HOW BRAINS DEAL WITH PAIN P. 40 BUILDING OUR CELLULAR ATLAS P. 62

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MARCH 2019

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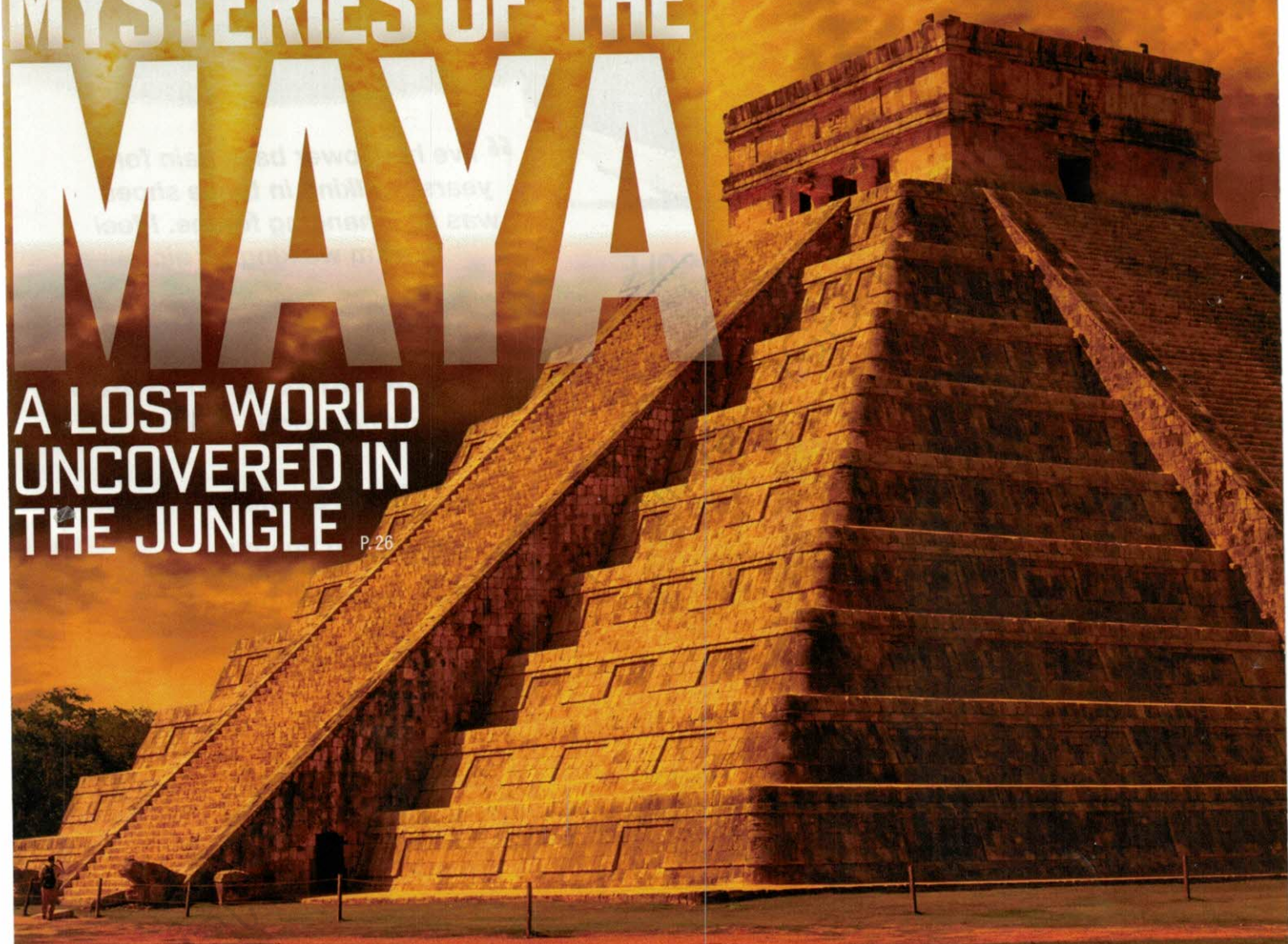
## A LOST WORLD UNCOVERED IN THE JUNGLE P. 26



PLUS

MESSAGES FROM DEEP SPACE P. 34

THE HAPPINESS DILEMMA P. 48

SETI'S SECRET ORIGIN STORY P. 68

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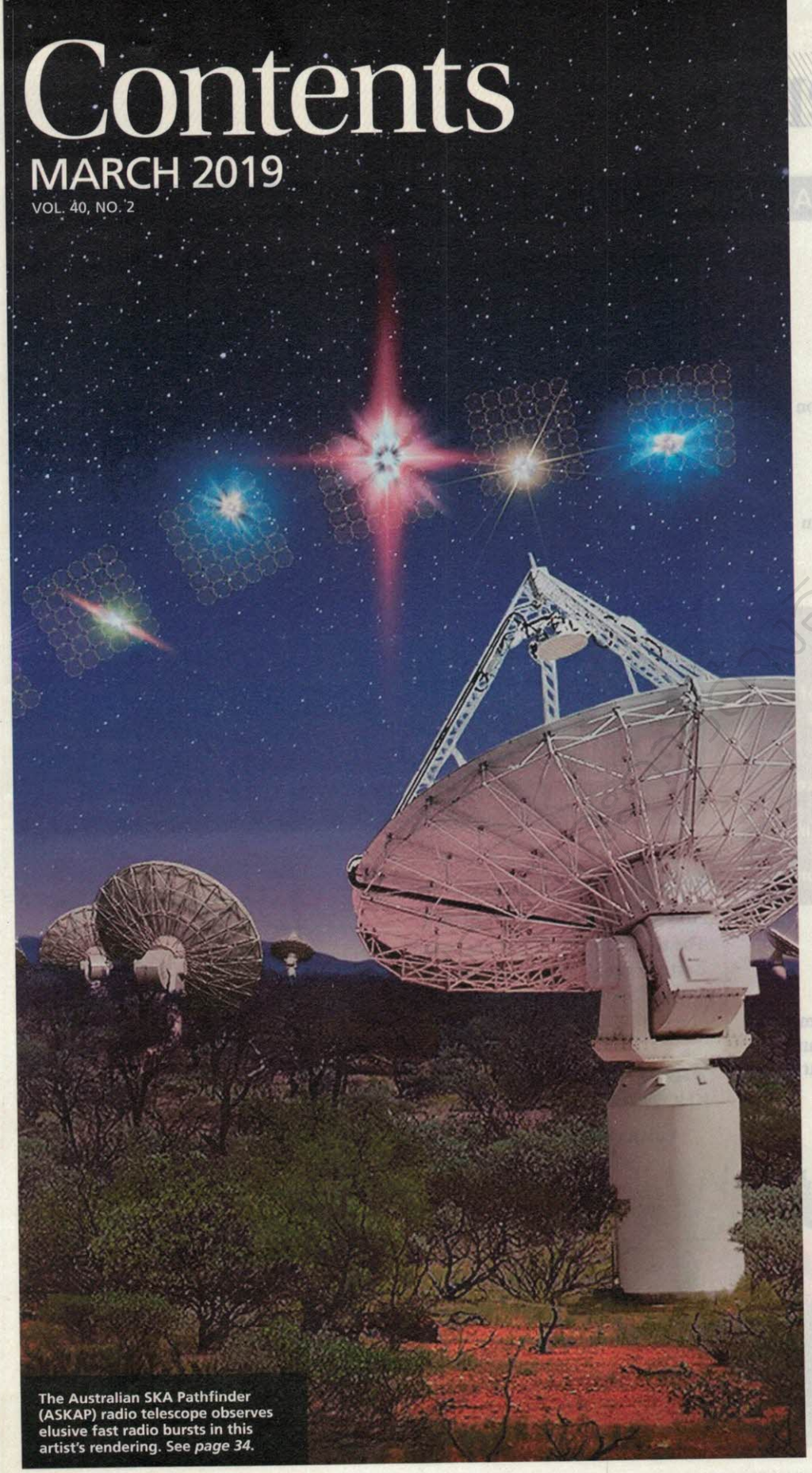
# Contents

MARCH 2019
VOL. 40, NO. 2



The Australian SKA Pathfinder (ASKAP) radio telescope observes elusive fast radio bursts in this artist's rendering. See *page 34*.

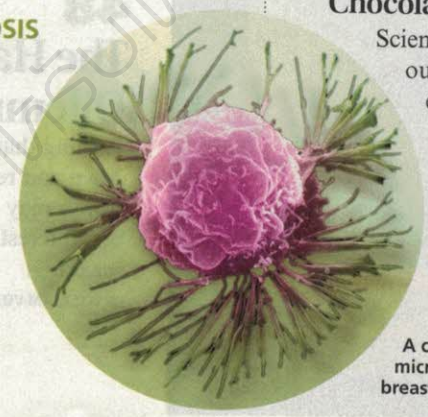
OZGRAV/SWINBURNE UNIVERSITY OF TECHNOLOGY

## FEATURES

# Contents

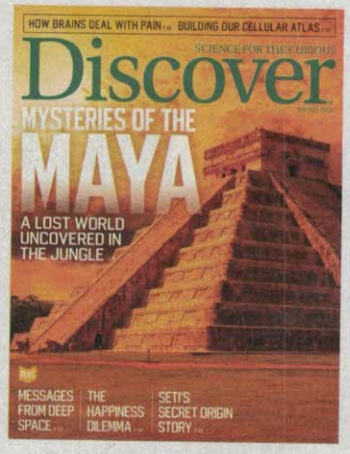
## COLUMNS & DEPARTMENTS





A color-enhanced micrograph of a breast cancer cell.



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*News Flash....*

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# Remains of Our Day

What will we leave behind, after this millennium's civilizations fade away?

I had this notion rolling around in my brain on the way to work this morning, as I threaded the car through a ridiculously overbuilt highway interchange.

We've got the infrastructure; we've got our churches, city halls and museums; and we have our homes and apartment buildings, some smack up against forests and others hanging along our coastlines. But as fire and water eventually scorch and swallow them up, our tracks will start to disappear.

Our lives could sink into mystery just as those of the Maya, a vast civilization that thrived more than 1,000 years ago and has since disappeared. Now the jungles of Guatemala are beginning to spill their stories.

Assistant Editor Nathaniel Scharping was along for some of the detective work last year when researchers visited recently uncovered archaeological sites. Special imaging that virtually cleared away all that foliage revealed massive structures that scientists had marched right past for years.

The on-high view of the topography has given them new leads to chase, and it may upend a few assumptions about how this well-studied society operated. Researchers are only just beginning to figure out the complexities, from military strategy to suburban development.

The Maya's immense structures and networks, now enveloped by dense forest, remind me of the fleeting nature of our time on this planet. How will those in the future know us?

Becky Lang

Feel free to send comments and questions to **editorial@discovermagazine.com**

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# Inbox

## PRINT FEEDBACK

### Junk in the Trunk

**("A Sprite-ly Spacecraft," November 2018)**

The development of a new micro satellite called Sprite is interesting, but there is a down side to this technology that was not addressed in the article. Launching them in multiples of 100 increases the very real problem of orbital debris, also known as space junk.

According to NASA, there are about half a million objects in orbit that are larger than a marble. If the micro satellite trend catches on, it could mean thousands of new micro bullets in orbit. Collisions of orbital debris increase geometrically, and the problem could reach a point where the chance of damage to functioning satellites will be high. Even Hollywood has picked up on this issue in the release of *Gravity* in 2013. I hope this remains in the realm of science fiction.

***Harry Grogan***
*Weaverville, N.C.*

### Driving to Destruction

**("Baby, Can You Drive My Car?" November 2018)**

Has anyone bothered to canvass the public to see if the majority of drivers actually want a self-driving car? As for myself, I enjoy driving and have zero interest in sitting back as a helpless passenger, putting my life in the hands of "foolproof" algorithms. Thanks, but no thanks!

***Al Keith***
*New Hampton, N.H.*

### Roots of Superstition

**("Knock on Wood," November 2018)**

I enjoyed Galadriel Watson's article on superstitious behavior and would have liked more. For instance, I wonder how many superstitions are just extensions of common sense. Walking under a ladder could, in fact, be dangerous, especially to the person on the ladder. Opening an umbrella indoors could break objects or poke an eye. You can cut yourself on a broken mirror. Over time, practical advice on behavior could simply have been exaggerated culturally.

It reminds me of when my son was 3 and refusing to brush his teeth. I told him if he didn't, they would fall out. He thought that I meant that very night, and I didn't disabuse him of that thought. Common sense oral hygiene took on an air of unlikely superstition. He knows better now, but nonetheless has gone 16 years without a single cavity.

***Tom Schnauber***
*Belmont, Mass.*

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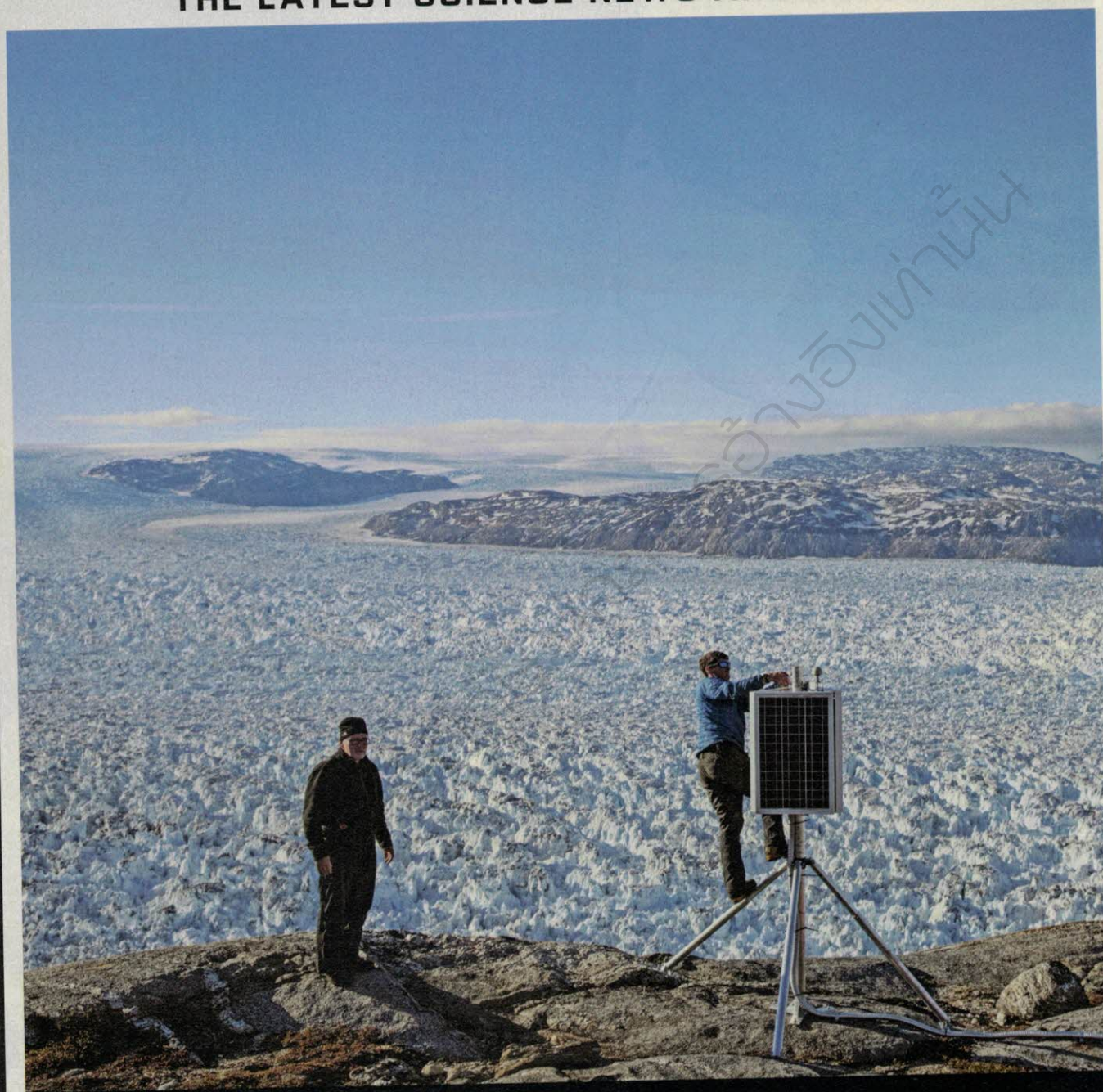
# THE CRUX

## THE LATEST SCIENCE NEWS AND NOTES



**ON SHAKY ICE**

Greenland's vast Helheim Glacier sprawls before oceanographer David Holland (left) and safety officer Brian Rougeux as they repair a solar panel array last summer. The setup powers a nearby seismometer that detects "icequakes" and helps researchers learn how the ice fractures. It's part of a land-, sea- and air-based program led by NASA's Jet Propulsion Laboratory, dubbed Oceans Melting Greenland. The effort will help scientists better understand the effect of rapidly warming deep ocean currents and how they melt Greenland's coastal ice from below. —ERNIE MASTROIANNI; PHOTO BY LUCAS JACKSON/REUTERS

NASA and National Nuclear Security Administration engineers lower the wall of a vacuum chamber around the Kilopower reactor system. The chamber will help test how the system performs in spacelike conditions.

BIG IDEA

# NASA's Powerful Plan

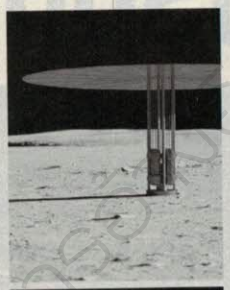
The agency's new nuclear reactor could change space exploration.

**WANT TO START A SPACE COLONY?** Even if you don't, space agencies across the globe do. Whether it's a moon base now, à la the Trump administration's plans for NASA, or a Mars landing later, such a colony will need a lot of power. And given the possibility of light-obscuring dust storms on the Red Planet and the moon seeing an uneven amount of sunlight, solar panels may not cut it. But don't worry — Los Alamos National Lab has a plan.

It hinges on nuclear power, which, at its most basic, consists of harnessing energy from radioactive elements. Often, this energy comes from a process called fission, when a neutron rams through an atom's nucleus, splitting it. A nuclear reactor houses this chaos and uses the resulting heat to generate power.

Now, experts at Los Alamos are pushing to get a high-power, next-generation nuclear reactor into space. Their best shot is called Kilopower: a reactor the size of a paper towel roll, enclosed in protective casing the size of a tall trash can, weighing around 900 pounds. It relies on splitting uranium atoms and generates up to one kilowatt of power — enough to run 10 43-inch LED TVs for an hour or, more practically, a rover like Opportunity, currently roaming Mars, for up to around six and a half hours.

Remarkably, none of Kilopower's components are that new. NASA has been working on space-ready nuclear reactors almost since the agency's inception in 1958. But according to David Poston, a nuclear engineer at Los Alamos who's working on the technology, such programs "grew too expensive or went on too long to be continuously funded." Instead, NASA has relied on so-called radioisotope thermoelectric generators (RTGs), small generators filled with an isotope of plutonium — an element that's increasingly in short supply. RTGs provide power from the heat generated by this isotope's decay, rather than splitting any atoms.



Their best shot is called Kilopower: a reactor the size of a paper towel roll.

Kilopower's uranium fuel is much more abundant, but the real beauty of Kilopower is "how we glued it together," says Poston. He and Patrick McClure, another Los Alamos nuclear engineer, found a way to repurpose existing parts into a new, streamlined technology. The reactor itself — where the atom-splitting actually happens — sits inside a heat pipe. Usually, heat pipes funnel out heat that's a byproduct of radioactive decay. But Kilopower's pipes trap that heat and use it to power one of several built-in engines that generates electricity. There are nuclear emissions as well, but it's still a safe device: People can stand near it a few minutes at a time while it's powered on, and while it's turned off, it emits less radiation than what you'd inherently experience on Mars. (Unlike Earth, the Red Planet lacks a magnetic field to block harmful solar radiation.)

Poston and McClure just wrapped up a prototype phase to test the system's potential. They put the current version through its paces with an array of simulated challenges — it passed with flying colors.

And the timing couldn't be more perfect. With plutonium scarcity making RTGs less useful, NASA needs a new source of power for its upcoming missions. Kilopower's first trial run, on a robotic lunar mission, could come as soon as the mid-2020s. Early proposals from the agency also call for a charging station on the moon's north pole, and Kilopower could fit the bill. The reactor would charge two autonomous rovers of around 250 watts each as they explore that area.

Assuming it works out, next would be a fleet of four scaled-up versions of Kilopower. These 10-kilowatt reactors could power a base on the Red Planet. A human habitat there would need about 15 kilowatts to run smoothly, with the rest of that power going to recharging equipment.

Kilopower's uses extend beyond moon rovers and Mars bases. The most exciting, Poston says, is using the reactor for something called electric propulsion. This would involve using electric motors powered by a combination of Kilopower and other fuel sources to produce thrust in rockets and probes, allowing for detailed studies of faraway celestial bodies like Jupiter and Pluto.

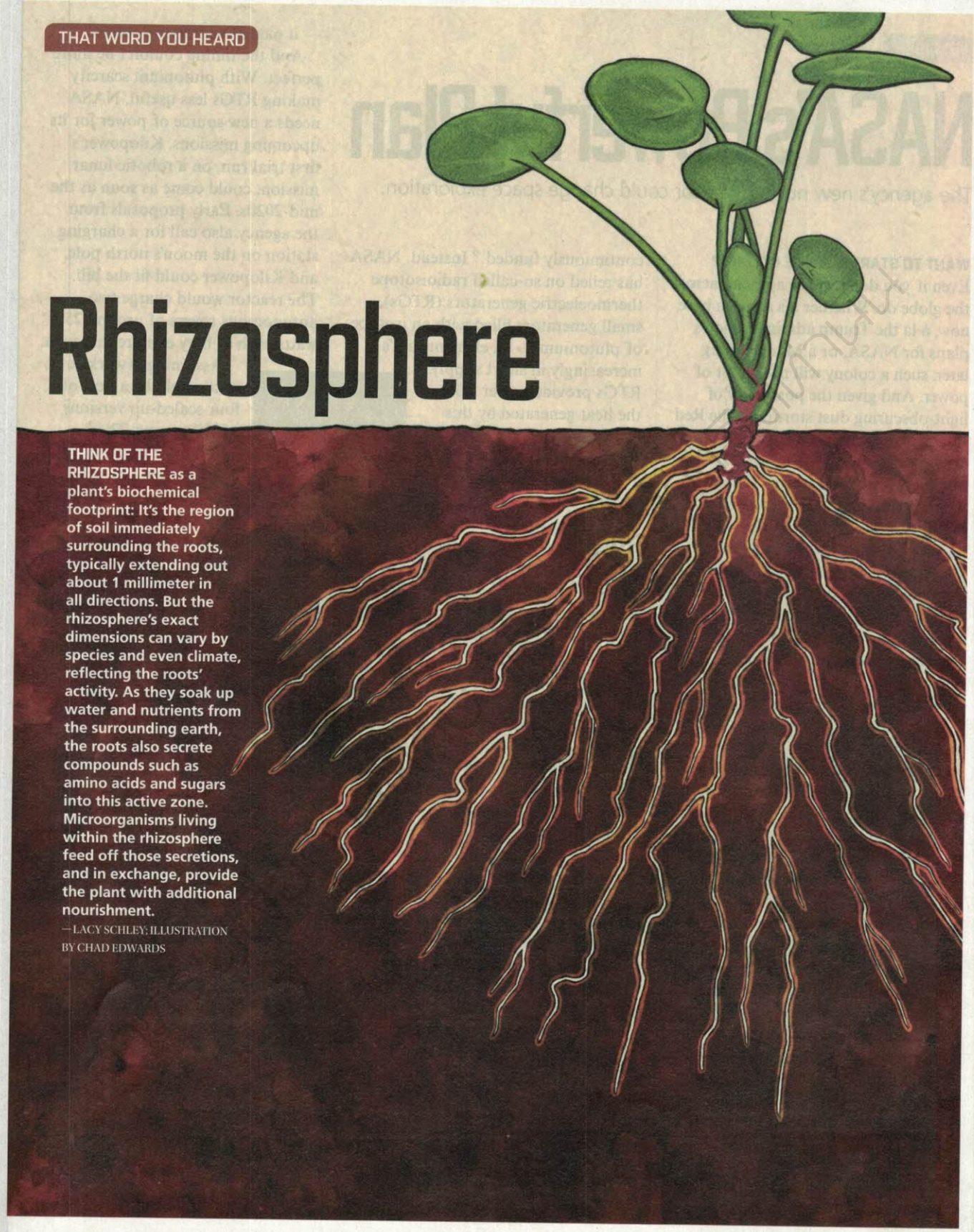
Plus, the reactor even has a few Earth-based applications. "We actually have designs for the ocean floor or an island or the Arctic, maybe an army base in a theater of war, or even disaster relief," McClure says. "There are lots of applications for this type of technology."

Whenever people in an isolated area need electricity, Kilopower could pave the way, old technology made new. — JOHN WENZ

NASA (2)

THAT WORD YOU HEARD

# Rhizosphere



**THINK OF THE RHIZOSPHERE** as a plant's biochemical footprint: It's the region of soil immediately surrounding the roots, typically extending out about 1 millimeter in all directions. But the rhizosphere's exact dimensions can vary by species and even climate, reflecting the roots' activity. As they soak up water and nutrients from the surrounding earth, the roots also secrete compounds such as amino acids and sugars into this active zone. Microorganisms living within the rhizosphere feed off those secretions, and in exchange, provide the plant with additional nourishment.

—LACY SCHLEY; ILLUSTRATION BY CHAD EDWARDS

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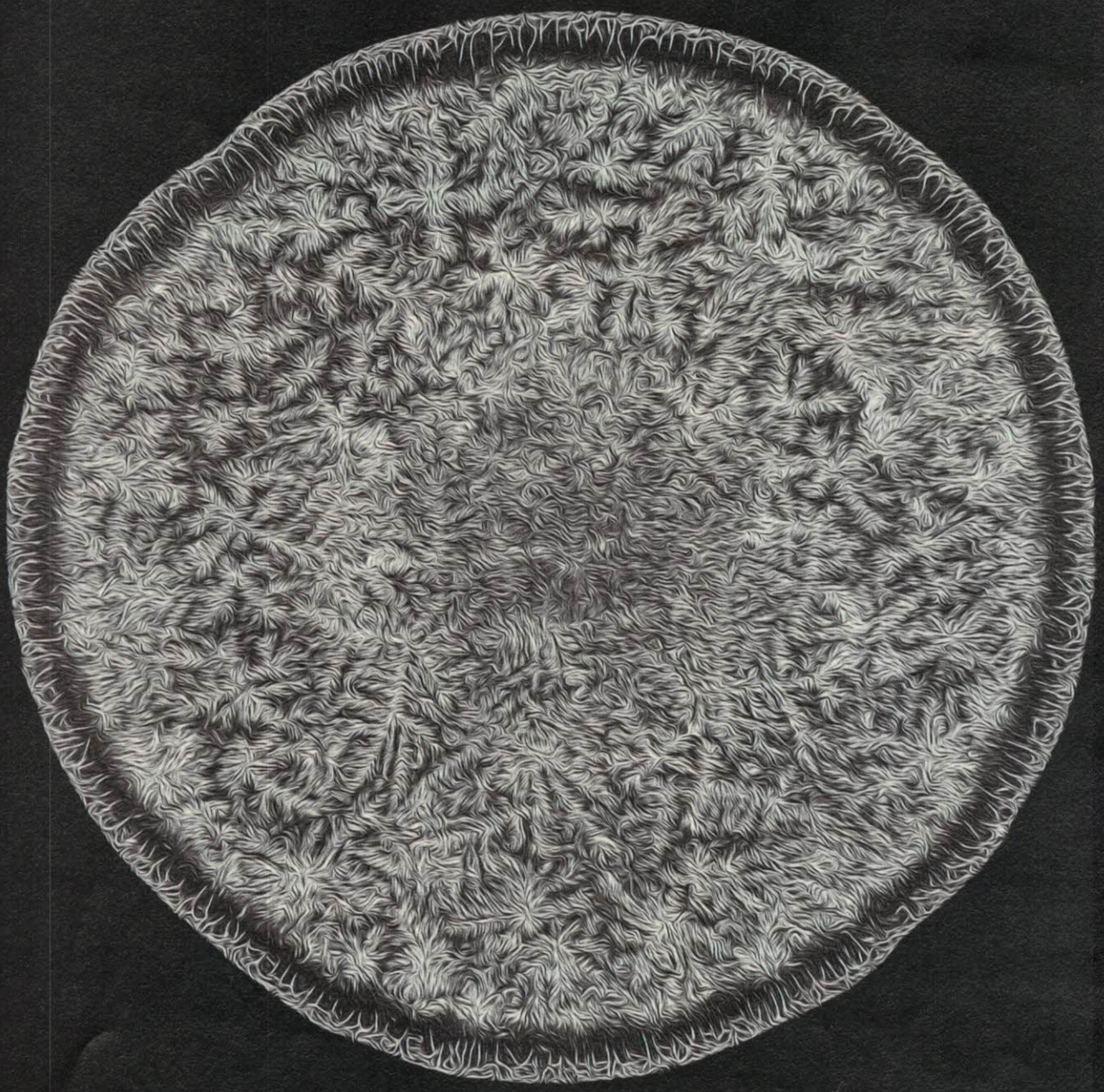

## DRY YOUR TEARS

Tears often leave our faces feeling (and tasting) salty, but a closer look reveals the intricate patterns they can leave behind. Norm Barker, director of pathology photography at Johns Hopkins University School of Medicine, focused his microscope on a human teardrop, using a lighting technique to enhance contrast. Barker saw that as it started to dry, the salt and other substances in the teardrop bunched together and crystallized in these intricate, snowflakelike shapes. The picture ranked among the top 10 in the 2018 Nikon Small World Photomicrography Competition. —ERNIE MASTROIANNI; PHOTO BY NORM BARKER

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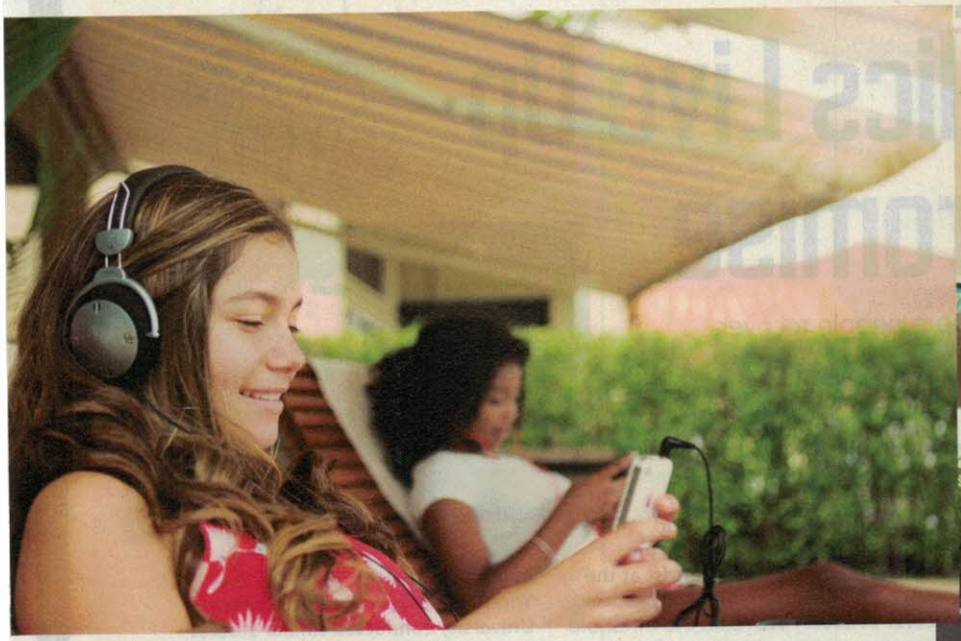

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ReDISCOVER

# Psychedelics Live Up to Early Promise

Mind-bending drugs are helping more people recover from disabling mental disorders.


**A DECADE AGO,** *Discover* explored psychedelics' potential to heal treatment-resistant psychiatric conditions. The May 2008 story, "Acid Test," described the efforts of Charles Grob and a handful of other scientists to revitalize research on hallucinogens' mind-altering properties to restore mental health.

Evidence from the 1950s and '60s suggested hallucinogen-induced mystical experiences could jump-start recovery from substance abuse and alleviate end-of-life angst. That work came to an abrupt halt in the 1970s after Congress banned the drugs to curb widespread recreational use.

But a new generation of psychedelic researchers persisted, making "dramatic progress" on the hardest cases, Grob, a psychiatrist at the University of California, Los Angeles, told *Discover* in 2008. "We're on the threshold of opening up an exciting new field."

His optimism was well placed. In 2011, Grob showed that 12 advanced-stage cancer patients experienced relief from acute anxiety and despair after receiving a moderate dose of psilocybin — and in many cases, the effects lasted at least six months. Teams at New York University and Johns Hopkins University conducted similar studies with more patients in 2016. The two resulting papers, which both appeared in the *Journal of Psychopharmacology*, reported sustained relief in 80 patients.

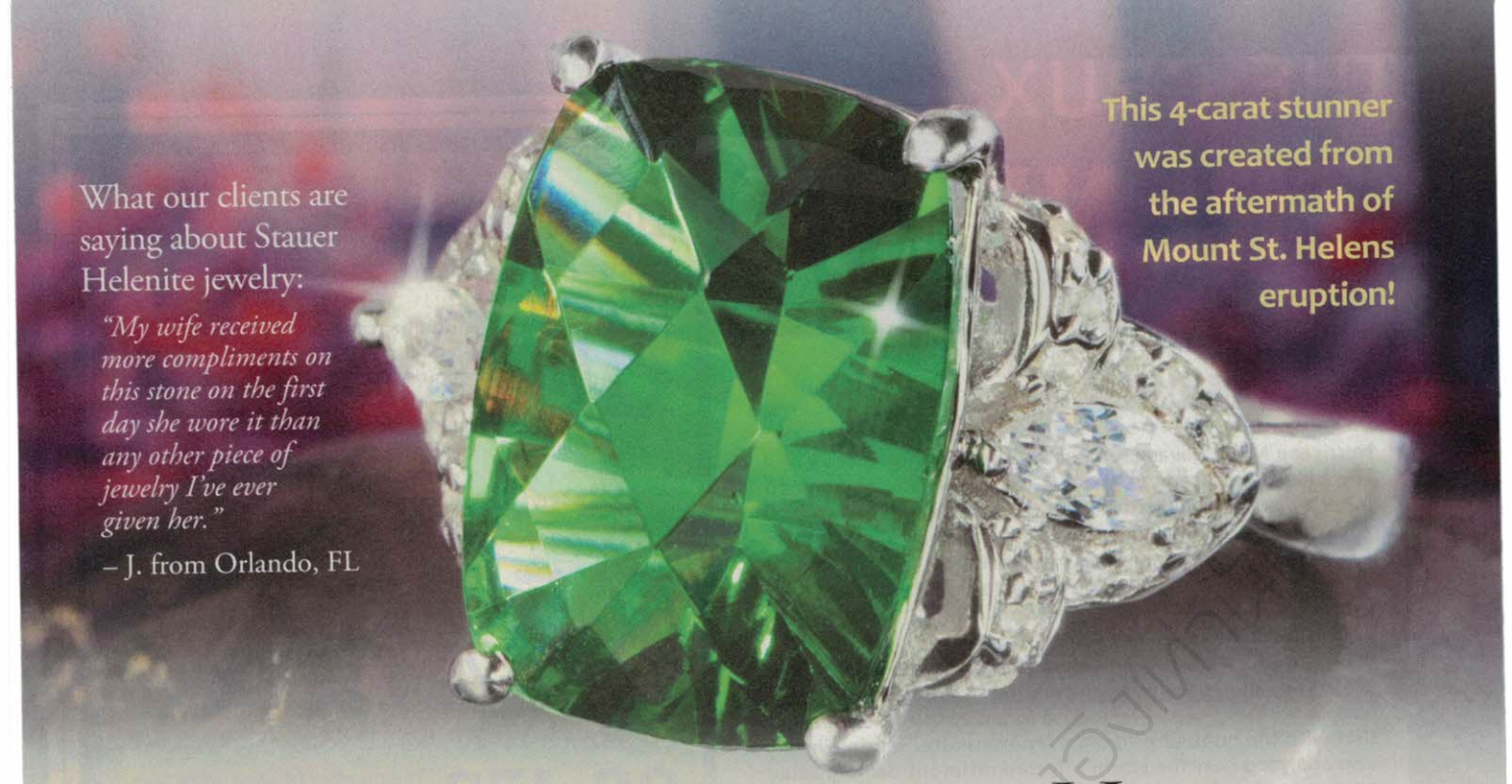
Stephen Ross, a psychiatrist who led the NYU trial, told multiple news outlets in 2016 that a single dose of a drug producing substantial and enduring relief from depression and anxiety is unprecedented.

Psychedelic medicine got another boost in August 2017 when the FDA designated MDMA, better known as ecstasy, as a breakthrough therapy for post-traumatic stress disorder. The nod came after several reports showed the benefits of MDMA for patients with PTSD. In 2010, for example, nearly 85 percent of PTSD patients who took MDMA during therapy in clinical trials recovered, with most still seeing benefits an average of three and a half years later. Additional trials in the wake of the designation will test the drug on a broader scale.

Psychedelic research is finally moving into mainstream psychiatry, Grob says. "There's a realization that some 30 years were lost because of the culture wars, and that these compounds may represent new and novel treatment models that we need to explore."

For all the promising results, Grob remains cautious. "The biggest challenge at this point is ... not to get too far ahead of ourselves. If there are any glitches in safety, it could set the field back again." — LIZA GROSS

FUTURE VECTORS/SHUTTERSTOCK (2)

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# TRENDING

BY ANNA GROVES

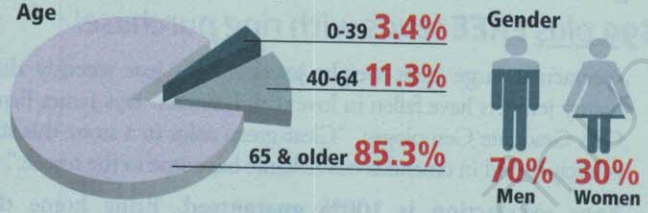
## Maria's True Toll

Hurricane Maria devastated Puerto Rico in September 2017. The following December, the U.S. territory's local government reported an official death count of 64, while an analysis by *The New York Times* suggested the storm claimed more than 1,000 lives. To determine how many lives Maria really took, the Puerto Rican government contracted with a team of independent analysts at George Washington University.

They used the territory's death records to find the typical death rate for each month before the hurricane, back to July 2010. They then used that information to predict how many people normally would have died in fall 2017 and compared that with the number of deaths reported after Maria. They also analyzed how the storm affected different demographic groups on the island and found that men who were age 65 and older and living in the least developed areas died at disproportionately higher rates due to Maria.

In total, Maria was responsible for 2,975 deaths — more than Hurricane Katrina, which claimed 1,833 lives along the northern Gulf Coast in 2005.

### Who Was Most Likely to Be a Victim?




### Increase in Death Rate Based on an Area's Socioeconomic Development


### Population Decreased By:


*deaths plus citizens who fled the island

Source: "Differential and persistent risk of excess mortality from Hurricane Maria in Puerto Rico: a time-series analysis," *Lancet*, 2018.

## Degrees of Separation

From literacy levels to vitamins.

**80** The number of books that adults with average literacy levels remembered having on the shelves of their homes at age 16. An international team of social scientists analyzed survey data from 160,000 respondents across 31 countries and found adult literacy was highly dependent on exposure to books as a teen — with positive effects of home library size tapering off at about 350 books.

**2.5%** The proportion of American children up to age 17 who were diagnosed with a traumatic brain injury (TBI) in their lifetime, based on a recent study's analysis of data from 2011-2012.

**68,479** The number of plays from Ivy League football games that researchers analyzed to see if a 2018 rule change intended to reduce concussions worked. The change was meant to decrease tackle opportunities in certain plays. As a result, the average concussion rate fell from nearly 11 per 1,000 plays to about 2 per 1,000 plays.

**18** The length — measured in nucleotides, the building blocks of DNA and RNA — of a type of RNA that could expose blood doping. Duke University researchers found that this particular RNA marks previously drawn red blood cells as being older than ones still circulating in the body. This is important, since some athletes draw their own blood days or weeks before an event, store it, then reinfuse it to increase their blood's oxygen-carrying capacity, which boosts physical performance.

**776** How many different over-the-counter diet supplements had undeclared, potentially harmful pharmaceutical substances, according to a recent study. One of the most common culprits added to products was sildenafil, better known as Viagra. Analysts also found unlisted laxatives and appetite suppressants in alleged weight-loss aids and anabolic steroids in muscle-building supplements.

**11** The number of new vitamins, according to one researcher's report in *PNAS*, that we should add to the current list of 30 vitamins and minerals recommended for optimal health. A growing body of evidence suggests these 11 compounds, including so-called carotenoids often found in red and yellow produce, could amp up proteins necessary for healthy aging.

FROM TOP: ALISON MACKEY/DISCOVER; SHUTTERSTOCK ILLUSTRATIONS BY CAPTAIN COBI AND GUNGWIYAT

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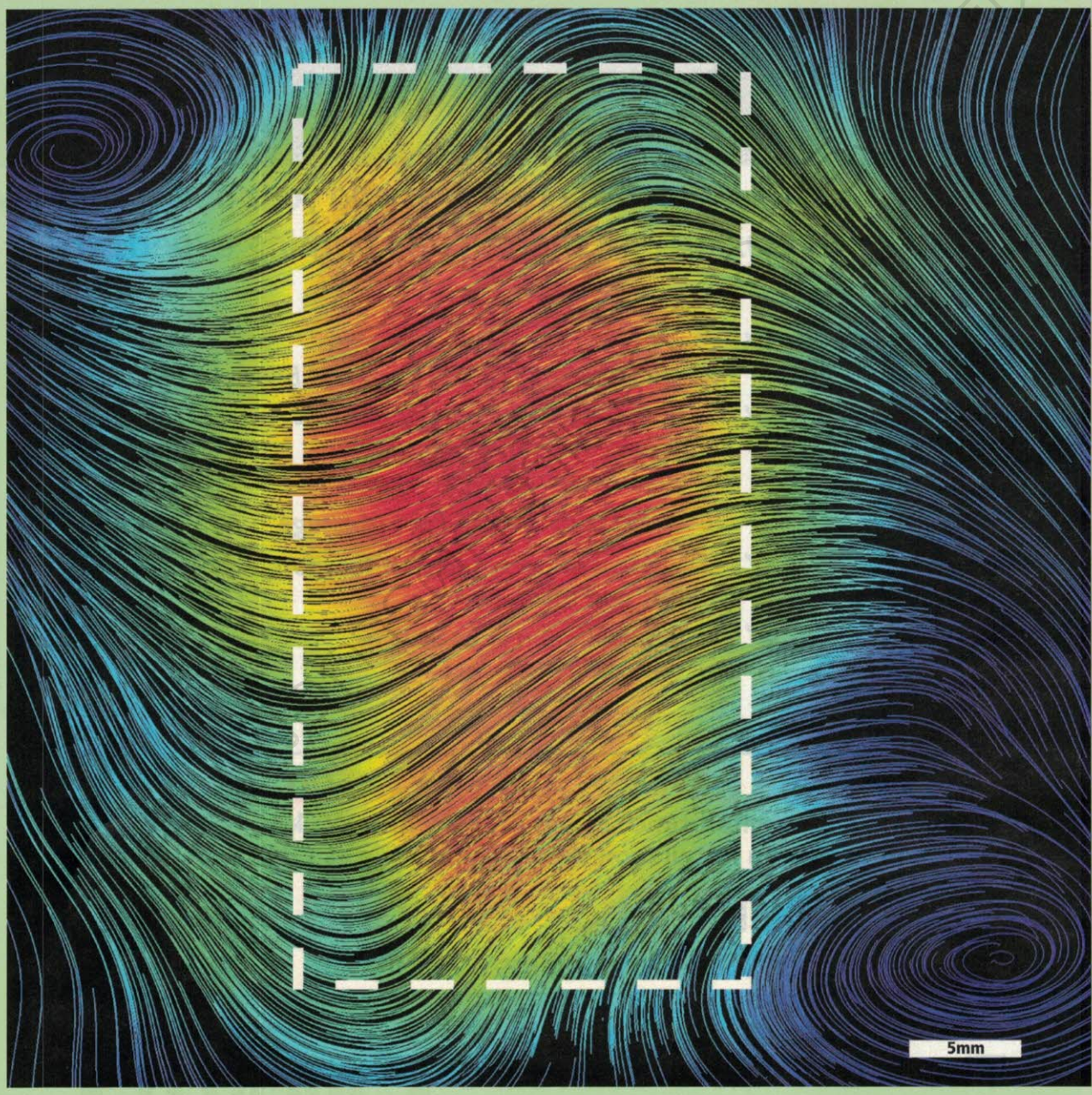
# Inner Magnetism

Although it might not be obvious, a material like lead has multiple magnetic fields, one inside and another on its surface. Until recently, researchers could confidently measure only surface fields. Now, in a recent *Nature Communications* paper, materials scientists in Germany describe a way to create detailed maps of the direction and strength of magnetic fields inside bulky materials like those used in electric engines and high-efficiency transformers.

The new method uses neutrons, neutrally charged subatomic particles that spin in the opposite direction of a magnetic field's alignment. Because neutrons are so small and chargeless, they easily penetrate many materials. The team took advantage of these properties, scanning a sample of lead with neutrons that all had the same spin. When they hit a magnetic field inside the sample, their spin changed detectably, letting researchers plot the information.

Below is the magnetic field in and around the lead sample (outlined in white). Warmer colors denote stronger sections of the magnetic field.




I. MANKE ET AL./NATURE COMMUNICATIONS VOLUME 9, ARTICLE NUMBER: 4023 (2018) CC BY 4.0

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# Delusions of Grandeur

An economics grad student suddenly believes he's become a disease-fighting doctor.

BY **DAMON TWEEDY**

When Alvin arrived at the hospital, he believed he'd been sent there as a doctor working on behalf of the U.S. government. "Which patient do I need to see first?" he asked the triage nurse.

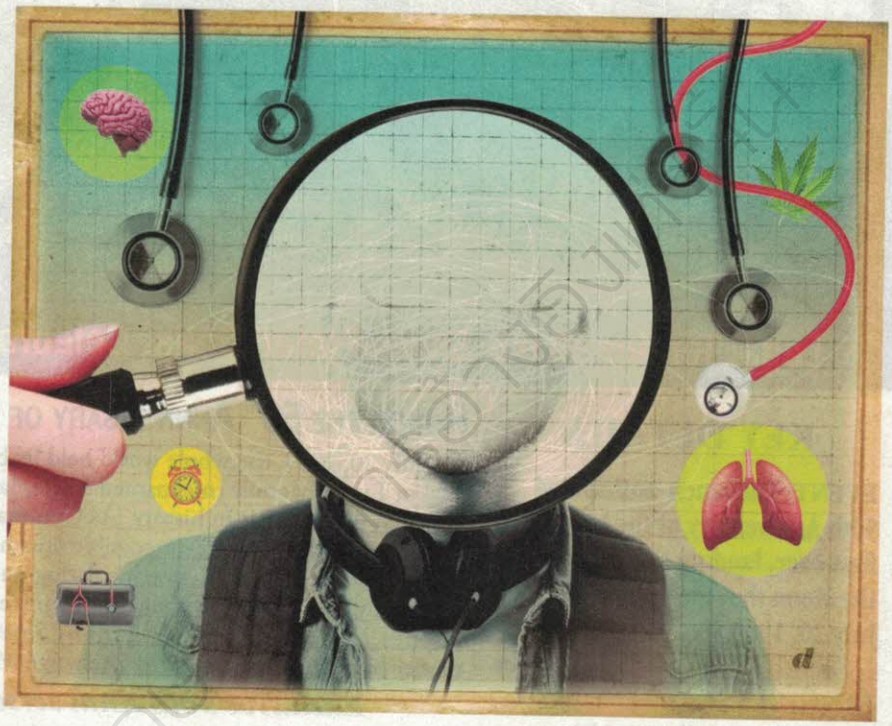
Until recently, Alvin had been an ordinary economics graduate student. But somehow he'd become convinced that he was a trailblazing physician who needed to identify a rare strain of tuberculosis before it spread throughout campus.

That morning, he arrived at his graduate school classroom with a stethoscope around his neck, a surgical mask over his face and a bag containing more masks and several thermometers. He began to practice medicine on his classmates.

At first, his manner and physician attire made them think he was joking, as Halloween was just around the corner. But when he tried to remove the shirt of a female student to better listen to her lungs, their late-arriving professor called the police. And the police called an ambulance.

What caused this previously healthy 25-year-old man to become delusional? After an initial screening from the emergency medicine physician on duty, I was called to sort this out.

At the time, I was a new psychiatry resident. But even at that early part of my career, I knew to focus on four possibilities for Alvin's behavior: a stress reaction from a trauma, a manic phase, a psychotic episode or a drug-induced state. I'd also heard about medical conditions, such as lupus and hyperthyroidism, that could cause severe psychological changes. But the emergency room doctor found no supporting evidence for those possibilities after his examination.



Skimming Alvin's medical records, I learned that he had visited the student health clinic the year before. He was diagnosed with depression but declined treatment. The note also mentioned occasional marijuana use, but not in more than a year. He told the doctors he hadn't used any other street drugs. In terms of his physical health, the records showed he'd recently visited the health clinic for cold symptoms and received a prescription decongestant.

Essentially, I was starting from scratch.

## DIALED TO 11

I met Alvin in a small room in the emergency department's psychiatric wing. He paced in a circle and was doing some sort of counting exercise with his fingers. He seemed a few days overdue for a shave and a shower.

"Are you OK, doctor?" he asked, observing me closely. "You look stressed."

I smiled and gently told Alvin that his classmates and teachers had concerns about his mental state, as did the nurses and doctors at the hospital. He nodded. I asked him why he thought they were worried.

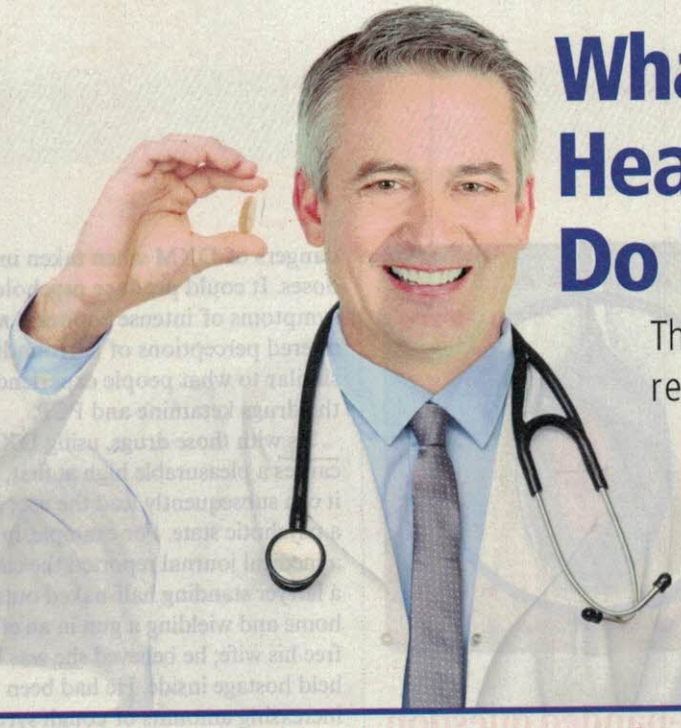
"Because I have been energetic," he answered. "Maybe too much so for them."

"How long have you been feeling this way?" I asked.

"A few days. Maybe a week. Conventional time isn't as important for me now."

He told me that he hadn't slept more than two or three hours a night.

DAVID VOGIN



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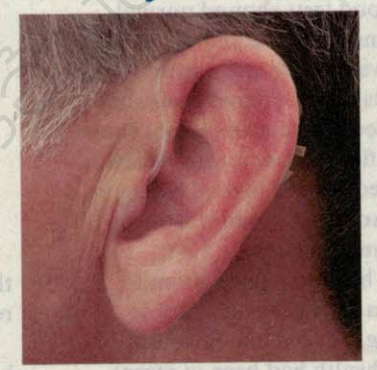

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And even that felt like too much because he had so much lifesaving work to do. He said he hadn't had any recent traumatic experiences in his life or with anyone close to him.

It sounded like textbook mania. But from what?

## THE X FACTOR

Alvin's lab results came back. Stepping away to a nearby computer station, I saw that his alcohol level was zero. Also, his urine drug screen — which tested for marijuana, cocaine, phencyclidine (PCP), opioids, benzodiazepines and amphetamines — came back clean. It appeared that drugs weren't causing his state.

His blood tests showed normal liver, kidney, glucose and electrolyte/mineral values. We still needed to wait for results on his thyroid levels, but I suspected the data would not show an identifiable cause for his behavior. He seemed headed toward a diagnosis of bipolar disorder and treatment through medications.

I went back to Alvin's room to perform a physical exam. Before beginning, I asked him how his physical health had been in recent months. He told me he had a bad cold five or six weeks ago and missed a few days of classes. He saw a doctor who wrote him a prescription, but the medicine didn't help his condition.

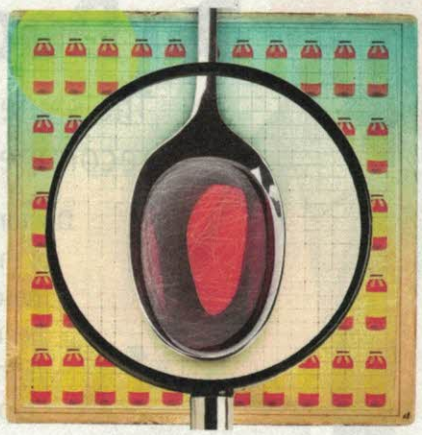
Alvin said he began to improve only after taking an over-the-counter medicine. Out of curiosity, I asked him its name.

"DXM," he said.

I stared blankly.

"Dextromethorphan," he continued. "It's the active ingredient in most cough suppressants. I started with the pills. I switched over to the liquid a few weeks ago."

Switched over a few weeks ago? The instructions on cold medicines always say to stop use after a week, or at most 10 days. "How long did you end up taking it?" I said.



**My off-handed question about the medicine's name opened a new path of investigation. Could this drug explain his behavior?**

"I'm still using it," he said, reading the confusion on my face. "For recreational purposes."

I frowned in surprise. I'd always been naïve and cautious about drugs in my personal life. And while I'd seen TV reports on the decongestant pseudoephedrine being used to produce crystal methamphetamine, I hadn't heard anything similar about dextromethorphan to make me view it as a drug that could be abused. Nor had I heard about this in medical school.

My off-handed question about the medicine's name opened a new path of investigation. Could this drug explain his behavior?

## LESSONS LEARNED

After looking into DXM's history, I found that it was approved by the FDA in 1958 as a non-prescription cough suppressant. During the 1990s, a handful of obscure medical case reports described the potential dangers of DXM when taken in high doses. It could produce psychological symptoms of intense euphoria and altered perceptions of surroundings, similar to what people experience with the drugs ketamine and PCP.

As with those drugs, using DXM causes a pleasurable high at first, but it can subsequently lead the user into a psychotic state. For example, in 1996, a medical journal reported the case of a lawyer standing half-naked outside his home and wielding a gun in an effort to free his wife; he believed she was being held hostage inside. He had been using increasing amounts of cough syrup with DXM for three months.

In 2005, a few years after my encounter with Alvin, the FDA published a warning on the dangers of taking DXM in high doses. Today, the drug is still part of over 100 cough and cold medicines. In recommended amounts, it's safe. But the potential for abuse is always there.

Alvin acknowledged that DXM had clouded his thinking, and he agreed to be admitted to the inpatient psychiatric hospital floor for observation. Once he stopped taking the drug, he returned to his normal state within three days. He said during his discharge that what had started out as fun had gotten out of hand, and that he'd learned his lesson.

Alvin's case was an eye-opener for me early in my career. Realizing that both I and the emergency room doctors had almost overlooked this less well-known type of drug abuse, I learned two important lessons: ask patients extra questions and be humble enough to let them lead you to their diagnoses. D

***Damon Tweedy*** *is an associate professor of psychiatry at Duke University School of Medicine and author of the book* Black Man in a White Coat: A Doctor's Reflections on Race and Medicine. *The cases described in Vital Signs are real, but names and certain details have been changed.*

DAVID VOGIN

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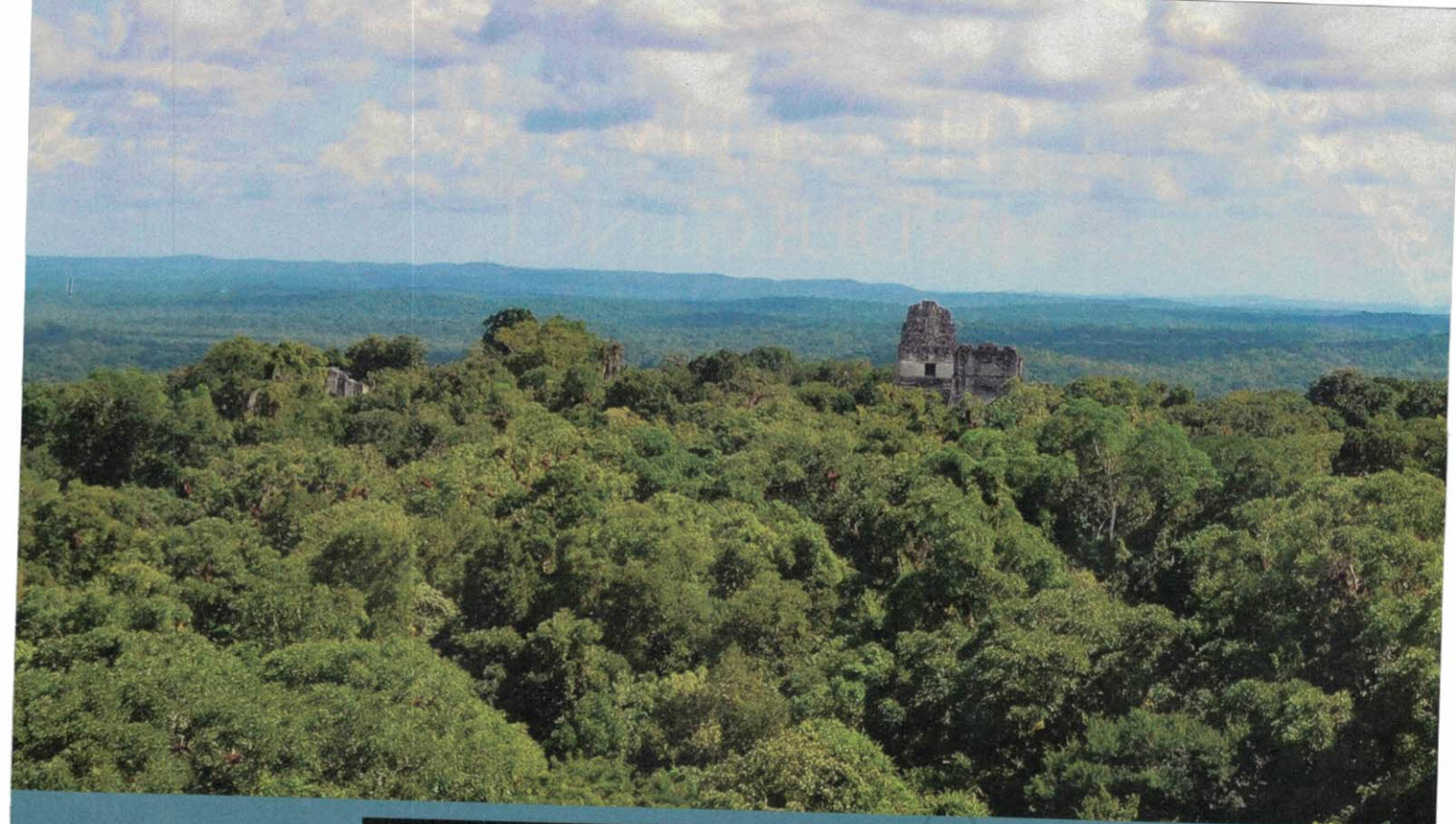
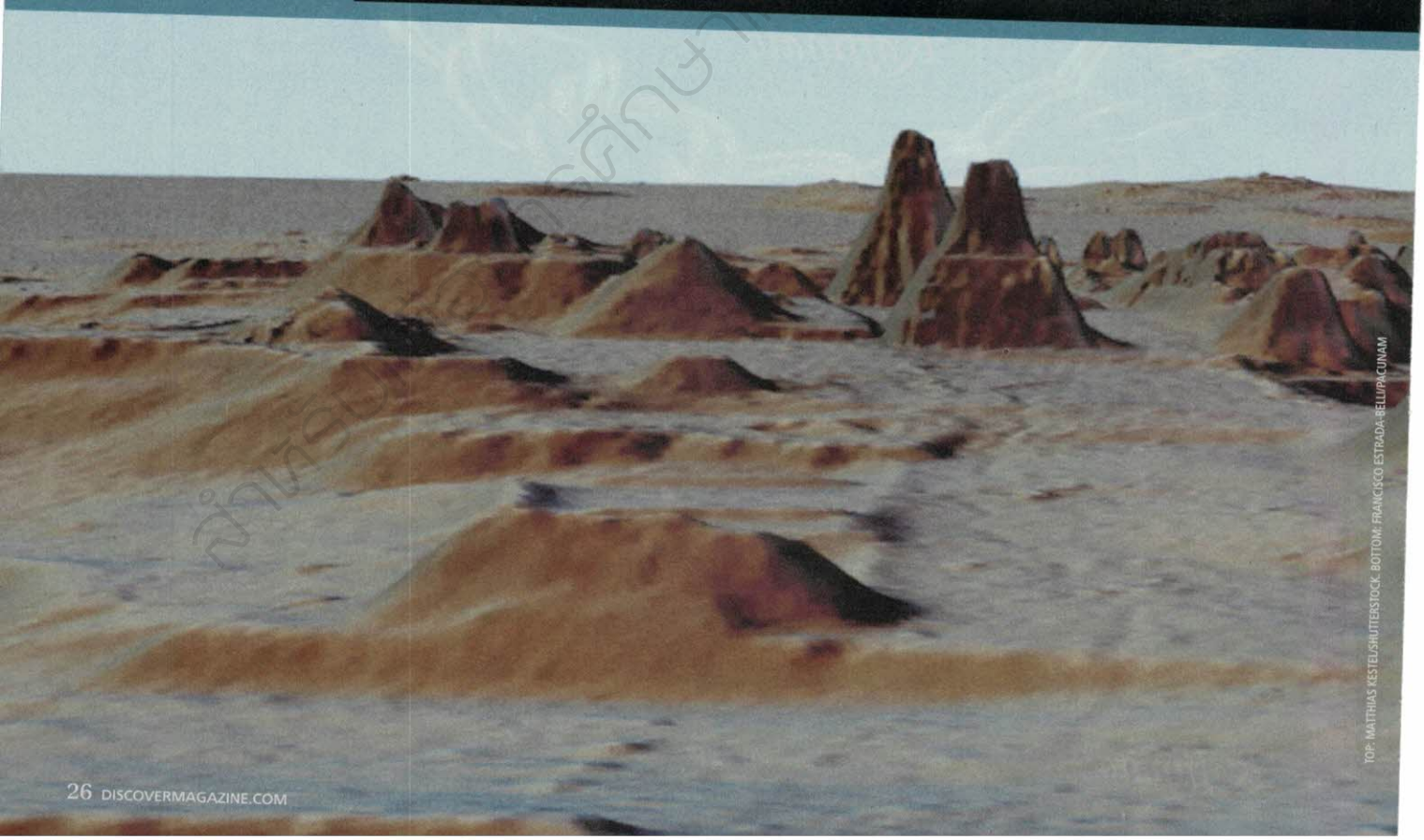


# A LOST WORLD

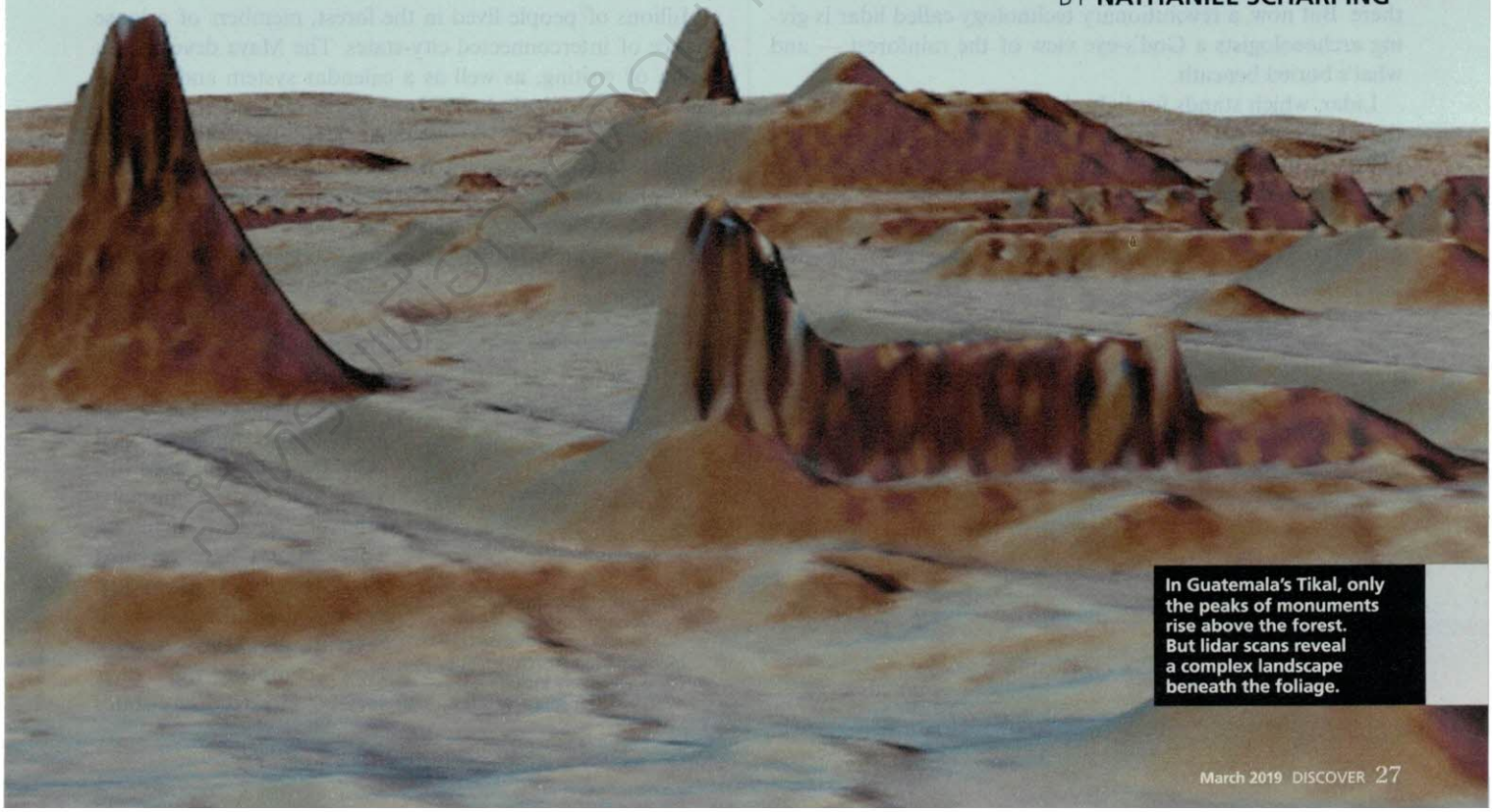


TOP: MATTHIAS KESTEL/SHUTTERSTOCK. BOTTOM: FRANCISCO ESTRADA-BELLI/PACUNAM

# EMERGES

From massive fortresses to sprawling suburbs, a bold new vision of the Maya takes shape.

BY **NATHANIEL SCHARPING**



In Guatemala's Tikal, only the peaks of monuments rise above the forest. But lidar scans reveal a complex landscape beneath the foliage.

THOMAS GARRISON pauses in the middle of the jungle.

"That's the causeway right there," he says, pointing into a random patch of greenery in the Guatemalan lowlands.

I squint, trying to make out features in the tangled rainforest undergrowth. There's a small lump, rising no more than a foot or two from the forest floor.

The Ithaca College archaeologist has spotted the buried remnants of a Maya road, a ribbon of limestone that once cut through the wrinkled landscape. We're a full day's walk from civilization, standing in the remains of a once-populous kingdom. The road before us is just one piece of a vast network leading to terraced fields, reservoirs, defensive fortifications and more, all sprawling invisibly throughout the forest.

In the 1,000-plus years since the Maya society collapsed, the jungle has returned with a vengeance. A tide of flora has swallowed up roads and temples, turning stone structures into lumps and mounds indistinguishable from the natural topography.

Garrison, an expert at picking out buried structures, had walked right by this road for years, never knowing it was there. But now, a revolutionary technology called lidar is giving archaeologists a God's-eye view of the rainforest — and what's buried beneath.

Lidar, which stands for light detection and ranging, bathes the jungle canopy in a stream of laser beams delivered from planes flying above. As the light bounces back, it creates a precise map of surface contours beneath the forest canopy.

Back in camp, Garrison pulls up the data on his laptop. Maya ruins leap from the featureless jungle, giving new meaning to the landscape that surrounds us. The researchers' base shows up as a small huddle of buildings; surrounding it, hundreds of Maya structures stipple the ground in every direction. Some Garrison knew about — the majority, however, are brand new. To him, at least.

Back in 2016, Garrison and a group of archaeologists organized a sweeping lidar survey of the heart of Maya civilization, once centered here in the Guatemalan lowlands. Their scans covered 800 square miles across the Petén region, which covers much of Guatemala's northern half. It's just a fraction of the former Maya territory, yet lidar revealed some 60,000 previously unknown structures.

Now, researchers can comprehend the full scale of this ancient civilization, from vastly expanded trade and agriculture to surprising military sophistication. After decades of digging, new and exciting dimensions of Maya society are finally coming to light.

## PEEPHOLE TO PANORAMA

Over a thousand years ago, the Maya dominated this environment. They emerged around 1000 B.C. and, over the next millennia, rose to become the pre-eminent Mesoamerican civilization.

**LIDAR IS PUTTING THE ANCIENT SOCIETY INTO A MUCH BROADER CONTEXT. MOUNDS AND HILLS STAND OUT AS TEMPLES AND FORTRESSES TIED TO SUBURBS AND FARMLANDS.**

Millions of people lived in the forest, members of a loose alliance of interconnected city-states. The Maya developed a system of writing, as well as a calendar system and sophisticated astronomical charts. In a world without metal, they built towering temples in cities like Tikal and Chichén Itzá, as well as roads, reservoirs, irrigation networks and terraced fields. Their civilization spanned thousands of square miles of jungle across Central America.

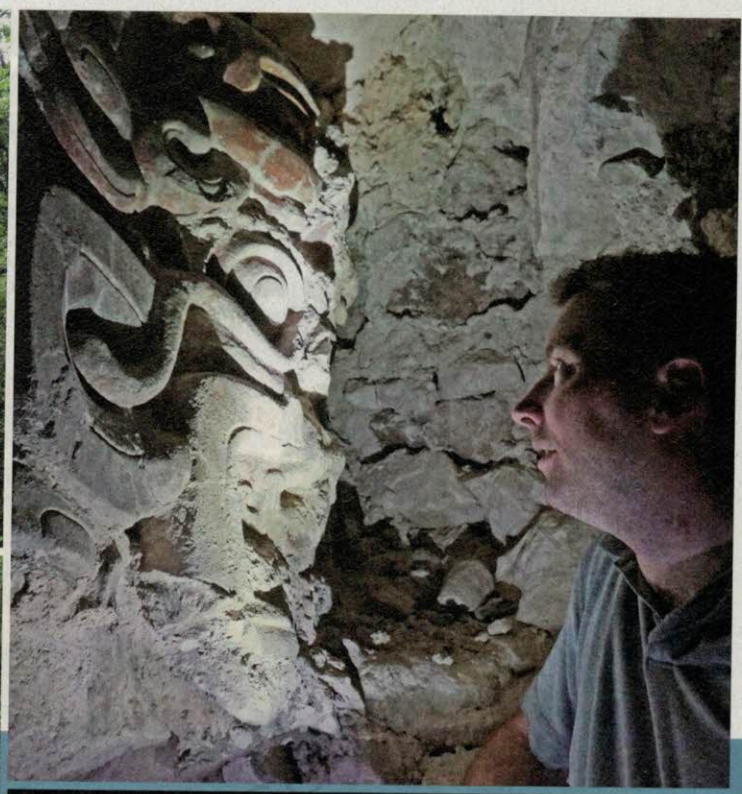
In the past, archaeologists have relied on small, scattered dig sites to describe the scope of this vast civilization. That's given us a limited view of the Maya.

We've unlocked the secrets of the Maya language, peeled back the jungle at sites like Tikal, and stuffed museums full of ancient artifacts. These efforts have revealed many details of Maya life, but not the full scope of it. Several mysteries remain. How complex was their society? How did city-states


Lidar scans of individual locations in northern Guatemala have revealed many hidden structures. Future scans will likely include an even broader range of sites.

Source: "Ancient lowland Maya complexity as revealed by airborne laser scanning of northern Guatemala," *Science*, 2018.

ALISON MACKEY/DISCOVER



**Clockwise from bottom left: Rough roads and heavy rains make travel to and from Thomas Garrison's site difficult; teams must leave before the rainy season or risk getting stuck, like this truck. A crumbling wall near the top of the Temple of the Wooden Lintel, at El Zotz, is one of the few structures Garrison has been allowed to clear of vegetation. Garrison inspects a large stone mask — the Jaguar God of the Underworld — in the Temple of the Night Sun, part of the El Diablo group of structures near the Temple of the Wooden Lintel.**

CLOCKWISE FROM BOTTOM LEFT: NATHANIEL SCHARPING/DISCOVER (2); ROBERT PERKINS/USC

grow and fall and grow again? And how did a civilization untouched by the Iron Age rise from the forbidding jungle — only to fall apart?

"If we just do excavations of small areas, you get just this little peephole view of the Maya people," says Timothy Hare, a professor of anthropology at Morehead State University who's involved in a similar mapping project. Lidar is putting the ancient society into a much broader context. Mounds and hills now stand out as temples and fortresses tied to suburbs and farmlands.

"It gives you a sense of connections across a big area, as opposed to just little points of information from this mound or that pyramid or that temple," says Stephen Houston, a Maya archaeologist at Brown University who works with Garrison's team. "Suddenly everything becomes connected, everything is seen as being part of a single functional space."

## VIOLENT PAST

The iconic Temple IV at Tikal — once featured in *Star Wars* — draws tourists from around the world. Tikal's famed summit is barely visible across the jungle canopy from the Temple of the Night Sun, a hidden pyramid in the nearby ruined city of El Zotz. Unlike Tikal's tourist mecca, the Temple of the Night Sun is still slowly fading into the jungle. As I travel with Garrison, it's our destination — if we can make it through the dense foliage.

Fifteen hundred years ago, the jungle would have been much more hospitable. Tikal, where temples have been methodically cleared of overgrowth, offers a hint of what Guatemala may have looked like back then. Broad pathways linked temple complexes. Stone buildings bounded spacious courtyards. Outside of city centers, clusters of fields and reservoirs broke up the jungle. Villages were nestled into nearby clearings.

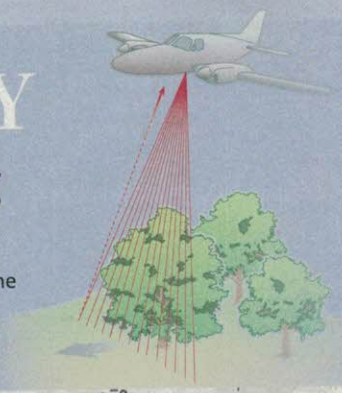
Today, some 14 miles of thick jungle separate El Zotz from Tikal's metropolis. But in the time of the Maya, the two were almost too close for comfort. Garrison's excavations here reveal an alternating history of aggression and allegiance with Tikal, as the dynasty at El Zotz waxed and waned in concert with their larger neighbor.

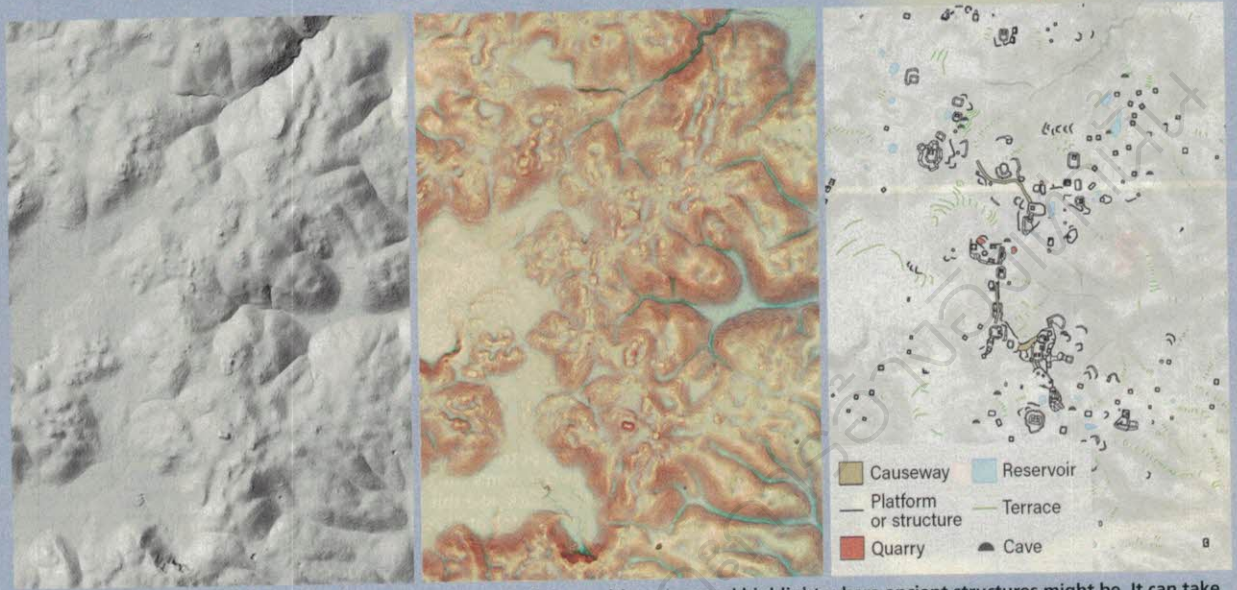
On one side of the Temple of the Night Sun's pyramid, archaeologists have carved a tunnel. It twists and turns through layers representing hundreds of years of Maya construction. Inside, fearsome stucco masks adorn what was once a temple atop the structure. They represent a central figure in the Maya pantheon, the Sun God, who transformed into a jaguar at nightfall. Deeper inside lies a find unearthed during the 2010 season: a royal tomb containing the remains of the El Zotz dynasty's founder, alongside exquisite ceramics and the

# BENEATH THE CANOPY

## Lidar = Light Detection And Ranging

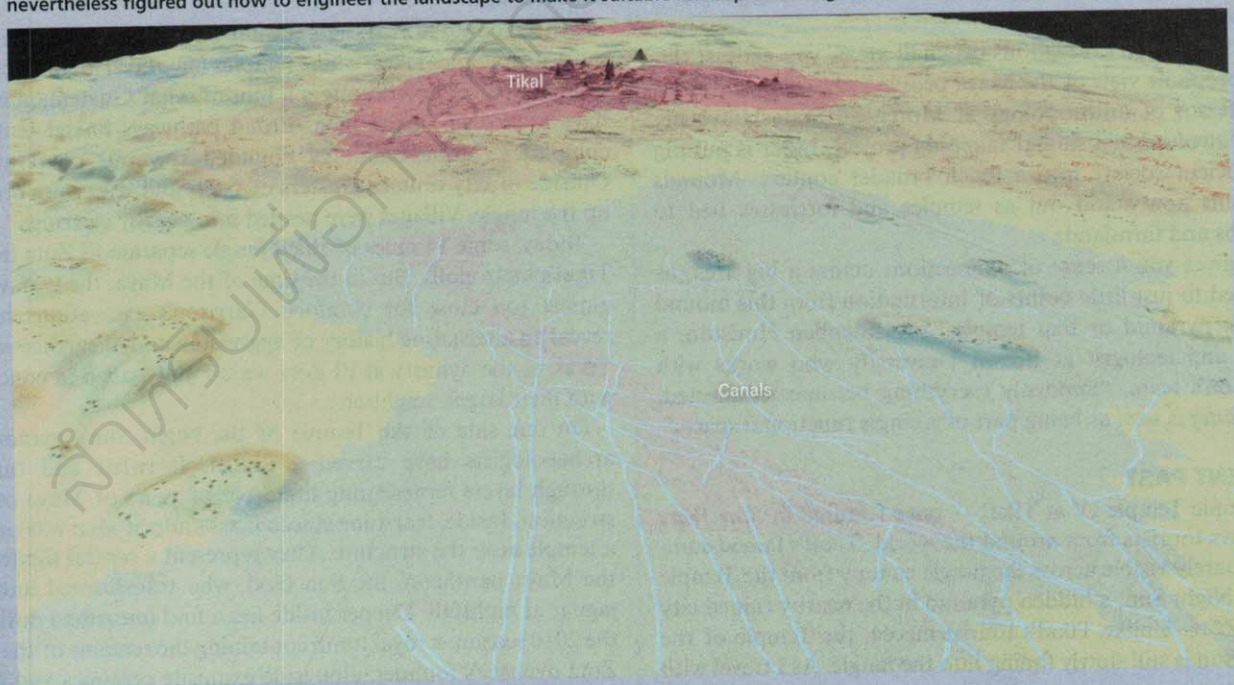
To create Lidar images, airborne instruments fire at the ground millions of laser pulses, which reflect back up. By timing how long it takes the pulses to return, and combining that data with precise GPS data, researchers can create a map of the surface beneath the vegetation. These can be accurate down to about a square meter, enough to pick out hidden temples, roads, watchtowers and much more.






**Garrison uses various filters to draw further contrasts out of the resulting maps and highlight where ancient structures might be. It can take months to turn lidar data into useful information — such as these terrain maps of Dos Torres, in the hills between Tikal and Uaxactun.**

**The network of crowded canals (blue lines) revealed near Tikal are evidence of centuries of work — infilling, erosion and re-excavation — by the ancient Maya. They are located in a low, swampy area called a bajo, common in much of the Guatemalan lowlands. The Maya nevertheless figured out how to engineer the landscape to make it suitable for crops. Buildings (black dots) huddle nearby.**




FROM TOP: JAY SMITH; LUKE AULD-THOMAS AND MARCELLO A. CANUTO/PACUNAM; PACUNAM

bones of sacrificial children.

At some point, however, the Maya abandoned this temple complex, uprooted the heart of the kingdom and moved to a new location, about a half-mile downhill. Garrison thinks the sudden move was likely related to a time of great upheaval in this part of the Maya world.

In A.D. 378, Tikal fell to a distant power — the city today known as Teotihuacan, far to the northwest in Mexico. Tikal's king was killed and replaced by an outsider, and the kingdom became something like a vassal state to the foreign state.

Garrison and Houston disagree as to the exact effects of this violent usurping. Houston argues it was a time of devastation and tragedy for the Maya; their dynasty was toppled and their culture was subsumed by another. To live in Tikal at this time would have been to exist under the heel of a foreign power, he says.

Garrison sees a different narrative. Though the change of rulers was certainly brutal, he argues that the result was ultimately beneficial. As evidence he points to the fact that the city rapidly expanded its territory in the aftermath, and likely allied itself with El Zotz.

**Garrison (left) and his excavation team work on reopening a tunnel into the Temple of the Wooden Lintel, one of the main pyramids in the ruins of El Zotz. His team's finds have helped expand our understanding of the city-state, and its tumultuous relations with its neighbors. The advent of lidar mapping has only accelerated the pace of discovery.**

The result was a new era of prosperity for El Zotz still evident today. Walking through the grassy city center, we pass multiple temples, mortuary complexes and a ball court. Public markets were likely held nearby, and the city is surrounded by outlying groups of Maya homes where thatched huts once stood; what were likely cacao fields lie farther up in the hills.

This area has been thoroughly examined and plotted, the result of seven years of meticulous work. Had lidar been around then, that work would likely have been much quicker. The technology has transformed the day-to-day work of archaeology in the jungle. Uncovering ruins once required informed guesswork; now the team can pinpoint spots of interest.

"Some days you'd go and you'd be trudging all day and you'd get to this hilltop where you're excited to find something, and you get there and there's just nothing," Garrison says. "That never happens with lidar. When you go out to do your recon or your ground truthing, you know exactly where you're gonna end up that day."

ROBERT PERKINS/USC

## HIDDEN CONNECTIONS

Garrison has a surplus WWII gas mask bag slung over his shoulder — the same satchel Indiana Jones carried. He's got the jacket, too, and once had a whip to complete the look, though it has since been lost. "An ex-girlfriend took it to Burning Man," he says.

Garrison exudes an understated confidence after nearly 20 years of fieldwork, but he'd been getting restless at El Zotz, which had been shaping up to be fairly unspectacular by Maya terms. Other than the royal tomb, they'd uncovered few major finds. That is, until 2016. And lidar.

"Now it's like a whole new place," he says.

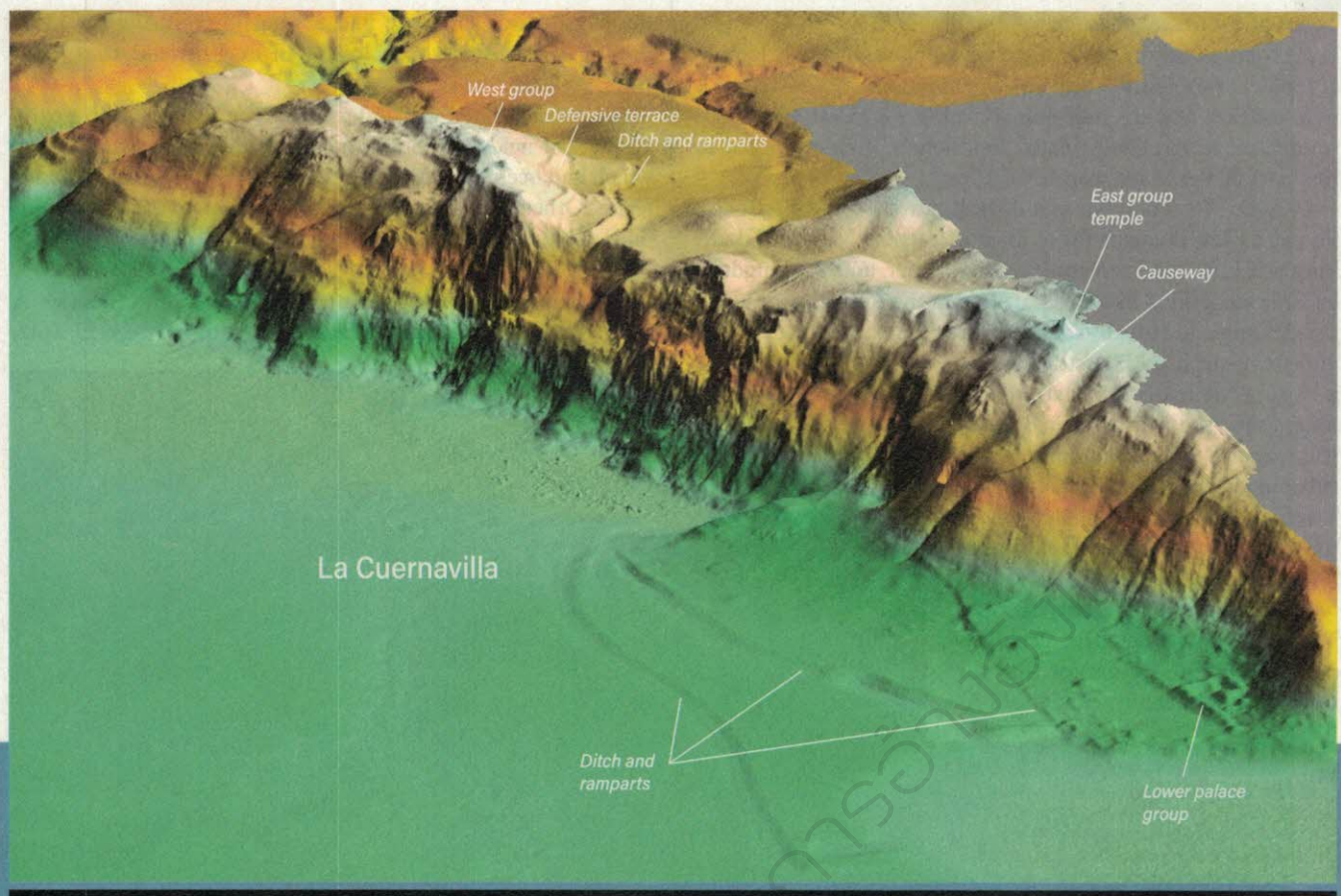
The new data is enough to upend some previous theories. A 2,700-year-old site called El Palmar sits not far from El Zotz, and was once thought of as a small town. Now, it appears to have been a major metropolitan area. Roads radiate out from its center, connecting the city's heart to outlying villages, nearly all of which were hidden before the lidar scans.

"We thought [it] was this Podunk little ... site on the edge of this lagoon, and now it's enormous. It's 40 times larger than we thought it was," Garrison says. "This is now this huge city that would have been a rival to Tikal."

The scans also hint that the Maya territory wasn't homogenous. In the eastern Petén Basin, there's a strange concentration of agricultural fields. It may have been a kind of breadbasket for the rest of the region, Garrison thinks.

And near El Zotz, the cacao fields could indicate a form of specialization, where farmers traded beans for other staples. Large community markets were likely common in Maya society.

In addition to turning towns into cities, the lidar data occasionally reveals something even more exciting — not just new structures, but new dimensions of Maya society. On a hillside near the old temple complex at El Zotz, lidar revealed a dotted line that ended up being rudimentary fortifications, built to slow incoming attackers. Just this year, Garrison's team uncovered a mound of sling stones at the site, potential ammo cached over 1,000 years ago by some prudent defender.




**Structures at a previously unknown Maya site, which Garrison has named La Cuernavilla, show that it was heavily fortified. Lidar revealed a palace group below a steep ridge, with a causeway leading to more structures atop the hills. Ditches, ramparts, moats and walls indicate that its inhabitants were prepared for war. La Cuernavilla spans about 1.5 miles across.**

The hillside reveals that the threat of warfare was more pervasive in Maya society, even far before its collapse, than archaeologists believed.

And bolstering that theory is an even more surprising discovery. Nearby, in the hills above El Zotz, Garrison has found the ruins of something unprecedented in Maya archaeology.

## MAYA WARFARE

Named La Cuernavilla by Garrison, the site is mostly unstudied. But lidar scans reveal a clear function: The place was a fortress.

Set atop an imposing ridgeline, the fort's impressive scale indicates that whoever occupied it either felt a real threat of attack or wanted to make a show of overwhelming force.

La Cuernavilla includes a temple, palace and the remains of housing platforms, as well as a moat and a massive wall some 25 feet high. One side is protected by a sheer cliff, and the other is strategically fortified with defensive terraces. A watchtower sits nearby — another first for Maya archaeologists — part of a newly discovered defensive network that spreads throughout the entire Maya lowlands.

It's the first time archaeologists have found Maya structures built expressly for warfare, and it implies an unexpected level of military engineering. Garrison estimates he came within about 100 feet of it on previous digs.

"It's amazing. It's so new. This is the kind of thing that no one ever suspected to show up," says Michael Coe, a Yale University archaeologist and Maya scholar who's not involved with the team. "It's a major discovery."

Excavations so far suggest the site was occupied for centuries. Garrison's team also unearthed a building that resembles those at Teotihuacan. It's a strong hint that, after the Mexican city-state's invasion of Tikal, they began expanding their influence on the surrounding countryside in earnest. The fortress was likely overtaken by Tikal's new rulers, and could have served as a military stronghold for the occupying forces.

When combined with the network of watchtowers, the fortifications look even more strategic. The defensive network seems to spread for miles around El Zotz. And if Garrison is right about this fortress's association with Tikal, it means that the city-state was building military outposts throughout the region to consolidate control on behalf of far-away Teotihuacan.

This includes the fortifications that Garrison discovered at El Zotz, which may be part of a larger network. The series of paved limestone platforms interspersed with rocky, tortuous terrain would let defending troops rain sling stones and

THOMAS GARRISON/PACUNAM

projectiles down on incoming warriors.

"To me, it's obvious that these are not just Balkanized little hilltop fortifications, but this represents some kind of system," says Houston, a former site director at El Zotz. "Someone invested a lot of money in these, a lot of sweat, a lot of effort."

Though some researchers have long argued that Maya civilization was bigger than assumed, this is the first evidence of strategic defensive fortifications, or what Houston calls "an aggressive landscape of surveillance."

The organized military activity hints at a new conception of Maya society. The level of resources and planning needed to build La Cuernavilla implies a society with powerful militaristic organization, something that researchers have never before suspected.

## DIGGING IN

This evidence of sophisticated military might could be the final piece of evidence that solidifies a theory long gestating in Maya archaeology: that they were much more hierarchically organized than previously thought. The presence of sophisticated agriculture and widespread engineering projects had hinted at a high level of societal control. But University of Nevada, Las Vegas, archaeologist Arlen Chase argues a focus on interpreting Maya hieroglyphics kept getting in the way.

"They're far more centralized than people have given them credit for," Chase says. "Because the hieroglyphs didn't talk about economics, it was assumed that there was no centralized control of economics, no centralized control of anything."

Now, thanks to lidar, new sites like La Cuernavilla are indicating the opposite. "This is the activity of a well-oiled state machine," Garrison says.

His team is now excavating the fortress grounds themselves, collecting pottery fragments to find out when the site was occupied. The scans are great for finding things, but can't establish a timeline. For this task, old-fashioned digging is really the only option, and Garrison sees years of work ahead. He and Houston recently secured two grants, from the National Science Foundation and the National Endowment for the Humanities, to fund more excavations at the site.

## THE VANISHING

This new picture could also help unravel why Maya society quickly — and for the most part mysteriously — vanished around A.D. 900. Though there's evidence of increased warfare toward the end, what likely precipitated the fall was a drought. A study by scientists from Cambridge University and the University of Florida, Gainesville, published in *Science* last August, shows that rainfall dropped by roughly half at the time of the civilization's collapse.

For a society dependent on irrigation to water their crops, it could well have been a death knell.

For centuries, ingenious Maya engineers had altered the landscape in their favor: creating canals to water fields, reservoirs to hold rain through the dry season, turning wetlands to fertile soil, and carving terraces into hillsides. But even with these human enhancements, the Maya remained at the mercy of nature's beneficence. Eventually, it ran out.

As the drought dragged on, warfare, already somewhat common between antagonistic city-states, seems to have become even more prevalent. The discovery of La Cuernavilla is poised to help researchers probe this angle further by illuminating the intricacies of Maya militarism. Though the site seems to have been most active centuries before the collapse, better understanding how the Maya engaged in conflict, and to what extent it was integrated into their society, will help researchers understand the sequence of events that led to the demise of their society.

We do know, though, that little food and too much fighting likely led people to abandon cities; many probably perished. The Maya population dropped around 90 percent during this time. Though a few cities would struggle on, the Maya never returned to their former glory. Those who survived fell back into the jungle or squatted in cities.

**IT'S THE FIRST TIME ARCHAEOLOGISTS HAVE FOUND MAYA STRUCTURES BUILT EXPRESSLY FOR WARFARE, AND IT IMPLIES AN UNEXPECTED LEVEL OF MILITARY ENGINEERING.**

## ECHOES OF CIVILIZATION

Leaving the research camp, we drive into the gloom of an approaching thunderstorm. Dark mounds loom around us as the battered truck pushes past concrete huts. Occasional lightning bolts paint the distant hills in silhouette, and I wonder what lies beneath them. Garrison's data make clear that the Maya didn't just build cities and towns here in the Petén — they inhabited nearly every square mile of the area.

Each hill, every bump in the ground, may conceal the remains of civilization, and with the echoes of laser beams raining down through the jungle, we'll soon find them.

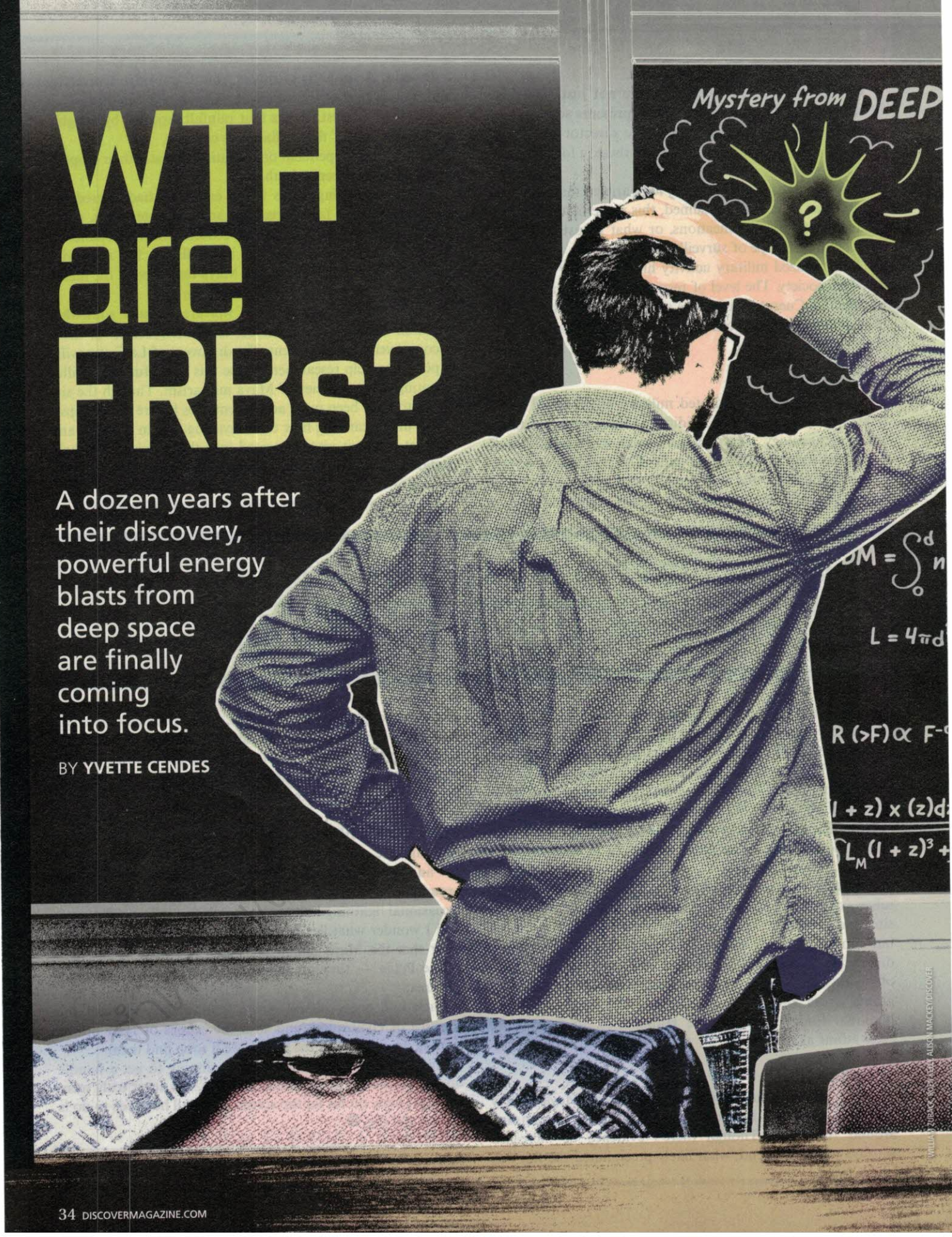
Garrison is confident that he's beginning to get a handle on this landscape he's trekked for years, but never truly seen. It's right here, on his laptop screen. Now all he needs to do is go out and dig. D

***Nathaniel Scharping*** *is an assistant editor at* Discover.

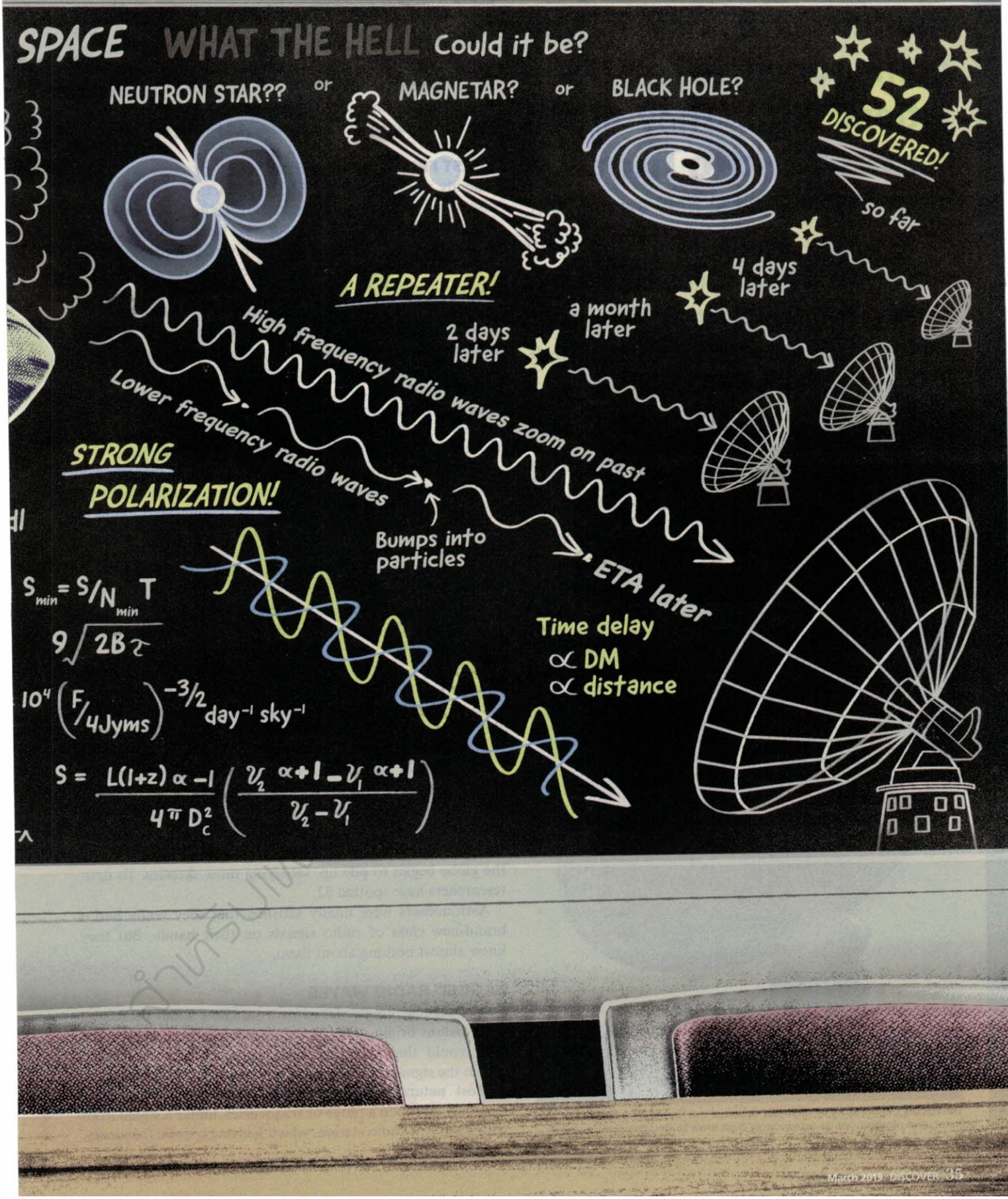
# WTH are FRBs?

A dozen years after their discovery, powerful energy blasts from deep space are finally coming into focus.

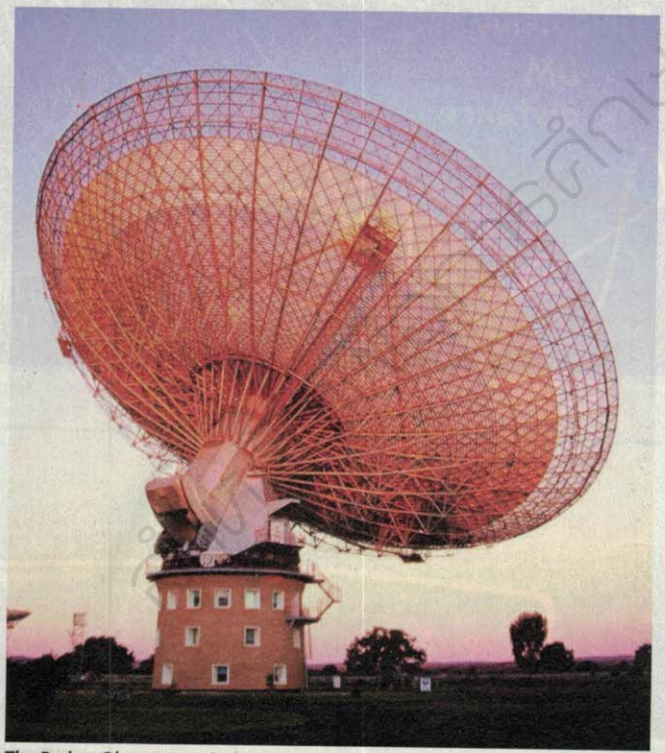
BY **YVETTE CENDES**




WILLIAM TRACY JORDAN; ALISON MACKEY/DISCOVER


SPACE WHAT THE HELL Could it be?
NEUTRON STAR?? or MAGNETAR? or BLACK HOLE?
52 DISCOVERED!
so far
A REPEATER!
4 days later
a month later
2 days later
High frequency radio waves zoom on past
Lower frequency radio waves
STRONG POLARIZATION!
Bumps into particles
ETA later
Time delay
∝ DM
∝ distance
$S_{min} = S/N_{min} \, T$
$9\sqrt{2B\tau}$
$10^4 \left(F/_{4Jyms}\right)^{-3/2}$ day$^{-1}$ sky$^{-1}$
$S = \frac{L(1+z)\alpha-1}{4\pi D_c^2}\left(\frac{\nu_2^{\alpha+1}-\nu_1^{\alpha+1}}{\nu_2-\nu_1}\right)$

**The greatest mystery of modern radio astronomy comes down to just three letters: FRB. They stand for fast radio bursts,** signals that continue to defy explanation. As the name implies, these bursts of radio waves last just a millisecond or two. They're also incredibly strong, among the brightest radio sources in the sky. That's despite traveling an incredible distance, up to billions of light-years. Do the math, and it's clear how powerful these things are. One FRB can easily broadcast more energy in a moment than the sun produces in a day.



The Parkes Observatory in Australia detected the first known fast radio burst, and remains one of astronomy's best tools to find the elusive signals.

J. SMITH/CSIRO

Visible light is only a part of the electromagnetic spectrum, but if your eyes could see radio waves, you'd probably spot FRBs in the sky all the time — thousands of them a day, from all directions. Despite their prevalence, though, no one had ever detected one — or even heard of one — as little as 20 years ago. Today, it remains unclear what FRBs really are. But thanks to improved technology and some lucky breaks, astronomers are finally on the verge of finding out.

## BURST FROM THE HEAVENS

Nobody was looking for FRBs. In fact, the first one was discovered almost by accident in 2007. Undergraduate student David Narkevic had been working for radio astronomer Duncan Lorimer at West Virginia University, looking through old data and hunting for the ghosts of dead stars.

When big enough stars die in a fiery supernova, they can leave behind corpses — cores made entirely of neutrons, called (naturally) neutron stars. These can emit beams of radiation and spin several times a second, so when the beams sweep past Earth, they appear as pulses, akin to a cosmic lighthouse blinking in the distance. It was these "pulsars" that Narkevic sought. He was combing through observations from the Parkes Observatory in Australia for pulses from two satellite galaxies, called the Magellanic Clouds, that orbit our Milky Way.

But one cold winter day, a strange burst of radiation in that old data — definitely not a pulsar — caught Narkevic's attention, and he told his boss that he thought he'd found … something. It was a single, bright pulse, but it did not appear to come from the Magellanic Clouds. Instead, the origin was an area of deep space well beyond our galactic neighborhood. "I was stunned," recalls Lorimer, "and didn't know what to make of it." He knew it was unlike anything he'd seen before, and he published the findings later that year, eventually dubbing the event an FRB.

At first, no one else knew what to make of it, either. Many astronomers were skeptical, speculating that mundane sources such as lightning strikes or even microwave ovens created the signal. "Even my own wife [radio astronomer Maura McLaughlin] argued the burst wasn't real!" Lorimer recalls.

FRB seekers don't have it easy: The signals are very brief, the sky is very big and many radio telescopes, like Parkes, can observe only a tiny part of the sky at a time. Astronomers found many false positives, too, which didn't help. Eventually though, verified FRB signals from radio telescopes around the globe began to pile up, satisfying most skeptics. To date, researchers have spotted 52.

Astronomers were finally satisfied that they really had a brand-new class of radio signals on their hands. But they knew almost nothing about them.

## RAGGED RADIO WAVES

One of the few things astronomers did know about FRBs was their distant origin, with each one coming from deep space. How could they tell? The information is actually hidden within the signal itself.

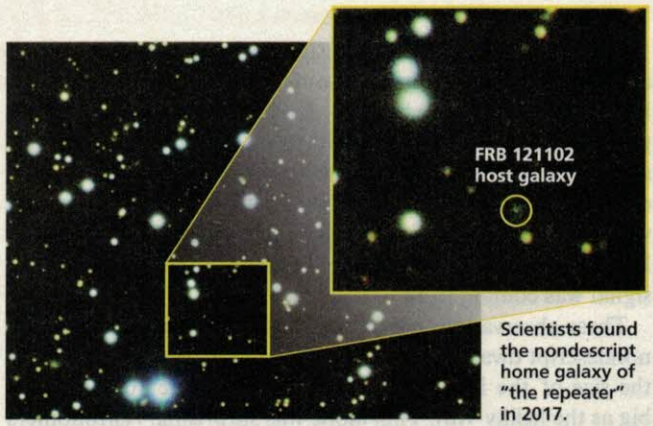
Most naturally generated radio signals are broadband, meaning they span a range of frequencies, unlike a signal from your local FM radio station, which has one specific frequency.

(We use narrow-band signals on Earth to maximize the available spectrum, which we all share, but nature is not so considerate.)

Look closely at any given astronomical radio signal, and you'll see that its lower frequencies arrive slightly later than its higher ones. This is because while space is a better vacuum than any on Earth, it's not a perfect one, and a stray particle still lurks here and there. Those stray bits of stuff interact with radio signals and slow the lower, weaker parts down, while the more energetic higher frequencies don't interact as much, and can zoom past. The greater the distance the signal has traveled, the greater the delay of the lower frequencies usually is. Astronomers call this characteristic of a signal its dispersion measure (DM).

If one of these pulses were starting out in our own galaxy, we might get a DM of around 30. The Magellanic Clouds are over 200. The oldest detected FRB, found later in archival data preceding Lorimer's discovery, had a DM of 790, meaning it came from billions of light years away.

That distance tells astronomers a lot about the provenance of FRBs: To see such a brief signal, so bright, from so far away, would require an extremely energetic source. The trouble is, even now, no one knows what such an event might be. "None of the models exist without major problems," says Victoria Kaspi, a radio astronomer at McGill University.



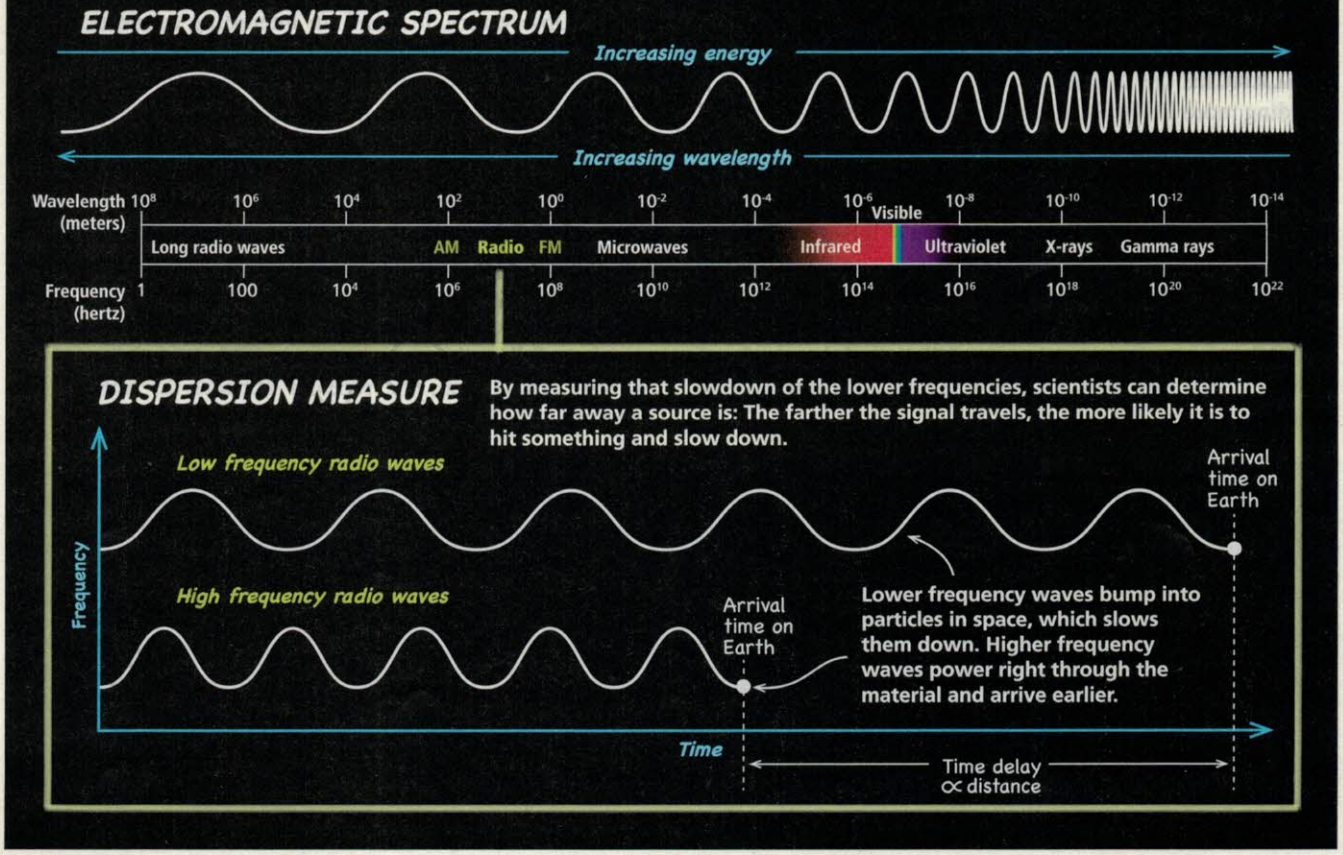

Scientists found the nondescript home galaxy of "the repeater" in 2017.

## THE REPEATER BECKONS

The first major FRB breakthrough came with the discovery of a special one called FRB 121102. (FRBs are named by the date they were discovered, this one on Nov. 2, 2012.) It stands out because unlike all other known FRBs — which only burst once and are never seen again, despite extensive follow-up observations — FRB 121102 *repeats*. Sometimes "the repeater," as it's known, will be quiet for weeks or months at a time, and then sometimes it will burst several times a day. There is no pattern.

## MEASURING FREQUENCIES

**Fast radio bursts, like many natural emissions, are broadband in nature: They span a wide range of frequencies. The lower ones are less energetic, so bumping into stray bits of matter in space can slow those (and only those) frequencies down.**




TOP: GEMINI OBSERVATORY/AURA/NRC/NSF/NRAO. BOTTOM: ROEN KELLY/DISCOVER

But the repetitive, erratic signals have allowed patient astronomers to learn more about this FRB than any other. Knowing generally where to look in the sky for repeat performances has allowed them to pin down its coordinates more precisely than they can with one-off FRBs. This level of precision is what finally allowed astronomers to follow up with giant optical telescopes, like the Gemini Observatory in Hawaii and the Hubble Space Telescope, and see where the signal was coming from.

These observations have revealed the repeater's home to be a nondescript dwarf galaxy 3 billion light-years away. It's about the size of the Large Magellanic Cloud, some 10 percent as big as the Milky Way. That alone was surprising: Astronomers anticipated something like an FRB would come from a large, active galaxy with a bright supermassive black hole or active star formation, not this cosmic pipsqueak.

In 2018, researchers went even deeper. By carefully analyzing the tremendous twisting of the repeater's radio waves, called the signal's polarization, they learned its home environment is an unusual one. "I think a neutron star is involved in creating the bursts, in an extreme environment," says the study's lead author, Daniele Michilli at McGill University.

The signals could originate from a specific type of neutron star known as a magnetar, which has extraordinarily strong magnetic fields. They're so powerful that they could kill you from thousands of miles away by compressing the electron clouds in your atoms. A magnetar's powerful signals, warped by an extreme environment such as the area near a supermassive black hole, may explain the FRB's strong polarization. Or, it could be something else entirely — the repeater is still one of a kind, so it's hard to draw any broad conclusions.

## AVALANCHE OF DATA

"Finding more FRBs is the most urgent goal at the moment," says Emily Petroff, a radio astronomer at the University of Amsterdam. "We just don't have enough information on where they're coming from."

Petroff discovered some of the first FRBs, back when people weren't certain if they were real, and she helped legitimize the field by building the first comprehensive catalog of the signals. She believes that in order to solve the mystery of FRB origins, astronomers must first find hundreds of examples and then look for patterns and standouts in that large population.

"Currently, each FRB is like a unique snowflake where we admire each one's individual details," Petroff says. "What we need next is a snowbank."

The first snows are already falling, with a radio telescope in Canada becoming an FRB-hunting machine. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) has, as its name implies, the primary goal of mapping hydrogen clouds in galaxies. But since the radio telescope looks at a lot of the sky at once, FRBs should also pop up during the mapping.

Further, the stationary CHIME will look at the same patch of sky once a day as it drifts overhead, making it ideal to spot repeating FRBs. Should one turn up within CHIME's field of view, the experiment can check in on it every day automatically, looking for new bursts. Last July, the science team spotted its first FRB, and it expects to find several repeating FRBs — if more are out there.

## FLASHES OF LIGHT

Already, that growing snowbank of data has produced some surprises. The latest twist in the FRB story came from a project at the Australian Square Kilometer Array Pathfinder (ASKAP) radio telescope in October, when astronomers announced the discovery of 20 bright FRBs, nearly doubling the total number known at the time.

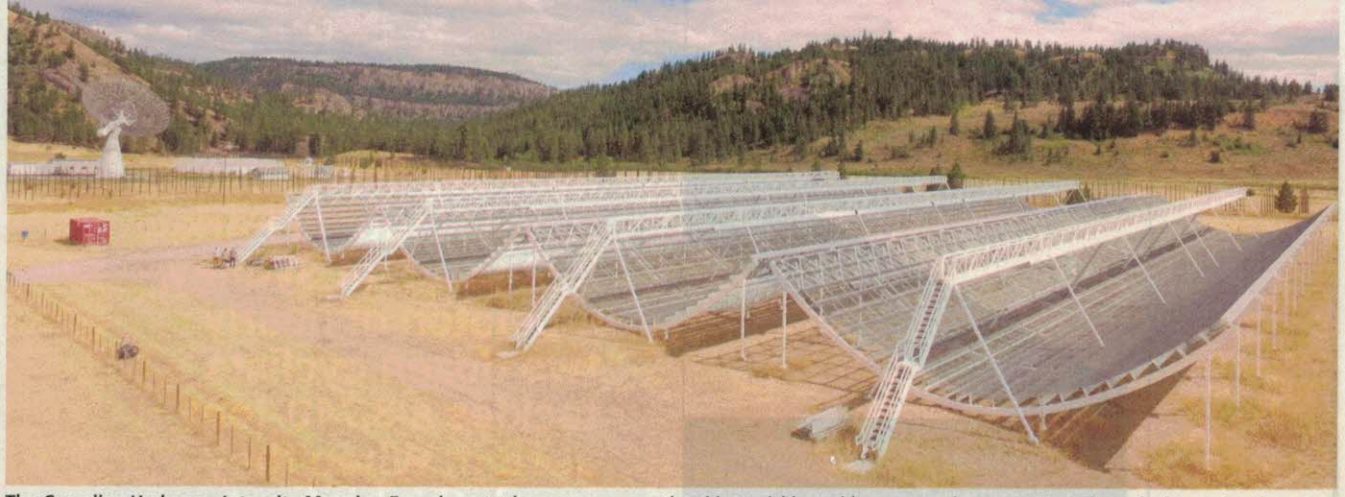
"We chose 50 [locations] all over the sky very carefully and hammered them for hundreds of hours of observing to see if we could find another repeater," says Keith Bannister, one of the scientists involved in the survey. None of the 20 repeated — but that wasn't the big deal.

When the ASKAP team compared its FRBs with others from Parkes Observatory, it found an interesting connection. The ASKAP FRBs were all brighter but had lower DMs, meaning they were all closer as well. This makes sense: On a foggy night, a flashlight that's closer appears brighter. You could even measure how far away it is by studying its relative brightness. ASKAP's data showed that FRBs follow the same pattern.

But imagine if you saw a flashlight at a distance you knew precisely, but it appeared much fainter than it should have. If nothing else had changed, you'd wonder if you were looking at a second, different flashlight. The repeater, FRB 121102, is that second flashlight: While all non-repeating FRBs appear to follow the same pattern in DM and brightness that ASKAP established, the repeater appears far fainter than expected at its DM.

The Australian Square Kilometer Array Pathfinder consists of 36 separate dish antennas spread across a wide area, working together as one. It can detect millions of other radio signals in a matter of days, and found 20 FRBs in 2018, almost doubling the current total.

CSIRO



The Canadian Hydrogen Intensity Mapping Experiment telescope can scan the skies quickly and has no moving parts. Its unique design makes it an ideal instrument to detect transient radio emissions such as FRBs.

This has left many astronomers scratching their heads. Could different phenomena create one-off and repeating FRBs?

"Whether all FRBs are the same is really an open question," says Bannister. "I try not to be opinionated as a scientist; I like to just go off and measure. But ... my gut feeling is we end up finding two versions [of FRBs]." It wouldn't be the first time astronomers turned one discovery into two. (See "Out of One, Many," below.)

## MYSTERIOUS MESSENGERS

For every answer about FRBs, the data have provided us with several new questions. Do they all repeat? Is there any pattern in the repetition? Are they all even the same type of phenomenon? "There are more theories than bursts," Lorimer would quip before the recent flood of FRBs, "and nobody knows for sure."

Kaspi goes even further. "I'm very puzzled by it," she says, "and I think there's a lot of possibility, including things that we can't imagine right now." Perhaps young neutron stars are more energetic than anyone expects, or maybe FRBs involve physics we don't understand, or the bursts could require conditions so rare that it turns out nothing in our galactic neighborhood sets them off. Extraordinary claims, of course, require extraordinary evidence, but FRBs definitely fit that bill.

Even better, FRB signals, regardless of what causes them, may be useful in deciphering mysteries about the universe, thanks to the vast distances they travel. New research suggests the bursts could be a new way to learn about the relatively unstudied and sparse material that lies between galaxies by studying the dispersion measures they cause. Researchers may even detect the existence of magnetic fields out there, a phenomenon about which we currently know almost nothing.

Despite all the lingering questions, at least one thing is clear: The FRB era of astronomy has arrived. D

*Yvette Cendes is a radio astronomer at the Dunlap Institute for Astronomy and Astrophysics, University of Toronto. Visit her website at* ***www.whereisyvette.com***

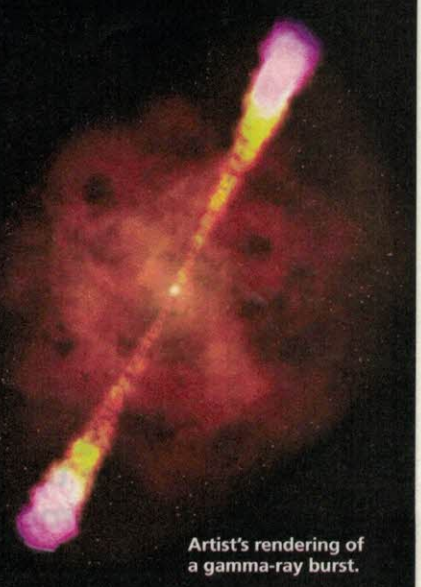
## OUT OF ONE, MANY

**Astronomers may end up finding out FRBs come in different flavors, with different phenomena causing different kinds of bursts — and there is precedent for this in astronomy.**

**In 1973, the U.S. military declassified the existence of gamma-ray bursts (GRBs), first detected in the 1960s by military satellites designed to find gamma radiation from nuclear weapons tests. By 1994, at least 118 models of GRBs were published, with every new discovery ruling out a handful.**

**It turned out GRBs actually come in two major categories (plus a few rarer ones): About 90 percent of detections are so-called "long GRBs," which arise when a supermassive star collapses into a supernova. Most of the rest are "short GRBs," whose origins, involving the merger of two neutron stars, were confirmed only in 2017.**

**Similarly, supernovas themselves turn out to have multiple origins. The most common supernova occurs when an extra-large star runs out of fuel and dies in a titanic explosion, leaving behind a neutron star or black hole. However, a smaller subset of supernovas occurs when a white dwarf — the glowing ember left behind when a regular-sized star dies — reignites and rips apart. Astronomers believe this happens when the white dwarf gains mass, either by siphoning it from a companion star or merging with another white dwarf, or perhaps both. The exact circumstances of what causes these types of supernovas remain a mystery — for now.** — Y.C.



Artist's rendering of a gamma-ray burst.

TOP: NATIONAL RESEARCH COUNCIL OF CANADA. BOTTOM: NASA'S GODDARD SPACE FLIGHT CENTER

# TAME THE PAIN

Just one incident can make the brain overreact to future experiences. Researchers believe the solution is to reframe and retrain.

BY **CATHRYN JAKOBSON RAMIN**

On a misty autumn morning in Australia's Royal National Park, just south of Sydney, a peloton of nearly two dozen cyclists tackles a 3,740-foot ascent. When they reach the highest point of the day's 45-mile ride — the first leg of a weeklong journey — they're rewarded with cookies and candy from support staff, followed by a downhill glide along a sandstone escarpment. Far below them, waves of the Pacific barrel toward shore and explode in clouds of foam.

The group is not training for an athletic event. Instead, the 21 cyclists and their support crew have united to promote an unconventional pain management approach. **The team wants to start a revolution.** The road ahead is a long one.

COREY PERSIC (2)

Australian physical therapist and pain scientist Lorimer Moseley, 48, got the idea for the annual ride because he wanted to connect with other practitioners, and patients, to change how they thought about and treated chronic pain, particularly in rural areas where access to care is limited. The first Pain Revolution outreach tour hit the road in 2017. Covering more than 500 miles of southern Australian roads, the cyclists spent their nights in small towns and hamlets, offering talks on pain science and its practical application. The response was so enthusiastic that Moseley and his University of South Australia colleagues developed a formal training program for local pain educators. The inaugural class convened in 2018.

Chronic pain is a common and expensive problem. In the U.S., 1 in 3 Americans deals with the condition. The price tag of treatment — including medication, surgery and other often invasive options, as well as lost productivity and additional costs — runs more than $600 billion annually. Moseley and his colleagues believe, however, that much of what we spend on chronic pain — not just money, but also time, energy and quality of life — could be saved.

The solution that they advocate, which has its share of critics, is essentially to retrain the body's pain system, particularly the brain, to be less sensitive. According to the Pain Revolutionaries, that process begins by understanding that pain is the brain's response to perceived threat.


PETE THORNTON

## ALL ABOARD THE BRAIN BUS

"If a part of your body seems to be in danger and needs protecting, then your brain will make that part of your body hurt," says Moseley.

He became interested in the brain-pain connection after sustaining a near-fatal snakebite on his ankle while hiking in 2000. Moseley recovered, but months afterward, a twig brushing against his ankle caused him to experience extreme pain. He realized that his brain

had concluded, incorrectly, he'd been bitten again.

"All pain is very real," Moseley says. "But there are many situations in which pain does not seem to match the amount of danger your body tissues are truly in. ... Pain depends on your evaluation of danger and the likely benefit of protective behavior, not on the true danger level or the true benefit of protective behavior."

Contrary to what most of us have been told, says Moseley, there are no "pain pathways or pain messages." Instead, he says, there are peripheral nerve endings all over the body that send signals to the brain, which makes a judgment based on what seems, given all data on hand, to be in the organism's best interest. But that judgment is not infallible.


The Pain Revolution peloton (top) rides near Wollongong, Australia. There, members the tour's outreach staff, aboard the Brain Bus (right), invite locals to participate in sensory experiments. In one classic exercise, a participant's brain registers touch on a fake rubber hand (below).

FROM TOP: CATHRYN JAKOBSON RAMIN (2); PETE THORNTON

The Brain Bus, a white Econovan sporting a Pain Revolution logo, is waiting for the cyclists when they reach their Day One destination, the seaside city of Wollongong. Part of the tour's educational outreach, the bus is loaded with exhibits and experiments that illustrate the brain's fallibility. It's already drawn a crowd of health care professionals, patients and family members.

"Your brain can be tricked, [which can] shape perception," says clinical pain neuroscientist Tasha Stanton, part of the Brain Bus team.

She demonstrates with an experiment on a local physical therapist. The woman is seated at a folding table, with her left hand positioned behind a curtain. In front of her, a fake, rubber left hand lies next to her real right hand. For a few seconds, Stanton gently caresses both her real left hand and the rubber one. The woman's surprised squeal reinforces Stanton's point: Her brain has registered the sensation of being stroked on the fake hand as if it were her own.

The rubber hand experiment and other Brain Bus exhibits use audience engagement to highlight the brain's sometimes iffy judgment. A large chart on display nearby might not be as flashy, but it's arguably more important: Two mountains, each sliced horizontally into three different zones, illustrate the core of what Moseley and the Pain Revolution preach.

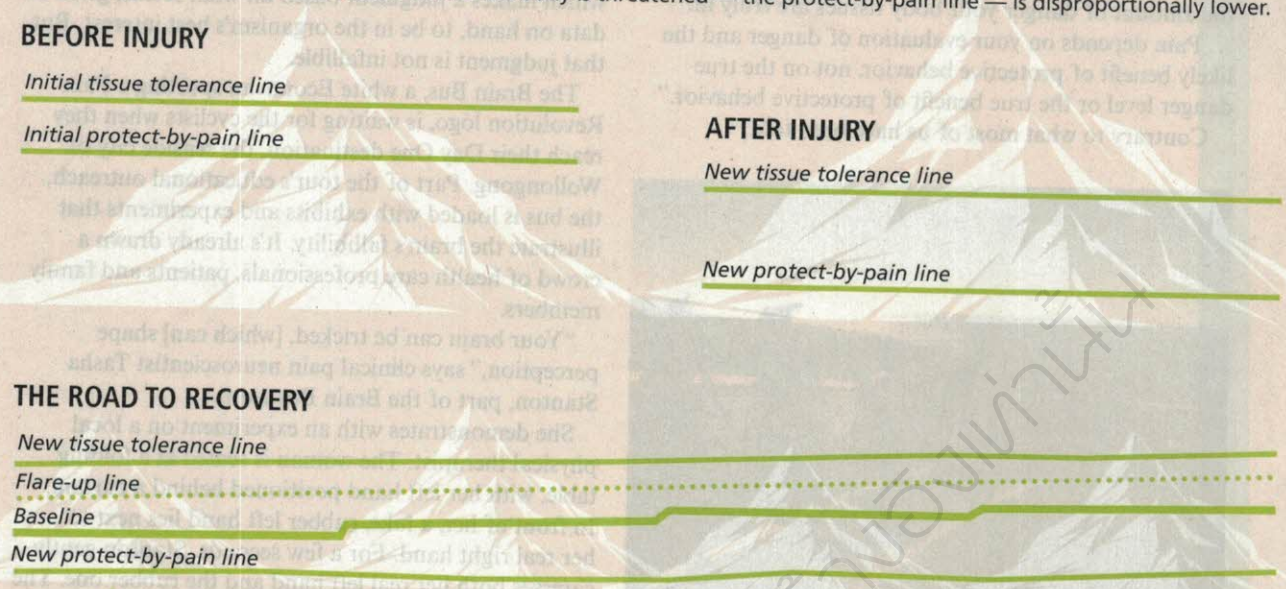
Imagine an individual's activity, whether it's getting out of bed or running a marathon, as a hiker trekking toward a summit. One of the mountains represents a pain system with normal sensitivity. The bottom zone is pain-free. Above it is what Moseley calls the protect-by-pain line, when the brain determines, based on available data from peripheral nerves, that a part of the body is in danger of being damaged and needs to be protected — so the brain starts to make it hurt.

There's a narrow buffer zone between that protect-by-pain line and the line above it, the "tissue tolerance line," where actual damage to the body part may occur if the activity continues.

The other mountain on the chart represents people with chronic pain. The top line, tissue tolerance, is a little

## A Mountain of Pain — and How to Conquer It

Pain Revolutionaries believe chronic pain can result from an injury oversensitizing the brain. Before the injury, the brain would send out pain cues only if an activity is about to cause actual tissue damage. After the injury, although the tissue may be at risk of reinjury, the threshold for the brain to feel the body is threatened — the protect-by-pain line — is disproportionally lower.




**1** For chronic pain sufferers, retraining the brain starts with careful, planned baseline activity. Individuals work above their artificially lowered protect-by-pain threshold, but aren't at risk of actual tissue damage.

**2** Individuals increase activity gradually to avoid a flare-up: a warning from their oversensitive brain that they've overdone it. By avoiding flare-ups, individuals reduce the perceived threat to their brains.

**3** By doing a little more each day — but not much more — than the day before, individuals can raise their protect-by-pain line as they retrain their brains.

**4** Over time, as tissues get stronger and fitter, the tissue tolerance line will also return to a pre-injury level.

Source: adapted from Explain Pain materials

lower, due to the initial injury, than that of a person with normal pain sensitivity. But the protect-by-pain line is much lower, leaving a large buffer zone between them. For these brains, benign sensations from ordinary activity may be misinterpreted as threatening, causing pain to kick in. In other words, when chronic pain patients experience flare-ups, says Moseley, it's usually not because they have reinjured themselves, but because their pain systems are hair-trigger sensitive.

### TAG, YOU'RE IT

The idea that the brain can get oversensitized is not new. In the mid-1960s, for example, the brain was seen as a mass of neural networks. The more a specific network was used, the more sensitive it became. Later work described the phenomenon of central sensitization: Long after an injury has healed, the central nervous system remains persistently overreactive to stimuli — like Moseley experiencing agonizing pain at the same site months after his snakebite.

How patients think of their chronic pain, even how they and their health care team talk about it, can also play a role in how they experience pain. (See "Watch Your Language," opposite page.) Moseley recalls a patient who consistently referred to his back as his "Roman ruins." The patient even kept a photo of Rome's crumbling Forum above his desk. A physician he consulted pointed to structural problems on his MRIs and X-ray reports, without acknowledging that these were typical of an aging spine. Convinced that his spine could "go" at any time, Mr. Roman Ruins' brain created a neurotag, a network of brain cells that fire together to produce, essentially, a conditioned response. Because he felt and acted as if he had something seriously wrong with him, and the people around him reinforced this idea, the patient repeatedly strengthened that neurotag.

Numerous studies have documented that connection between an individual's expectation of pain, formed through both previous experience and the way the anticipated pain is discussed, and the subsequent intensity of the pain response. The actual mechanisms underlying pain expectation and perception have been difficult to identify, however.

In November in *Nature Human Behaviour*, researchers

MOUNTAINS: SPINYANT/SHUTTERSTOCK

reported on the first model to correlate pain expectation and response with specific neural activity. Using brain imaging, the team found that individuals who expected greater pain showed more neural activity in regions of the brain involved in fear and threat response, even *before* they experienced the unpleasant stimulus used in the study — a painful but harmless application of heat to their arms or legs. Once the stimulus was applied, participants cued to expect higher levels of pain reported higher pain ratings, even when they actually received low-pain levels of heat. Their brains also generated greater activity in areas associated with pain.

Surprisingly, the researchers found that for individuals anticipating high levels of pain, receiving a low-pain stimulus did not change their expectation for the next round: They still anticipated a lot of pain, and that anticipation was reflected in their brain activity, including the pain response.

Moseley and his colleagues believe, however, that thanks to the inherent plasticity of our neural networks, a brain that becomes oversensitized can, over time, relearn normal sensitivity. And that's where the Pain Revolution focuses.

The researchers think that the way to return chronic pain patients to normal function — to raise their lowered protect-by-pain line — is a combination of awareness and activity. Pain educators help patients understand that their pain is, as Moseley puts it, "an output of the brain designed to protect you. It's not something that comes from the tissues of your body."

The educators encourage patients to gradually increase physical activity, and not to let a little pain stand in the way. Over time, the patient retrains their pain system, including their brain, reducing oversensitivity.

At a local surf club in Wollongong, Pain Revolution cyclists, still in their black and polka-dotted Lycra, are working the lobby and meeting locals. Among the team is David Butler, an associate professor of pain science at the University of South Australia and the founder of the Neuro Orthopaedic Institute in Adelaide. The support staff and educational content lead for the cycling tour, Butler plays an even larger role in the Pain Revolution itself. He collaborates closely with Moseley on Explain Pain seminars and handbooks for practitioners and their patients. His inner showman emerges when he takes the stage to address the entire group.

"You and I hurt when our brains weigh the world, weigh everything going on, inside us and out, and judge that there is more that is dangerous to us than safe," he says. "Equally, we will not hurt when our brains weigh the world and judge that there is more safety out there than danger."

Butler runs through the factors that he and Moseley believe make people vulnerable to chronic pain by producing certain neurotags. The stimuli that create these tags can be either internal — your thoughts and beliefs, physical changes in your body — or external, ranging from places you go to things you see, smell and hear.

The key difference between these tag-producing cues is whether the brain perceives them as signs of danger or safety. A "danger in me" stimulus (DIM), which produces a danger neurotag, could be the ominous whirring of a dentist's drill, a whiff of burning rubber or your inner voice proclaiming you'll never get rid of those love handles. "Safety in me" stimuli (SIMs), which build and strengthen safety neurotags, might include hearing your favorite song, getting a massage or feeling in control of your life.

If the scale tips hard, if there are too many DIMs, your brain may conclude that you are in jeopardy. It may ultimately trigger an inflammatory response that, in turn, can result in pain. To convince your brain cells that you don't need protection, the scale must be rebalanced. This is best accomplished, says Butler, by pursuing SIMs, the experiences and activities that

## Watch Your Language

While working with patients early in his career, Moseley observed that the attitudes health care providers displayed, and the language they used, could actually worsen their patients' discomfort. Terms such as *degenerated, desiccated, stuck, bone-on-bone, jammed, out of alignment, locked* and *twisted* can color a patient's self-perception of pain.

Instead of describing pain with such daunting and imprecise language, says Moseley, it should be reframed as a smart, protective mechanism that sometimes goes off the rails. Pain is modulated by context, expectations and experience, so what the practitioner says to the patient makes a big difference. —C.J.R.

| Phrases to forget | Consider instead |
|---|---|
| "I know what you're going through." | No, you don't. Replace with something like, "I can listen and try to understand what you are going through." |
| "You must be a bad/poor/slow healer." | Reinforces negative self-perception. Just don't say it. |
| "Learn to live with it." | Honor and acknowledge the individual's current condition and attempt at coping before offering another approach. |

Source: adapted from Explain Pain materials

"open up that drug cabinet in your brain," spurring the production of endorphins and other feel-good chemicals such as serotonin and dopamine. Knowledge through education and understanding is the "master key to the drug cabinet," says Butler.

## FOCUS ON PAIN, NOT BLAME

While the Pain Revolution rolls on, not everyone is going along for the ride. Many peers remain skeptical, and studies have yielded inconclusive results.

In 2016, for example, *The Journal of Pain* published a systematic review of various back pain treatments, including both exercise and cognitive strategies like those promoted by the Pain Revolution, as well as combinations of the different methods. The review showed little difference in outcome.

Other critics, such as Canadian professor of spine biomechanics Stuart McGill, believe Moseley, Butler and their colleagues are too focused on the brain's role in chronic pain.

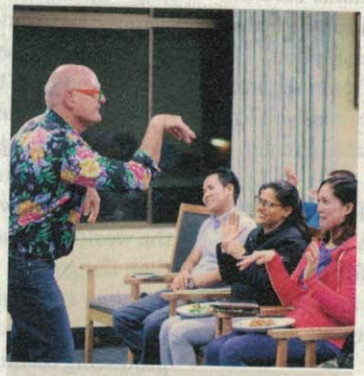
"Both Lorimer and David, while they're good scientists, they have a very brain-centric view of the world," McGill says. "And this is natural. Scientists find what they look for."

Moseley, says McGill, "studies the brain, and he finds things out about the brain and the neuroscience side of things. But that doesn't mean by default that the brain is the ultimate variable for helping a patient with back pain."

Instead, McGill believes that all back pain is rooted in actual tissue damage that can be detected through careful and thorough physical assessment. Moseley and Butler's work is interesting, McGill says, but adds, "I haven't seen any convincing evidence that helps me with the patient in front of me.

"When I perform an assessment with enough detail and rigor, I am shown what the mechanism of their pain is," he explains, "and I find exactly what motions, postures and loads trigger their pain, and what activities take it away."

For McGill and other skeptics, their greatest concern with the Pain Revolution approach is that enthusiastic followers will misinterpret Moseley and Butler's science, particularly if they are short on clinical experience and expertise. These well-intentioned but misguided Pain Revolutionaries could, contends McGill, make the patient's situation worse by leading them to believe the pain is all in their head.



**Knowledge through education is the "master key to the brain's drug cabinet," says Butler.**

Other peers are more optimistic. Beth Darnall, a pain psychologist at Stanford University, believes the Pain Revolution and Explain Pain initiatives offer a more comprehensive approach to managing pain.

"I'm a fan of the Explain Pain wisdom because it is so accessible," says Darnall. "These messages around what pain is, and how it's a product of the brain, and how an individual can learn ways to best control their pain experience, this equips and empowers people to have the best control over their own suffering, and that translates into fewer doctors and fewer pills."

She adds: "It's not to the exclusion of medical care, and it's not necessarily to the exclusion of pharmacological treatments. But ... everybody wins when the patients are educated, when they understand which choices can best support reduced pain and increased function and best outcomes."

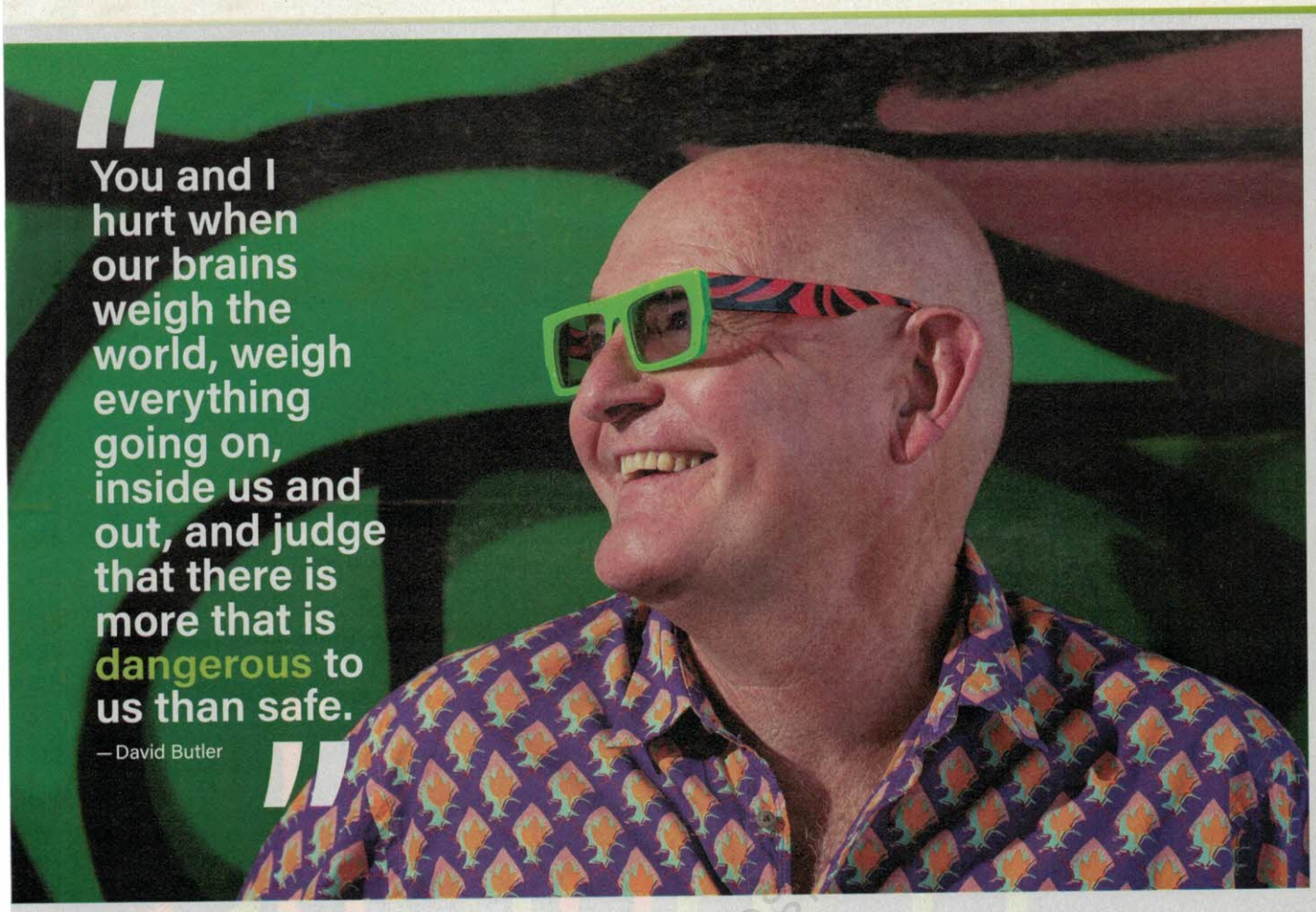
More of the field overall may be coming around to Moseley and Butler's approach. In 2018, *The Lancet* published a pair of papers, plus a related opinion piece, that challenged current treatment guidelines for chronic low back pain, including spinal fusion surgery, opioid therapy, cortisone injections and nerve ablation procedures. The authors suggested instead that physicians tell chronic back pain patients to exercise or remain active, and to seek counseling to deal with the psychological aspects of managing chronic pain.

That was a step forward, says Moseley, but something important was missing. Accessible neuroscience education for the patient and the practitioner — just what the Pain Revolution and Explain Pain projects offer — must come first. If a person believes, as many back pain patients do, that hurt means harm, "telling him to exercise or remain active is futile," says Moseley. If he doesn't understand what is going on in his brain, "it's daft to think that an exercise program alone will resolve chronic pain." If he's instructed to seek counseling, without that understanding, says Moseley, "he's going to feel like his health care practitioner doesn't believe him, leaving him frustrated and angry."

## THE ROAD GOES ON

A couple of days into the Pain Revolution cycling tour, after a grueling, non-stop climb, Simon Summers, a Ph.D. student taking part in the ride, is trying to deal with a cramp in his low back. His brain is issuing furious protect-by-pain messages.

COREY PERSIC




PETE THORNTON

Moseley takes advantage of the teachable moment. "Imagine that you have reached a threshold at which you begin to trigger positive adaptation in your body tissues," he says. "You're a fit, healthy guy. Be confident in yourself and courageous in pushing things a little, in the knowledge that your system will protect you."

In a few minutes, Summers is back on his bike and pedaling.

But convincing people outside the Revolution of the brain-pain connection remains an uphill task. While the peloton stops in Canberra, Australia's capital city, some members attend a panel discussion called "The future of pain management beyond codeine."

The topic is timely: A couple of months earlier, the Therapeutic Goods Administration, Australia's FDA equivalent, ordered pharmacies to remove over-the-counter codeine products from their shelves. The idea was to avoid a U.S.-style opioid crisis, but many Australians have long relied on codeine to manage chronic pain. Now that the shelves are empty, the people who used the products want to know what to do.

The audience of some 200 people includes practitioners, researchers and policymakers, as well as patients, some of whom express skepticism over the role of the brain in their chronic pain. Well-trained local pain educators, Moseley believes, will be key to bringing these patients around to his approach — and these health professionals seem eager to join the Pain Revolution's ranks.

On the last full day of the tour, the cyclists trade urban Canberra for sheep pastures punctuated with rows of poplar trees. In wind gusts reaching nearly 50 mph, they climb more than 9,000 vertical feet, crossing over the Snowy Mountains to the hamlet of Corryong. No forum is planned in this town of 1,200, deemed too tiny to draw a crowd. But 22 health professionals from outlying areas show up anyway, thanks to what Butler calls the "bush telegraph." To feed everybody on such short notice, local residents throw a massive potluck dinner.

The next day, the cyclists cross the broad Murray River and complete their course. They're already planning for next year's Pain Revolution tour: more than 400 miles on the back roads of Australia's island state of Tasmania. There, the prevalence of spinal fusion surgery for low back pain is seven times higher than it is in South Australia. Opioid abuse is also rife, and the need for pain education is profound. The Pain Revolution is in high gear, but it still has miles to go. D

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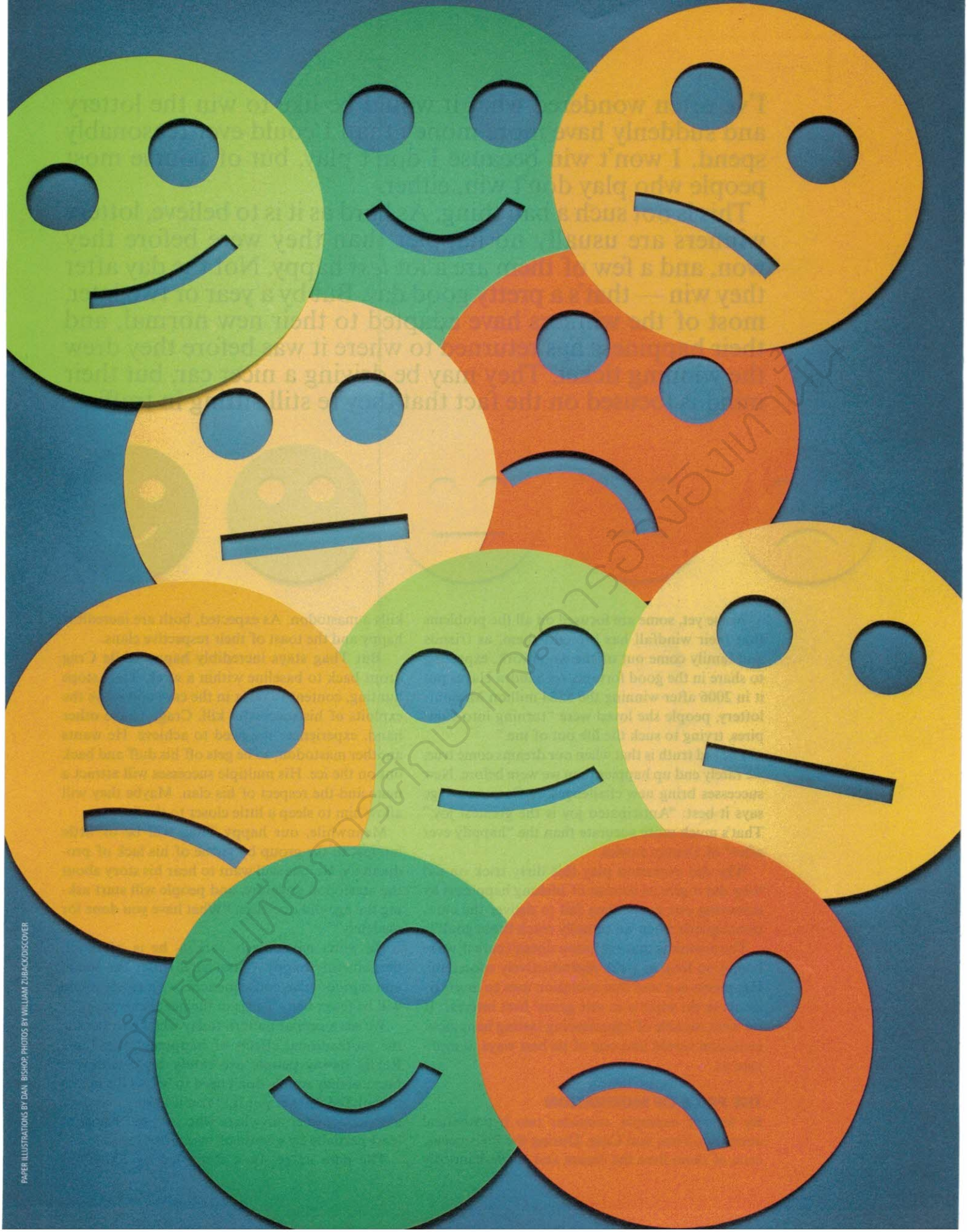
***Cathryn Jakobson Ramin*** *is the author of* Crooked: Outwitting the Back Pain Industry and Getting on the Road to Recovery.

# The Happiness Dilemma

## Why satisfaction in life is never guaranteed — thanks to natural selection.

BY **WILLIAM VON HIPPEL**



PAPER ILLUSTRATIONS BY DAN BISHOP. PHOTOS BY WILLIAM ZUBACK/DISCOVER

I've often wondered what it would be like to win the lottery and suddenly have more money than I could ever reasonably spend. I won't win because I don't play, but of course most people who play don't win, either.

This is not such a bad thing. As hard as it is to believe, lottery winners are usually no happier than they were before they won, and a few of them are a lot *less* happy. Not the day after they win — that's a pretty good day. But by a year or two later, most of the winners have adapted to their new normal, and their happiness has returned to where it was before they drew the winning ticket. They may be driving a nicer car, but their mind is focused on the fact that they're still sitting in traffic.

Worse yet, some are focused on all the problems that their windfall has brought them, as friends and family come out of the woodwork, expecting to share in the good fortune. As Sandra Hayes put it in 2006 after winning the $224 million Missouri lottery, people she loved were "turning into vampires, trying to suck the life out of me."

The sad truth is that when our dreams come true, we rarely end up happier than we were before. New successes bring new challenges. A German adage says it best: "Anticipated joy is the greatest joy." That's much more accurate than the "happily ever after" of Disney movies.

Why did evolution play this dirty trick on us? Why did it give us dreams of lifelong happiness by achieving our goals, then fail to deliver the emotional goods when we actually reach those goals?

The answer is that evolution doesn't care if we're happy, so long as we're reproductively successful. Happiness is a tool that evolution uses to incentivize us to do what is in our genes' best interest. If we were capable of experiencing lasting happiness, evolution would lose one of its best ways to motivate us.

## THE PRICE OF MOTIVATION

By way of example, consider two hypothetical ancestors, Thag and Crag. During the Pleistocene, each of them lives the dream and single-handedly kills a mastodon. As expected, both are incredibly happy and the toast of their respective clans.

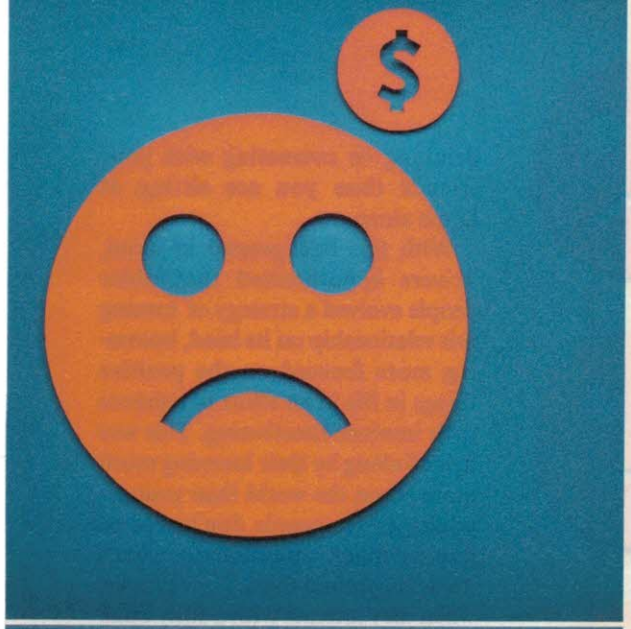
But Thag stays incredibly happy while Crag drops back to baseline within a week. Thag stops hunting, content to relax in the cave and relive the exploits of his successful kill. Crag, on the other hand, experiences the need to achieve. He wants another mastodon, so he gets off his duff and back out on the ice. His multiple successes will attract a mate and the respect of his clan. Maybe they will allow him to sleep a little closer to the fire.

Meanwhile, our happy Thag will be of little interest to the group by virtue of his lack of productivity. No one will want to hear his story about the mastodon anymore, and people will start asking the age-old question, "What have you done for me lately?"

He won't particularly care — he is, after all, permanently happy — but he'll suffer the social and reproductive consequences. As a result, there will be fewer baby Thags in the next generation.

We see a similar pattern today when we examine the motivational effects of happiness over time. Really happy people are rarely high achievers because they simply don't need to be. As the media mogul Ted Turner put it, "You'll hardly ever find a super-achiever anywhere who isn't motivated at least partially by a sense of insecurity."

The data agree. In a study led by Shigehiro



Oishi of the University of Virginia, researchers examined people's self-reported level of happiness from the mid-1980s. Then, they compared that with their future earnings in the early 2000s. They found that people who were unhappy back then went on to earn less money than their happier compatriots. No surprise here: Happy people are more energetic and compelling than sad people, and being energetic and compelling helps them earn more money.

But more important to our point: People who self-identified specifically as moderately happy went on to earn the most money 15 years later, while people who said they were very happy went on to earn only about as much as the unhappy folks.

Clearly, some joy is good for success in life, but too much happiness is a financial disaster. This is why evolution designed us to be reasonably happy, with occasional moments of giddiness that soon fade as we return to our individual baseline level of happiness.

**People who self-identified specifically as moderately happy went on to earn the most money 15 years later, while people who said they were very happy went on to earn only about as much as the unhappy folks.**

Numerous self-help professionals would have us believe that attaining maximal or permanent happiness should be our goal, but an evolutionary perspective clarifies that such a goal is neither achievable nor desirable. Happiness evolved for a reason — it gets us out there killing mastodons. But happiness is more than just a motivator; it also plays a critical role in the connection between mind and body.

So let's spend a little time figuring out why happiness is important even for the unrepentant curmudgeons among us.

## AGE, HEALTH AND HAPPINESS

Studies show that older people tend to remember the positive things in life rather than the negative things, while younger people remember the positive and negative equally well. The predominant psychological theory to explain this is that older people are aware of their limited time left, so they prioritize positive emotional experiences.

But about a decade ago, I worked with biologist Robert Trivers on his idea that there was an evolutionary basis for older people's increased positive outlook. Our research took us in the intriguing

direction of exploring how the body uses its energy.

When our ancestors needed more energy than usual, perhaps while being chased by a saber-toothed tiger, they had to get that energy from somewhere in the body. Could they borrow it from the brain? No. That organ uses 20 percent of our metabolic output, whether we are solving math problems or watching television reruns. Due to this constant energy requirement, borrowing energy from the brain when our need exceeds the available supply is not an option.

Perhaps we could borrow energy from our muscles. Because we use way more muscle energy when we are active than when at rest, in principle, we could borrow energy when we are sedentary. But the problem is that most of the energy-demanding emergencies of our ancestors required a muscular response. There was no way to borrow energy from our muscles during an emergency because relaxing when a mastodon showed up was not an effective response.

This brings us to our immune system, which, when strong, protects us from many illnesses and diseases. Like the brain, the immune system hums along at great metabolic cost, but largely in the service of keeping us healthy in the future. Because we have an enormous number of immune cells coursing through our body, a momentary break from production is OK. So, when our body needs extra energy, one of the places it goes is our immune function.

When you're being chased by a tiger or thwacking enemies with a club, you don't need to waste energy making immune cells to fight off tomorrow's cold. What you need is to shift all available energy resources to your legs, with the hope that you will live to experience another cough or sneeze.

As a result, our immune system evolved to run at peak capacity when we're happy, but to slow down dramatically when we're not. This is why long-term unhappiness can literally kill you through its immune-suppressing effects, and why loneliness in late adulthood is deadlier than smoking. Indeed, once you're over 65, you're better off smoking, drinking or overeating with your friends than you are sitting at home alone.

With this background in mind, Trivers hypothesized that older people evolved a strategy of turning this relationship on its head, becoming more focused on the positive things in life in an effort to enhance their immune functioning. This was helped along by their knowing much more about the world than younger adults. Older people don't need to pay as much attention to what's going on around them. For example, when they interact with a surly bank employee or a harried flight attendant, they have a library of related experiences to draw upon and can respond to the situation effectively without giving it much thought. As a result, they can afford to gloss over some of the unpleasant things in life.

## PUPPIES AND PLANE CRASHES

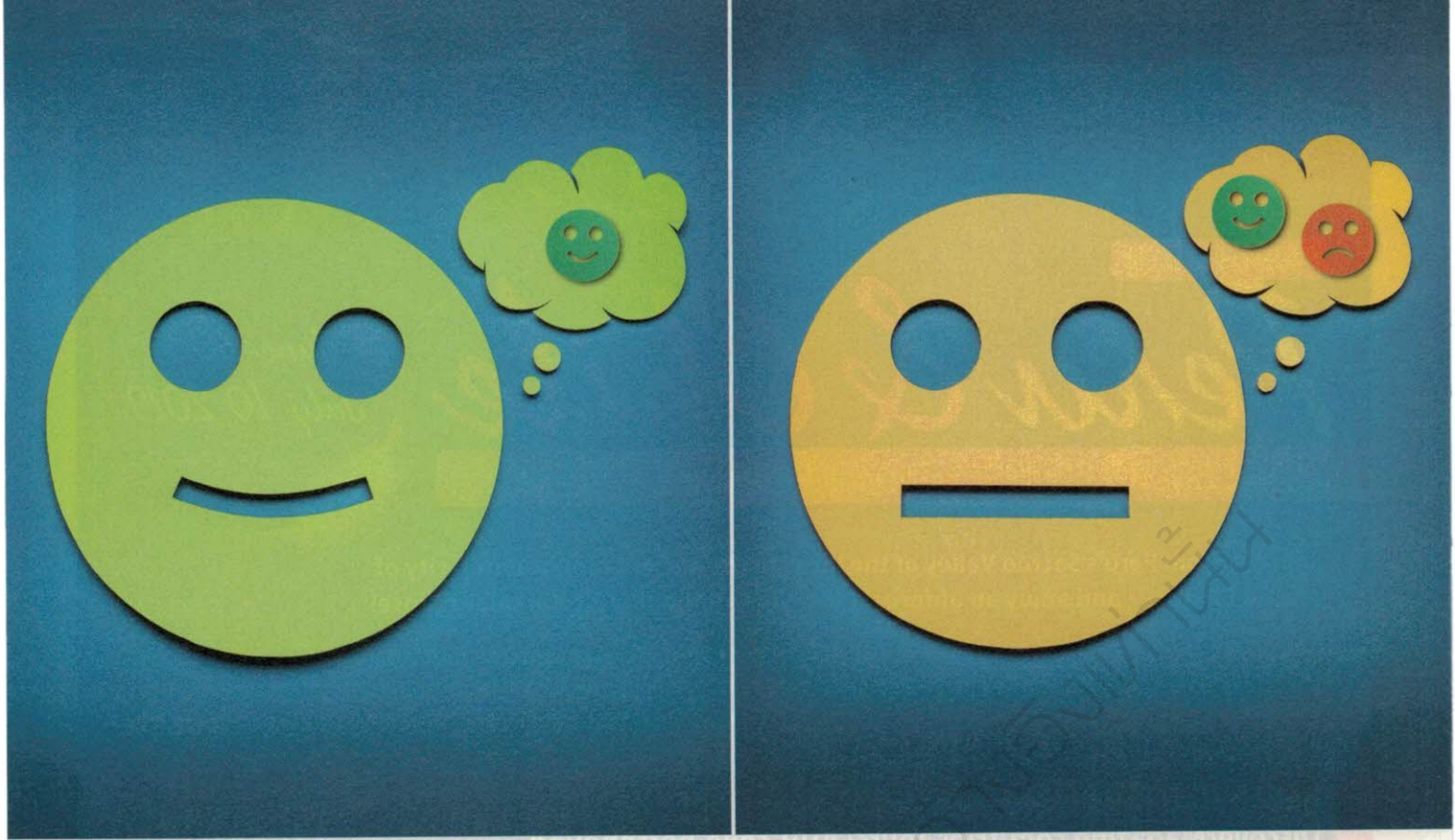
The hypothesis was later tested by a Ph.D. student of mine named Elise Kalokerinos. Over the course of a year in a lab, she showed young and old adults photographs of nice things, such as baskets of puppies, and of nasty things, such as plane crashes. She then tested their memory of the images.

Sure enough, the participants who were over 65 tended to remember the puppies better than the plane crashes (which suggests that they were paying more attention to the positive), while our younger participants remembered both equally well.

Kalokerinos then asked our older participants to return to the lab one and two years later in order to draw blood to assess their immune functioning.

The immune system is vast, but in this initial study, we decided to focus on a type of white blood cells known as CD4+ cells. These cells facilitate immune functioning by triggering other white blood cells (known as B cells) to produce antibodies. Kalokerinos found that better memory for positive, but not negative, pictures was associated with higher CD4+ counts and lower CD4+ activation.

Higher CD4+ counts usually indicate a greater preparedness to fight off illness. In contrast, higher



**Our immune system evolved to run at peak capacity when we're happy, but to slow down dramatically when we're not. This is why long-term unhappiness can literally kill you.**

activation of CD4+s indicates that the person is busy fighting infection, and thus is in poor health. In other words, their positive memories seemed to help them be healthier next year and the year after. This relationship between positivity and CD4+s raises the possibility that focusing on happy things enhances our own immune functioning.

The findings don't fit the theory that older people are more positive because of awareness of their limited time on this planet. But they're consistent with other research showing that happiness plays an important role in health and longevity.

For example, when researchers intentionally expose people to cold viruses, they find that those who are happy and have good social support are less likely to catch a cold than unhappy people and those with poor social support. Happy and well-supported people also heal more quickly when purposely wounded (not seriously, though) in the name of science.

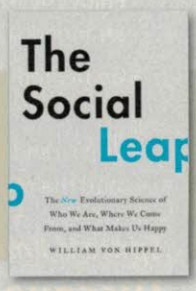
This effect holds for our primate cousins as well. Wild monkeys in the mountains of Morocco that have stronger friendship ties show a decreased physiological stress response to cold weather and aggression from other monkeys. Notice that the key issues for monkeys and for us are friendship and social support. Satisfying relationships play an important role in proper immune functioning.

## TAKE THE GOOD WITH THE BAD

So what is the purpose of happiness? As you can see, there is no single answer. Happiness motivates us to do things that help us survive and reproduce, and it helps keep us healthy. But happiness is not an end in and of itself.

Evolution often sacrifices our happiness in the service of other goals. People who don't experience setbacks, failures and despair are severely constrained in learning how to avoid bad people, bad situations and bad ideas. Indeed, negative emotions are just as important as our positive emotions, and perhaps even more so. Learning from plans gone wrong can far outweigh the benefits of success. D





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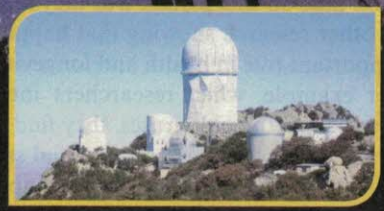

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# OUT THERE

## POWERED BY *ASTRONOMY* MAGAZINE

**OUTER SPACE, UNDER WATER**

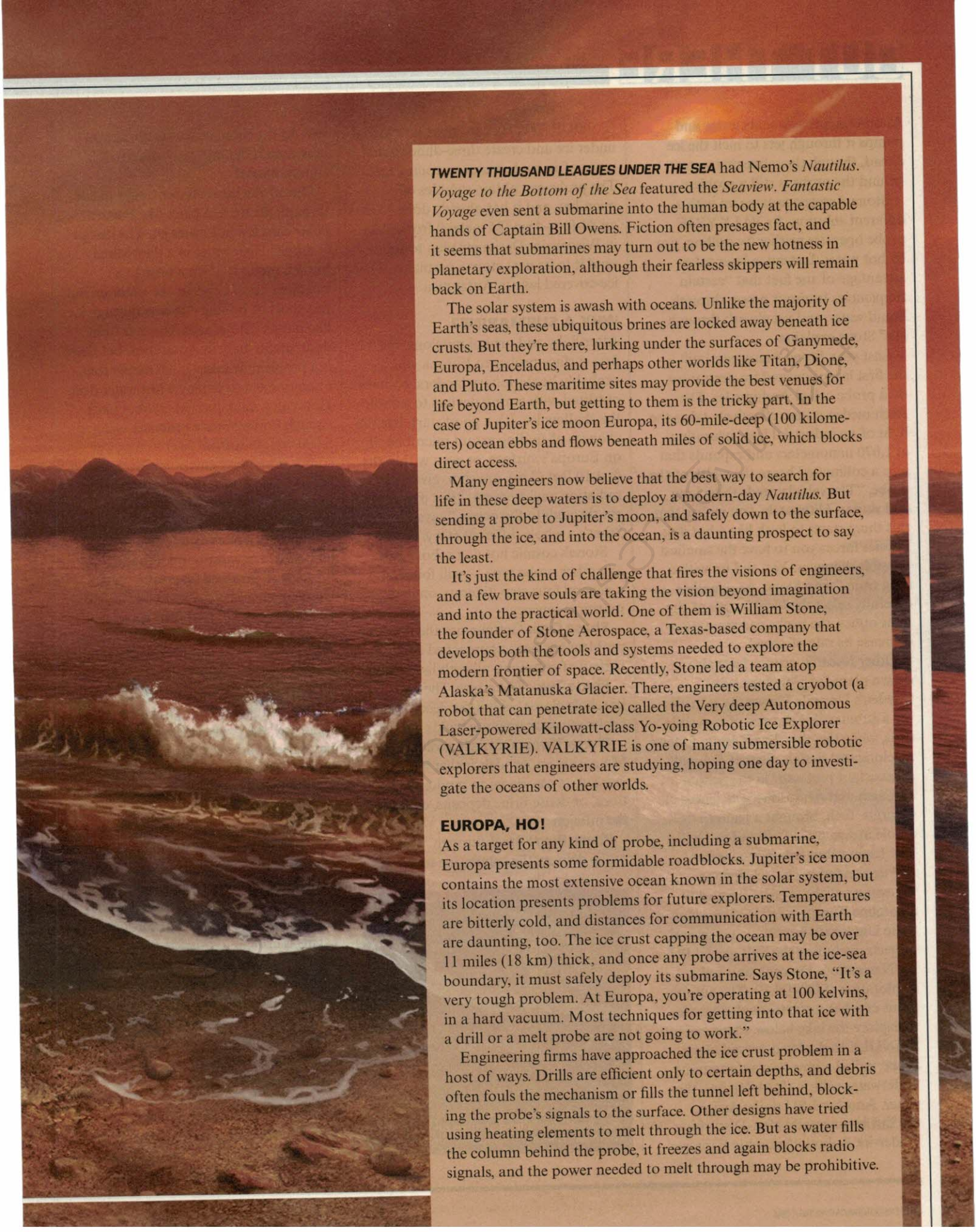
**Future spacecraft might penetrate the thick ice that covers the liquid ocean of Jupiter's moon Europa, as this NASA illustration shows. Such off-world seas might be the best place to search for extraterrestrial life. Read about the possibilities starting on page 56.** — ERNIE MASTROIANNI; ILLUSTRATION BY NASA/JPL

# Voyage to the Bottom of an Alien Sea

The next step in space exploration may be replacing rovers with underwater robots.

TEXT AND ILLUSTRATIONS BY **MICHAEL CARROLL**

The outer solar system is rife with alien oceans. But to explore them, we'll need to get creative.



***TWENTY THOUSAND LEAGUES UNDER THE SEA*** had Nemo's *Nautilus*. *Voyage to the Bottom of the Sea* featured the *Seaview*. *Fantastic Voyage* even sent a submarine into the human body at the capable hands of Captain Bill Owens. Fiction often presages fact, and it seems that submarines may turn out to be the new hotness in planetary exploration, although their fearless skippers will remain back on Earth.

The solar system is awash with oceans. Unlike the majority of Earth's seas, these ubiquitous brines are locked away beneath ice crusts. But they're there, lurking under the surfaces of Ganymede, Europa, Enceladus, and perhaps other worlds like Titan, Dione, and Pluto. These maritime sites may provide the best venues for life beyond Earth, but getting to them is the tricky part. In the case of Jupiter's ice moon Europa, its 60-mile-deep (100 kilometers) ocean ebbs and flows beneath miles of solid ice, which blocks direct access.

Many engineers now believe that the best way to search for life in these deep waters is to deploy a modern-day *Nautilus*. But sending a probe to Jupiter's moon, and safely down to the surface, through the ice, and into the ocean, is a daunting prospect to say the least.

It's just the kind of challenge that fires the visions of engineers, and a few brave souls are taking the vision beyond imagination and into the practical world. One of them is William Stone, the founder of Stone Aerospace, a Texas-based company that develops both the tools and systems needed to explore the modern frontier of space. Recently, Stone led a team atop Alaska's Matanuska Glacier. There, engineers tested a cryobot (a robot that can penetrate ice) called the Very deep Autonomous Laser-powered Kilowatt-class Yo-yoing Robotic Ice Explorer (VALKYRIE). VALKYRIE is one of many submersible robotic explorers that engineers are studying, hoping one day to investigate the oceans of other worlds.

## EUROPA, HO!

As a target for any kind of probe, including a submarine, Europa presents some formidable roadblocks. Jupiter's ice moon contains the most extensive ocean known in the solar system, but its location presents problems for future explorers. Temperatures are bitterly cold, and distances for communication with Earth are daunting, too. The ice crust capping the ocean may be over 11 miles (18 km) thick, and once any probe arrives at the ice-sea boundary, it must safely deploy its submarine. Says Stone, "It's a very tough problem. At Europa, you're operating at 100 kelvins, in a hard vacuum. Most techniques for getting into that ice with a drill or a melt probe are not going to work."

Engineering firms have approached the ice crust problem in a host of ways. Drills are efficient only to certain depths, and debris often fouls the mechanism or fills the tunnel left behind, blocking the probe's signals to the surface. Other designs have tried using heating elements to melt through the ice. But as water fills the column behind the probe, it freezes and again blocks radio signals, and the power needed to melt through may be prohibitive.

Another approach heats water and pumps it through jets to melt the ice ahead, though the refreezing water behind the probe is still a problem.

Stone Aerospace came up with a different solution. Its VALKYRIE probe operates neither by drilling, nor by hot water. Instead, a laser takes advantage of the fact that "certain frequencies transmit power through liquid water, and yet absorb through ice," Stone explains.

Last year, Stone Aerospace built the first laser-powered ice penetrator, on a probe called Archimedes. The Archimedes system effectively takes the light of an industrial laser operating at 1,070 nanometers and expands that into a collimated beam the width of the probe. "The vehicle needs to be long and skinny. Ultimately, you realize that this thing starts to look like a hot dog. Physics forces you to have the smallest possible diameter. You end up with a long train," says Stone. As scientists carefully select the focal length of the laser optics, the probe can increase or decrease its rate of speed.

Other research groups have also drawn plans for planetary subs. Sweden's Uppsala University is exploring a submersible the size of two soda cans, while Georgia Tech's Icefin follows an elongated design. Britney Schmidt, an assistant professor in the School of Earth and Atmospheric Sciences at Georgia Tech, brought a team to drill a hole in Antarctica's Ross Ice Shelf. The Icefin robot entered the water and descended to the ocean floor, following a flight profile identical to a baseline Europa mission. Louisiana State University is working on several projects, including the Sub-glacial Polar Ice Navigation, Descent, and Lake Exploration (SPINDLE). The autonomous cryobot melts through dense ice to explore the lake below. Plans call for SPINDLE to deploy a second-stage probe, called a hovering autonomous underwater vehicle (HAUV), into the water. Another LSU probe design, the Environmentally Non-Disturbing Under-ice Robotic Antarctic Explorer (ENDURANCE), can travel untethered under ice and create three-dimensional maps of its underwater surroundings. The probe can obtain samples of microbes, and it has already done so in an 80-foot-deep (25 meters) frozen lake in Wisconsin. Designers plan to soon send it to its next stop: a permanently ice-covered lake in Antarctica.

## WHY A SUBMARINE?

After flyby and orbital missions, the first surface probes to Europa will probably be stationary landers, perhaps outfitted with coring devices to sample the shallow ice. It's a good start, but the chances of finding extant microbial life on Europa's surface, or even within the first 10 feet (3 m), are slim, given the radiation environment. "But if you can get through to the ocean," says Stone, "that's a whole different story."

Stone's cosmic hot dog robot — or any other probe type — will follow a general four-step itinerary on its maritime journey:

**Phase One:** Getting into the ice. This problem has been approached using a variety of solutions, all with limitations.

**Phase Two:** The cruise. The entry borehole closes behind the descending probe as vapor pressure builds above.

**Phase Three:** Obstacle avoidance. Meteoritic impact debris that has worked its way down to random locations, or dense brine deposits, could end the mission.

**Phase Four:** Breakthrough. The probe delivers the submarine to the sea. As the submarine hits the ocean, how does it deploy? How does it communicate?

NASA's Titan Mare Explorer lander was one possible design aimed at analyzing organic compounds found on Saturn's largest moon.

One of the most efficient ways to cut through the ice in a place like Earth's polar caps is a hot water jet. The design is simple: Heat water in a diesel-fired burner, pump it down a hose to a weighted nozzle, and let the water jet out just short of boiling. "It cuts through ice like butter," Stone says. This has been done successfully in Antarctica, but there is a problem: It takes 1,000 metric tons of equipment to deploy a hot water drill. How can a miniaturized cryobot pack enough power? Stone proposes using a 5,000-watt industrial laser as a power source. Engineers envision a laser on the lander that powers a microprobe, with the probe itself spooling fiber behind it. Other designs, like the VALKYRIE, would carry a nuclear power system on board. The laser power comes through an armored fiber optic cable. Designers have been able to fabricate a 12.5-mile-long (20 km) fiber spool that fits in a 1-quart bottle. Proof of concept was carried out by Stone Aerospace's Artemis probe, which utilized a 9.3-mile (15 km) fiber optic spool.

Once the cruise through the ice is underway, the probe must avoid hazards and buried obstacles too small to see by orbiters with ground-penetrating radar. The VALKYRIE test bed carried an onboard ice-penetrating radar that could, within a range of about 330 feet (100 m), detect objects as small as 4 inches (10 centimeters) across. Tests carried out in Alaska in 2015 proved that the probe could look ahead with enough warning to avoid a collision.

This is critical to mission success, says Stone. "We don't want to risk a $4 billion mission on something like a trash can-sized piece of rock and then you're done." With a tunable laser system, the pathway of the probe through the ice can be changed as the laser shifts its focus to one side.

## SAILING THE ALIEN SEAS

Once deployed in the ocean, the robot would map the seafloor, chart currents

An underwater explorer could be designed to collect exotic samples from the oceans of other worlds for onboard analysis. Or it could simply return the samples to a more functional laboratory nearby.

and chemical streams, and look for life. The cryobot could even be programmed to search for sources that may support living organisms.

For example, a plume with a higher sulfur content might indicate hydrothermal vents, so the probe would try to follow the sulfur trail back to its source. The next step would be to maneuver to that site, and look for changes in the background that would suggest the presence of microbial communities (such as mats or changing colors). The cryobot would then take close-up, high-definition video. Finally, a sample would be pulled into a microscope for confirmation and characterization of living systems.

With the remoteness of Jupiter's system, the robot must think for itself. But how do we train it to recognize life? One possibility is to load a digital library of Earth's microbial life architectures into its memory for comparison. Anything that moves within the probe's field of view is then compared to various microbial structures and patterns. Because form follows function, microbes of other worlds should have some characteristics similar to those seen in the animal kingdom on Earth.

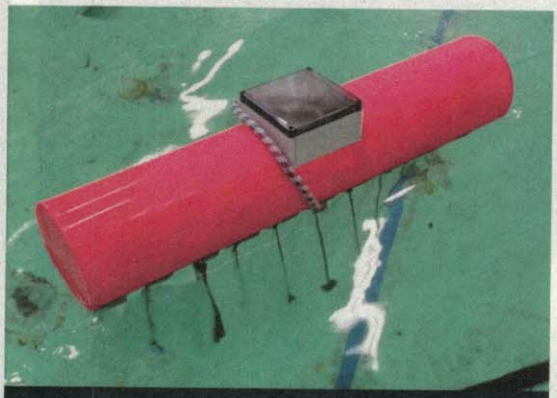
## GETTING AROUND

In addition to studying propellers, engineers have been creating propulsion systems based on life-forms in Earth's seas. These biomimetic designs emulate the agility and mobility of biological forms.

The ocean's inhabitants exhibit high-endurance swimming that outpaces current underwater propulsion systems for stealth, flexibility, and speed. For example, the glass knifefish (or "glassfish") uses a single ventral fin, which runs the length of its entire body, to change direction or hover in place. Designers at the University of Edinburgh are working on SquidROV, a biomimetic submarine propulsion system that utilizes a glassfish-style fin to maneuver. Some engineers suggest that such a propulsion system is more efficient than a propeller-based system of equivalent thrust. The design also generates much less turbulence, making it ideal for research and observation of a host of marine conditions.

Engineers at the Swiss Federal Institute of Technology in Zurich are currently testing a nautical robot that incorporates four fins inspired by those of the cuttlefish. Called Sepios, the 28-inch-long (70 cm) remotely operated underwater vehicle (ROV) exhibits a high degree of maneuverability, along with the capability for precise multidirectional travel in tight spots.

Researchers at Canada's Dalhousie University have combined forces with McGill University and York University to create the AQUA robot. This aquatic vehicle is a hybrid, with the capacity to walk along the seabed as well as to "swim" using its legs.



SquidROV, currently under development at the University of Edinburgh, is a biomimetic submarine propulsion system that uses a glassfish-style fin to get around. In addition to being more efficient than a propeller-based system, SquidROV also creates less turbulence.

Yet another approach, under study at the Jet Propulsion Laboratory, uses a buoyant robot that floats against the underside of ice, crawling or wheeling along upside down. There are many options available for underwater exploration, but considering the vast geological differences between the various watery worlds in our solar system, no single submersible vehicle is equipped to effectively explore every wet environment.

## CHALLENGES AT TITAN

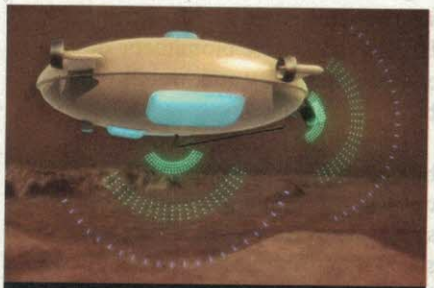
While Europa's ice crust presents a barrier to its ocean (as does the crust of the geyser-spouting moon Enceladus, which orbits Saturn), one moon in the solar system has seas on its surface.

Saturn's Mercury-sized moon Titan is shrouded in an orange haze. Since the 1960s, researchers have suspected that conditions on Titan's surface were at the triple point of methane: Methane could exist as a gas, a liquid, and a solid (ice).

Earth's surface is at the triple point of water, and it was tempting to see Titan as a cryogenic version of Earth's coastal regions, with surf breaking on alien shores. But the actual conditions there were not known in detail. Studies for landing probes often included a spectrum of designs to accommodate thick or thin atmospheres, and surfaces ranging from rock or ice to snowbanks and liquid ponds.

With the arrival of the Cassini orbiter and the European Huygens probe in 2004, the true nature of Titan's unique landscape became clear. Vast lakes of methane and ethane, rivaling the Black Sea in extent, wash across the northern hemisphere, with another huge body — Ontario Lacus — in the south. The largest of Titan's hydrocarbon oceans is Kraken Mare, followed closely by Ligeia Mare. To Johns Hopkins University Applied Physics Laboratory's Ralph Lorenz, it seems a perfect place for a submarine: "There are some aspects about Titan's methane bodies that are actually easier for a submarine [than terrestrial seas] because hydrocarbons are not electrically conductive, so you don't need to worry so much about exposed connectors. There's a possibility that you can send a radio signal through the liquid, which is something you can't do very easily on Earth. You might be able to have higher bandwidth. We know that at least one of Titan's seas is very radio transparent, because we bounced Cassini radar off the bottom of it."

But despite its advantages, Titan presents a new set of challenges for submersible design. The liquid is cold (94 K; –290 degrees F), so just staying warm will draw a large part of a probe's energy and dictate its structure. Another problem is how Titan's atmosphere reacts with its methane seas. On Earth, submarines can use air to fill their tanks and regulate buoyancy. But the nitrogen that makes up the majority of Titan's atmosphere is soluble in liquid methane, so it has less power to make the sub buoyant. If designers use nitrogen for flotation, the gas will be effective only at limited depths. The other option is to use a noble gas, such as neon.



A robotic submarine explores the depths of Kraken Mare, the largest body of water on Titan, in this illustration. Using radar, such a sub could map the seafloor of Titan, perhaps uncovering life-supporting hydrothermal vents like those found at the bottom of Earth's oceans.

Nitrogen dissolved in methane presents another problem, Lorenz explains. "If you have a patch of your submersible which is leaking heat, you could raise the temperature of that liquid enough that it reduces the amount of nitrogen that can dissolve. Think how much $CO_2$ you can dissolve in water on Earth (imagine a soda bottle), and that's the picture. You could get bubbles on [the outside of] your submarine. That's not going to make the thing sink, but it reduces movement, and they might influence a side-scan sonar to image the seabed. This is a problem that just doesn't happen on a terrestrial submarine."

Another probe under consideration is more akin to a dinghy. Known as an unmanned surface vehicle (USV), this robot would float atop the surface of Titan's sea rather than diving below. Lorenz says, "It simplifies things to have a capsule that just floats and doesn't have to do buoyancy control. You can imagine a propelled vehicle — a boat — that would be interesting."

But a boat loses the ability to profile the liquid column to see if the mix of methane and ethane is stratified. Does Ligeia Mare have an ethane-rich layer 328 feet (100 m) down at the bottom, something like the anoxic layer found at the bottom of the Black Sea? Researchers see evidence of evaporites — minerals left over after a body of water evaporates — on the shores of Titan's seas, as if the seas have dried out and refilled a number of times over the course of Titan's history. That story is told in the layers of sediment, not only on the coastline, but also on the seafloor.

Still, it may be prudent to do some

TOP: UNIVERSITY OF EDINBURGH. BOTTOM: NASA GLENN RESEARCH CENTER

Although we are still in the early stages of exploring the outer solar system using robots, someday we will find a way to set foot on another world. When that day comes, researchers will undoubtedly want to get their hands dirty.

surface exploration of the seas with a boat first, something akin to the HMS *Challenger* expedition of 1872 to 1876. As part of the world's first global oceanographic expedition, the *Challenger* crew sampled the seafloor by lowering a simple weight with a hole in the bottom before winching it back up. A Titan boat could explore the depths in similar fashion. But are these underwater explorers our best option for exploring the seas of other worlds like Titan?

"If you're asking me, 'Is a submarine cool?', the answer's definitely yes," Lorenz says. "Are the seas worth exploring? Definitely, yes. Is a submarine the next logical step in Titan exploration? I'm not so sure. It's a whole new world, and there are an awful lot of unknowns. Maybe a sub is a step or two away."

Titan is a wonderfully alien world, but when it comes to the search for life, the majority of astrobiologists have their eyes set on other targets. Stone puts it this way: "The possibility of life on Europa and Enceladus is pretty good; it's non-zero. Life acts like a battery. It needs electron donors, it needs electron receptors, it needs water, and it needs carbon. Those four constituents are likely to exist on Europa and Enceladus. Both are good targets. There are other ocean worlds out there, but by far and away, Europa is the one to cut our teeth on."

Stone points out that a Europa flyby mission — NASA's Europa Clipper — is fully in motion and set for launch sometime between 2022 and 2025. Furthermore, a proposed lightweight companion craft, named the Europa Lander, is currently accepting instrument proposals. So, although researchers would love to explore the seas of Titan, Europa will likely be the first world to have its water appraised.

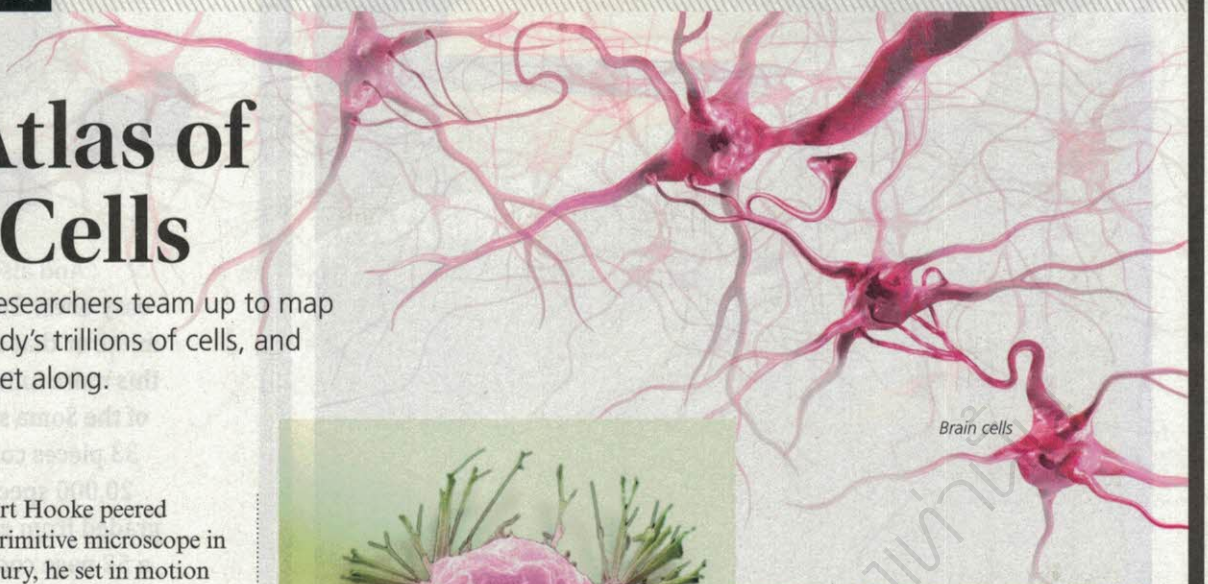
Either way, the pieces seem to be falling into place for a voyage to the bottom of an alien sea. D

*Frequent* Astronomy *contributor* ***Michael Carroll*** *featured planetary submarines in his latest scientific novel,* Europa's Lost Expedition *(Springer, 2017).*

# An Atlas of Our Cells

Hundreds of researchers team up to map the human body's trillions of cells, and how they all get along.

BY **LINDA MARSA**



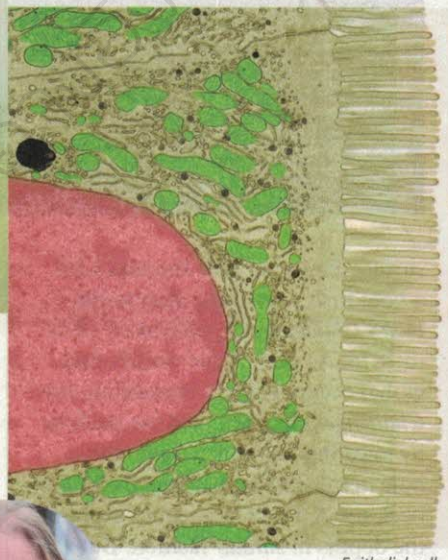
Brain cells

When Robert Hooke peered through a primitive microscope in the mid-17th century, he set in motion a revolution. Today's understanding of the fundamental structure of living organisms began when he examined thin slices of cork and saw tiny walled compartments that looked like a monk's dwelling: He called them cells.

Subsequent advances over the centuries deepened our understanding of these structures, which we now know to be the basic unit of life. In the past decade alone, quantum leaps in technology have enabled scientists to explore the Lilliputian universe of the cells with unprecedented precision. The developments have sparked the creation of a massive scientific juggernaut that rivals the Human Genome Project in scope and importance.

Called the Human Cell Atlas (HCA), the international research effort aims to create a comprehensive 3D reference map of how genes are expressed, or activated, in different cell types and their states in every organ system of the human body. The global consortium includes more than 1,000 scientists from 584 institutes in 55 countries. While they won't attempt to plumb all 37 trillion cells in the human body, initial research is zeroing in on five main areas, including cancer; the brain and nervous system; the immune system; the epithelial tissues that serve as a protective layer throughout our body; and human development, starting with cell differentiation in the womb.

Breast cancer cell



Epithelial cell

**"Every tissue and every organ has a biological meaning in and of itself."**

—SARAH TEICHMANN

The work has the potential to usher in a new era of precision medicine that will transform our understanding of health and disease, leading to better detection, monitoring and treatment of the ills that plague humanity. "There's much more diversity in the cells than we previously imagined, and there has been an explosion in technology that is shedding light on that," says Sarah Teichmann, head of cellular genetics at the U.K.'s Wellcome Sanger Institute and co-chair of the Human Cell Atlas organizing committee. "Every tissue and every organ has a biological meaning in and of itself."

## THE UNIVERSE OF THE CELL

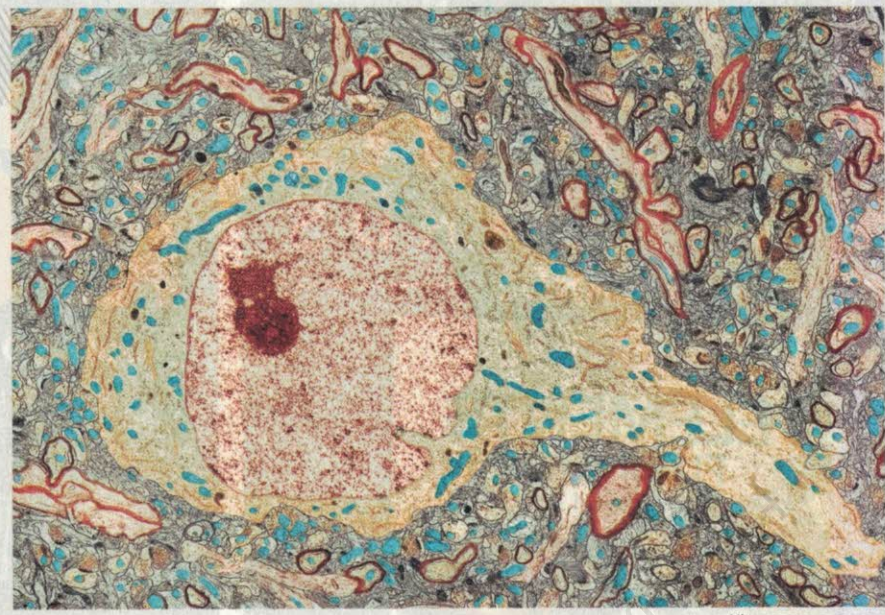
Our cells are complicated creatures. Each one is composed of many millions of molecules, which continuously transmit messages to each other to complete the cell's basic work, whether that particular cell's job is to repair tissue damage, mop up debris or send messages along the brain's neural circuitry. Coiled inside the nucleus of each cell is the double helix of DNA,

FROM TOP: HENNING DALHOFF/SCIENCE SOURCE; SCIENCE SOURCE; THOMAS DEERINCK/SCIENCE SOURCE; WELLCOME SANGER INSTITUTE/GENOME RESEARCH LTD

two intertwined strands of chemicals dotted with more than 20,000 genes that provide the basic blueprint of life. As each gene is expressed, it produces RNA, which then produces proteins, the workhorses of the cells. Proteins also sit on the cell's surface, like tiny periscopes scanning the immediate surroundings for food or hazards or foreign invaders. They relay that information to the proteins inside, which use that data to begin anew the process of cell turnover and regeneration that starts with messages from the genes.

But while each cell carries the same genes, every cell only uses some of these instructions, like a sonata that only uses some of the keys on the piano. The consortium's lofty goal, in their quest to categorize the 37 trillion cells in the human body, is to understand which specific genes are activated in each cell type — or in scientific parlance, the patterns of gene expression.

They plan to decipher how genes inside healthy cells are properly expressed. Taking this information and using it as a point of reference will allow them to immediately see where gene expression deviates from normal. It illuminates when genes are being expressed at the wrong time, in the wrong cell type or in the wrong amount, says Dana Pe'er, a leading member of the consortium and chair of the computational and systems biology program at Memorial Sloan Kettering Cancer Center in New York. "We're looking at a host of complex questions," she says. "These range from how an ensemble of cells function together to fight pathogens or how a cell's regulatory circuits go awry in disease."



Hippocampus neuron

**The team is looking at many questions, "from how an ensemble of cells function together to fight pathogens or how a cell's regulatory circuits go awry in disease."**

— DANA PE'ER

Eventually, this massive library of cell types — indexed by their states, their locations and their gene expressions — could help scientists make countless new discoveries.

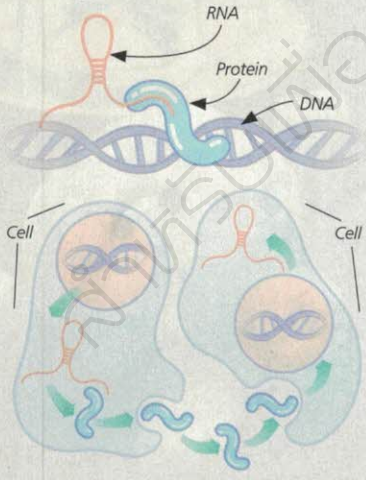
One of the more immediate applications: identify how gene signals go wrong in diseases such as cancer or hereditary disorders, which are triggered by mutant DNA.

Researchers also could gain a better understanding of brain cells to help treat neurodegenerative diseases like Alzheimer's, Parkinson's and ALS. And the cell atlas might tease out which medicines an individual patient's genes will respond to best. The same goes for treatments to which their body might already have resistance.

The research could also help a doctor know which medicines to avoid giving patients altogether. Drugs can often be unexpectedly toxic. That's because treatments may target a specific protein, but we don't realize that said protein may serve a useful function in another part of the body. "These are things we can spot quickly once we have a good reference tool," says Aviv Regev, a computational and systems biologist at the Broad Institute of MIT and Harvard who helped spearhead the creation of the HCA and now co-chairs its organizing committee.

## Cell Communication

DNA, RNA and proteins work together to allow cells to send messages and "talk" to each other.




FROM TOP: THOMAS DEERINCK/NCMIR/SCIENCE SOURCE; MEMORIAL SLOAN KETTERING CANCER CENTER; JAY SMITH

# What Adult Diaper Companies Don't Want Men To Know...

*Men's Liberty keeps you dry and leak free for up to 24 hours.*

100% STAY DRY COMMITMENT

## The Diaper Dilemma

Urinary incontinence affects more than 5 million men in the United States of all ages. Diapers trap moisture, causing UTIs, discomfort and odors.

*"I can keep doing what I want to do, without having to worry about running to the bathroom or changing my clothes. It's a Godsend."*

*– John in Michigan*

## Men's Liberty Alternative

Finally there is an alternative solution for men that dependably replaces diapers, pads and condom catheters. Men's Liberty is a non-invasive external catheter option that is more comfortable and sanitary than adult diapers, easy to apply, discreet and keeps you dry 24/7. Whether you just dribble a bit or suffer from complete incontinence, Men's Liberty could be the discreet, dignified, and dependable solution for you!

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Millions of men spend thousands of dollars each year on diapers, which are not covered by Medicare. Diapers and pads can cost as much as $300 out of pocket each month. Men's Liberty is covered by Medicare, VA/Tricare and over 3,000 insurance plans. Standard deductibles and co-pays apply.

Get your insurance card and call Men's Liberty today to get started. We handle all paperwork, claims and billing your insurance or medicare provider.

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### A CELLULAR SMOOTHIE

Scientists had long wanted to understand how the complex array of genes works its magic inside each individual cell, but the technology just wasn't there until the past decade. By about 2012, a technique called single-cell genomics had grown in popularity and provided a new way to categorize individual cells. Scientists could pluck a single cell out of a test tube and sequence its genetic information. But that meant hundreds of thousands, sometimes millions, of cells didn't get sequenced. To get around this, scientists blended the results of various cells to stand in for the entire cell population — a process that Regev compares to making a fruit smoothie.

The technique missed the range of variation in individual cells or, to extend the smoothie metaphor, failed to distinguish between the taste of strawberries and blueberries and kiwis. "By the end of the smoothie preparation process, it might look pink," says Regev. "But if there were a few kiwis inside, you might not recognize that. And we knew that the cells are probably different from each other — and these differences matter because they all reflect on what the cell can be or will be doing."

Scientists can now simultaneously sequence thousands of individual cells thanks to the development in 2015 of a microtechnology that Regev helped invent. The new technique encapsulates each cell inside tiny droplets. A process then breaks the cell apart, during which pieces of its RNA are captured inside tiny beads for analysis. This led to a host of discoveries that revealed there may be thousands — not just hundreds — of different cell types, according to Teichmann. In the immune system alone, we now know there are more than 200 cell types, and even the tiny retina that coats the surface of the eye has about 100 different types of cells.

**Now that researchers can see what cells are doing, "you can listen to the chatter between these different cells."**

— AVIV REGEV

Energized by these findings, scientists around the world began talking about the tantalizing prospect of peering deep inside each cell and mapping their constituent parts. By 2014, Regev had started "evangelizing" about creating a Human Cell Atlas and eventually got interest from Teichmann that pushed them both to make the big leap to actually doing it.

### EARLY SUCCESSES

The HCA, which kicked off in 2017, has already notched some intriguing discoveries. In 2018, Regev and researchers from the Broad Institute and Massachusetts General Hospital discovered that the lining of the trachea has seven cell types — one more than expected. That new type of cell is especially important in the expression of a specific gene that, when mutated, causes cystic fibrosis, and could prove crucial for understanding and eventually developing a cure for the genetic disease. The discovery also could lead to a better treatment for asthma.

In another 2018 study, Teichmann's team, along with collaborators from the University of Cambridge and the Newcastle University, characterized the cancer cells behind the most common childhood and adult kidney cancers. Specifically, they found that childhood kidney cancer cells appear just as they did while they were still developing in the womb, indicating that the cells are trapped in an immature fetal state. "We found which cells are driving the tumor," says Teichmann, "which is a tremendously important finding." She believes it can lead to more precisely targeted therapies.

Recent research by Regev's team also provided some clues as to why a new class of cancer drugs known as checkpoint inhibitors, which prompt the immune system to attack malignant cells, only work for a handful of patients. In a study that looked at how genes were activated in melanoma cells, her team found that some tumors have a subset of cells that simply don't respond to immunotherapy, preventing immune system cells from thwarting the cancerous cells. The researchers are now looking at ways to reverse this resistance. Now that they can drill down to see what cells are doing, says Regev, "you can listen to the chatter between these different cells" to understand where the wrong signals are being sent and which ones halt tumor growth or restore the efficacy of the therapy.

There are many technological hurdles ahead for the HCA — just establishing platforms to share data between all the labs will be a challenge. But Regev is undaunted and predicts they'll have a complete map within a decade. D

*Linda Marsa is a Discover contributing editor.*

CASEY ATKINS/BROAD INSTITUTE

## Big Funders Step In

The HCA has already generated strong institutional support that includes $200 million from the National Institutes of Health and about $9 million from the Wellcome Trust, a London-based biomedical research charity. It also has landed a $15 million grant from the Chan Zuckerberg Initiative, which is underwriting the open-source data coordination platform that will store the terabytes of data generated by researchers. — L.M.

# Leading Acid Reflux Pill Becomes an Anti-Aging Phenomenon


*Clinical studies show breakthrough acid reflux treatment also helps maintain vital health and helps protect users from the serious conditions that accompany aging such as fatigue and poor cardiovascular health*

**by David Waxman**
**Seattle Washington:**

A clinical study on a leading acid reflux pill shows that its key ingredient relieves digestive symptoms while suppressing the inflammation that contributes to premature aging in men and women.

And, if consumer sales are any indication of a product's effectiveness, this 'acid reflux pill turned anti-aging phenomenon' is nothing short of a miracle.

Sold under the brand name AloeCure, it was already backed by clinical data documenting its ability to provide all day and night relief from heartburn, acid reflux, constipation, irritable bowel, gas, bloating, and more.

But soon doctors started reporting some incredible results…

"With AloeCure, my patients started reporting less joint pain, more energy, better sleep, stronger immune systems… even less stress and better skin, hair, and nails" explains Dr. Liza Leal; a leading integrative health specialist and company spokesperson.

AloeCure contains an active ingredient that helps improve digestion by acting as a natural acid-buffer that improves the pH balance of your stomach.

Scientists now believe that this acid imbalance is what contributes to painful inflammation throughout the rest of the body.

The daily allowance of AloeCure has shown to calm this inflammation which is why AloeCure is so effective.

Relieving other stressful symptoms related to GI health like pain, bloating, fatigue, cramping, constipation, diarrhea, heartburn, and nausea.

Now, backed with new clinical studies, AloeCure is being recommended by doctors everywhere to help improve digestion, calm painful inflammation, soothe joint pain, and even reduce the appearance of wrinkles – helping patients to look and feel decades younger.

## FIX YOUR GUT & FIGHT INFLAMMATION

Since hitting the market, sales for AloeCure have taken off and there are some very good reasons why.

To start, the clinical studies have been impressive. Participants taking the active ingredient in AloeCure saw a stunning 100% improvement in digestive symptoms, which includes fast and lasting relief from reflux.

Users also experienced higher energy levels and endurance, relief from chronic discomfort and better sleep. Some even reported healthier looking skin, hair, and nails.

A healthy gut is the key to a reducing swelling and inflammation that can wreak havoc on the human body. Doctors say this is why AloeCure works on so many aspects of your health.

AloeCure's active ingredient is made from the healing compound found in Aloe vera. It is both safe and healthy. There are also no known side effects.

Scientists believe that it helps improve digestive and immune health by acting as a natural acid-buffer that improves the pH balance of your stomach.

Research has shown that this acid imbalance contributes to painful inflammation throughout your entire body and is why AloeCure seems to be so effective.

## EXCITING RESULTS FROM PATIENTS

To date over 5 million bottles of AloeCure have been sold, and the community seeking non-pharma therapy for their GI health continues to grow.

According to Dr. Leal, her patients are absolutely thrilled with their results and are often shocked by how fast it works.

"For the first time in years, they are free from concerns about their digestion and almost every other aspect of their health," says Dr. Leal, "and I recommend it to everyone who wants to improve GI health without resorting to drugs, surgery, or OTC medications."

"I was always in 'indigestion hell.' Doctors put me on all sorts of antacid remedies. Nothing worked. Dr. Leal recommended I try AloeCure. And something remarkable happened… Not only were all the issues I had with my stomach gone - completely gone – but I felt less joint pain and I was able to actually sleep through the night."

With so much positive feedback, it's easy to see why the community of believers is growing and sales for the new pill are soaring.

## THE SCIENCE BEHIND ALOECURE

AloeCure is a pill that's taken just once daily. The pill is small. Easy to swallow. There are no harmful side effects and it does not require a prescription.

The active ingredient is a rare Aloe Vera component known as acemannan.

Made from of 100% organic Aloe Vera, AloeCure uses a proprietary process that results in the highest quality, most bio-available levels of acemannan known to exist.

According to Dr. Leal and several of her colleagues, improving the pH balance of your stomach and restoring gut health is the key to revitalizing your entire body.

When your digestive system isn't healthy, it causes unwanted stress on your immune system, which results in inflammation in the rest of the body.

The recommended daily allowance of acemannan in AloeCure has been proven to support digestive health, and calm painful inflammation without side effects or drugs.

This would explain why so many users are experiencing impressive results so quickly.

## REVITALIZE YOUR ENTIRE BODY

With daily use, AloeCure helps users look and feel decades younger and defend against some of the painful inflammation that accompanies aging and can make life hard.

By buffering stomach acid and restoring gut health, AloeCure calms painful inflammation and will help improve digestion… soothe aching joints… reduce the appearance of wrinkles and help restore hair and nails … manage cholesterol and oxidative stress… and improve sleep and brain function… without side effects or expense.

Readers can now reclaim their energy, vitality, and youth regardless of age or current level of health.

**One AloeCure Capsule Daily**

- **Helps End Digestion Nightmares**
- **Helps Calm Painful Inflammation**
- **Soothes Stiff & Aching Joints**
- **Reduces appearance of Wrinkles & Increases Elasticity**
- **Manages Cholesterol & Oxidative Stress**
- **Supports Healthy Immune System**
- **Improves Sleep & Brain Function**

## HOW TO GET ALOECURE

This is the official nationwide release of the new AloeCure pill in the United States. And so, the company is offering our readers up to 3 FREE bottles with their order.

This special give-away is available for the next 48-hours only. All you have to do is call **TOLL-FREE 1-800-808-5114** and provide the operator with the Free Bottle Approval Code: AC100. The company will do the rest.

Important: Due to AloeCure's recent media exposure, phone lines are often busy. If you call and do not immediately get through, please be patient and call back. Those who miss the 48-hour deadline may lose out on this free bottle offer.

# SETI's Secret Origin Story

How the Order of the Dolphin helped establish the scientific search for aliens.

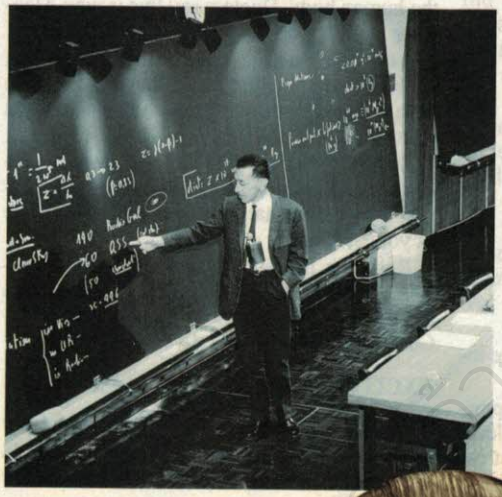
BY JOHN WENZ

Aliens are serious science. The search for extraterrestrial intelligence, or SETI, constitutes major research projects at radio telescopes the world over, and it is championed by the non-profit institute that shares its name. Multiple experiments on the subject, and citizen science projects like SETI@home, have been going strong for decades. Every year, papers, conferences and initiatives discuss how best to seek out — and maybe even talk to — E.T.

But it wasn't always that way.

While UFO sightings and depictions in movies and comics spiked during the 1950s, the topic of aliens was considered unprofessional among scientists. Only a handful of professionals would speculate on the possibility of alien life, and even they made sure it was only a small part of their research. So when a group of science luminaries from a variety of disciplines met at a rural observatory in West Virginia to talk about little green men, they did so in secret.

They called themselves the Order of the Dolphin, and almost single-handedly launched modern SETI research.



Clockwise from above: Physicists Giuseppe Cocconi and Philip Morrison published some of the first SETI research. The 85-foot radio telescope in Green Bank, West Virginia, was instrumental for Frank Drake's initial SETI experiments.

## FIRST SETI STEPS

In 1958, a newly minted Harvard University Ph.D. named Frank Drake came to the National Radio Astronomy Observatory in Green Bank, West Virginia, home to the biggest, baddest telescope in the burgeoning practice of radio astronomy. He usually sought typical radio astronomy targets: the radiation belts around Jupiter, for example, or the surface temperature of Venus.

But one day in 1960, Drake and his colleagues instead tuned in to two nearby stars, Tau Ceti and Epsilon Eridani. Their goal was simple: They were alien hunting, hoping to hear radio signals originating from intelligent extraterrestrials. Drake had long been interested in the topic, and he was reassured of its scientific merit by the work of physicists Giuseppe Cocconi and Philip Morrison. The previous year, the pair co-authored a *Nature* paper with the provocative title "Searching for Interstellar Communications."

Much to Drake's surprise, his team actually heard something in those first experiments. Unfortunately, it was just a high-altitude plane. Project Ozma, as the research was called (after L. Frank Baum's fictional monarch of Oz), was both the first SETI experiment and the first SETI false alarm.

As Drake would later write in his book *Is Anyone Out There?*, co-authored with science writer Dava Sobel, "We had failed to detect a genuine alien signal, it was true, but we had succeeded in demonstrating that searching was a feasible, and even reasonable, thing to do."

## TALKING TO DOLPHINS

As Drake conducted his first furtive SETI searches, John Lilly — a physician, philosopher, writer and inventor — was attempting to communicate with a different alien intelligence. He just wasn't looking quite as far away.

Humans are, in fact, surrounded by intelligence. Our fellow great apes understand the rudiments of

CLOCKWISE FROM LEFT: CERN; CORBIS/GETTY IMAGES; NRAO/AUI/NSF; EMILIO SEGRE VISUAL ARCHIVES/AMERICAN INSTITUTE OF PHYSICS/SCIENCE SOURCE

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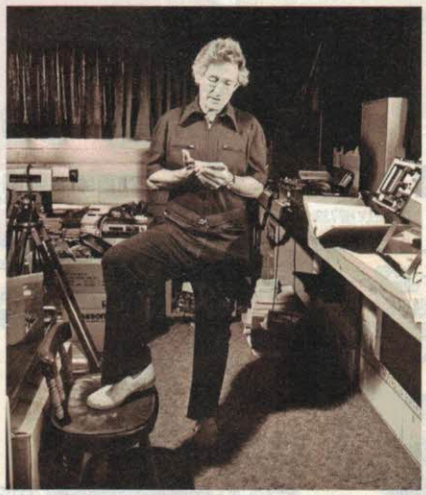
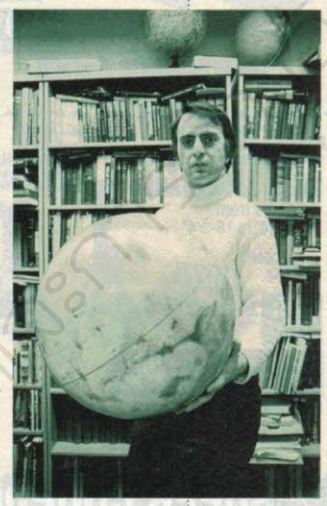
language, and creatures great and small — from elephants to crows — seem to possess highly organized social structures, tool-making skills and self-awareness. Intelligent life isn't limited to land: The octopus brain is one of the most remarkable on Earth, and its cousin the cuttlefish is no slouch, either. But the superstars of the sea are marine mammals, especially dolphins and whales.

Lilly wanted to understand and communicate with dolphins — literally, to speak their language. And his ideas were taken seriously. He founded the Communication Research Institute in the late 1950s, and he published work suggesting that his attempts to talk to dolphins were working.

He also saw the experiments as a way to help efforts to contact aliens. If we can crack the code of dolphin language, Lilly thought, we might just have a shot at decoding other alien communications, too. If only he had a way to communicate that potential to other researchers ...





Scientist and inventor John Lilly (top) tried to communicate with dolphins (above), work that thrilled the Order of the Dolphin. The group's most famous member is Carl Sagan (right).

## READY, SETI, GO

While Drake and Lilly were pioneering new fields, it fell to a government scientist to turn such individual efforts into a broader, scientifically diverse program. In 1961, ballistics and rocketry expert J. Peter Pearman — a staffer for the National Academy of Sciences' Space Science Board — arranged a meeting to expand the search for alien intelligence. While it wasn't officially a secret meeting, it definitely wasn't well publicized. The topic was still on the fringes of established research, and no one would put their career on the line to search for little green men.

The fabled meeting of the Order of the Dolphin wound up taking place in autumn 1961 at Green Bank. Counting Pearman, 10 scientists were gathered. Drake and Lilly were there, as well as Drake's inspiration, Morrison. Also in attendance were radio astronomer Dana Atchley, preeminent biochemist Melvin Calvin, astrophysicist Su-Shu Huang (who first conceived of "habitable zones," areas around stars where liquid water could form on planets), computing pioneer Barney Oliver and Russian astronomer Otto Struve.

The final attendee was a young Carl Sagan, now perhaps the best known of the bunch. (One more unofficial attendee: A supply of champagne to celebrate the likely announcement of a Nobel Prize for Calvin's work on plant photosynthesis.)

The group met for three days starting on Halloween and hashed out the outlines of a research program. While much of the structure and approach of today's SETI protocols began here, the biggest concrete outcome was the Drake equation.

To know if aliens are out there, it helps to have an idea of how abundant they might be. The Drake equation estimates the odds of various factors necessary for intelligent life to exist, including the rate of star formation, the fraction of stars that have planets and the fraction of habitable planets actually being inhabited. Written out, it reads $N = R_* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$.

Despite its output of hard numbers, the Drake equation is more symbolic than descriptive — depending on how you figure the estimates, we could be one of thousands of civilizations, or utterly alone. Instead, the equation is a tool to guide how scientists should think about looking for alien life, offering a way to combine various existing scientific disciplines.

## CAUSE FOR CELEBRATION

As it happened, Calvin did win the Nobel during the group's meeting, and the attendees busted out the bubbly. But Lilly became another star of the show, playing recordings of dolphins that he said showed signs of language and empathy.

"In fact, if we slowed down the playback speed of the tape recorder enough, the squeaks and clicks sounded like human language," Drake wrote in his book. "We felt some of the excitement in store for us when we encounter nonhuman intelligence of extraterrestrial origin."

FROM TOP: JOHN BRYSON/THE LIFE IMAGES COLLECTION/GETTY IMAGES; THE ESTATE OF JOHN C. LILLY; SANTI VISALLI/GETTY IMAGES

# Break Free from Neuropathy with a New Supportive Care Cream

## A patented relief cream stands to help millions of Americans crippled from the side effects of neuropathy by increasing sensation and blood flow wherever it's applied

*Raymond Wilson*
*The Associated Heath Press*

**AHP** – A recent breakthrough stands to help millions of Americans plagued by burning, tingling and numb legs and feet.

But this time it comes in the form of a cream, not a pill, suggesting the medical community may have been going about the problem all wrong.

The breakthrough, called *Diabasens*, is a new relief cream developed for managing the relentless discomfort caused by neuropathy.

When applied directly to the legs and feet, it causes arteries and blood vessels to expand, increasing the flow of warm, nutrient rich blood to damaged tissue.

However, what's most remarkable about the cream...and what makes it so brilliant...is that it contains one of the only natural substances known to activate a special sensory pathway right below the surface of the skin.

This pathway is called TRPA1 and it controls the sensitivity of nerves. In laymen terms, it determines whether you feel pins and needles or soothing relief.

Studies show that symptoms of neuropathy arise when the nerves in your legs deteriorate and blood flow is lost to the areas which surround them.

As the nerves begins to die, sensation is lost. This lack of sensation is what causes the feelings of burning, tingling and numbness.

This is why the makers of *Diabasens* say their cream has performed so well in a recent clinical use survey tria: it increases sensation and blood flow where ever its applied.

### No Pills, No Prescriptions, No Agony

Until now, many doctors have failed to consider a topical cream as an effective way to manage neuropathy. *Diabasens* is proving it may be the only way going forward.

"Most of today's treatment methods have focused on minimizing discomfort instead of attacking its underlining cause. That's why millions of adults are still in excruciating pain every single day, and are constantly dealing with side effects" explains Dr. Esber, the creator of *Diabasens*.

"*Diabasens* is different. Since the most commonly reported symptoms – burning, tingling and numb legs and feet – are caused by lack of sensation of the nerves, we've designed the formula increase their sensitivity.

And since these nerves are located right below the skin, we've chosen to formulate it as a cream. This allows for the ingredients to get to them faster and without any drug like side effects" he adds.

### Study Finds Restoring Sensation the KeyTo Effective, Long Lasting Relief

With the conclusion of their latest human clinical use survey trial, Dr. Esber and his team are now offering *Diabasens* nationwide. And regardless of the market, its sales are exploding.

Men and women from all over the country are eager to get their hands on the new cream and, according to the results initial users reported, they should be.

In the trial above, as compared to baseline, participants taking *Diabasens* saw a staggering 51% increase sensitivity in just one week. This resulted in significant relief from burning, tingling and nubmness throughout their legs.

Many participants taking *Diabasens* described feeling much more balanced and comfortable throughout the day. They also noticed that after applying, there was a pleasant warming sensation that was remarkably soothing.

**_Diabasens_ is shown to provide relief from:**

- Burning
- Swelling
- Tingling
- Heaviness
- Numbness
- Cold extremities

### *Diabasens* Users Demand More

Many of *Diabasens* users say their legs have never felt better. For the first time in years, they are able to walk free from the symptoms which have made life hard.

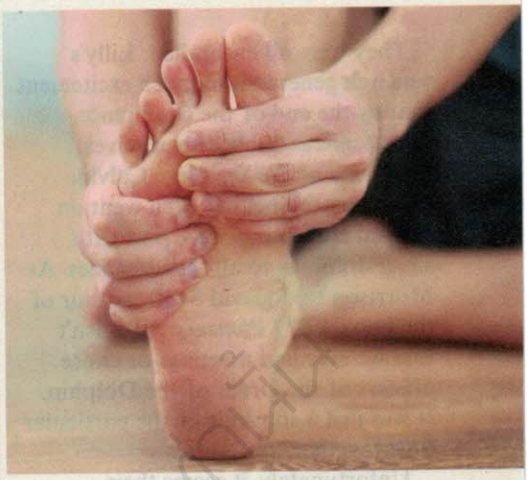
"I have been using the cream now for about ten days. It has given me such relief.

I've had very bad foot pain from injuries and overuse of my feet for years which have contributed to severe itching/tingling and pain for some time. (My father also suffered from this pain and itching. I wish I would have had this for him.)

The first time I used the cream, I felt an almost immediate relief from this.

I now use it at least twice a day: once in the morning before work and once at night before I sleep.

I am so delighted with this. It has helped my walking, also. It has helped generate feeling again in my feet," raves Marsha A. from Texas



**Topical Cream Offers Sufferers a Safer, More Effective Avenue of Relief:** Diabasens increases sensation and blood flow wherever its applied. It's now being used to relieve painful legs and feet.

### Targets Nerve Damage Right Below the Skin's Surface

*Diabasens* is a topical cream that is to be applied to your legs and feet twice a day for the first two weeks then once a day after. It does not require a prescription.

Studies show that neuropathy is caused when the peripheral nerves breakdown and blood is unable to circulate into your legs and feet.

As these nerves deteriorate, sensation is lost. This is why you may not feel hot or cold and your legs and feet may burn, tingle and go numb.

Additionally, without proper blood flow, tissues and cells in these areas start to die, causing unbearable pain.

An ingredient called cinnamaldehyde in *Diabasens* is one of the only compounds in existence that can activate TRPA1, a special sensory pathway that runs through your entire body.

According to research, activating this pathway (which can only be done with a cream) increases the sensitivity of nerves, relieving feelings of tingling and numbness in your legs and feet.

Supporting ingredients boost blood flow, supplying the nerves with the nutrients they need for increased sensation.

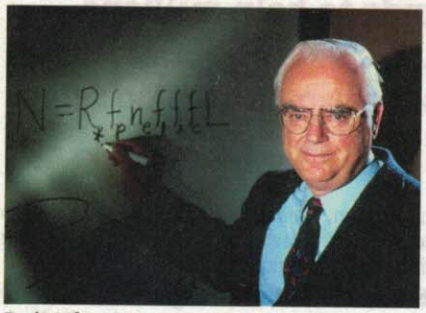
### How to Get *Diabasens*

In order to get the word out about *Diabasens*, the company is offering special introductory discounts to all who call. Discounts will automatically be applied to all callers, but don't wait. This offer may not last forever. **Call toll-free: 1-800-670-1013.**

They were all enthralled. Lilly's research generated so much excitement that by the end of the conference, the attendees dubbed themselves the Order of the Dolphin. Calvin, in his post-Nobel joy, even went on to send commemorative pins with silver dolphins to all the attendees. As Morrison told David Swift, author of the book *SETI Pioneers*: "It wasn't that we ever had meetings or chose officers of the Order of the Dolphin. It was just a souvenir of the particular time together."

Unfortunately, it seems their excitement may have been a little hasty. "In retrospect," Drake wrote, "I now think that Lilly's work was poor science. He had probably distilled endless hours of recordings to select those little bits that sounded humanlike."

Shortly after the Order of the Dolphin meeting, Lilly began using ketamine and LSD (legal at the time) as part of his research on brain function. While Sagan visited the subsequent experiments, reporting back to Drake on Lilly's progress, the science became hazier, and Sagan's interest soon drifted as well. Lilly's later work is now considered little more than pseudo-science, and it has tainted attempts to understand the intelligence of dolphins ever since.



Drake's famous equation can — in theory — predict the abundance of alien civilizations.

## SWIMMING AWAY

Despite Lilly's departure from legitimate science, the Order of the Dolphin's legacy endures. The Drake equation remains a useful way to frame SETI research, and the scientific advances we've made in quantifying its pieces are significant. We've found thousands of planets in other star systems and understand them better than ever — within the next few years, we'll probably know not just if a world is in its star's habitable zone, but whether it's truly habitable. Maybe soon we'll be able to determine if alien life actually exists on any of those worlds, narrowing down one more variable of the Drake equation.

More resources than ever are pouring into SETI efforts, including a $100 million project from Russian billionaire Yuri Milner called Breakthrough Listen. Even if that effort fails to detect intelligent alien communication, increased exploration efforts by NASA and other agencies may find evidence of life closer to home, either in Mars' past, or today on the moons Enceladus, Europa or Titan.

In other words, scientific literature on aliens may become a reality in the next few decades. While the man who inspired the Order of the Dolphin's name may have been pushed into the fringes, the work of the order itself continues, vital as ever. D

*John Wenz is a freelance writer based in Lincoln, Nebraska.*

## Digging Into the Drake Equation

It is less a formula for obtaining hard numbers, and more a frame for how to think about alien life.

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

The number of technologically advanced civilizations in the Milky Way.

The rate of star formation in the galaxy.

The fraction of those stars that have planetary systems.

The number of planets within each solar system that have an environment suitable for life.

The fraction of suitable planets that actually are home to life.

The fraction of inhabited planets where intelligent life emerges.

The fraction of civilizations capable of releasing detectable signs of their existence into space.

The length of time such civilizations actually do release detectable signals into space.

TOP: SETH SHOSTAK/SCIENCE SOURCE. BOTTOM FROM LEFT: SHUTTERSTOCK FROM ALEX MIT, NASA, DOTTED YETI, VIBRANT IMAGE STUDIO, GIOVANNI CANCEMI, BUTEO, ANTON FOLTIN, CANONEER

## 20 Things You Didn't Know About ...

# Chocolate

BY GEMMA TARLACH

From top: Theobromine is one of many chemicals naturally found in chocolate; candy bars are an end product of a long process that begins with post-harvest fermentation of the gooey white pulp surrounding raw cocoa beans; residues in ceremonial vessels from South America are the oldest evidence of chocolate.

**1** Chocolate is everywhere, but science is still sorting out this adored product of the domesticated *Theobroma cacao* tree's beans. **2** For centuries, based on linguistic and archaeological evidence, researchers thought chocolate originated in Mexico or Central America about 4,000 years ago. **3** In October, however, a *Nature Ecology & Evolution* study of organic residues on artifacts concluded that the Mayo-Chinchipe culture was making the stuff nearly 5,500 years ago, in what's now Ecuador. **4** Analysis of ancient and modern *T. cacao* DNA confirmed the shrubby tree was first domesticated in that upper Amazon basin region. **5** As it spread north, chocolate became a luxury commodity worthy of tribute to the gods for the Aztec, Maya and other Mesoamerican civilizations. **6** But Mesoamerican chocolate has little in common with the modern treat. It was a paste of ground cocoa beans mixed with combinations of water, corn, fruit, chili peppers or honey, creating a porridge or beverage. **7** When chocolate first arrived in Europe in the 16th century, it was as a warm drink made with "chocolate liquor." The term refers to ground cocoa paste, about half of which is cocoa solids. The rest is cocoa butter. **8** Chocolate liquor is better known today as baking chocolate. "Eating chocolate" came into being in the mid-19th century, when European confectioners added sugar and extra cocoa butter to chocolate liquor, creating what's known today as dark chocolate. **9** In the 1870s, a Swiss chocolatier added milk powder, inventing, yes, milk chocolate. White chocolate, a 20th-century invention, doesn't contain cocoa solids, so it's not technically chocolate. **10** Megacompany Barry Callebaut introduced ruby chocolate with much marketing fanfare in late 2017, but won't share the science behind the rosy-hued concoction. Independent experts have speculated it's made from unfermented cocoa beans that have been acidified — a process the firm patented in 2009. **11** If true, the lack of fermentation could explain why foodies who've tried it say it has no real chocolate taste: Chocolate relies on fermentation for a lot of its flavor. **12** After harvest, diverse microbes produce acids and other waste products, mostly in the gooey pulp that surrounds the raw cocoa beans. This kicks off biochemical changes in the beans themselves, ultimately affecting taste. **13** In September in *Royal Society Open Science*, researchers published the first quantitative model for this complex process. Complicating things even more: Small-scale cocoa growers, who produce 90 percent of the world's beans, vary widely in fermentation techniques. **14** These mom-and-pop operations are struggling; less than 1 percent of chocolate could be considered "fair trade." Inequality between large companies and growers is actually increasing, as is chocolate production-associated deforestation. **15** Feeling bummed? Don't expect chocolate to lift your spirits. In 2018, *Planta Medica* published a review of previous research on chocolate's effect on mood: The authors found that few of the studies had chemically analyzed the chocolate consumed by participants. **16** That matters, said the authors, because chemicals present in chocolate vary widely based on how it's processed, such as roasting temperature and time. Also, any effect on health may result from one specific chemical, interaction between multiple chemicals or something else entirely. **17** Our brains naturally produce the "bliss molecule" anandamide, for example, but it's also found in chocolate, leading to claims that the sweet stuff is the ultimate feel-good food. **18** But, as the 2018 review noted, chocolate has only tiny amounts of anandamide, and it breaks down quickly. Instead, concluded the authors, any bliss chocolate provides is more likely to be from a chemical combo, plus the sensory experience of taste, texture and smell. **19** Chocoholics take *Heart*, literally: A 2015 meta-analysis published in the journal linked higher chocolate consumption with a lowered risk for coronary heart disease, stroke and other cardiovascular troubles. **20** Speaking of chocoholics, an April review of food addiction research found evidence that chocolate produced neurobiological changes similar to those seen with drug use. The studies were not conclusive, however. So science still has to sort that one out, too. D

*Gemma Tarlach is senior editor at* Discover.

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