in the United States escape slavery. In the weeks leading up to Mardi Gras, groups parade throughout New Orleans, each with their own chiefs and flag bearers. Travis Carter, pictured here, carries the "krewe" flag, an ornately decorated staff, for the Uptown Warriors. Each suit is handmade, with intricate bead- and featherwork.

HAITI Jacmel is home to one of the most creative Carnivals in the region. Photographer Charles Fréger says that some participants choose an elemental approach, using colorful body paint and other readily available materials. Haiti's first organized Carnival was in 1927, when the country was occupied by the United States. During Carnival season, participants masquerade to highlight the historical and current struggles of Haitian society.

and indigenous perspectives in a ritual of spirited rebellion. With their identities disguised behind ornate masks, revelers tell stories, release frustrations, and in places like Haiti, agitate for political and social change against a backdrop of pulsating pageantry and parody. Costumes and songs provide social commentary and political critique.

"This is a rebellion that is a cultural resistance," says Henry Navarro Delgado, an associate professor at Ryerson University who has explored the role of fashion in Carnival. "This is an opportunity for them to parade themselves as they really want to."

Some cover their bodies in paint and mud. Others dress in the vivid colors of African deities such as the fiery red and black of Ogun, the African god of war and iron, or the blue and gold of Erzulie Dantor, the goddess of jealousy and passion in the Haitian Vodou paradigm.

A central figure in many Carnivals is the mischievous *diablo,* the devil. In the Dominican Republic he might be a limping trickster parading around with a whip. In Trinidad he's sometimes a blue devil mocked and beaten by other devils to symbolize the brutality of slavery. And in Panama he's often the whip-wielding slave master fighting with escaped slaves, the cimarrons, in a traditional Congo dance that celebrates the slaves' resistance to their Spanish masters. The devil, of course, is bad in a Roman Catholic or European context. But during Carnival, he's usually the impish spirit who's needed to balance out the world and shake things up.

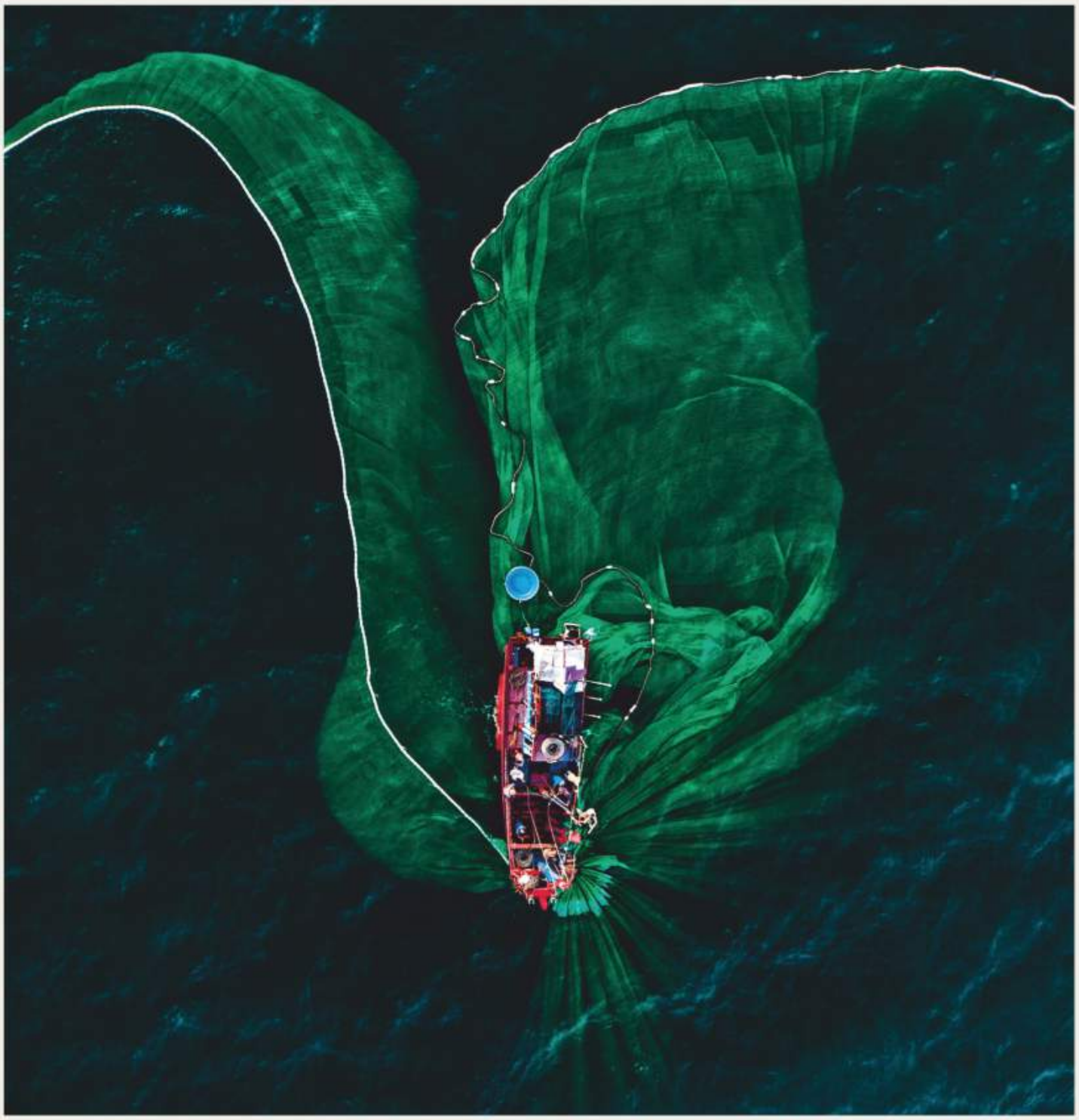
No Carnival is complete without the masked dances that capture the relationship between slaves and their colonizers, or in some cases, mock their oppressors.

Many of the dances require training, says Amy Groleau, curator of Latin American and Caribbean Collections at the Museum of International Folk Art in Santa Fe, New Mexico. She notes common themes, representing different social classes and ethnicities and even animals. "The characters have a sacred element to them," she says.

Whether it's the animal characters from Colombia or the Qhapaq Negro dance depicting Afro-Peruvians as enslaved laborers arriving with Spanish conquistadores, Carnival is more than just a bacchanal. It's a symbol of our history and heritage that unites us as blacks, regardless of language or geography. ▯

Jacqueline Charles covers Haiti and the Caribbean for the *Miami Herald.* **Charles Fréger**'s *Cimarron: Freedom and Masquerade* will be out this spring.

BRAZIL Across the country and in Boa Hora, a small sugar town in Piauí, Three Kings' Day is celebrated during the first week of the year. This masquerader, representing one of the three wise men who brought gifts after the birth of Jesus, is taking part in a *reisado,* a tradition in which groups of singers, dancers, and musicians serenade villagers and are offered food and drink in return.



YOUR SHOT

TRUNG PHAM HUY

PHOTOS FROM OUR COMMUNITY

WHO

Trung, a telecom engineer and, since 2016, a recreational photographer

WHERE

Hon Yen, a tiny island off the east coast of Vietnam

WHAT

A Phantom 4 Pro drone

From his home in Ho Chi Minh City, Trung traveled to the eastern Vietnamese islet of Hon Yen to photograph a village known for lobster fishing. One summer evening, with his drone several hundred feet in the air, he noticed an anchovy fishing boat in the corner of his monitor. As he watched, the boat released its nets into the water. They unfurled and drifted in the waves, almost lifelike. He repositioned the drone over the boat and snapped five images. "It looked like a flower on the sea," he says.

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RAISE ONE

TO THOSE WHO NEVER LET YOU DOWN.

–Raised Right–

Globe-horned Chameleon *(Calumma globifer)*
Size: Head and body length, 35 - 38.5 cm (13.8 - 15.2 inches) **Weight:** Up to 150 g (5.3 oz) **Habitat:** Montane humid forest **Surviving number:** May be as low as 130,000

Photographed by Jurgen and Christine Sohns

WILDLIFE AS CANON SEES IT

Madagascan mystery. Little is known of the globe-horned chameleon's life in the wild. What does it eat? How does it behave? The answers elude us. We do know that the forest denizen is well adapted to its environment, with microstructures on its feet and tail increasing friction on branches to ease its movement through the trees. But its habitat is shrinking due to logging and slash-and-burn agriculture, and poaching for captive collections remains rampant. This mystery may vanish before it can be solved.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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