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Surviving on Venus P.10

LIVING WORLD
Cannibals … They're Everywhere! P.56

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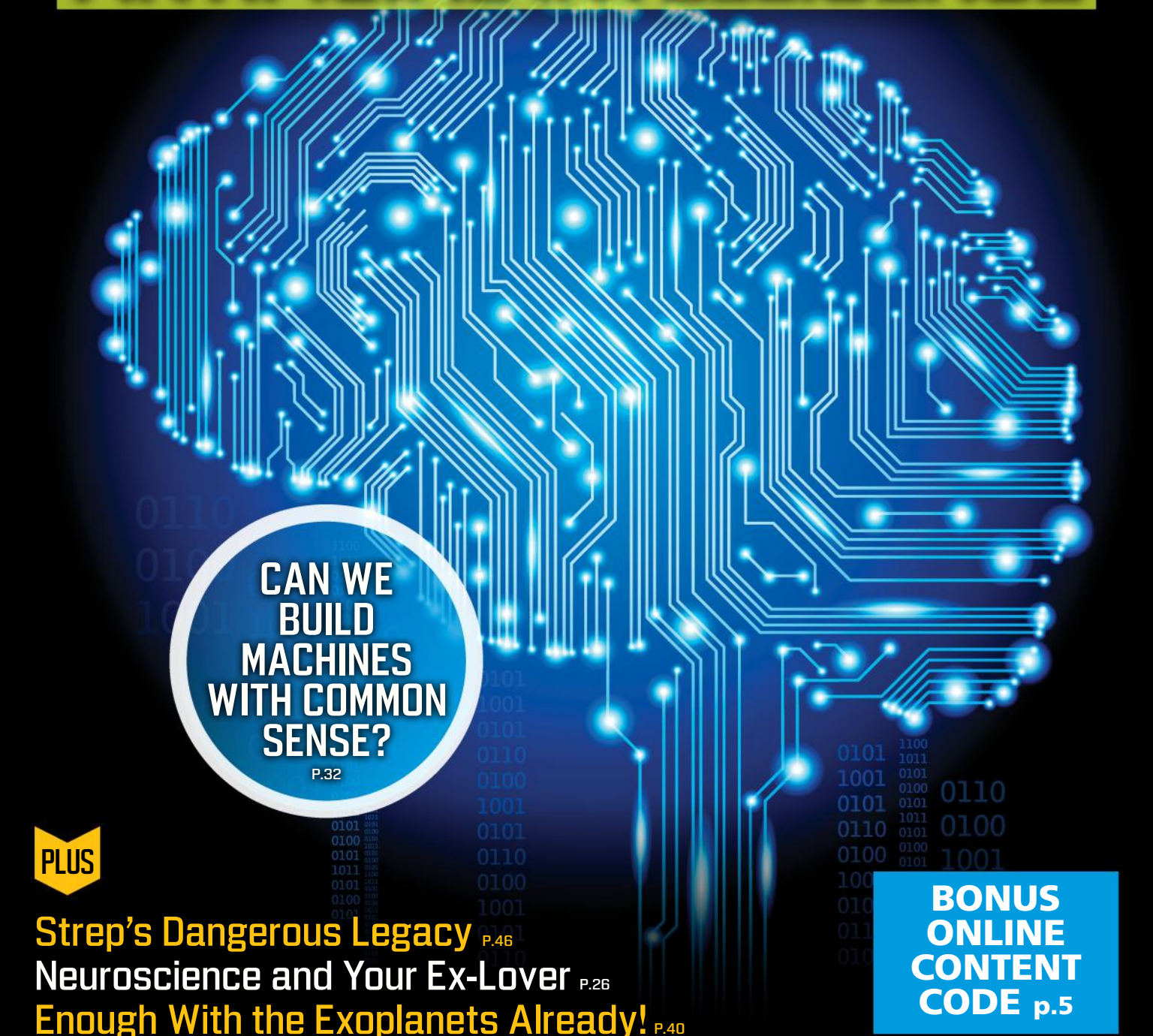
SCIENCE FOR THE CURIOUS

APRIL 2017

ARTIFICIAL INTELLIGENCE



CAN WE BUILD MACHINES WITH COMMON SENSE?

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PLUS

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Enough With the Exoplanets Already! P.40

BONUS ONLINE CONTENT CODE p.5

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— Don, January 2016

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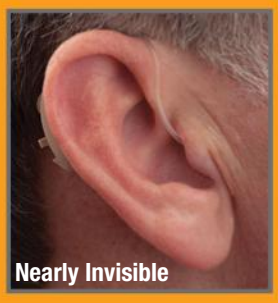

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Contents

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NASA's Kepler telescope has discovered thousands of alien planets resembling fun house versions of the worlds in our solar system. We ain't seen nothing yet! *See page 40.*

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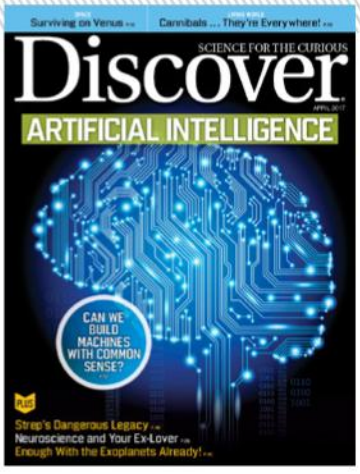
FEATURES



ON THE COVER

Illustration by VLADGRIN/Shutterstock

COLUMNS & DEPARTMENTS

LYNETTE COOK/SCIENCE SOURCE

Inbox

Night Lights

I enjoyed reading "Let There Be Dark" (Prognosis, December 2016) and am cleaning up my act regarding light while sleeping.

There are 13 full moons a year giving light bright enough to definitely say the night is not dark. Cave-dwelling came upon the scene rather late, and even then I'm assuming a fire was kept burning for a lot of that time. I'm wondering why humans still seem to be so sensitive to light at night?

I'm interested, but I promise not to lose any sleep over it.

Gary Keith, *Arroyo Grande, CA*

When Birds of a Feather Snooze Together

No. 43 of your top stories (January/February 2017) talks about birds sleeping during flights.

We live in the Catskill Mountains of New York state. Some years ago in the fall, my father was watching a very large V formation of Canada geese flying over our home. They were flying low, surprising us because the nearby mountains are high. The V flew directly into the mountain with great chaos and cacophony — the birds were all over the place in disarray.

The lead bird must have been asleep and on autopilot. We feel certain that he was ousted and replaced by another.

It is fun for us to see that others have found evidence for this ability to sleep during flight. Thank you for the interesting variety of top stories — this one was our favorite.

Helen Chase, *Shokan, NY*

Letters are edited for length and clarity.

From the Web

Worried about asteroids colliding with Earth? NASA has a plan for that — but not enough money for it. Nathaniel Scharping's D-brief story on the push to fund the agency's asteroid defense plan got readers talking.

Trevor Krouskop I don't want to be saved, I wanna look up and see the greatest show on Earth.

Hunter G. Hornet The money will appear as soon as it's too late to do anything about it. See: climate change.

Jo Katzenjammer That's uh … that's something we might want to pony up the cash for, just in case.

Rob Francis The entire planet benefits from detecting and preventing possible asteroid impacts. Why should only those nations with space agencies be expected to foot the bill for this?

Matthew Dancz Well, yeah. Something like this would be a public good, for the entire planet. This kind of system won't happen without a global government.

ROEN KELLY/DISCOVER

Editor's Note

A Little Common Sense, and Control

Control. Most of us like to feel we have some semblance of it in our daily lives. And we tend to get a little edgy when it looks like it's slipping away. It's why the thought of self-driving cars mixing it up with human drivers on the roads makes us pause. Certainly our brains' inherent predictive powers supersede what's been programmed into a car's computer, right?

That factor — prediction — is a key objective for the artificial intelligence research team featured in our cover story. For all the stories we've read and heard about machines that are geared up to drive, grocery shop and pick up our kids for us, AI is still in its infancy. Researchers are working hard just to get AI into the throes of toddlerhood.

Machines will do only as they're told; their actions and "smarts" only as good as the data they're fed. While scientists design neural networks and write algorithms to gradually teach them, we are a long way from the point where machines can independently predict behavior of people or things in any situation. As babies, we learn to predict the path of a dropped ball, and, though it's in fits and starts, we also learn a bit of common sense about how our world works.

It's common sense that is the underpinning of our feelings of control. We're still in the driver's seat. At least for now.

Becky Lang

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

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- Visit **Lowell Observatory**, journey through red rock country around **Sedona**, marvel at the cliffs of **Zion National Park,** enjoy a storied lodge in **Yellowstone,** visit the **Grand Canyon,** pay your respects at **Mount Rushmore,** and much more.
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P28947

See all the tours at DiscoverMagazine.com/trips-tours

THE CRUX

THE LATEST SCIENCE NEWS AND NOTES

PONDERING THE PAST

On the final day of digging last September, archaeologists in Yehud, Israel, unearthed this unusual ceramic creation. It's an ordinary Bronze Age jug, but perched on top is a figure frozen in contemplation. The 3,800-year-old piece was probably a funerary offering made for a respected community member, according to dig director Gilad Itach of the Israel Antiquities Authority. He said the figure was added to the jug before firing, but each might have come from separate craftsmen. The researchers were collecting artifacts before construction of residential buildings began. — ERNIE MASTROIANNI; PHOTO BY MENAHEM KAHANA/AFP/GETTY IMAGES

BIG IDEA

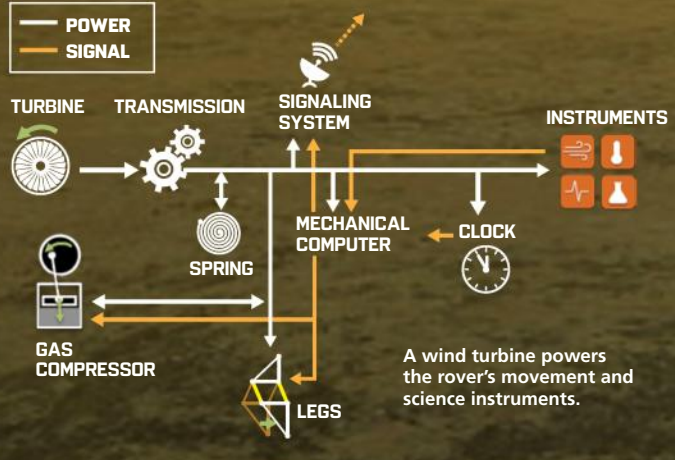
Walking With Venus' Wind

The hellishly hot planet fries spacecraft electronics, so NASA scientists devised a machine inspired by ancient technology.

VENUS IS NOT A FORGIVING PLANET. The longest that any machine has survived there is 127 minutes. Surface temperatures surpassing 800 degrees Fahrenheit and clouds of sulfuric acid are a perfect recipe for frying circuits. So Jet Propulsion Lab engineer Jonathan Sauder and his team designed a futuristic Venus rover that doesn't need electronics. Instead it uses mechanical systems that would have been familiar to Leonardo da Vinci.

The Automaton Rover for Extreme Environments (AREE) — which recently received a NASA Innovative Advanced Concepts grant — is built entirely of hardened metals and guided by a clockwork computer. The rover is still far from a planned mission, but it would be able to collect weeks' worth of climate and seismic data from Venus' surface, all recorded on phonograph-style records that periodically would be lifted by balloon to an overhead drone. Then NASA just needs to salvage an old Victrola. —JONATHON KEATS

HOW TO MARCH ACROSS A HELLSCAPE



A wind turbine powers the rover's movement and science instruments.

RELAY DRONE
A solar-powered drone could safely fly dozens of miles over the surface, where temperatures and pressure are Earth-like. Gas-filled balloons would tote rock samples and phonograph records up to the drone, which would record the findings and relay it to an orbiting spacecraft. That craft would then beam data back to Earth.

PHONOGRAPHS
Designers are exploring several ways to send information to Earth, but the base concept has seismic data cut into records that are subsequently launched above the clouds by gas balloons. A simpler approach would involve retro-reflectors bouncing signals from Venus' surface.

INTERNAL COMPUTER
History provides many examples of mechanical computers, like the Greek Antikythera mechanism, which calculated eclipse dates more than 2,000 years ago. AREE's computer would need to track temperature, pressure, winds and seismic events.

SAMPLE DRILL
Like the Mars Curiosity rover, AREE's drill would let scientists see into Venus' interior — and past.

WIND TURBINE
Venus' winds would spin AREE's fan blades, generating energy that's stored in a spring.

SEISMOMETER
Astronomers know little about Venus' interior, and that impedes our understanding of how planets form. So one prime objective is to set up "Earth's Twin" with a seismometer, which measures geologic activity.

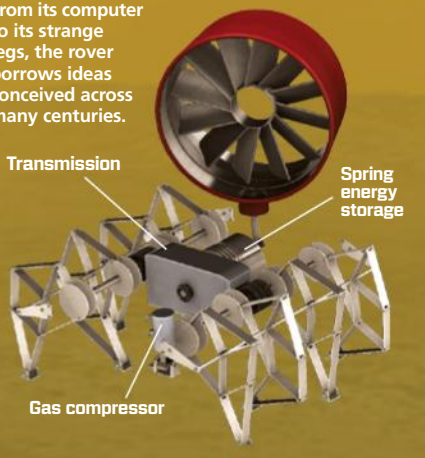
JANSEN MECHANISM WALKING LEGS
Kinetic sculptor Theo Jansen designed a system of legs that walk naturally, powered only by the wind. His autonomous Strandbeests gained fame roaming Earth's beaches. His legs inspired those used by AREE.

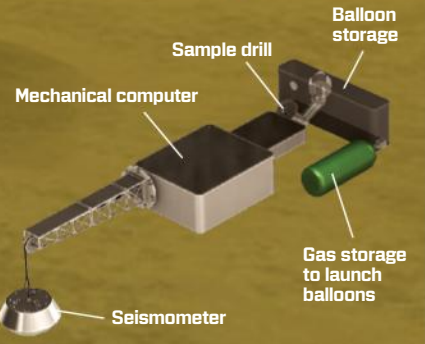
INSPIRATION

NASA engineer Jonathan Sauder found inspiration in both ancient and modern automatons.

MECHANICAL SYSTEMS

From its computer to its strange legs, the rover borrows ideas conceived across many centuries.





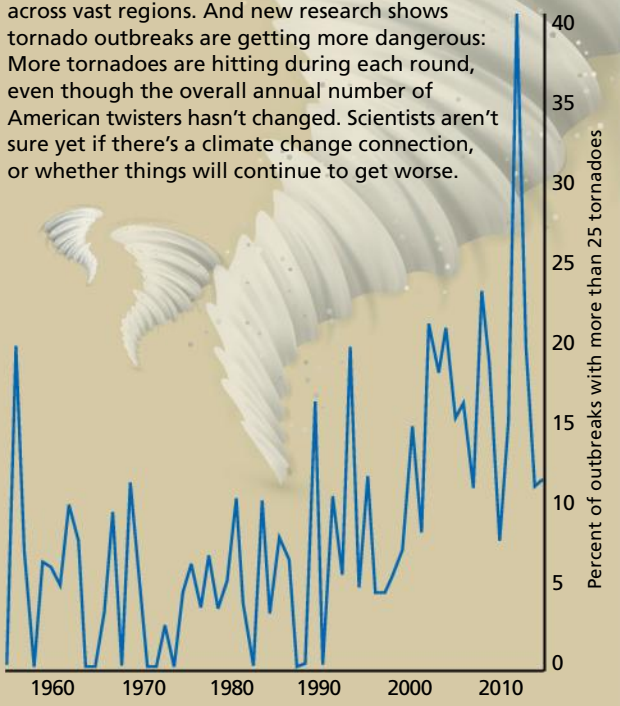
VENUS ROVER ILLUSTRATIONS: NASA/JPL-CALTECH/NIAC. BACKGROUND: ESA/J. WHATMORE. ANTIKYTHERA MECHANISM: TILEMAHOS EFTHIMIADIS/CREATIVE COMMONS 2.0. STRANDBEEST: LOEK VAN DER KUS, COURTESY OF THEO JANSEN

TRENDING

BY ERIC BETZ

Tornado Outbreaks on the Rise

Just one twister can cause devastation. But when outbreaks bring dozens of tornadoes over days, they can leave a path of death and destruction across vast regions. And new research shows tornado outbreaks are getting more dangerous: More tornadoes are hitting during each round, even though the overall annual number of American twisters hasn't changed. Scientists aren't sure yet if there's a climate change connection, or whether things will continue to get worse.



Building Blocks

BAT TALK

It turns out that bats have one-on-one chats, a behavior previously observed in just a few creatures such as primates and dolphins. Tel Aviv University researchers studied 15,000 Egyptian fruit bat calls over 75 days and pinpointed specific vocalizations in the cacophony for the first time. Learning the nuances of these conversations will help experts build a better picture of bat societies.

BLACK HOLE SNAPSHOT

Astronomers using the Event Horizon Telescope over 10 days in April hope to grab the first image of a black hole. Black holes emit no light, so to get the shot, the radio telescope array will focus on the hot gas circling the event horizon that surrounds the tiny target.

HEAVY METAL MISSIONS

In January, NASA announced plans to send a spacecraft to visit Psyche, a metal asteroid that could be a dead planet's core, in 2023. Also on deck at the agency: a spacecraft aiming for an asteroid group near Jupiter in 2021. The missions' aim is to bring our solar system's evolution into focus.

> "I'd be **surprised** if we landed on **Planet X** and found someone sitting there **drinking** a can of Coors."
>
> — Jeffrey Bada, a chemist at the University of California, San Diego, on why we should expect aliens to be truly alien

THIS PAGE CLOCKWISE FROM LEFT: DAN BISHOP/DISCOVER AFTER M.K. TIPPETT ET AL./SCIENCE/17 NOVEMBER 2016; MACROVECTOR/SHUTTERSTOCK; KIM TAYLOR/NATURE PL; ESO/L. CALÇADA; NASA/JPL-CALTECH. OPPOSITE: DAN BISHOP/DISCOVER AFTER J. TAULMAN ET AL./JOURNAL OF BIOGEOGRAPHY/1 APRIL 2014; MANEKINA SERAFIMA/SHUTTERSTOCK; BELOW: NASA/CXC/SAO (8)

TIMELINE

Stars Explode in Earthly Skies

About twice each century, a star in our galaxy explodes in a supernova. Only a few of those explosions happen close enough to Earth to be visible with the naked eye. By comparing ancient observations with today's spacecraft data on supernova remains, scientists hope to nail down when those stars exploded. Here's a look at eight supernovas that caught earthlings' attention throughout history.

A.D. 185

RCW 86

Chinese and possibly Roman astronomers recorded a strange new star in the skies.

A.D. 393

G347.3-0.5

Chinese observers reported a so-called "guest star" that shone for months, appearing as bright as Jupiter.

A.D. 1006

SN1006

This stellar explosion surpassed Venus in brightness and captivated skywatchers worldwide.

Movin' On Up

Armadillos roamed the Western Hemisphere during the Ice Age. But by the time naturalist John James Audubon first noted their presence in 1854, the mammals had just a tiny toehold north of the U.S.-Mexico border along Texas' hot Rio Grande Valley, with a broader range across Mexico and countries farther south. Since then, armadillos have been ceaselessly marching north and east, with scientists citing climate change as a likely factor. The critters are tough to study, living much of their lives underground and avoiding above-ground traps, so researchers track them via live sightings by the public and numerous reports of armadillo roadkill. Despite their less-than-stellar self-preservation skills, their march continues.

1054

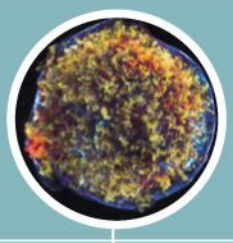
Crab Nebula

The supernova responsible for the famous Crab Nebula lit up even daytime skies, possibly rivaling the full moon in brightness.

1181

3C58

The aftermath of this exploding star was visible for six months, giving Chinese and Japanese astronomers ample time to record it.



1572

Tycho's SNR

Danish astronomer Tycho Brahe recorded a clear description of this supernova, and astronomers have watched its detritus glow ever since.

1604

Kepler's SNR

Johannes Kepler, a German-born mathematician and astronomer, tracked this supernova for a year, lending it his name.

1680

Cass A

This star exploded nearly unnoticed, with only a possible identification by John Flamsteed, England's first Astronomer Royal.

—KOREY HAYNES

THAT WORD YOU HEARD

Superhydrophobic

THOUGH IT MIGHT TEMPT YOU to break out into a *Mary Poppins* song, *superhydrophobic* has nothing to do with dancing penguins or carousels come to life. The term refers to a material's ability to repel water. When water droplets hit surfaces with this property, they don't flatten like they normally would — they bead up, often contacting the surface at angles exceeding 150 degrees, and roll off. You can see this phenomenon in nature when water falls onto a lotus leaf. Outside of nature, researchers are applying superhydrophobic coatings to the interiors of food containers, like bottles of honey and soda cans, to get out every last drop and cut down on food waste. — LACY SCHLEY; ILLUSTRATION BY CHAD EDWARDS

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Q&A

Yuri Milner

Russian-born entrepreneur co-founded the Breakthrough science prize.

YURI MILNER was pretty much destined to do something in science. Born in Moscow in November 1961, he was named after Soviet cosmonaut Yuri Gagarin, who, about six months earlier, had become the first person to venture into outer space. Inspired by Carl Sagan and others, Milner majored in physics at Moscow State University. Then, in the middle of earning a Ph.D. in particle physics, he quit. Eventually, he started his own internet company and invested in other companies like Facebook, quickly amassing a fortune.

Since then, Milner has used his wealth to support science. He co-founded the Breakthrough Prize, which recognizes important advancements in physics, life sciences and math by awarding $3 million prizes in each category.

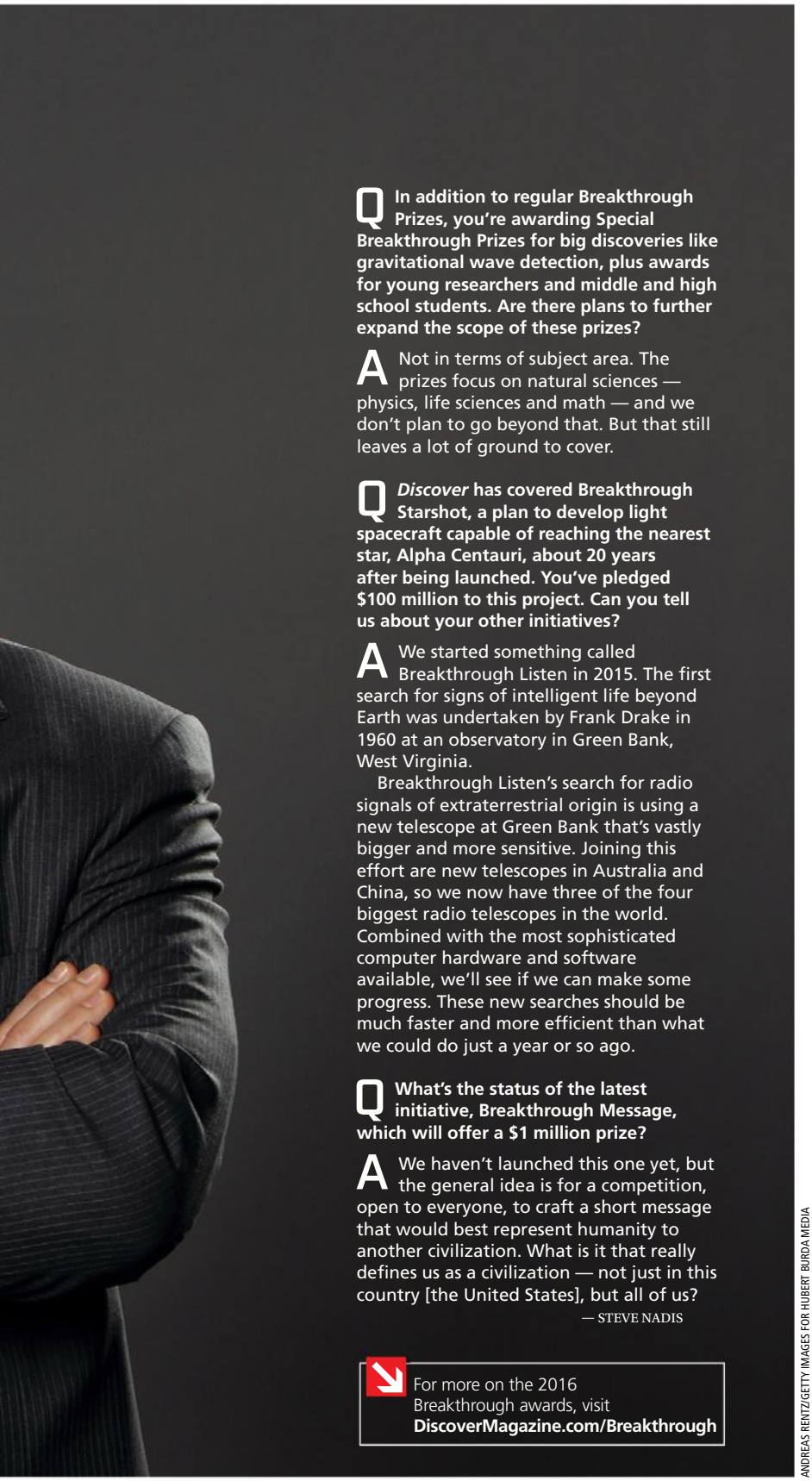
Milner spoke by phone with *Discover* contributing editor Steve Nadis days before the fifth annual Breakthrough Prize ceremony in December in Silicon Valley, where Milner now lives.

Q Did you abandon a research career in physics because you felt you could do more to help science from the outside?

A I quit physics around 1990 when I decided I was not good enough to make a big contribution to the field. But I continued to track developments in science. It's like your first love — you want to keep in close touch.

Q What prompted you and your friends, including Facebook CEO Mark Zuckerberg and Google co-founder Sergey Brin, to start giving out prizes, first in physics, then in other branches of science?

A Recognition of science among the general public is lower than it should be, partly because it is not easy to explain. We need to explain science better, communicate it to a wider audience and celebrate it. Because, in the end, science is really the biggest asset our civilization has.



Q **In addition to regular Breakthrough Prizes, you're awarding Special Breakthrough Prizes for big discoveries like gravitational wave detection, plus awards for young researchers and middle and high school students. Are there plans to further expand the scope of these prizes?**

A Not in terms of subject area. The prizes focus on natural sciences — physics, life sciences and math — and we don't plan to go beyond that. But that still leaves a lot of ground to cover.

Q ***Discover* has covered Breakthrough Starshot, a plan to develop light spacecraft capable of reaching the nearest star, Alpha Centauri, about 20 years after being launched. You've pledged $100 million to this project. Can you tell us about your other initiatives?**

A We started something called Breakthrough Listen in 2015. The first search for signs of intelligent life beyond Earth was undertaken by Frank Drake in 1960 at an observatory in Green Bank, West Virginia.

Breakthrough Listen's search for radio signals of extraterrestrial origin is using a new telescope at Green Bank that's vastly bigger and more sensitive. Joining this effort are new telescopes in Australia and China, so we now have three of the four biggest radio telescopes in the world. Combined with the most sophisticated computer hardware and software available, we'll see if we can make some progress. These new searches should be much faster and more efficient than what we could do just a year or so ago.

Q **What's the status of the latest initiative, Breakthrough Message, which will offer a $1 million prize?**

A We haven't launched this one yet, but the general idea is for a competition, open to everyone, to craft a short message that would best represent humanity to another civilization. What is it that really defines us as a civilization — not just in this country [the United States], but all of us?

— STEVE NADIS

For more on the 2016 Breakthrough awards, visit **DiscoverMagazine.com/Breakthrough**

ANDREAS RENTZ/GETTY IMAGES FOR HUBERT BURDA MEDIA

FAR, FAR AWAY

STELLAR NURSERY

This colorful vista reveals glowing clouds full of budding stars near our galaxy's center. But neither the human eye nor ground-based telescopes can see this spectacular sight, which is obscured by cosmic dust. NASA's space-based Spitzer and WISE telescopes, though, view the heavens in infrared light, which can punch through the dust. Judy Schmidt, an expert in processing spacecraft images, combined photos from both telescopes to reveal this complex region centered on the Milky Way's invisible supermassive black hole, called Sagittarius A*.

— ERNIE MASTROIANNI; PHOTO BY NASA/JPL-CALTECH/JUDY SCHMIDT

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!

Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days

Drivers' Alert: Driving can expose you to more dangerous glare than any sunny day at the beach can… do you know how to protect yourself?

The sun rises and sets at peak travel periods, during the early morning and afternoon rush hours and many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle, the pavement, or even from waxed and oily windshields that can make matters worse. Early morning dew can exacerbate this situation. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

Not all sunglasses are created equal. Protecting your eyes is serious business. With all the fancy fashion frames out there it can be easy to overlook what really matters—the lenses. So we did our research and looked to the very best in optic innovation and technology.

Sometimes it does take a rocket scientist. A NASA rocket scientist. Some ordinary sunglasses can obscure your vision by exposing your eyes to harmful UV rays, blue light, and reflective glare. They can also darken useful vision-enhancing light. But now, independent research conducted by scientists from NASA's Jet Propulsion Laboratory has brought forth ground-breaking technology to help protect human eyesight from the harmful effects of solar radiation light. This superior lens technology was first discovered when NASA scientists looked to nature for a means to superior eye protection—specifically, by studying the eyes of eagles, known for their extreme visual acuity. This discovery resulted in what is now known as Eagle Eyes®.

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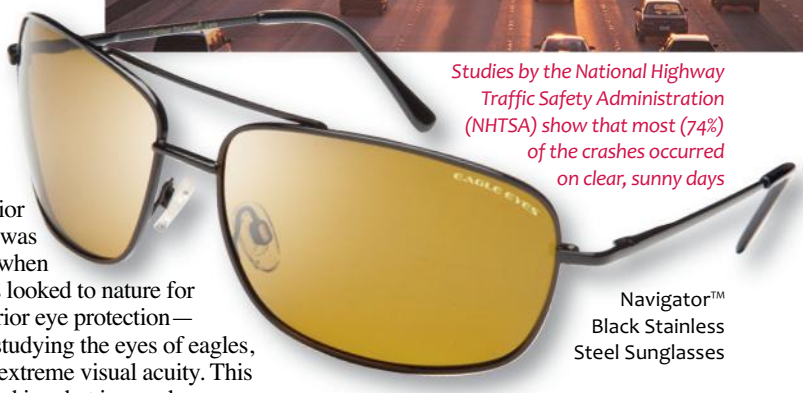

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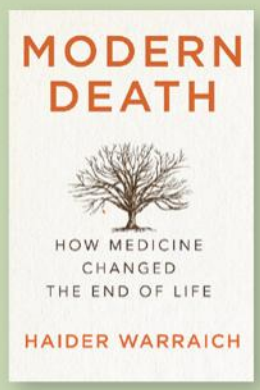
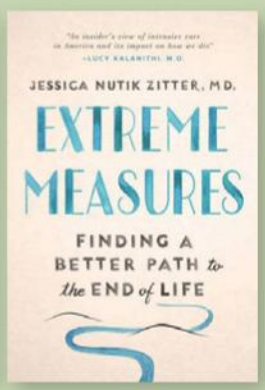


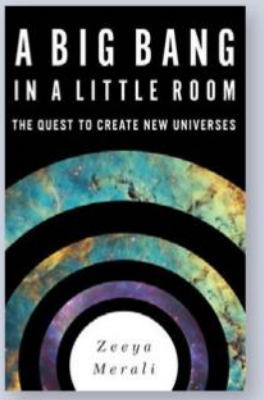
MODERN DEATH
How Medicine Changed the End of Life
By Haider Warraich



EXTREME MEASURES
Finding a Better Path to the End of Life
By Jessica Nutik Zitter

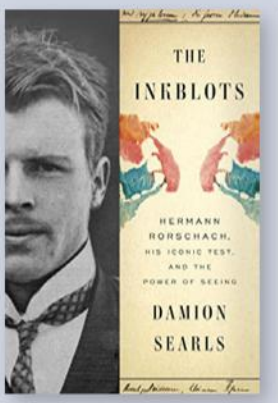
Two physicians, each gifted, thoughtful observers, tackle a subject that's rarely discussed ahead of the event: death. Zitter, whose work in an Oakland ICU was the subject of the recent Netflix documentary *Extremis*, has a deft directness. She presents multiple perspectives — the anxious family, a confused patient, clashing opinions between health care professionals and her own internal conflicts — in spare, riveting prose. Warraich, a cardiology fellow at Duke University, leans more toward the poetic. Both writers, however, look tough end-of-life issues right in the eye and, with intelligence and sensitivity, invite their readers to do the same.

QUICK TAKES



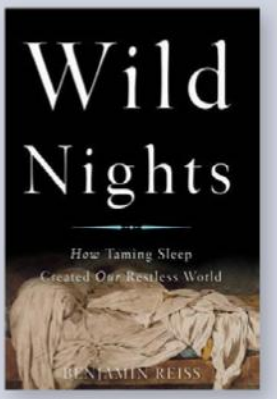
A BIG BANG IN A LITTLE ROOM
The Quest to Create New Universes
By Zeeya Merali

Frequent *Discover* contributor Merali blends physics with philosophy on a journey to learn whether humans will soon be able to make entirely new universes (spoiler alert: quite possibly, yes) and, if so, whether our universe could be the science project of other intelligent life.



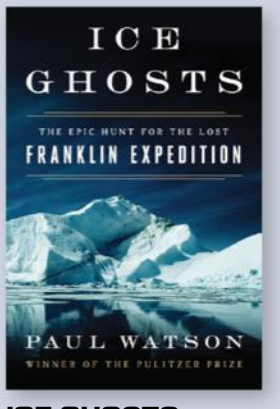
THE INKBLOTS
Hermann Rorschach, His Iconic Test and the Power of Seeing
By Damion Searls

Searls provides a detailed recounting of a man whose creativity and curiosity about the human mind drove him to create a new way of "reading" people — an innovation that was quickly embraced, and misunderstood, by the masses.



WILD NIGHTS
How Taming Sleep Created Our Restless World
By Benjamin Reiss

Get a solid eight hours in, no electronic screens in bed, wake up at the same time every morning, yeah, yeah. We modern folk have it all figured out, don't we? Maybe not, says Reiss, as he explores how getting a good night's sleep evolved and why it varies from one culture and era to the next.



ICE GHOSTS
The Epic Hunt for the Lost Franklin Expedition
By Paul Watson

Pulitzer Prize winner Watson crafts a thrilling tale of science's hunt to solve one of naval history's greatest riddles: What happened to two ships lost while searching for the Northwest Passage in the mid-19th century? His intimate familiarity with key players and places gives the reader an insider's view of the operations.

— ALL REVIEWS BY GEMMA TARLACH

Head in Hand

A healthy man in his 30s starts lifting weights, and his physical condition worsens.

BY **SHILPA RAVELLA**

Jay, a physician in his early 30s, was a healthy guy who ran 6 miles a day, loved nature and animals, and spent free time hiking and biking. One summer, he decided to start weight training.

The problem started simply. He had finished a training session at the gym, doing upper and lower body exercises with barbells and finishing with sit-ups. A few days later, he felt more sore than usual. "My neck feels really stiff," he told me. "I probably overdid it at the gym."

I examined his neck and could see no external injuries. He didn't have any pain when I pressed on the area, and he could move his head freely. He had no neurological issues, and an X-ray was normal. It likely was just a routine muscle strain.

These kinds of strains around the neck are common and usually caused by sports activities, automobile accidents or falls. We didn't see any red flags, and Jay started taking ibuprofen, an anti-inflammatory medication that's standard initial treatment for neck strains. I expected him to recover and soon make appearances at the gym again.

That didn't happen. A few weeks later, Jay was back in my office in worse shape. "Something's not right," he said. "The ibuprofen only helped a little, and the muscles in the back of my neck are getting weaker. My head feels heavier, like it has stones in it."

This was alarming. Simple muscle strain usually gets better with rest and anti-inflammatory drugs. Why wasn't Jay improving? Was this one-time strain from a heavy workout causing lasting muscle fatigue? Or were his nerves affected?

We scheduled him for an MRI of the head and neck and an appointment with Dr. Sanders, a neurologist.

The MRI and lab tests, including a complete blood count and basic metabolic panel, all came back normal.

"Something's not right," he said. "The ibuprofen only helped a little, and the muscles in the back of my neck are getting weaker. My head feels heavier, like it has stones in it."

Sanders checked muscle enzyme levels and found unusually high concentrations of the enzyme creatine kinase, an indicator of muscle injury. High levels are found in people with inflammatory muscle diseases, as well as in elite athletes and in people of moderate fitness who participate in a physically demanding event, like a marathon. Strenuous exercise builds muscles by creating micro-tears in muscle fiber that the body regenerates, which increases the enzyme.

We started Jay on high-dose prednisone, a steroid that decreases inflammation, and referred him to Dr. Baker, a rheumatologist. His condition might have been due to an especially strenuous workout. He might also have developed an autoimmune disease, a condition in which the immune system reacts against and destroys healthy tissue — in this case, the muscles in the back of his neck. While prednisone could knock down the inflammation, we still needed to find out what was causing it.

DYING MUSCLES

A week later, Jay walked into Baker's office. He was carrying something in

FILE 404/SHUTTERSTOCK

his hands: his head. He had developed a complete head drop over the course of two weeks and could not raise his chin off his chest.

Jay used both hands to cup his chin and push it up, supporting the entire weight of his head while interacting with Baker and me. He rested often due to exhaustion. The average human head weighs about 10 pounds; the seemingly effortless act of holding your head up involves an intricate balance among the neck muscles.

Jay was now unable to drive and no longer working. His voice was shaky, and it looked like he hadn't slept in days. At this point, with Sanders and Baker collaborating, Jay underwent many more tests, including electromyography, which evaluates how well muscle fibers are working, and nerve conduction studies, used to diagnose nerve disorders and help differentiate between muscle and nerve problems. The tests did not reveal an ailment.

Finally, a biopsy taken from a muscle near Jay's neck showed that his muscle cells were dying, but offered no clue why this was happening. Inflammation was minimal, and blood levels of specific antibodies, indicating that the immune system was reacting against the body, were absent.

"Will this improve? Will I ever be able to hold my head up and function normally?" Jay asked.

"It's impossible to tell right now," Baker said. "The symptoms are very unusual, and you haven't responded to prednisone, but we can try increasing the dose. This could be a form of Parkinson's or ALS [amyotrophic lateral sclerosis]."

Jay swallowed hard. He knew from his medical experience that all of these options were serious.

ALS, or Lou Gehrig's disease, is a rapidly progressive and fatal neurological condition in which the nerve cells controlling muscles are attacked. Patients lose the ability to move their arms and legs, swallow food or speak. Muscles in the diaphragm and chest wall soon weaken, causing an inability to breathe. Within a few years, patients usually die from respiratory failure.

"I feel like I should start my bucket list," Jay told me after the appointment.

"What would be on it?" I asked.

"Running away to an island, somewhere warm with clean air and plenty of greenery," he said.

A biopsy taken from a muscle near Jay's neck showed that his muscle cells were dying, but offered no clue why this was happening.

INNER DESTROYER

Jay was fitted with a body brace that extended to his waist so he could continue with his daily activities. The brace had a neck support that immobilized and held up his head, and the weight of his head was redistributed to the muscles in his back. He took off the device only to sleep or shower. It was an uncomfortable contraption, but he was determined to continue working and living as much of a normal life as possible.

Yet his condition worsened. He easily became short of breath, barely able to walk two blocks before getting fatigued. He also started to have trouble swallowing.

His symptoms, imaging and lab results didn't fit any specific disease pattern, and none of the consultants had ever seen a case like his. His body seemed to be reacting against itself, destroying healthy muscle tissue and causing inflammation.

Baker, the rheumatologist, decided to start intravenous immunoglobulin (IVIG), which consists of pooled antibodies extracted from the blood of thousands of plasma donors. IVIG is used to treat a variety of autoimmune diseases by suppressing harmful inflammation. He also started Jay on two powerful immunomodulating drugs: tacrolimus and azathioprine. These drugs are typically used in patients receiving organ transplants to prevent their immune systems from rejecting donated organs. They have many side effects, such as infection, kidney disease and diabetes.

If Jay's body was turning on itself, it was time to do everything possible to stop the damage.

For the next 18 months, Jay went through several rounds of IVIG and used powerful immunomodulating medications. The final diagnosis was an extremely rare condition called necrotizing autoimmune myopathy, which meant his muscles had been attacked and destroyed by his immune system. No one knows what triggers this reaction in the body. Suspects include exercise, muscle overuse or injury, viruses and even medications, such as cholesterol-lowering drugs.

Jay went through painful, rigorous physical therapy. His condition finally improved, and he stopped using the body brace and tapered off the medications. He recovered about 50 percent of his baseline strength in his neck muscles and returned to performing daily activities, although his neck was weaker and could ache at the end of a long day or with moderately strenuous use. He couldn't run marathons, but he took up hiking again — on a beautiful island where he opened a medical practice and continues to treat patients. D

Shilpa Ravella *is a gastroenterologist at Columbia University Medical Center in New York. The cases described in Vital Signs are real, but names and some of the details have been changed.*

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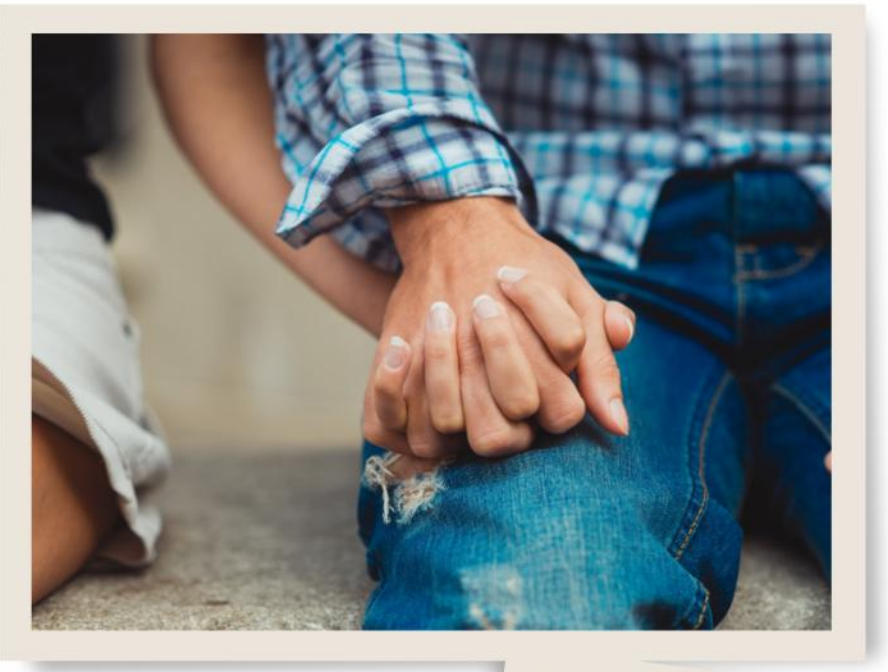
Fired Up

What happens in the brain when you reconnect with an old flame.

BY **AMY PATUREL**



When I arrived at the wine bar, there was only one open table — dimly lit and intimate. The booze, music and candlelight felt like a callback to our first kiss 15 years before, almost to the day.

There was no sign of him, so I ordered a chardonnay and two small plates, and tried to focus on the novel I brought with me, ironically titled *What She Knew*. Instead, I found myself flashing back to the last time I saw him.

We had just returned from a trip to Napa to scout wedding venues. After a heated kiss, I drove to my apartment 95 miles away.

Days later, I learned he'd been cheating on me, and I ended our six-year relationship — the best of my life up to that point — with a two-line email. He fired back with a litany of messages, which began with profanity and culminated in pleas.

"PLEASE DON'T LEAVE ME … YOU ARE MY EVERYTHING," he screamed through the screen.

He sent texts, letters, roses, and initiated countless hang-up calls.

I never responded. I never told him a mutual friend confirmed my suspicions. I never considered reconciling.

Over the years, we corresponded intermittently, but not about anything deep — and never to revisit our history. But when work took me to his hometown of Santa Barbara, I reached out and asked if he'd like to meet.

I'm happily married with kids. He's engaged. What's the harm?

Apparently my urge to reconnect with an ex makes sense. "The brain develops pathways based on learned patterns," says love expert Helen Fisher, a senior research fellow at the Kinsey Institute, Indiana University. "So, if you laid down a powerful pattern that this person was your life partner, your brain can retain traces of that circuitry, even after you've bonded with someone new."

"If you laid down a powerful pattern that this person was your life partner, your brain can retain traces of that circuitry, even after you've bonded with someone new."

Nevertheless, I struggled to understand why, even though it's certainly not the case for everyone — especially those who have had toxic relationships — I felt so comfortable sitting across the table from someone who pulled the rug out from under me. So down the rabbit hole I went to find out what happens in our brains when we reunite with an old love.

LAYING DOWN A TEMPLATE

I met Ben (not his real name) when we were both 26. We had a sweet, albeit star-crossed romance. He was an irrepressible free spirit, a dreamer, a romantic. I was an ambitious type A who played it safe. Like peanut butter and jelly, we complemented each other.

He was the first to make me dinner, teach me to surf in ice-cold waters and

TOP: GORYNVD/SHUTTERSTOCK. BOTTOM: GAUDILAB/SHUTTERSTOCK

unlock the seemingly impenetrable fortress of my body. Together, we formed our identities and defined what love meant. In the process, he ingrained himself into my psyche.

Experts say the neurological attachment that happens between young lovers is not unlike the attachment a baby forms with its mother. Hormones like vasopressin and oxytocin are key in helping create a sense of closeness in relationships and play a starring role in both scenarios.

If that person was your first, best or most intimate, the mark is even more indelible. Such preferential encoding in the brain is one reason why stories of people reconnecting with a high school or college flame are commonplace.

"The person you have your first orgasm with, especially if they cuddle with you afterward, lays down a template for what you find attractive."

"The person you have your first orgasm with, especially if that person cuddles with you afterward, lays down a template for what you find attractive," says Jim Pfaus, a professor of psychology and neuroscience at Concordia University in Montreal.

It goes something like this: According to a 2010 study published in *The Journal of Neurophysiology*, feelings of romantic love trigger the brain's dopamine system, which drives us to repeat pleasurable experiences. The brain's natural opiates help encode the experience, and oxytocin acts as the glue that helps forge those feelings of closeness.

"Oxytocin unleashes a network of brain activity that amplifies visual cues, odors and sounds," explains Larry Young, a psychiatry professor at Emory University in Atlanta. That, plus the effects from your brain's natural opiates and dopamine, and your romantic partner's traits — strong jaw, piercing blue eyes, musky scent — leave a sort of neural fingerprint. Those preferences become soft-wired into your reward system, just like an addiction.

Even creatures prone to promiscuity, like rats, are often primed to revisit their first pleasure-inducing partner, according to a 2015 study co-authored by Pfaus. And it seems humans may follow a similar pattern.

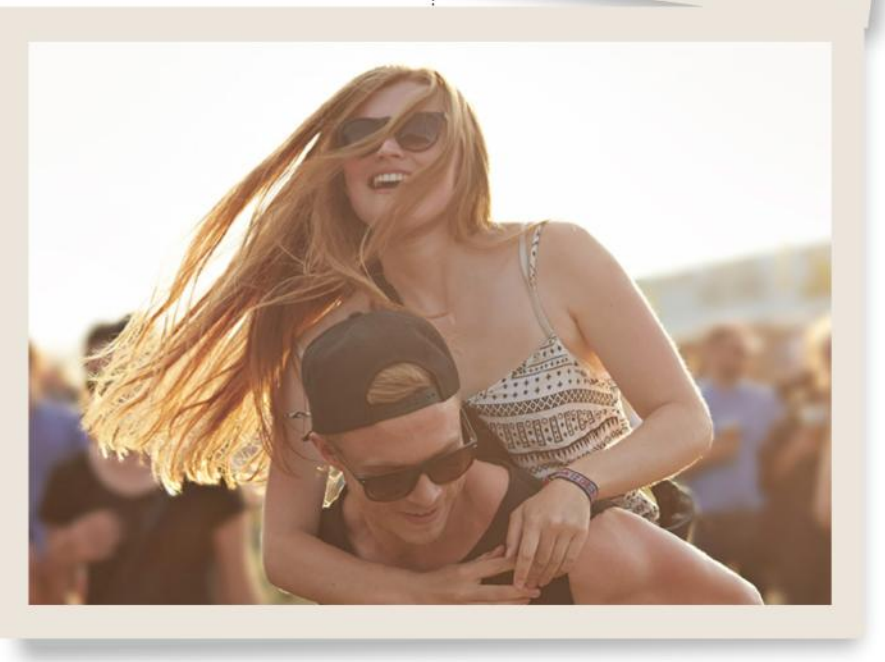
DRAWN TO THE PAST

When Ben walked into the bar, I stood up, navigated my way toward him and gave him a big hug, standing on my tiptoes to reach his neck. My first thought: He bulked up! I felt like a doll enveloped in his 6-foot-1 frame.

"Congratulations," I whispered. "You look great!"

He puffed up with the compliment, that familiar sparkle gleaming in his eyes.

It was comfortable. Easy. Seeing him instantly reactivated the networks my mind encoded 15 years before. Throw a bear hug into the mix — and the accompanying flood of oxytocin — and that old brain circuitry lit up like fireworks. Justin Garcia, the associate director for research and education at the Kinsey Institute, says that's no surprise. Just like a recovering alcoholic craving a drink



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after decades of sobriety, we can still be drawn to an old lover.

"It doesn't mean you still want to be with that person," he says. "It doesn't mean there's something wrong with you. It means there's a complex physiology associated with romantic attachments that probably stays with us for most of our lives — and that's not something to be afraid of, particularly if you had a great run."

FOCUS ON THE GOOD

While high school sweethearts typically meet, fall in love and dissolve before their brains are fully developed — somewhere in their mid- to late 20s — I met Ben just as my brain's frontal lobes were reaching maturity. In fact, once I began operating with a full mental deck, we were entering our final act.

By the time we split, my 32-year-old brain was viewing life in high definition. I wanted a family. He wanted freedom. We reached an impasse.

Today, our lives couldn't be more disparate. He'd been living in a loop since I left — upscale dinners, regular happy hours, exotic vacations — and before his engagement, a different woman by his side every few years. I married, bore three children and spent most days with a toddler attached at the hip — or more often the knee because both hands are full.

But I don't regret our relationship. Instead, I treasure the time we spent together. And that's in line with how many people look back on their old, positive relationships. The human mind not only becomes more sentimental with age, it's also adept at rewriting our early romantic history.

"After we resolve a romantic relationship," Fisher says, "we have this remarkable ability to forget the bad parts and focus on the good ones." So while I could easily recall the time Ben scattered hundreds of rose petals throughout my apartment, I conveniently forgot the time he took off on a guys' ski trip without warning.

I still love Ben, for the role he played in my story. The experiences we shared together, and even how we separated, stay with me in a positive and healthy way and they helped form the person I am today. D

Amy Paturel *is a health journalist based in Temecula, Calif.*

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CULTIVATING COMMON SENSE

A band of Seattle computer scientists is on a mission to make artificial intelligence actually INTELLIGENT. BY **CARL ENGELKING**

Nestled among Seattle's gleaming lights on a gloomy September day, a single nonprofit wants to change the world, one computer at a time. Its researchers hope to transform the way machines perceive the world: to have them not only see it, but understand what they're seeing.

At the Allen Institute for Artificial Intelligence (AI2), researchers are working on just that. AI2, founded in 2014 by Microsoft visionary Paul Allen, is the nation's largest nonprofit AI research institute. Its campus juts into the northern arm of Lake Union, sharing the waterfront with warehouses and crowded marinas. Across the lake, dozens of cranes rise above the Seattle skyline — visual reminders of the city's ongoing tech boom. At AI2, unshackled by profit-obsessed boardrooms, the mandate from its CEO Oren Etzioni is simple: Confront the grandest challenges in artificial intelligence research and serve the common good, profits be damned.

AI2's office atmosphere matches its counterculture ethos. Etzioni's hand-curated wall of quotes is just outside the table tennis room. Equations litter ceiling-to-floor whiteboards and random glass surfaces, like graffiti. Employees are encouraged to launch the company kayak for paddle breaks. Computer scientist Ali Farhadi can savor the Seattle skyline from the windows of his democratically chosen office; researchers vote on the locations of their workspaces. It's where he and I meet to explore the limits of computer vision.

At one point, he sets a dry-erase marker on the edge of his desk and asks, "What will happen if I roll this marker over the edge?"

"It will fall on the floor," I reply, wondering if Farhadi could use one of those kayak breaks.

"Exactly! Clearly it's going to fall. This is so trivial," he says, laughing. "But this is still so difficult for a machine to do." Predicting the effects of forces on objects — something I do instantly — requires first perceiving that object; today's computer vision systems excel here. But estimating an object's *future* location demands understanding scene geometry, an object's attributes, how force is applied and the laws of physics. Computers aren't quite there yet.

If these are the frontiers in AI research, then our much-prophesied computer overlords might be a long time coming: Artificial intelligence overall is still pretty dumb. Even today's "smart" programs are driven by narrow, or weak, AI. Strong AI, also called general AI, doesn't exist.

Narrow AI systems are like savants. They're fantastic at single, well-defined tasks: a Roomba vacuuming the floor, for example, or a digital chess master. But a computer that can recognize images of cats can't play chess. Humans can do both; we possess general intelligence. The AI2 team wants to pull these computer savants away from their lonely tasks and plant seeds of common sense. "We still have a long way to go," Etzioni tells me.

Etzioni's 20-year vision is to build an AI system that would serve as a scientist's apprentice. It would read *and* understand scientific literature, connecting the dots between studies and suggesting hypotheses that could lead to significant breakthroughs. When I ask Etzioni if IBM's Watson is already doing this, I feel I've struck a nerve. "They've made some very strong claims, but I'm waiting to see the data," he says.

AI2's researchers hope to transform the way machines perceive the world: to have them not only see it, but understand what they're seeing.

Whether in Pioneer Square (bottom left) or the waterfront (top right), Seattle is a city where the expression of our humanity literally lives on the walls. AI2 researchers like Ani Kembhavi (top left) and CEO Oren Etzioni (bottom right) hope to teach machines how to better understand such expressions.

But there's also a darker side to this noble endeavor. If we grow to depend on these emerging technologies, certain skills could become obsolete. I can't help but wonder: If smarter AIs gobble up more human-driven tasks, how can we keep up with them?

IT'S ONLY MATH

Grunge rock grew up in Seattle during the late 1980s and '90s in clubs like the Off Ramp and the Vogue. The dirty guitar licks and angst-filled lyrics were a giant middle finger to mainstream acts of the time — those spandexed, Bedazzled, hair-metal bands selling out arenas. Grunge wasn't a cog in the corporate machine, man.

The so-called "Seattle sound" still resonates in the damp concrete of the Emerald City. I see it in the graffiti coloring the gray city, and I hear it in Etzioni. The 52-year-old Harvard grad smiles more than Kurt Cobain, and he prefers a button-up to a thrift-store flannel plaid. But

CLOCKWISE FROM TOP LEFT: STUART ISETT; CARL ENGELKING; ISETT; ENGELKING

underneath his friendly demeanor, there's an us-versus-the-world edge, a longing to chart his own path. AI2 isn't like Facebook, Google or the other tech behemoths, and Etzioni doesn't want it to be. When we spoke, he used AlphaGo's story as an example.

In March 2016, Google researchers pulled off the year's crowning achievement in the field when their AI, AlphaGo, mastered the ancient Chinese board game Go. Due to the astounding number of board combinations (approximately a 2 followed by 170 zeroes), Go was considered the white whale in computer science. In a highly publicized showdown in South Korea with Lee Sedol, the world's top Go player, AlphaGo came out on top, 4 games to 1.

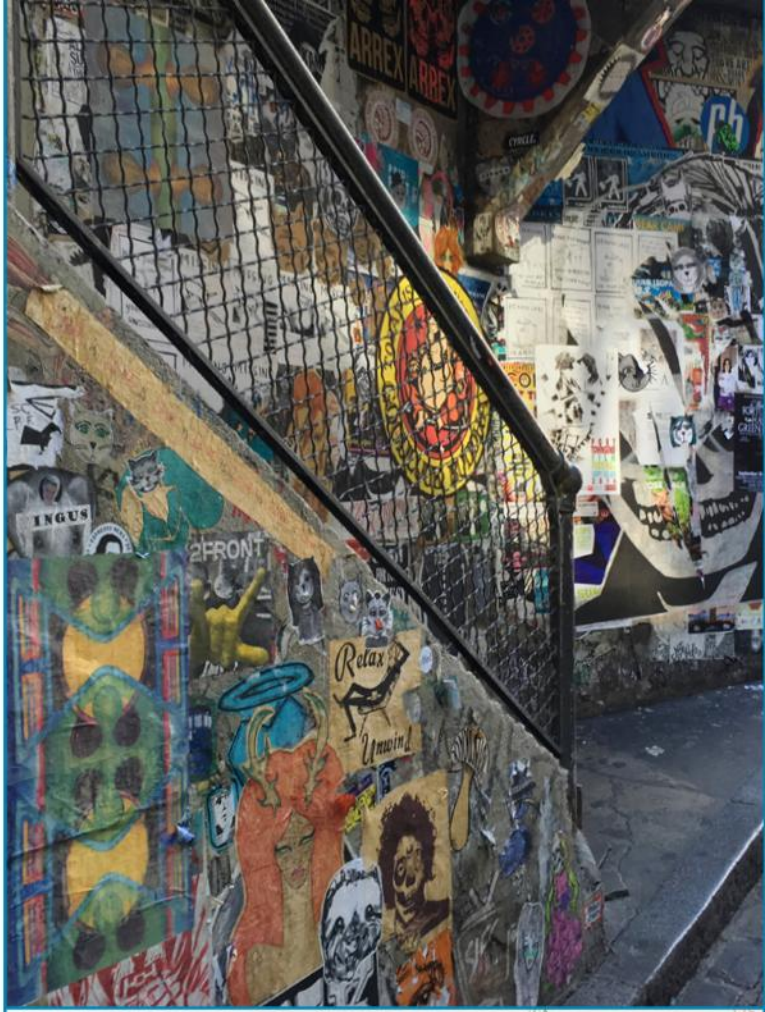
AlphaGo was soon cited in various click-baity "news" stories as a harbinger of superintelligence and *Terminator*-inspired apocalypse, but Etzioni takes issue with these simplified narratives. "AI isn't magic. It's math," he says with a sigh. AlphaGo isn't a sign of the end times. It's a powerful demonstration of deep learning, a hot subfield of AI research thanks to renewed interest in artificial neural networks, or ANNs.

BRAINY COMPUTERS

ANNs are algorithms — sets of rules — inspired by the way researchers believe the human brain processes information. To understand how they work, it's easiest to start from the beginning, in 1943, when neurophysiologist Warren McCulloch and mathematician Walter Pitts used math to describe the function of neurons in animal brains.

The McCulloch-Pitts neural model is an equation used to convert a series of weighted inputs into a binary output. Lots of data go in, and a 0 or 1 comes out. Add up a mess of numbers and if the solution is greater than or equal to a predetermined total, the output is a 1. If the solution falls below the total, the output is a 0. It's a simplified simulation of how neurons in the brain work: They either fire or don't fire.

Over decades, computer scientists have built upon this foundation, subtly tweaking the mathematical logic of model neurons, connecting multiple neurons and assembling them into hierarchical, layered networks — ANNs. Many ANNs in use today were actually fully described and theoretically executable decades ago, but they weren't as useful then. "AI's overnight success has been 30 years in the making," says Etzioni.



AI researchers configure ANNs for specific tasks, dictating how data flows through them in order to "teach" machines. To have an ANN learn to recognize images of Seattle's iconic Space Needle, for example, scientists might use neurons in the ANN's first layer to compute the brightness of a single pixel. Layers above it in the hierarchy might zero in on the structure's shape. As more Space Needle images are fed through the network, the weighted math that links these digital neurons automatically adjusts, based on the algorithm's parameters, strengthening connections that are unique to the Space Needle while weakening others.

This was the secret to AlphaGo's victory. It extracted winning strategies from thousands of Go games played by humans, pushing them through ANNs. It then played itself millions of times, tuning its networks to optimal Go strategies, always improving. "It was a huge success, but it was a narrow success that took years of work from a large group of people," Etzioni says. "AlphaGo can't even play chess. It can't talk about the game. My 6-year-old is smarter than AlphaGo."

AlphaGo isn't alone. Virtually every AI we interact with can be startlingly dense. A Roomba teaches itself the layout of your living room, but it will still run over dog poop on the rug and turn the house into a fecal Jackson Pollock painting. Microsoft's chatbot Tay, programmed to generate human-like conversations based on inputs from Twitter, morphed into a foul-mouthed racist within 24 hours. As Farhadi explains, AIs are only as effective as the data they are fed.

"Data is the golden key," Farhadi says. "The minute the data are lacking, it's going to cause us trouble." We know a butterfly is smaller than an elephant, but if no one took the time to write that, it's tough for a machine to learn it. If a tree falls in the forest and generates no data, that tree never existed, as far as an AI is concerned.

MAKING THE GRADE

Meanwhile, down the hall from Farhadi, AI2's senior research manager Peter Clark takes a different approach to learning. He forces his subjects to complete the New York Regents Science Test over and over again. It would be cruel and unusual were it not inflicted on machines.

"Passing even a fourth-grade science test isn't a single task. It's a collection of skills that need to come together," he says. In February 2016, AI2 challenged thousands of researchers worldwide to develop an AI that could pass a standard eighth-grade science test. The top prize went to Israel's Chaim Linhart, whose program scored 59 percent.

Science tests serve as a gateway toward commonsense computers. The exams require specific and general knowledge to pass, and Clark can easily check his research's progress by grading the computer's performance. The tests contain diagrams, open-response questions, reading comprehension questions and more.

Teaching machines just one facet of the test — understanding diagrams — exhausted Clark,

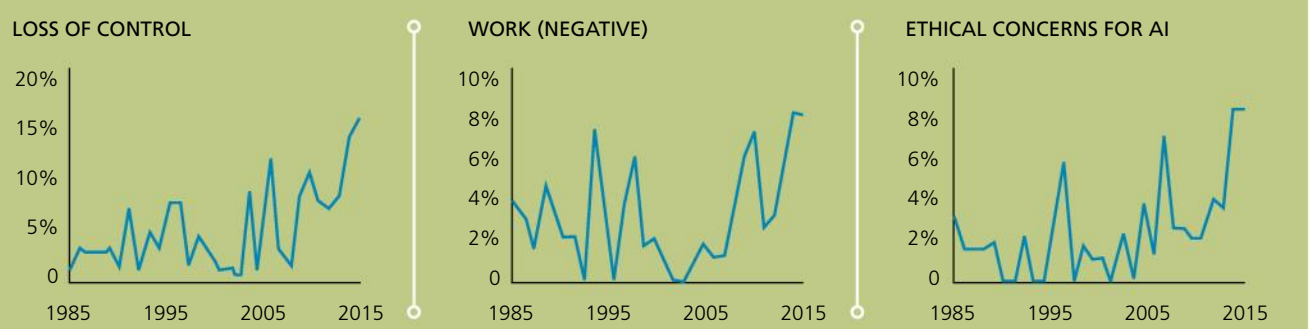
ANNs are algorithms — sets of rules — inspired by the way researchers believe the human brain processes information.

Opposite: Human brains can easily perceive the layers of posters and scrawled messages around a Seattle stairwell (top). The artificial intelligence of the computers that Peter Clark (below) works with would struggle to comprehend such a tableau — for now.

OPPOSITE: CARL ENGELKING (2)

How We Worry About Artificial Intelligence

Charting the percentage of AI-related articles in *The New York Times* that mention a specific concern reveals our changing attitudes.



SOURCE: "Long-Term Trends in the Public Perception of Artificial Intelligence," Association for the Advancement of Artificial Intelligence, Dec 2016.

who needed to build a new database of 5,000 annotated diagrams and 15,000 multiple-choice questions. All the data were then annotated, keystroke by keystroke, clarifying relationships and what the diagrams were saying. Only then could Clark's team design and train a system that could answer questions about diagrams.

Every new dataset created at AI2 — and every diagram, video or block of text parsed by a machine — improves upon the other, bringing Etzioni's vision of the scientist's apprentice closer to reality. Eventually, rather than eighth-grade science-test diagrams, Etzioni's team will design algorithms that interpret images, diagrams and text in advanced scientific papers to make new connections and insights, based on its knowledge. Currently, AI2's Semantic Scholar search engine is a glimpse of what's to come; it's the keystone project where all their research will flow.

Semantic Scholar uses numerous ANNs in parallel to identify valuable information from studies. It combines these skills to understand not only the information conveyed in a given study, but also its relevance to the larger body of research. "Medical breakthroughs should not be hindered by the cumbersome process of searching the scientific literature," Etzioni says. AI2 isn't alone in building AI-enhanced search engines, but again, this is just a first step.

It sounds great, and I'm sure Etzioni has the best intentions, but I admit, it's hard not to worry a little. The robot apocalypse presaged in *The Terminator* might not (and almost certainly won't) come to pass, but smarter machines aren't exactly risk-free.

A GRUNGY FUTURE

After my time at AI2's headquarters, I walk past several sagging tents beneath an overpass in downtown Seattle. Two feet stick out of one. A block away, a man without teeth yells incoherently at four police officers imploring him to stand and put on his shoes. He can't. His clothes are in tatters. Is this a glimpse of the future, where more and more people are left behind, replaced by machines that think better and act faster than humanly possible?

"We do need to think hard about the impact on jobs," Etzioni says. A World Economic Forum analysis last year estimated that by 2020,

Software engineer Roie Levin (left) works in the airy, countercultural offices of AI2's Seattle headquarters.

automation and robots will eliminate roughly 5 million jobs in 15 of the world's developed and emerging economies. In a 2016 global survey of 800 CEOs, 44 percent indicated they believe AI will make people "largely irrelevant" in the future of work.

Not all predictions are gloomy. The Obama administration published a 2016 report that outlined a generally optimistic future, with AI serving as a major driver of economic growth and social progress. Sure, AI technologies could displace low-wage, uneducated workers, but the report suggests it's the job of policymakers to ensure these people are "retrained and able to succeed in occupations that are complementary to ... automation." Bernie Meyerson, chief innovation officer at IBM, assured me that AI technologies won't displace us — they'll make us better. These things are resources, he says; they work by amplifying what a person already does best. We'll see if the pessimists or the optimists were closer to the mark.

But there's another difficulty with growing reliance on AI: It's a thoroughly human endeavor. Choosing what's in a dataset or what's not in it, adjusting parameters in algorithms and so on are all subjective decisions. Seattle grunge band Alice in Chains opened one of their most iconic songs, "Man in the Box," with the line, "I'm the man in the box / Buried in my s---." It reminds us of the messiness of existence, of addiction, of being buried in the filth of our imperfections. All of those shortcomings will be reflected in the designs of our machines. "Machine learning is 99 percent human learning," Etzioni says.

Take deep-learning software, widely used in the legal system today. These systems generate risk scores that assess the likelihood that a defendant will commit another violent crime. Independent journalism nonprofit *ProPublica* investigated 7,000 people arrested in Broward County in Florida, finding that only 20 percent of those pegged as high risk by the particular system, called COMPAS, went on to commit another violent crime. Other issues: COMPAS was twice as likely to flag black defendants as reoffenders, and it mislabeled as low risk white defendants who went on to commit additional crimes more often. The way the algorithms were designed, and the data that programmers chose to feed them, affected these results.

Etzioni has a theoretical workaround to these ethical quandaries: guardian AIs that would use deep-learning techniques to keep tabs on other AIs working on socially important tasks, like approving loans or assessing criminal behavior. "The guardian AI would have unlimited attention, unflagging patience and can keep up." It could ensure another AI doesn't fall off the rails.

But who will program the guardian AIs? Imperfect humans. AI studies quickly branch into questions of philosophy, ethics and spirituality. Researchers are already hard at work addressing them, but there are no easy answers.

The robot apocalypse presaged in *The Terminator* might not come to pass, but smarter machines aren't exactly risk-free.

AN END, OR A NEW BEGINNING

Down the street from AI2 is Seattle's iconic Gas Works Park. Its primary feature is the rusted guts of an old plant that fueled the city decades ago. For an outstanding view of the skyline, you can climb the switchbacks of the Great Mound, a pile of rubble from the old plant now covered in dirt and grass. Late in the afternoon, when the sun is low, I stand on top of the mound, casting a 15-foot shadow on the hulking machinery.

Staring at my shadow as it dances across the dormant pipes and barrels, I wonder if I'll share the fate of this industrial artifact within my lifetime. AIs are already writing sports recaps and financial news. Is it just a matter of time before they move on to science journalism? Will imperfectly programmed machines impact my life without my knowledge?

But the evening is perfect. The clouds have lifted, and the sky is clear — a luxury in this city. For now, I enjoy the setting sun. D

Carl Engelking *is the generally intelligent being serving as web editor at* Discover. *Follow him on Twitter,* ***@CarlJamesKing***

Our AI Associations

Researchers analyzed the top keywords in stories about AI from *The New York Times,* showing the public's developing relationship with the tech.

1986-1989
Galileo project, voice, automation, speech, UFO, space weapons, salvage, psychology, astronauts

1990-1994
dante ii, science fiction, handwriting, volcanoes, satellites, translation, maps, supercomputers, lasers, space platform

1995-1999
remote control systems, chess, Hubble telescope, space station, oceans, miniaturization, Mars, computer games

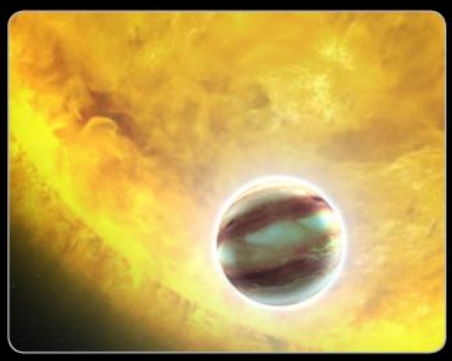
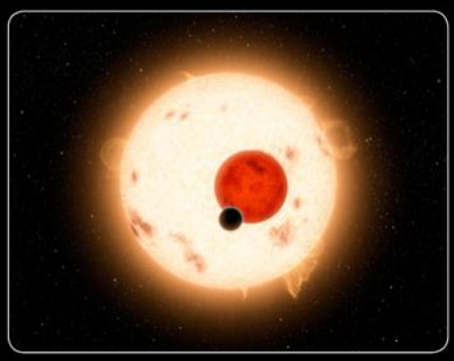
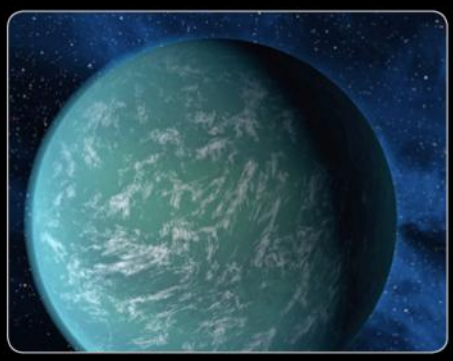
2000-2004
drones, vacuum cleaners, nanotechnology, military vehicles, Segway, dolls, virtual reality, longevity, comets, DNA

2005-2009
voice recognition systems, search engines, games, solar system, emergency medical treatment, GPS, transportation

2010-2015
driverless vehicles, empathy, start-ups, computer vision, quantumcomputing, cloud computing, doomsday, prostheses, e-learning

SOURCE: "Long-Term Trends in the Public Perception of Artificial Intelligence," Association for the Advancement of Artificial Intelligence, Dec 2016.

OPPOSITE: STUART ISETT

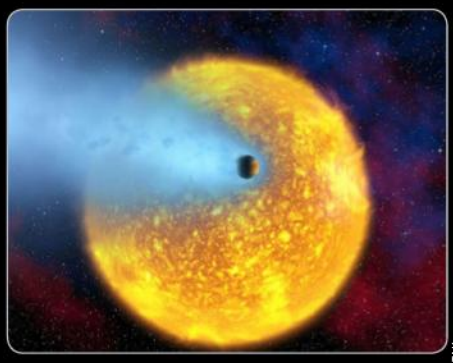
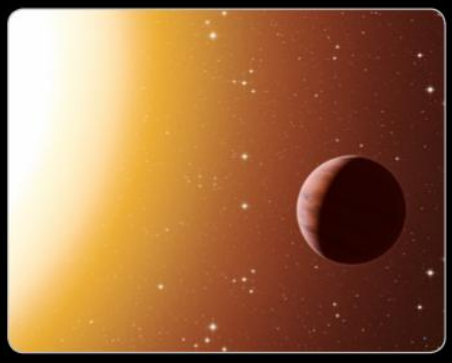




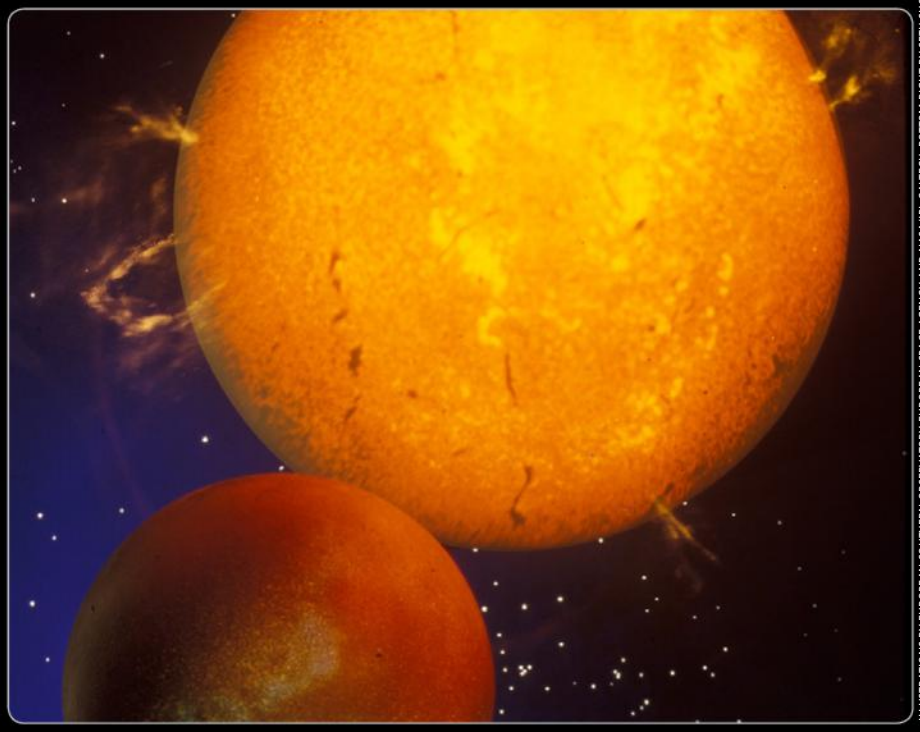
World Weary?

The Best Is Yet to Come

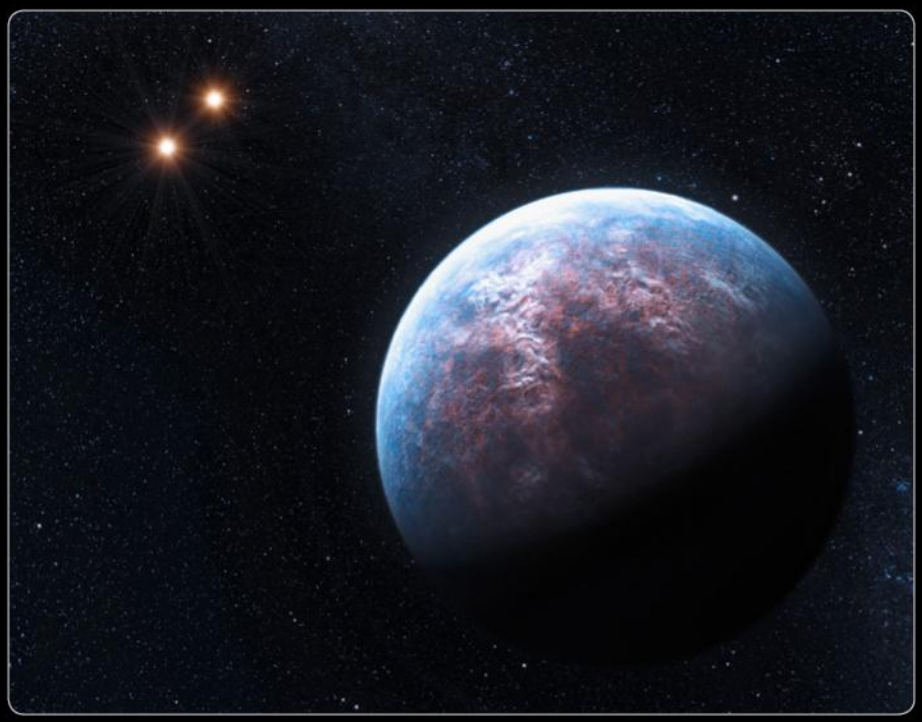
Call it exoplanet fatigue. With discoveries rolling in every day, here's why we should still care about finding new alien planets. BY **SARAH SCOLES**

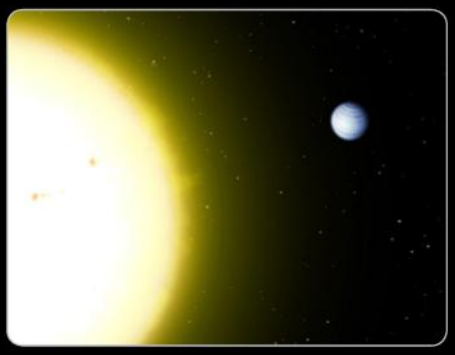


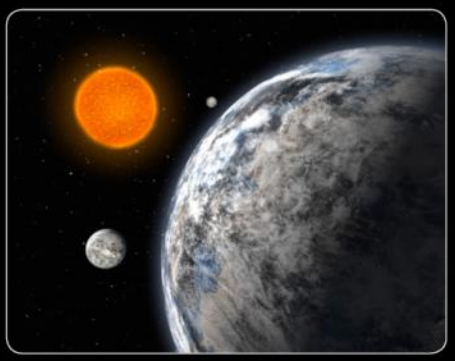



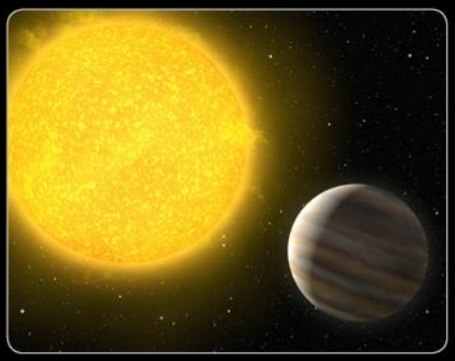


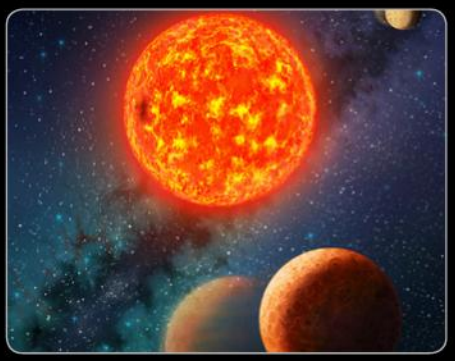
ILLUSTRATIONS BY EUROPEAN SOUTHERN OBSERVATORY, EUROPEAN SPACE AGENCY, AND NASA/JPL-CALTECH. BOTTOM RIGHT BY SETH SHOSTAK

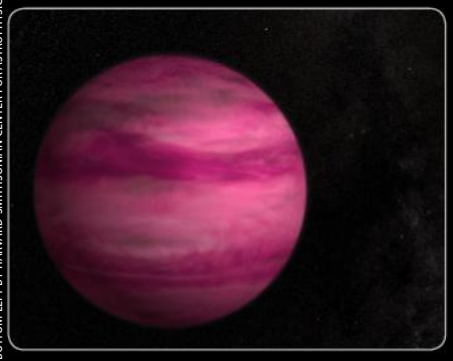


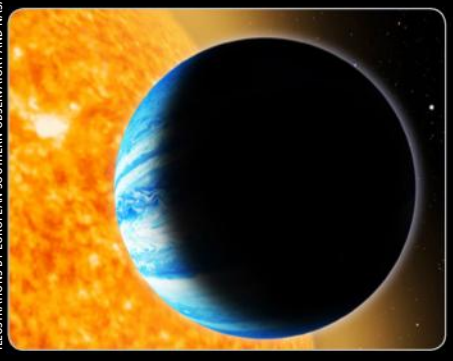






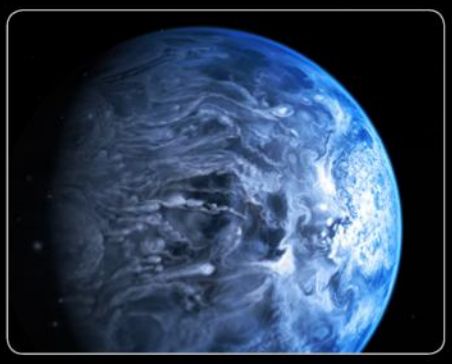


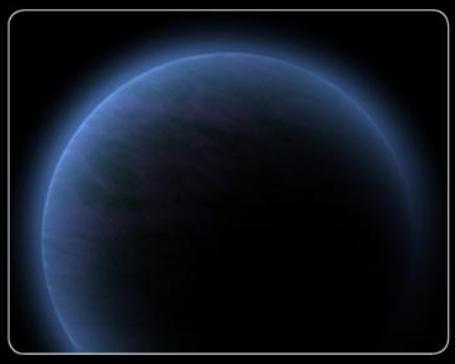




ILLUSTRATIONS BY EUROPEAN SOUTHERN OBSERVATORY AND NASA. BOTTOM LEFT BY HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

Astronomers have been finding exoplanets out in the cosmos for 25 years, and if we've learned anything about all those planets, it's that a lot of different, weird kinds exist. They are big and hot and close to their stars. They are smaller than Earth. They are gassy and Jupiter-y. They are rocky and terrestrial. They are so cold even the most extreme earthly organisms would freeze to death. They are so hot they could melt glass. They rain glass. They are by themselves. They have neighbors. They are far away. They are right next door.





And over the years, astronomers have found more and more planets that are increasingly "like" Earth — at least in terms of their size, their distance from their stars, and potentially their compositions and characters.

On Aug. 24, 2016, astronomers announced a potentially habitable, likely rocky planet orbiting the star nearest us, Proxima Centauri. Certain corners of the internet freaked out, dubbing it an "Earth-like planet" and calling for interstellar travel. Proxima b, as the world is known, is among the smallest known exoplanets, mass-wise, and it's as close to Earth as one can get. But it's not substantially smaller than many others, and it's not guaranteed to be any more Earth-like, either. Proxima b fell from the public consciousness and the front page within weeks, just one more among 3,565 other known exoplanets.

Because big announcements like this happen regularly now, every year or so, it's easy to just say "cool" and move on. Readers are used to seeing news stories about the next-closest-to-Earth-sized planet, the maybe-could-be-Earth's-twin planet, the no-really-this-time-it's-like-super-close-to-maybe-being-like-how-Earth-is planet. And with that escalation, exoplanets have begun to seem very normal, even possibly boring.

Astronomy fans have begun using the term "exoplanet fatigue" to describe the mindset that comes with yet another announcement of otherworldly, and potentially worldly, worlds. When every near-Earth-sized planet gets hype, and thousands of others are announced at a time, it's easy to feel like we should just put planets in the same been-there-done-that category as stars: Discovering more is *just* adding to a pile no one cares about.

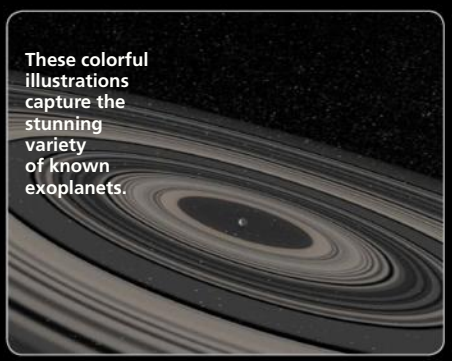
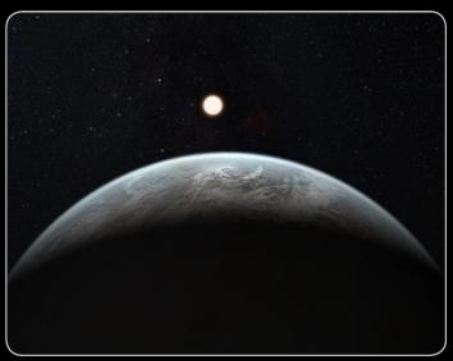
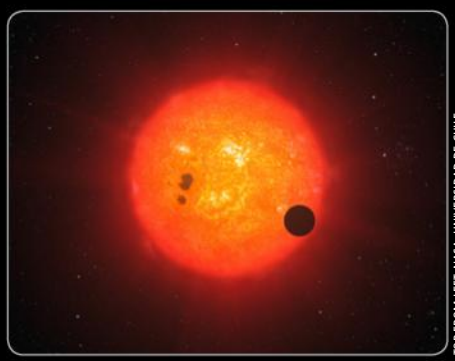
But we should resist that urge toward apathy. Exoplanets haven't finished changing our worldview, our universe-view, our view of life itself, scientists say. Their work is just beginning. They hardly know anything. After all, it wasn't that long ago that these worlds were little more than science fiction.

THE REALITY OF EXOPLANETS

For a long time, astronomers thought planets were hard to make, perhaps requiring "two stars to pass close enough to each other to pull out material in a disc," says Jill Tarter, who worked on some of the earliest exoplanet telescope plans and is considered a pioneer in searching for extraterrestrial intelligence. Planets emerged from that two-star-spun disk. But how often do two stars come that close to each other? Not often.

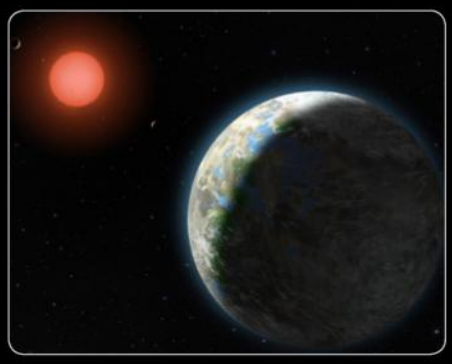
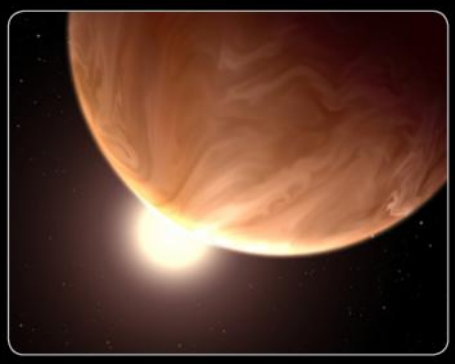
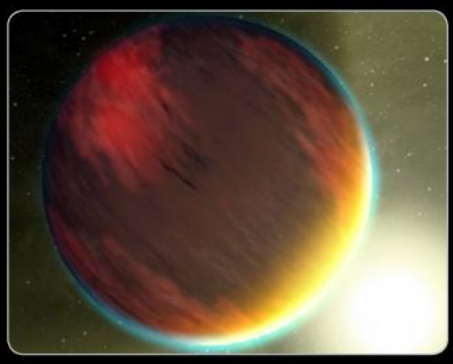
The current standard scientific canon suggests that stars, and planets, form from a shrinking cloud of gas. After the gas collapses into a dense enough clump to start its path toward stardom, its gravity flattens the remaining gas into a disk. Flecks of dust and molecules of gas smack into each other and stick together, giving them more mass, and hence more gravity, which attracts more dust and gas to them. This process snowballs, and eventually the small clumps grow into small planets, big planets, asteroids and comets. But this idea didn't mature until the 1980s, and even then most scientists continued to believe that conditions had to be just right to make planets, which they thought were uncommon.

But people began searching for them anyway, and then the discoveries started to trickle in. In 1992, astronomers Alexander Wolszczan and Dale Frail found two planets around a pulsar, the husk of a star left over after it explodes as a supernova. Three years later, astronomers Michel Mayor and Didier Queloz discovered a planet about half the mass of Jupiter, whirling around a

These colorful illustrations capture the stunning variety of known exoplanets.

TOP FROM LEFT: NASA; UNIVERSIDAD DE CHILE; KHENG GUAN TOH/SHUTTERSTOCK; BOTTOM: NASA (3)

sunlike star in a roughly four-day dance. Planets kept popping up, as people used ground-based telescopes to detect the stretching and shrinking of a star's light waves — the result of the tug of a planet's gravity. Scientists' ideas about the abundance of other worlds began to change; maybe it wasn't so hard to make a planet after all.

But there was an even better way of looking, first detailed in 1971 and revised by Bill Borucki, formerly of the NASA Ames Research Center in Mountain View, Calif., in the mid-1980s. A telescope could stare at a star and wait for it to dim — just a little — when a planet passed in front of it and blocked some of its shine. This is called a transit, and Borucki was convinced that it would work on a large scale. He wanted to build an orbiting telescope that would watch a wide swath of space, and all the stars within, at once. He began proposing it officially in the early 1990s and tried four times until, in 2000 (fifth time's the charm), NASA approved it.

With its launch nine years later, the Kepler space telescope was born. The underlying hope, of course, was biology-based: to find a planet truly like ours, where life could survive, or even thrive. And, along the way, scientists would be thrilled to learn more about planetary dynamics and demographics.

When the first results came back, Kepler mission instrument scientist Doug Caldwell took his first look at the data on a known planet. "It was so clear, and it looked like a fake computer model," he says. "We were amazed. It really worked!"

KEPLER'S CENSUS

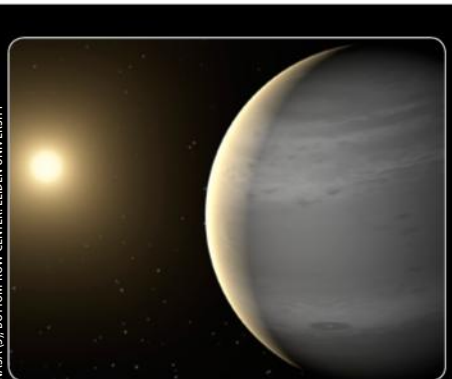
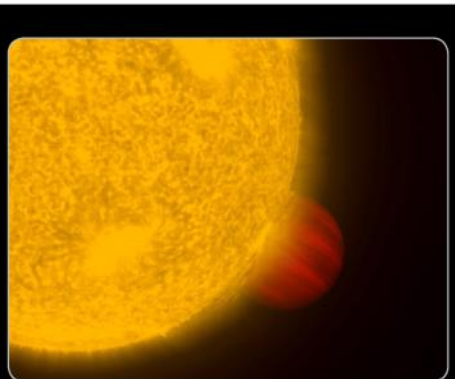
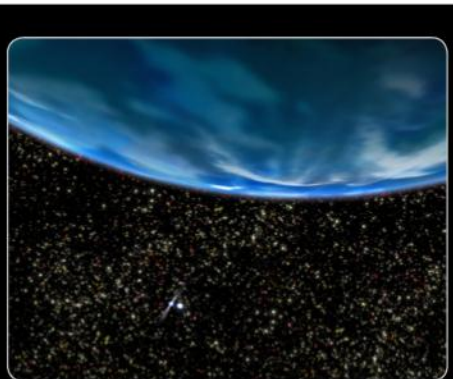
Kepler's impressive work has revolutionized the field. It gave us so many planets — and enough rocky, Earth-ish ones — that we now find these once-extraordinary worlds commonplace.

As Kepler stayed in space longer, it gathered enough data to detect smaller planets, farther from their stars. At first, Caldwell's team confirmed planets individually, pointing a ground-based telescope directly at a given star system. But soon, Kepler had amassed entirely too many candidates — the team had to find another way to confirm them.

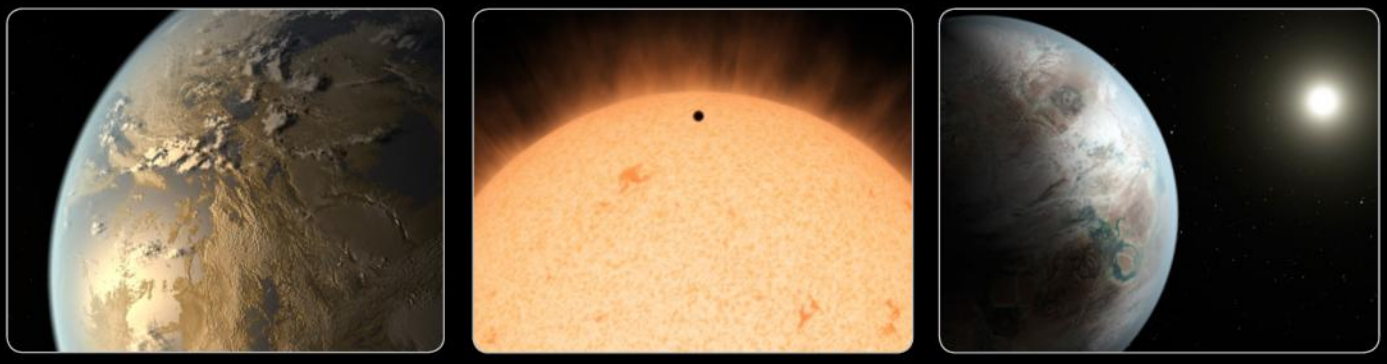
And that, says Caldwell, caused another shift in the field. Astronomers decided they didn't need to *know* each candidate planet was a true planet: They could just be 99 percent sure. They began confirming the existence of other worlds in batches, using a statistical validation technique that matches transits against models to see how likely it is that they *probably* come from a planet. "If you pick any individual one, it might not be a planet," he says. "Chances are it is, but it might not be. But if you take the whole set of them and you want to try to understand properties of them, you can make very good conclusions based on that because you know that most of those — 99 percent — are really going to be planets."

This idea works partly because planets are so common — so easy to make — that, chances are, the scientists aren't misinterpreting the signals. Astronomers estimate, based on past observations, that the number of Earth-sized planets in our galaxy approximately equals the number of stars, roughly 100 billion.

Suddenly, scientists could do demographic studies on the planets, just like pollsters do with census data. What percentage of people with incomes under $45,000 live in one-person households? What fraction of planets within 100 million miles of their star are more than twice the mass of Earth? That catalyzed another shift in scientists' thinking, from the quest for Earth's twin to the analysis of what its many

NASA (5); BOTTOM ROW CENTER: LEIDEN UNIVERSITY



and varied siblings are like. It went from "we're going to find Earth," says Caldwell, to "we're going to find lots of things that could be like Earth and try to understand how their properties vary around different stars."

Some solar systems mirror our own, with a neat set of planets lined up in a flat plane like a posed portrait, small ones mostly close to the sun and big ones farther out. Others have hot Jupiters, big planets that live very close to their stars; still others have planets in wonky orbits at weird angles to each other. Yet others have mini-Neptunes and super-Earths, varieties that don't show up at all in our own family photo.

Even 25 years after finding the first exoplanets, and thousands of discoveries later, we still don't have an answer to the questions that spurred the Kepler mission in the first place. How did solar systems get to be the way they are? And how often does a livable planet like Earth — really like Earth — come to be?

BUT WAIT, THERE'S MORE

That remaining uncertainty and potential don't always come through in headlines or TV reports, though, which focus more on excitement over the latest find. Take the coverage of Proxima b: Many press releases and breathless news stories splashed the words "habitable" and "Earth-like," adjectives that have also appeared in dozens of discovery articles in the past.

To be clear: Humans currently know of no certainly habitable or even just Earth-like planets. But when scientists and the media throw these terms around, they suggest that astronomers have already found everything they've been looking for in a planet. People think we've *already* found an Earth twin. No wonder they lose interest.

The first problem is that scientists' phrase "in the habitable zone" sometimes gets shortened — by scientists, the press and people's minds — to simply "habitable." Scientists say the former and mean "could host liquid water," but that gets morphed into the latter and, effectively, "could host life."

"Those words have different meanings in English, which is what the public is actually going to read," says Rory Barnes, an astrobiologist at the University of Washington. "'Oh, it's in the habitable zone, ergo it's habitable,' and it makes perfect sense to do that."

On top of that, the habitable zone means different things to different people. Determining the exact boundary — this side of the imaginary line can host liquid water, this side can't — depends on many factors beyond just the hike from the planet to the star. The planet's internal composition and its atmosphere, as well as the star's stability and intensity, all play a role.

To reflect that complexity, Barnes has developed a metric called the habitability index for transiting exoplanets, which comes a little closer to telling whether they'd be habitable, in the true English-dictionary sense of the word. The traditional habitable zone is binary: Yes or no, a planet is in it or it's not. But the habitability index gives the probability that a planet actually has liquid water, after taking into account the surface temperature of the planet. He hopes that scientists can use the index in the future to decide which planets next-generation telescopes should pay most attention to. Those telescopes will be able to tell not if a planet could be Earth-like, but if it actually is another Earth.

If the public knew how close we could be to finding an actually habitable planet — and that we hadn't really found another Earth yet — that'd surely spike their interest.

THE MEYERS-BRIGGS INVENTORY OF PLANETS

"'Earth-like' is probably even more fraught with problems than 'habitable zone,' because what does that mean?" says Caldwell. "To my mind, if something is Earth-like, there's trees, there's water, and [similar] things. That's certainly not what we're talking about because we have no idea."

But it turns out we soon might. The personality details of planets — details beyond their superficial attributes of size, weight and neighborhood — are starting to come into view. Some of the next generation of telescopes plan to zero in on Proxima b, a less-extreme zoom than what's required for other similarly sized planets that live farther away.

The coming studies with next-generation telescopes like the James Webb Space Telescope and the Transiting Exoplanet Survey Satellite aren't just about finding new worlds; they are about exploring them, via their atmospheres.

Scientists are interested in biosignatures, or combinations of molecules indicating the presence of life as it breathes, eats, photosynthesizes or otherwise interacts chemically with its environment. Biological processes like these leave chemical concentrations out of their natural equilibrium, telling scientists that something — or someone — must be altering them. On Earth, for instance, the atmosphere contains oxygen and ozone with

FROM LEFT: NASA/AMES/SETI INSTITUTE/JPL-CALTECH; NASA/JPL-CALTECH; NASA AMES/JPL-CALTECH/T. PYLE

relatively little methane, which indicates photosynthesis is happening.

So far, scientists have only been able to see the spectra from a few planets' atmospheres, as they need bigger and better telescopes, with special equipment to block starlight, to really get to know a planet. Maybe we should wait for that before giving in to boredom with exoplanets. After all, a pile of census data doesn't mean humans are boring and mundane because we know so many of them exist in so many forms. It's the individuals that really spark interest, that tell you why the population matters; we should give exoplanets the same chance.

VIVE LA RÉVOLUTION SCIENTIFIQUE

The scientists get it: So far, there's only been so much to get excited about. "Maybe a certain amount of fatigue in the public is natural and fine," says Aki Roberge, an astronomer at the NASA Goddard Space Flight Center in Greenbelt, Md., "as long as when the time comes that we really do discover something crazy-amazing, we're still able to get people to pay attention."

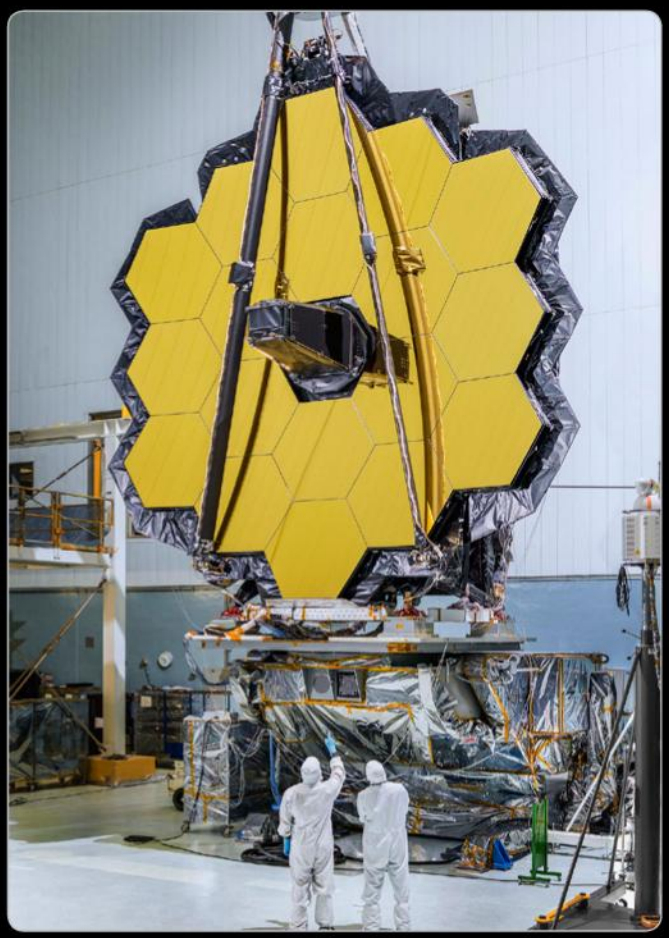
That crazy-amazing thing is an actually Earth-like, actually habitable, perhaps actually inhabited planet. And it's still in the future. Tarter calls the 21st century "the century of biology on Earth — and beyond."

Roberge elaborates on the same idea. "I do believe we're standing on the verge of a scientific revolution," she says. "But it's not in astronomy, per se. It's actually in biology. And the discovery of life on other worlds — of an independent line of life — would be as revolutionary as the realization that the sun was a star or that those moving lights in the sky are planets like the Earth." Or, perhaps, that Earths are as common as stars throughout the cosmos.

It could be in a couple of decades, Roberge says, or 100 years, or more. There's no way to know. But she imagines that just as Newton's laws of gravitation govern how planets interact with each other (and how you interact with the ground), a parallel set of laws governs how life arises or doesn't, and then survives (or doesn't). "Maybe life is rare," she says. "Maybe it isn't. But I think that the habitable conditions that Earth-like life could tolerate — I don't think those are rare."

The only way to know is to keep looking, to keep amassing more planets (and announcing them), to start probing their atmospheres from afar. With tomorrow's telescopes, that revolution will come, and it will be glorious. Now that's something to get excited about. D

Sarah Scoles *is a science writer in Denver. Her last article for* Discover *was September's cover story, "Target: Earth."*



LEFT: NASA/CHRIS GUNN. RIGHT: NASA/GSFC

Engineers recently assembled all 18 hexagonal components of the primary mirror of the James Webb Space Telescope (left), the successor to Hubble. The Transiting Exoplanet Survey Satellite (TESS, above) will directly search for new exoplanets among more than 200,000 stellar targets. Both next-gen telescopes will help us get to know exoplanets even better, perhaps even detecting the signatures of life — if it exists.

ALISON MACKEY/DISCOVER. BOY: SHAROMKA/SHUTTERSTOCK. BACTERIA: WHITEDRAGON/SHUTTERSTOCK

HIDDEN INVADERS

Infections can trigger immune attacks on kids' brains, provoking devastating psychiatric disorders.

BY **PAMELA WEINTRAUB**

At 7 years old, Paul Michael Nelson was the kind of quiet, brilliant kid you were likely to find in Silicon Valley — captivated by Legos, self-taught in origami, loving and sweet. But on March 2, 2009, he woke up in the middle of the night, monstrously changed. He tore up the flooring in his bedroom. He got hold of a knife and stabbed holes through his door. He began speaking a strange language no one could understand. He tried pulling his teeth out. He barked like a dog.

His parents hustled their son to the psychiatrist, leading to an alphabet soup of diagnoses: ADHD (attention deficit hyperactivity disorder), OCD (obsessive-compulsive disorder), ODD (oppositional defiant disorder), bipolar disorder, autism and, ultimately, straight-up psychosis. Yet no matter what medications Paul Michael tried, treatment failed. He leaped from moving cars. He broke the windows in his room, causing the family to install Plexiglas. For the Nelsons, 2009 included 15 trips to the emergency room, two months in and out of psych wards and calls to the sheriff to remove a violent, raging Paul Michael from the home.

Finally, experts suggested that he might not suffer from a traditional psychiatric disorder caused by some inborn biochemical glitch, but from a vasculitis — a swelling of blood vessels in the brain, provoked by a hostile *outside* force. So the Nelsons were sent to Stanford University, where pediatric rheumatologist Jennifer Frankovich already had some experience treating the psychiatric symptoms of autoimmune disease — a frightening scenario in which the body turns on itself and attacks the brain. Twenty vials of his blood helped tell the story: Dangerously low blood platelets suggested an underlying imbalance, and signature proteins signaled some type of autoimmunity at the root.

Thus commenced years of trial-and-error therapy, conducted mostly in a psychiatric ward. Frankovich and her colleague, psychiatrist Margo Thienemann, first prescribed steroids to dial down Paul Michael's immune response. But the symptoms abated only slightly, and his small body ballooned. Then, they shut down his immune system altogether with the chemotherapy drug Rituximab. To boost it back up and keep inflammation down, they added intravenous immunoglobulin, or IVIG, a total immune system-replacement made from the blood of thousands of healthy individuals. Frankovich hoped the approach would work, but Paul Michael's brain was potentially damaged, she warned, and it could take years to repair. It was late in 2013 when sweet, smart Paul Michael, rescued by years of treatment, finally stepped out of the psych ward and back into his life. Today a gentle young man of 15, he goes to public school and hopes to be a pastry chef. "He's an amazing baker," says his mother, Mary Nelson.

For years, Paul Michael Nelson struggled with a mysterious autoimmune disorder called PANS. Thanks to pioneering research, Paul Michael, now 15, is more himself these days. Here, he cuddles with his family's kitten.

COURTESY OF MARY NELSON

For Frankovich, Paul Michael was patient zero — her first encounter with a newly recognized, still-controversial diagnosis called pediatric acute-onset neuropsychiatric syndrome, or PANS.

PANS is thought to be an inflammatory condition that results when an infection or some other invasive trigger spurs the body to turn on itself and attack structures in the brain. For years, scientists had focused on a single infection — group A streptococcal disease — that produced antibodies that attacked the part of the forebrain involved in forming habits, resulting in OCD. Today, the paradigm has widened into a much bigger idea that expands our understanding of psychiatric disease: A whole host of infections and other unknown triggers lead to the production of antibodies and immune cells that can cross into the brain. Depending on where these immune responses land and which brain structures they block, erode or destroy, a range of psychiatric ills can result. In one person, it could be OCD; in the next, it could be hyperactivity and inattention, anxiety, restricted eating, even hallucinations or autistic behavior.

PANS IS THOUGHT TO BE AN INFLAMMATORY CONDITION THAT RESULTS WHEN AN INFECTION OR SOME OTHER INVASIVE TRIGGER SPURS THE BODY TO TURN ON ITSELF AND ATTACK STRUCTURES IN THE BRAIN.

When these symptoms are caused by immune disorders, standard psychiatric therapies that balance neurotransmitters are unlikely to work alone. Instead, immune therapies are the first line of treatment. At Stanford and elsewhere, the hunt is on for treatment cocktails that quell the inflammation and new strategies to keep a rogue immune system at bay.

CONFRONTING A MYSTERY

Scientists have long known that infection can cause neuropsychiatric disease. One of the first known examples was syphilis, a sexually transmitted disease caused by the bacterium *Treponema pallidum*. Until we learned to treat syphilis with antibiotics, it was one of the most common causes of dementia and was frequent among the insane. Likewise, some have proposed that *Bartonella*, the microbial cause of common cat scratch fever, can sometimes induce anxiety, rage and psychosis. These diseases are caused by living organisms active within the brain itself. Rid the brain of the organism early enough and the symptoms subside.

But Frankovich and her Stanford colleagues were dealing with something else: damage caused by the immune response, including antibodies, the large Y-shaped proteins the body produces to fend off infections or other foreign invaders. Normally, an antibody attaches to and neutralizes the infection that provoked its formation. But in cases similar to Paul Michael's, the antibodies *also* appeared to mistakenly recognize and interact with parts of the brain — a neural receptor here, a structural element there. In essence, the antibodies turned into *autoantibodies*: antibodies that attacked the self. They were passing from the bloodstream into the brain — something once considered rare — and attacking not just the infection, but the brain structures, too.

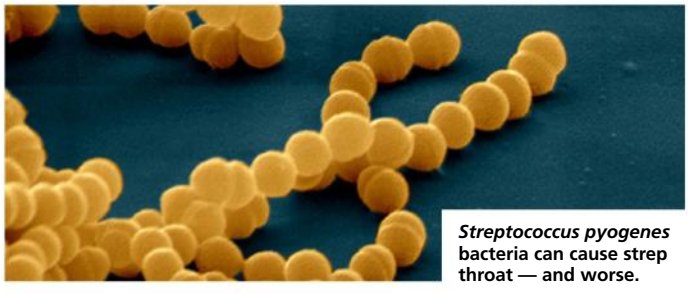
Frankovich and her team weren't the first to encounter this devastating state of affairs. For decades, a respected but beleaguered group of scientists had gathered increasing evidence that one particular bacterial infection — strep — led to the body pumping out antibodies that attacked the brain, causing OCD and tics. Because they limited the syndrome to strep infection alone, they came up with the tongue-twisting label of pediatric autoimmune neuropsychiatric disorders associated with streptococcal infections, or PANDAS.

The idea that OCD was a chemical imbalance in the brain goes back to the 1980s and psychiatrist Judith Rapoport, chief of child psychiatry at the National Institute of Mental Health (NIMH). Trying to find the right medicine for the sickest of these patients, Rapoport scanned their brains to zero in on regions involved in OCD and found increased activity in the basal ganglia, a center for movement and habits located at the base of the forebrain.

Not long after, Rapoport's protégé, pediatrician Susan Swedo, who now leads the NIMH's section on behavioral pediatrics, took notice. She proposed that one rare neurological disorder, Sydenham chorea, could shed some light on the OCD and tics the team had observed.

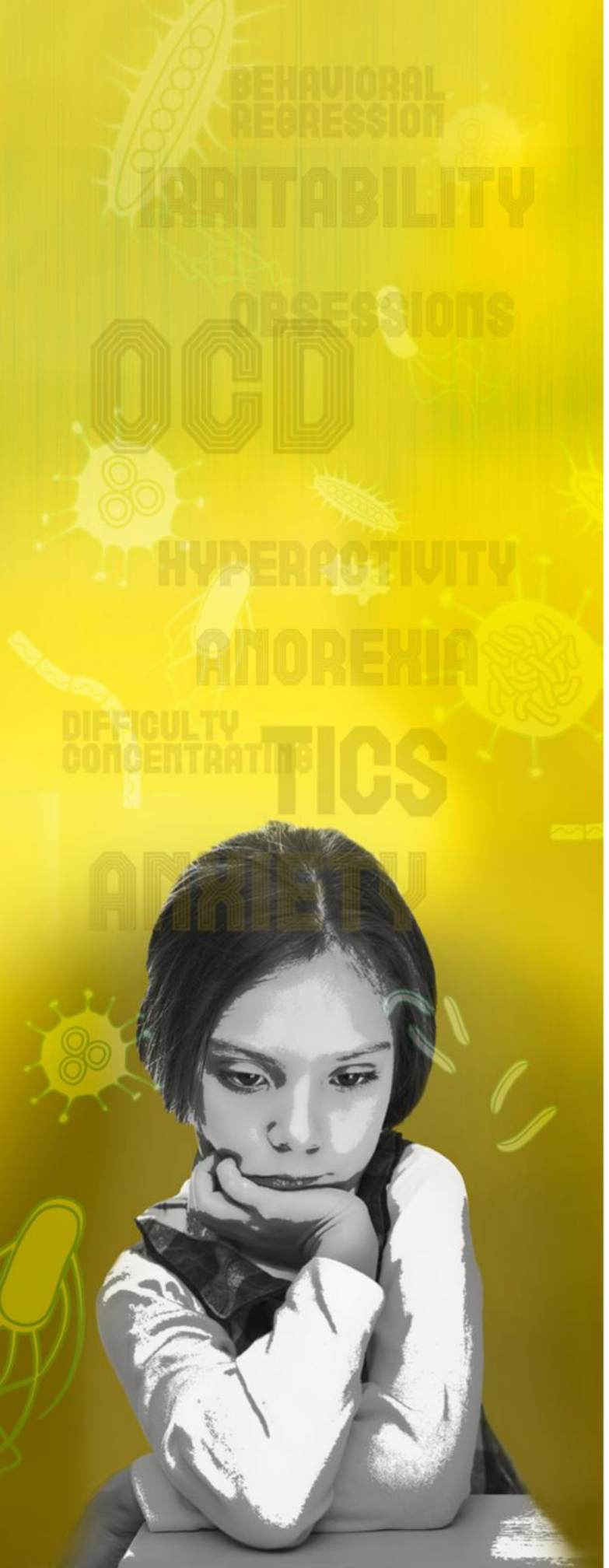
Swedo's reasoning made sense. Sydenham is an autoimmune illness characterized by rapid, involuntary, purposeless movements, especially of the face, feet and hands. And it results as a complication of catching strep, which evades the human immune system by adapting its outer surface to resemble human biomolecules, a phenomenon called molecular mimicry. The bacteria can seem so similar to human tissue that antibodies produced against it attack human organs as well.

Left untreated for as little as five days, strep could produce autoantibodies that damage heart tissue, resulting in rheumatic fever. Sydenham chorea was like rheumatic fever of the brain, thought to occur when rheumatic fever



EYE OF SCIENCE/SCIENCE SOURCE

Streptococcus pyogenes **bacteria can cause strep throat — and worse.**



progresses and strep (emboldened by fever) breaches the blood-brain barrier (BBB), the tight wall of endothelial cells ordinarily there to protect the brain from the outside world. Once they break into the brain, the autoantibodies attack the basal ganglia, causing the afflicted to jerk and writhe in a manner resembling the worst cases of the tic syndrome Tourette's. Because OCD also is often accompanied by tics, though perhaps not as severe, Swedo's medical model of Sydenham could work.

To see if the concept held — and whether Sydenham chorea even caused OCD — Swedo and her partner at NIMH, psychiatrist Henrietta Leonard, conducted a retrospective study in 1989 of three sites in the United States that had rheumatic fever outbreaks: Salt Lake City, the Ohio River Valley and Walden, Penn. Comparing children with and without Sydenham chorea, the duo found support for Swedo's proposal: Two-thirds of children with Sydenham chorea actually had obsessive-compulsive behaviors and thoughts. A critical revelation of the study was that the OCD appeared "about two weeks to a month before the movements did, often suddenly and out of the blue," Swedo says.

After the survey, her team at NIMH began seeing Sydenham children who were at the height of the disease. "We brought them in from all over the United States, and you couldn't make these stories up," Swedo says. "One of the boys had a very classic fear that school was contaminated and made his brother leave his shoes outside the house. Then they stepped inside the house and they had to take their socks off. And his mother had to wash those socks right away."

As a pediatrician, Swedo felt compelled to help these children with Sydenham, but neuropsychiatric medications focused on rebalancing brain chemistry just didn't work. So she began to consider treating the autoantibodies themselves. By the early 1990s, Swedo and the NIMH team were treating the Sydenham group and pioneering some of the same types of treatments used for patients like Paul Michael today: steroids such as prednisone to stanch the tide of immune molecules; plasmapheresis, a technique to filter the blood, cleanse it of autoantibodies, and return it intact to the patient; and intravenous delivery of a new, healthy immune system with IVIG.

But as Swedo and colleagues studied data from the drug trials for their Sydenham patients and controls without the disease, they found something else. Not just in the extreme situation of Sydenham's, but even with ordinary strep, autoantibodies appeared to careen though the brain, causing less severe forms of tics and OCD.

DISCOVERING A NEW DISEASE

Ultimately, three brothers in Swedo's clinic helped her grasp what was going on: The oldest had a diagnosis of Tourette's syndrome with physical tics. The second child had some tics. And the youngest had tics and movements so extreme that doctors diagnosed him with Sydenham chorea.

"He also presented to the clinic with very severe hoarding," Swedo recalls of the youngest. "He carried a brown paper bag with him and if he saw a piece of paper, he'd put it in the bag. After he came the first time, we had enough sense to clear the magazines out of the waiting room." The child also had an "incredibly complex tic where he waved his arm around just huge and he also was kind of floppy."

But the youngest brother, it turned out, did not have Sydenham. Instead, he had developed his psychiatric symptoms as the result of a more ordinary strep infection. "He was the first PANDAS case," Swedo says. The boys' mother, a medical technologist, helped to connect the dots. Her eldest son, the one diagnosed with Tourette's, had tics that waxed and waned. Whenever his symptoms reached a peak, his throat cultures tested positive for strep. Now Swedo and her team saw the picture clearly: Ordinary strep infection could cause neuropsychiatric symptoms in a far broader, more under-the-radar group of patients.

The strep model worked perfectly for Tanya Murphy, a University of South Florida psychiatrist who'd been observing the infection's footprint for years. Murphy had found that right after strep, psychiatric ills could suddenly manifest: not just OCD, but eating disorders like anorexia. "And these weren't typical anorexia patients worried about body image," she says. Like the OCD patients themselves, "mostly, they were worried about contamination."

Murphy's work, which spans two decades, helped to define the population in a nuanced way. As early as 2006, she established that children with OCD from PANDAS had truly toxic behavioral reactions to the same dose of serotonin-based medications that brought relief to those with standard forms of OCD. It was clear the two groups were not the same.

One of her most important contributions, published with Swedo in *Biological Psychiatry* in 2007, was based on a study of about 700 children, ages 3 to 12, all healthy at the start. Murphy followed the children for eight months, continually swabbing and testing for a strep infection, looking for signs of OCD and tics. By the end of the study, she had found a clear association between strep and the neuropsychiatric symptoms.

That connection was strengthened by immunologist Madeleine Cunningham, a rheumatic fever expert from the University of Oklahoma. Swedo recruited her in 1999 to explore what autoantibodies from strep could do to the brain. It was a wild ride. Cunningham and her postdoc at the time, Christine Kirvan, found that the antibodies literally bind to human neurons, activating an enzyme called calcium/calmodulin-dependent protein (CaM) kinase II. When patients had high levels of activated CaM kinase II floating around in their brains, nerve cells got overstimulated, and symptoms of OCD or a movement disorder could erupt. The protein marker offered a blood test for PANDAS.

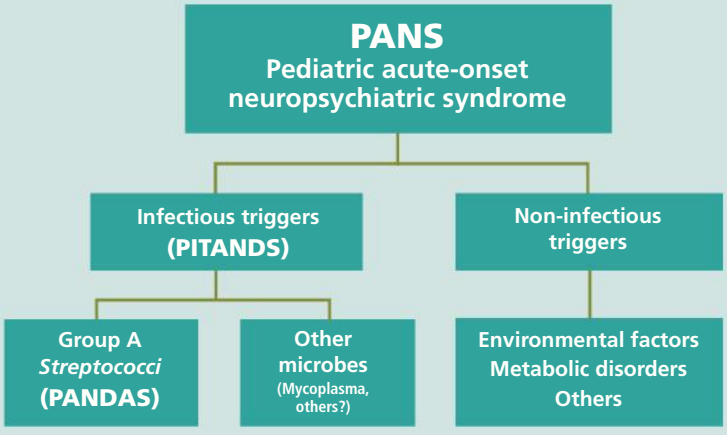
But that represented just part of the damage. Cunningham found that the same patients produced autoantibodies targeting lysogangliosides, molecules within the membranes of nerve cells in the brain. Although it hasn't been demonstrated yet, autoantibodies attacking these lysogangliosides are thought to disrupt nerve cell signal transmission and, presumably, the behavior of the patients. The autoantibodies also attached to tubulin, a protein molecule used to maintain a cell's physical structure. Cunningham suspects that when the strep antibodies target tubulin in the brain, the result is a gumming up of a cell's structural machinery and, apparently, neuropsychiatric ills. More recently, Cunningham has

A SYNDROME EVOLVES

PANS is just the latest acronym for the constantly evolving neuropsychiatric disorder. Here's the name game researchers have played to get there and how those names fit into our current understanding of the syndrome:

- In 1995, in the *Journal of the American Academy of Child and Adolescent Psychiatry*, Susan Swedo and Henrietta Leonard reported on five cases of a syndrome they called **PITANDs — pediatric infection-triggered autoimmune neuropsychiatric disorders**. Their sweeping hypothesis held that OCD and tics could be triggered or exacerbated by a host of infections, including strep, influenza and chickenpox.
- In 1998, Swedo pulled back from this broad-brush theory, focusing just on strep to raise awareness and create a medical model to speed discoveries. She renamed the syndrome **PANDAS**, for **pediatric autoimmune neuropsychiatric disorders associated with streptococcal infection**.
- In 2010, Swedo and her colleagues met at NIH, and in a wide-ranging, collaborative group decision, they eliminated the requirement for any specific infection as a bar for the syndrome. The name of the syndrome, published officially in a 2012 paper, is now **PANS**, for **pediatric acute-onset neuropsychiatric syndrome**.

PANS DIAGNOSTIC CLASSIFICATION



ALISON MACKEY/DISCOVER AFTER SUE SWEDO

found that strep antibodies target brain receptors for dopamine, a neurotransmitter important for cognitive focus.

SETTLING A DISPUTE

For years, such findings were met with the salvos of critics insisting the very notion of PANDAS was a fantasy — an absurd concept at loggerheads with neurology and logic.

How ridiculous, those critics said: Since 60 to 70 percent of children catch a strep infection at some point, naturally those with OCD or tics would, like everyone else, show evidence of exposure in their blood. Swedo, Murphy and others claimed that tics in kids with PANDAS appeared suddenly, yet, critics argued, the same was true for tics in Tourette's, so how could you tell them apart?

"Until more definitive scientific proof is forthcoming," neurologist Roger Kurlan and pediatrician Edward Kaplan wrote in *Pediatrics* in 2004, there was "insufficient evidence" to justify strep testing in children with neuropsychiatric symptoms. And most assuredly, there was not enough proof to treat these patients with antibiotics or immune-modifying therapies and drugs.

The dispute came to a head in 2010 at a contentious meeting at the National Institutes of Health. Swedo, Cunningham, Murphy and crew dropped their claim that the phenomenon caused tics ("even though we usually see them," Swedo says). But they and critics in the field were able to agree that infection wasn't a necessary trigger for symptoms, widening the scope of the phenomenon way beyond strep.

The field has moved on, emerging from the meeting with a new name for the devastating illness: pediatric acute-onset neuropsychiatric syndrome, or PANS. Writing in *Pediatrics and Therapeutics* in 2012, Swedo, along with Jim Leckman of the Child Study Center at Yale University and the famed Johns Hopkins University immunologist Noel Rose, set the criteria for PANS. To meet the diagnostic bar, patients would have to manifest abrupt, dramatic onset or recurrence of either OCD or an eating disorder like anorexia. They would also need to have at least two of seven additional symptoms: anxiety; sensory or motor abnormalities; developmental regression; irritability and aggression; deterioration in school performance; mood swings or depression; and things like frequent urination and insomnia. Doctors also had to first rule out other disorders, like lupus or Tourette's.

"MANY KIDS WERE DISABLED BY THEIR PSYCHIATRIC SYMPTOMS. THEY HAD OCD WITH SEVERE INTRUSIVE THOUGHTS, DEEP ANXIETIES AND FEARS, PANIC, RAGE."

A NEW DIAGNOSIS OF HOPE

Now, researchers have further refined their understanding of the syndrome, and a series of powerful new studies published over the past couple of years have helped establish autoimmunity's role in neuropsychiatric disease.

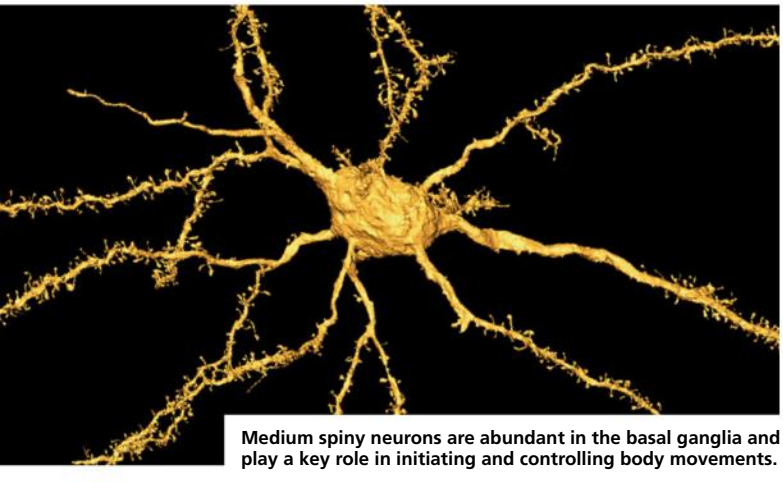
In the time since that tense 2010 NIH meeting, Murphy set out to study 43 children recruited soon after the sudden onset of OCD, capturing the early characteristics of the disease. The children were so impaired that a third of them had to be home-schooled. A large number had trouble eating due to fear of food; one was so dehydrated she was sent to the ER. Infectious triggers included strep and the bacterium mycoplasma.

Given these findings, Murphy treated the kids with azithromycin, an antibiotic that targets both infections. And she saw improvement, especially in kids with the most severe tics.

In 2012, Jennifer Frankovich opened the doors of her multidisciplinary PANS clinic, and patients flooded in. Whereas Murphy's patients were selected for the *recent* onset of symptoms, the children arriving at Stanford had progressed to advanced stages of the disease without appropriate treatment. And so, like Paul Michael Nelson, they seemed intractably ill. "Many kids were disabled by their psychiatric symptoms," Frankovich says. "They had OCD with severe intrusive thoughts, deep anxieties and fears, panic, rage." They also had cognitive problems: handwriting deterioration, slow processing speed and regressions so frightening that a once-normal 10-year-old might have the skills and behavior of a developmentally slow 3-year-old.

Tracing each illness back to the start of symptoms, Frankovich has managed to find clusters: groups of children from the same school or neighborhood who had all come down with the condition in the same month; individuals with a true, physical connection, like the family of three brothers Swedo had studied years before. In the course of her investigation, a host of alternate infections have emerged: not just strep, but bacterial mycoplasma, influenza, sinusitis, pneumonia and others.

By 2015, Frankovich and her team had led the effort



Medium spiny neurons are abundant in the basal ganglia and play a key role in initiating and controlling body movements.

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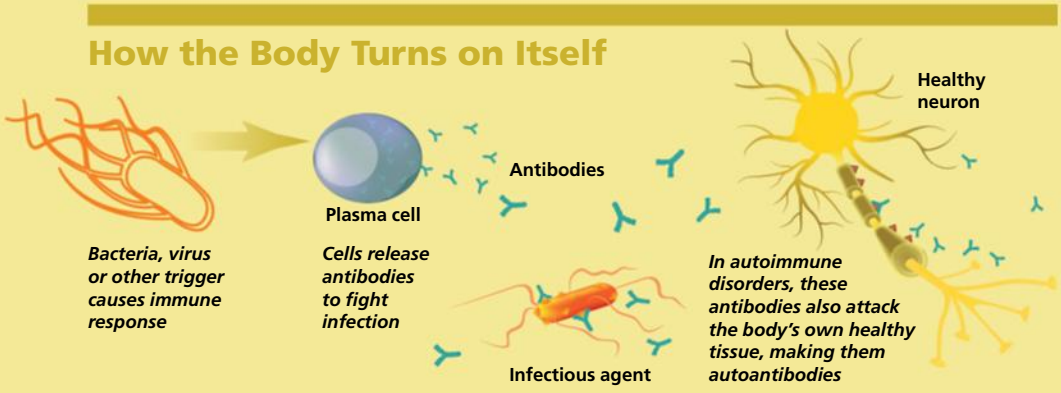
PINNING DOWN PANS

While medical experts have established criteria for diagnosing pediatric acute-onset neuropsychiatric syndrome, coming to that conclusion is still tough. Tests like the Cunningham Panel help, but researchers are still learning how PANS affects the brain. For now, here's where things stand.

How the Body Turns on Itself



Testing for PANS

The Cunningham Panel tests for specific autoantibodies and other features associated with the neuropsychiatric symptoms PANS patients display. If antibody levels are high, that suggests the autoimmune response was triggered by an infection.

The panel focuses on:

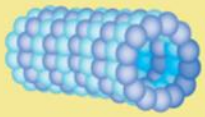
1) Anti-dopamine receptor D1
2) Anti-dopamine receptor D2L
3) Anti-lysoganglioside
4) Anti-tubulin
5) CaM Kinase II activity levels

The first four tests measure levels of antibodies in the blood that affect the following:

Dopamine
Neurotransmitter that, among other things, helps with motor control and cognition.

Lysogangliosides
Molecules in neuron membranes that help with signal transmission between neurons.

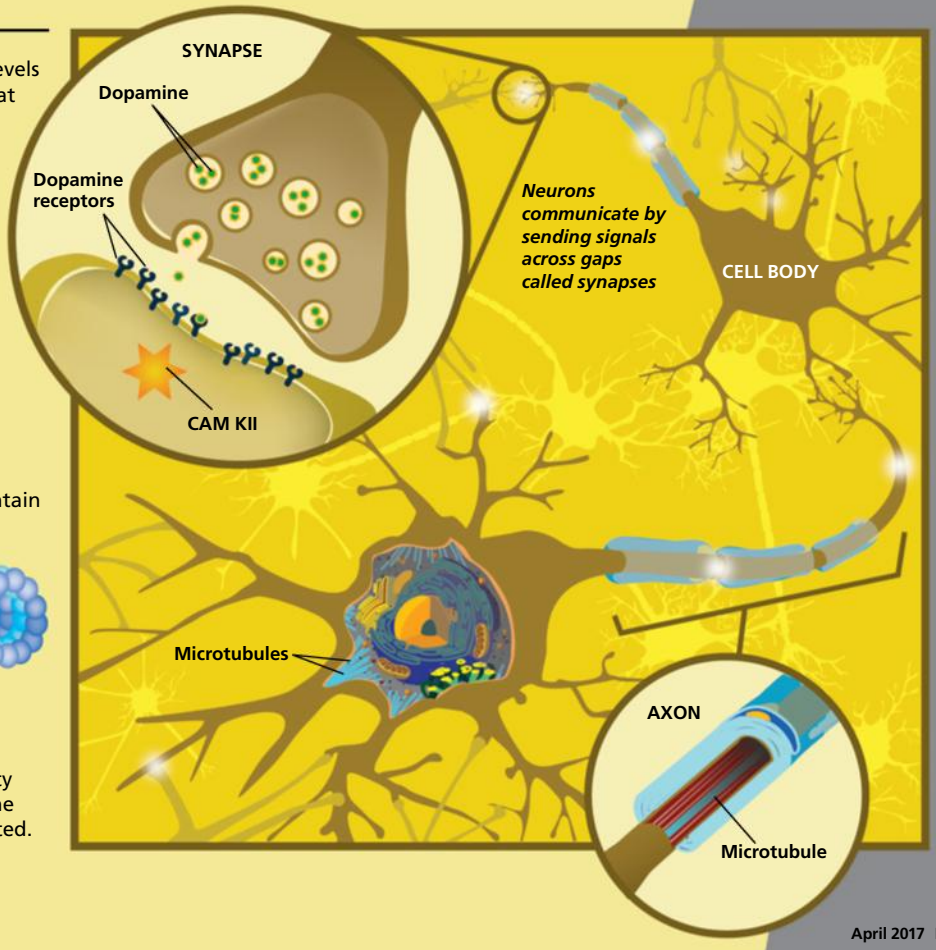
Tubulin A protein molecule involved in helping cells maintain structures.



Tubulin forms microtubules

The fifth test measures:

CaM Kinase II High activity levels of this enzyme cause the brain to become overstimulated.



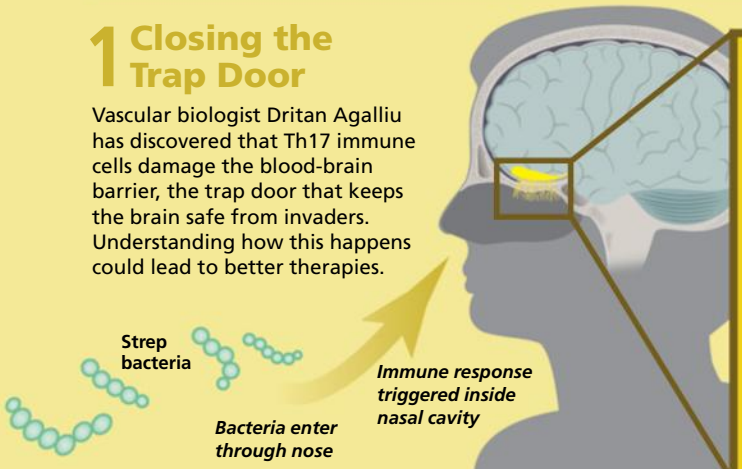
Basal ganglia
Contains many dopamine D2L receptors. This part of the brain is crucial for motor control and plays a role in movement disorders like OCD.

FUTURE FIXES?

New work is unlocking clues to how researchers might battle PANS in the future. Here's a closer look at two promising findings.

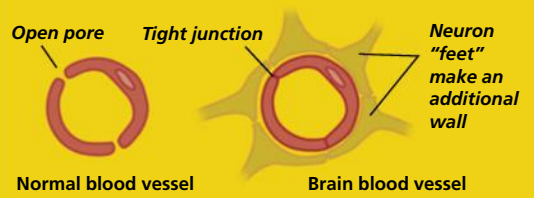
1 Closing the Trap Door

Vascular biologist Dritan Agalliu has discovered that Th17 immune cells damage the blood-brain barrier, the trap door that keeps the brain safe from invaders. Understanding how this happens could lead to better therapies.



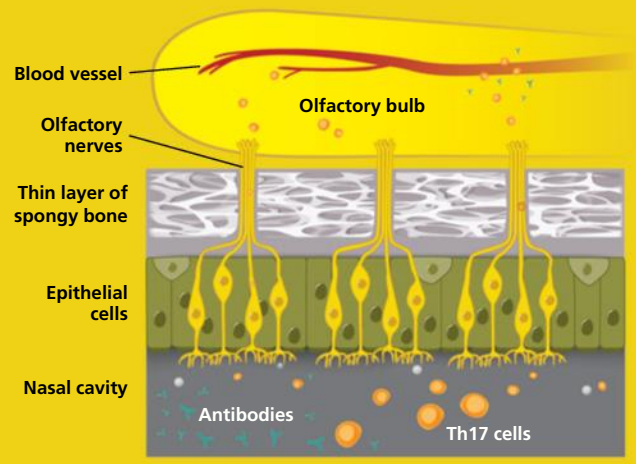
THE BLOOD-BRAIN BARRIER

The brain takes extra measures to keep out enemies.



HOW TH17 CELLS SNEAK IN THROUGH THE OLFACTORY AREA

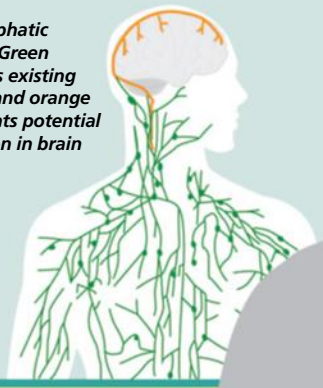
Since strep invades via the nose, Th17 cells gather near the olfactory bulb and mistakenly attack the blood-brain barrier, thinking it's strep.



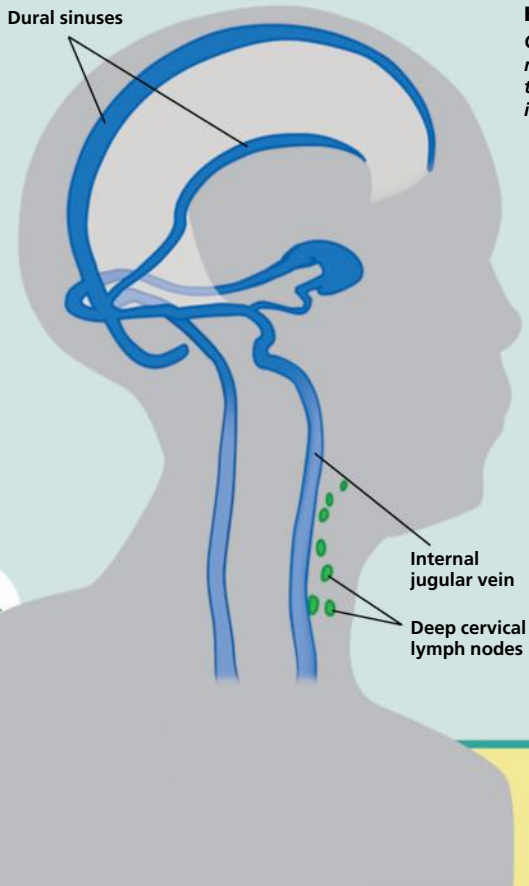
Once Th17 pokes holes in the blood-brain barrier, antibodies it would normally keep at bay flood the brain and cause it to turn on itself. Researchers think these attacks break down vital cellular structures and disrupt brain function, leading to the psychiatric symptoms seen in patients with PANS.

2 A Drain in the Brain

Neuroscientist Jonathan Kipnis and his team found, at least in mice, a vessel system that drains toxins out of the brain and into the lymphatic system. The team found similar structures in samples from human autopsies, but hasn't confirmed its location. If this system is faulty in PANS patients, repairing it could alleviate symptoms.

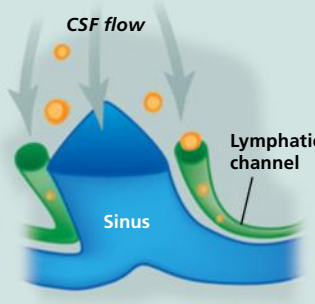


The lymphatic system: Green indicates existing system and orange represents potential extension in brain



HOW IT MIGHT WORK IN HUMANS

Cerebrospinal fluid (CSF) carrying nutrients and waste products circulates through cavities in the brain and drains into venous channels known as sinuses



The new lymphatic channels in the brain are thought to line the entire dural sinus system

Sinuses drain into jugular vein while lymphatic vessels drain into deep cervical lymph nodes in the neck

to create treatment guidelines for PANS patients. Though many young people in the Stanford PANS clinic had OCD, their psychiatric illnesses went well beyond that: 40 percent had suicidal thoughts; 19 percent had homicidal thoughts; and nearly two-thirds were at risk of committing violent acts. Some 26 percent had psychosis. This wide assortment of symptoms has Frankovich on a quest to identify subgroups in the hopes of tailoring treatments, but she longs for the day she can find and use a full array of biomarkers signaling disease and genetic risk. "Maybe we really have 10 disorders," she says. "Maybe strep-triggered PANS is different from flu-triggered PANS. This is a real disease, but we need more research to learn where the true lines lie and many treatment trials to understand the best therapies."

THE REAL HOPE, OF COURSE, IS FOR MORE EFFECTIVE TREATMENTS TARGETING THE UNDERLYING PROBLEM TO REPLACE THESE HARSH THERAPIES.

PEERING INTO THE BRAIN

One promising tool is the "Cunningham Panel," created by Cunningham through her commercial lab, Moleculera. Currently used for patients with neuropsychiatric symptoms, blood tests in the panel search for the autoantibodies Cunningham has found. The tests also look for whether the blood increases CaM kinase II activity.

The panel is so nuanced that it measures the level of autoantibodies against *two types* of dopamine receptors. Cunningham has come up with a formula based on the ratio of autoantibodies to the two dopamine receptors; depending on the balance between the two, she can predict a variety of symptoms, from ADD to compulsions to obsession to irritability and more. If a patient's blood shows high levels of the markers, it indicates that neuropsychiatric symptoms could stem from autoantibodies created in the wake of infectious disease — and that the treatment of choice might be steroids or IVIG.

The real hope, of course, is for more effective treatments targeting the underlying problem to replace these harsh therapies. Toward that end, potentially game-changing research comes from Dritan Agalliu, a vascular biologist and blood-brain barrier expert at Columbia University Medical Center in New York. Funded to focus on PANS by two wealthy parents whose child was diagnosed with the disease, Agalliu began searching in 2012 for controls to the trap door that autoantibodies use to sneak into the brain.

He exposed specially bred mice to strep and scrutinized their brains after death. How did repeated strep infection alter the integrity of the BBB? How did it induce rapid onset of neuropsychiatric disease?

One finding was that strep eventually led to massive production of a certain kind of immune cell, Th17, along with inflammation of the brain. In humans and rodents alike, Th17 cells take on the role of a conductor, telling other immune cells what to do. They have been implicated in the destruction of the BBB and are found in increased numbers in many autoimmune diseases. In the experimental mice, Agalliu saw that Th17 cells had poked holes in the BBB, opening the floodgates into the brain. Inside the brain, strep bacteria were nowhere to be found, but there were plenty of antibodies normally kept out by a healthy BBB.

Agalliu also found that Th17 cells induced by strep opened the BBB only in certain spots: Since strep enters the body through the nose, it made sense that he saw the BBB was pierced near the olfactory bulb, the structure in the front of the brain that processes odors. But strep also caused a leak in the BBB near the amygdala, the seat of fear and anxiety, and the lateral hypothalamus, where our sense of hunger begins. Given the primary PANS symptoms of OCD, anxiety and anorexia, this fit quite well. It's possible that finding ways to repair the BBB or safely block Th17 cells would better treat PANS patients.

Another potential tactic involves pumping the immune cells and toxic molecules out of the brain — considered a futile quest until just a couple of years ago. That's when University of Virginia neuroscientist Jonathan Kipnis and his team discovered a hidden core of vessels — a previously unknown sewage system for draining cellular waste from the brain into the lymph system at large. The work is in mice, but preliminary evidence suggests humans have it, too.

"Its existence," Kipnis says, "could explain how Alzheimer's plaque can be cleaned out by some of us but left for sludge in those who get disease. In some people, the vessels no longer work efficiently." The point for PANS: In diseases of autoimmunity, where rogue immune cells are stuck in the brain, returning these lymphatic vessels to greater function may be a potent means of clearing up disease.

These newest discoveries are so early that they won't enter the therapeutic arsenal without a wealth of additional research. And even where therapies have a track record, physicians (and parents) must differentiate between psychiatric disease, infectious disease and autoimmunity with care. Perhaps the best guideline here is that when psychiatrists call patients untreatable and show them the door, it only makes sense to explore PANS as another possible cause.

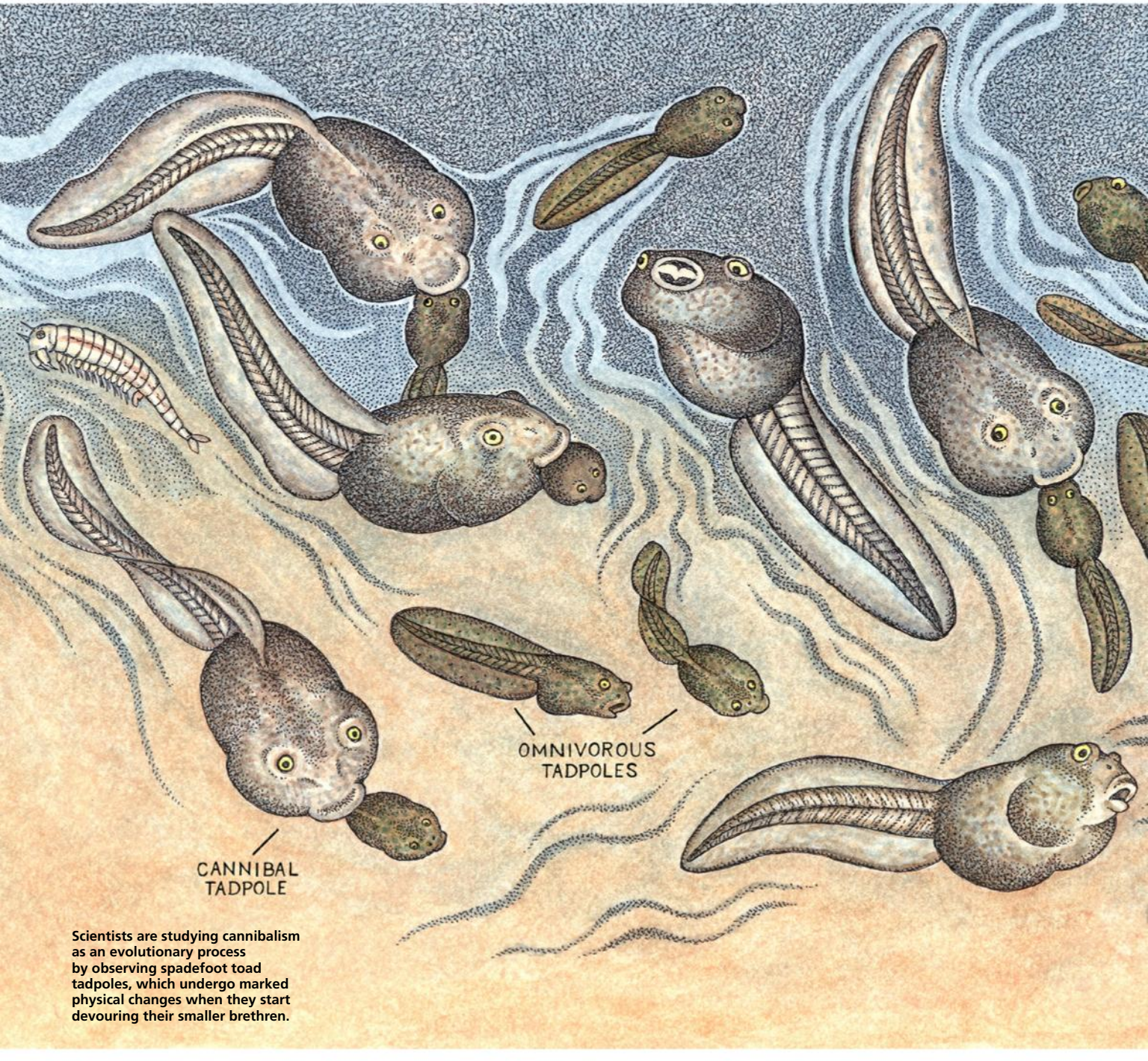
That unlikely detour brought reprieve to Paul Michael Nelson and his parents, who spent four years navigating violent rages and psychotic symptoms so overwhelming that the boy seemed forever lost. The Nelsons feared their child was, in many ways, dead. Tamping down his overactive immune system brought him back. D

Pamela Weintraub *is the psychology and health editor at* Aeon *and a contributing editor at* Discover.

ALISON MACKEY/DISCOVER. BRAIN: AULA MEDICAL MEDIA/SHUTTERSTOCK. OLFACTORY CLOSE-UP: DESIGNUSA/SHUTTERSTOCK. LYMPHATIC SYSTEM: ADAPTED FROM UNIVERSITY OF VIRGINIA HEALTH SYSTEMS

The Case for

A once taboo topic now appears perfectly natural in the animal kingdom. And



Scientists are studying cannibalism as an evolutionary process by observing spadefoot toad tadpoles, which undergo marked physical changes when they start devouring their smaller brethren.

Cannibalism

it's changing what we know about evolution.

BY **BILL SCHUTT** ILLUSTRATIONS BY **PATRICIA J. WYNNE**

I was knee-deep in a temporary pond that seemed to be composed of equal parts rainwater and cow dung when the cannibals began nibbling on my leg hair.

"If you stand still for long enough, they'll definitely nip you," came a voice from the shore.

"They" were cannibalistic spadefoot toad larvae, commonly known as tadpoles. The warning had come from David Pfennig, a biology professor at the University of North Carolina who had been studying these toads in Arizona's Chiricahua Mountains for more than 20 years.

At Pfennig's invitation, I had arrived at the American Museum of Natural History's Southwestern Research Station in mid-July — just after the early summer monsoons had turned cattle wallows into nursery ponds and newly hatched tadpoles into cannibals. But the real reason I had come to the ancestral land of the Chiricahua Apaches wasn't because the tadpoles were eating each other. It was because some of them *weren't* eating each other. In fact, when this particular brood had hatched about a week earlier, they were all omnivores, feeding on plankton and the suspended organic matter referred to in higher-class journals as "detritus."

Then, two or three days later, something peculiar took place. Some of the tiny amphibians experienced dramatic growth spurts, their bodies ballooning in size overnight. Now, as I waded, scoop-net in hand, through Sky Ranch Pond (a slimy-bottomed mud hole with delusions of grandeur), the pumped-up proto-toads were four or five times larger than their poop-nibbling brethren.

"These look like two different species," I said, examining a handful of tadpoles that I'd just scooped up. I also noted that the larger individuals were light tan in color while the little guys had bodies flecked with dark green.

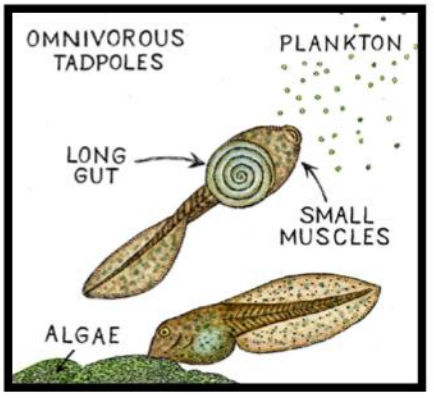
"Initially, people thought they were different species," Pfennig replied.

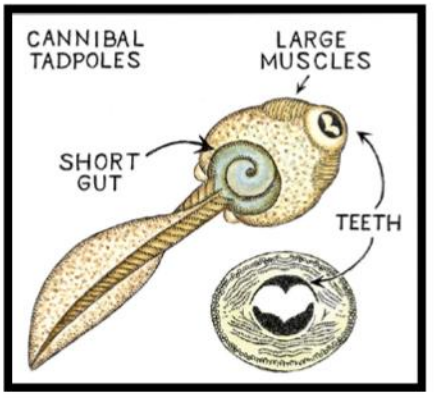
Using a magnifying glass to get a better look at my squirmy captives, I saw the differences went beyond body size and color. The larger tadpoles were also sporting powerful tails and serious-looking beaks.

"Yikes, nice choppers," I commented, always the scientist.

"They're made of keratin," Pfennig said. That's the same tough, structural protein found in our nails and hair.

Later, while comparing the two tadpole morphs — larvae transforming into toads — under a dissecting microscope, I saw that behind a set of frilly lips, the flat keratinous plates (which had worked fine for detritus dining) had been transformed into a jack-o-lantern row of sharp-edged teeth in the cannibalistic forms. The jaw muscles were also significantly enlarged in the cannibals, especially the





Omnivorous tadpoles need a long gastrointestinal (GI) tract to break down tough-to-digest plant matter. Cannibals, however, develop sharp teeth and large jaw muscles and have a significantly shorter GI tract, which works just fine for fleshy diets.

jaw-closing *levator mandibulae*, whose bulging appearance reminded me of a kid with six pieces of Dubble Bubble jammed into each cheek. Studies had shown that myofibers, the cells making up these muscles, were larger and greater in number — producing a more powerful bite. Of course, the extra bite force was necessary because, beyond latching onto the occasional unshaved human leg, these critters were using bulked-up bodies and the weaponry that accompanied them to consume their omnivorous pondmates.

Over a three-day period, I watched and captured tadpoles in bodies of water that ranged from tire-carved puddles to bovine swimmin' holes of the double-wide Olympic variety. From the researchers, I learned a great deal about the three species of the amphibious spadefoot toads that laid their eggs in such dangerously unpredictable conditions. Much of this information centered on the ecology, behavior and evolution of these creatures. Of course, the cannibalism angle was there, too, although these researchers treated that behavior as perfectly normal.

Until relatively recently, though, and with very few exceptions, cannibalism in nature would have been regarded as anything but normal. As a result, until the last two decades of the 20th century, few scientists spent time studying a topic thought to have little, if any, biological significance. Basically, the party line was that cannibalism, when it did occur, was either the result of starvation or the stresses related to captive conditions.

It was as simple as that.

Or so we thought.

PERFECTLY NATURAL

In the 1970s, Laurel Fox, a University of California, Santa Cruz, ecologist, took some of the first steps toward a scientific approach to cannibalism. She had been studying the feeding behavior of predatory freshwater insects called backswimmers. Fox determined that while the voracious hunters relied primarily on aquatic prey, "cannibalism was also a consistent part of their diets." Soon after, she began compiling a list of scientific papers in which cannibalism had been reported. Although there turned out to be hundreds of references documenting the behavior in various species, no one had linked these instances together or come up with any generalizations regarding the behavior. By the time Fox's review paper came out in 1975, she had concluded cannibalism was not abnormal behavior at all, but a completely normal response to a variety of environmental factors.

She also determined that cannibalism took place in every major animal group, including many long considered to be herbivores — like butterflies. She emphasized that cannibalism in nature also demonstrated a complexity that seemed to match its frequency. Fox suggested that the occurrence of cannibalism in a particular species wasn't simply a "does occur" or "doesn't occur" proposition, but was often dependent on variables like population density and changes in local environmental conditions. She even followed cannibalism's environmental connection onto the human branch of the evolutionary tree.

Until relatively recently, and with very few exceptions, cannibalism in nature would have been regarded as anything but normal.

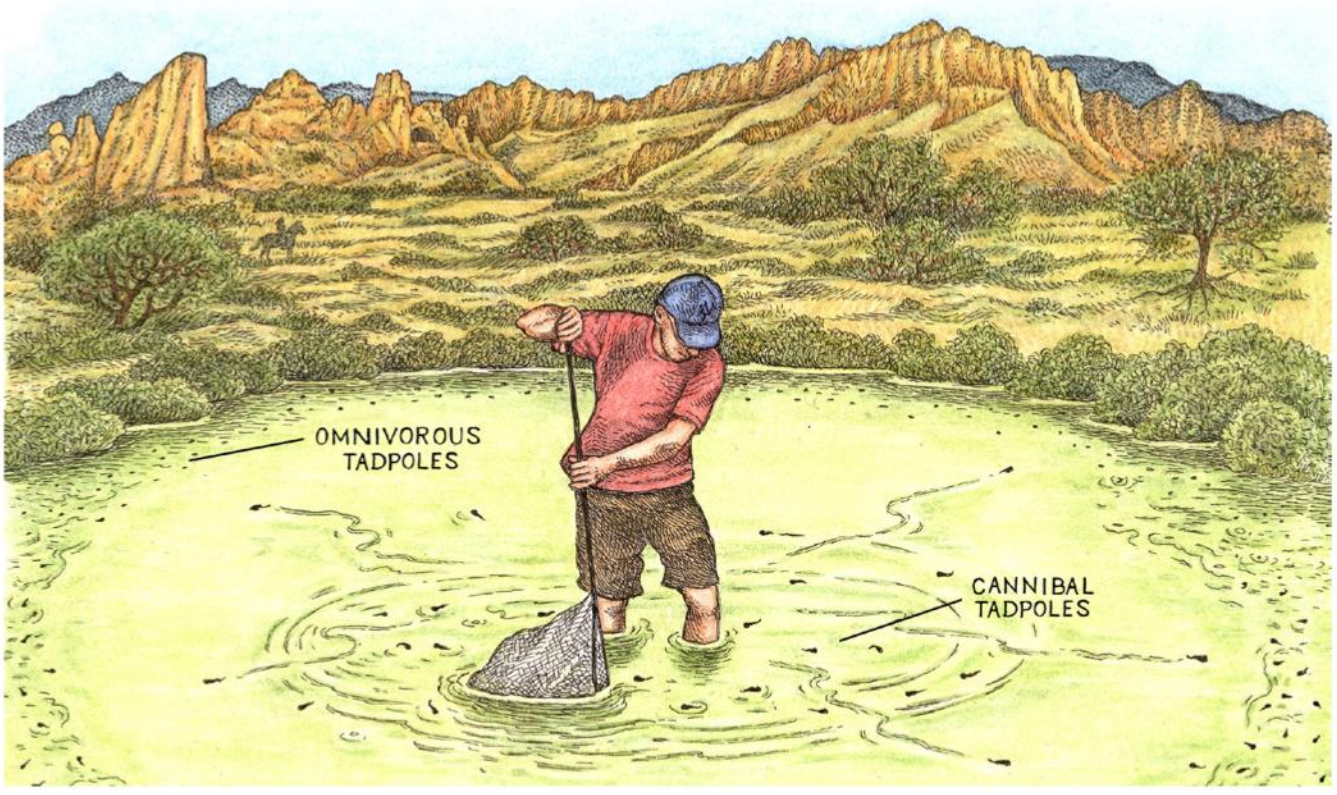
After pondering reports that humans practicing non-ritual cannibalism lived in "nutritionally marginal areas," she proposed that consuming other humans might have provided low-density populations with 5 to 10 percent of their protein requirements. Conversely, she suggested cannibalism was rare in settlements where populations were dense enough to allow for the production of an adequate and predictable food supply.

In 1980, ecologist and scorpion expert Gary Polis picked up the animal cannibalism banner and began looking at invertebrates that consumed their own kind. Like Fox, he noted that while starvation could lead to increases in the behavior, it was certainly not a requirement. Perhaps Polis' most important contribution was assembling a list of cannibalism-related generalizations under which most examples of invertebrate cannibalism could be placed: 1) Immature animals get eaten more often than adults; 2) Many animals, particularly invertebrates, do not recognize individuals of their own kind, especially eggs and immature stages, which are simply regarded as a food source; 3) Females are more often cannibalistic than males; 4) Cannibalism increases with hunger and a concurrent decrease in alternative forms of nutrition; and 5) Cannibalism is often directly related to the degree of overcrowding in a given population.

Polis emphasized that these generalizations were sometimes found in combination, such as overcrowding and a lack of alternative forms of nutrition (a common cannibal-related cause and effect), both of which now fall under the broader umbrella of "stressful environmental conditions."

In 1992, evolutionary biologists Mark Elgar and Bernard Crespi edited a scholarly book on the ecology and evolution of cannibalism across diverse animal taxa. In it, they refined the scientific definition of cannibalism in nature as "the killing and consumption of either all or part of an individual that is of the same species." Initially the researchers excluded instances where the individuals being consumed were already dead or survived the encounter — the former they considered to be a type of scavenging. Eventually, though, they decided these were variants of cannibalistic behavior observed across the entire animal kingdom.

As the study of cannibalism gained scientific validity in the 1980s, more and more researchers began looking at the phenomenon, bringing with them expertise in a variety of fields. From ecologists, we learned cannibalism was often an important part of predation and foraging, while social scientists studied its relationship to courtship, mating and even parental care. Anatomists found strange, cannibalism-related structures to examine (like the keratinous beak of the spadefoot toad) and field biologists studied cannibalism under natural



conditions, thus countering the previous mantra that the behavior was dependent on captivity.

GETAWAY SCHEME

Arizona's lowland scrub stood in stark contrast to the lush peaks and boulder-strewn valleys of the state's Chiricahua Mountains. These "sky islands" — isolated mountains surrounded by radically different lowland environments — provided a spectacular backdrop for my afternoon wade through yet another transient pond.

The air temperature had risen to 95 degrees Fahrenheit, which kept most of the area's terrestrial denizens hiding in shade or below ground. But the inhabitants of Horseshoe Pond reminded me of sugared-up kindergartners tearing around a playground (albeit with fewer legs and more cannibalism). By this time, I had already begun to see distinct patterns of behavior in the spadefoot tadpoles that motored hyperactively just below the water's surface.

I noticed that the smaller, omnivorous morphs generally stuck to the shallows bordering the shoreline. They buzzed through the brown water in a non-stop, seemingly random quest for food, changing direction abruptly and often. One explanation for the patternless swimming behavior became apparent as I waded farther away from the shore, for here in the deeper water was the realm of the cannibals. I stood quietly and watched as hundreds of conspicuously larger tadpoles crisscrossed the pond, making frequent excursions from the deeper water toward the shore in a relentless search for prey.

So why did certain spadefoot larvae exhibit cannibalistic behavior? There certainly seemed to be enough organic matter suspended in these algae-tinted ponds to feed the entire brood and more.

As I spoke to Pfennig and his team of researchers, I learned that the answer was directly linked to the aquatic environments in which the adult amphibians laid their eggs. Formed by spring and early-summer monsoons, the transient ponds frequented by the spadefoots are often little more than puddles, and as such they can evaporate quite suddenly in the hot, dry environment of southeastern Arizona. Natural selection, therefore, would favor any adaptations enabling the water-dependent tadpoles to get out of the pool as quickly as possible (i.e., to grow legs). In this instance, the phenomenon that evolved can be filed under the rather broad ecological heading of phenotype plasticity: When changing environmental conditions allow multiple phenotypes (observable characteristics or traits) to arise from a single genotype (the genetic makeup of an organism).

The selection pressure lies in the temporary nature of the brood ponds, where the eggs are deposited and hatch, and where the tadpoles develop into toadlets. The period from egg to juvenile toad normally takes around 30 days — unless, that is, the pond dries out first, killing the entire brood. In response to this particular environmental selection pressure, what evolved was a means by which some of the tadpoles can mature in about two-thirds of the time. The increased growth rate occurs because the cannibal larvae are getting a diet high in animal protein as well as a side order of veggies, the latter in the form of nutrient-rich plant matter their omnivorous prey had consumed during what turned out to be their last meal.

Though the story of spadefoot toad cannibalism has been well researched, it is not fully resolved. No one has yet been able to identify the precise stimulus within these brood ponds that triggers the appearance of the cannibal morphs.

However, Pfennig and his co-workers

Environmental cues can make tiger salamanders develop huge heads and elongated teeth — then eat their own kind.

did previously work on a completely different cannibalism-triggering stimulus in another amphibian. And this one happened to be one of North America's most spectacular species.

THE SMALL GET EATEN

Tiger salamanders (*Ambystoma tigrinum*) are the largest salamanders in the United States, reaching lengths of up to 13 inches. These thick-bodied, sturdy-limbed urodelans are widespread across much of the country. Their markings, yellow blotches against a black body, make them easy to identify, but they are rarely seen in the open except during annual marches to a nuptial pond. Tiger salamander eggs are laid in the late winter or early spring, and like other salamanders, and their cousins the frogs and toads, their larvae are fully aquatic with external gills and fishlike tails. They typically feed on zooplankton and other micro-invertebrates, but under certain environmental conditions, a small percentage develop traits that include huge heads, wide mouths and elongated teeth. Consequently, these toothy individuals exploit larger prey, among them other tiger salamander larvae.

Pfennig and his colleagues set up lab experiments on fertilized *A. tigrinum* eggs to investigate the stimuli that set these changes into motion. First, the researchers determined that the cannibal morphs only developed when larvae were placed into crowded conditions. Next, they used a variety of experiments to see whether the larval transformation might be triggered by visual cues (that didn't work), smell (nope) or touch.

"It looks like they had to have the tactile cues," Pfennig told me. "There's something about bumping into each other that triggers the production of the cannibals."

Immature animals get eaten far more often than adults, and this makes larvicide (or infanticide) the most common form of cannibalism in the animal kingdom. Intuitively, it doesn't seem logical to eat the next generation, but the behavior can make evolutionary sense for several reasons. Young animals not only provide a valuable source of nutrition, but in most species they're relatively defenseless. So they present instant nutritional benefits but little or no threat to larger members of the same species, most of which are invulnerable to attacks from immature forms.

But beyond acquiring a meal, cannibalism enables individuals of some species to accelerate their developmental process, as we saw with spadefoot toads, allowing them to quickly outgrow a stage in which they might be preyed upon or perish due to unpredictable environmental conditions. In species like the flour beetle (*Tribolium castaneum*), the behavior may also impart a reproductive advantage, since studies have shown that cannibalistic individuals produce more eggs than non-cannibals.

Finally, many animals maintain specific territories, within which they are intolerant to the presence of conspecifics (i.e., members of the same species). According to Polis, crowding increases the frequency with which individuals violate the space of others. By reducing overcrowded conditions, cannibalism can serve to decrease the frequency of territory violations.

THE CANNIBALISM CATCH

There are also serious drawbacks to being a cannibal.

In all likelihood, the most significant of these is a heightened chance of acquiring harmful parasites or diseases from a conspecific. Both parasites and pathogens are often species-specific and many of them have evolved defenses to defeat their host's immune defenses. As a result, predators that consume their own kind run a greater risk of picking up a disease or a parasite than predators that feed solely on other species. In the most famous example of cannibalism-related disease transmission, the Fore people of New Guinea were nearly driven to extinction as a result of their ritualized consumption of brains and other tissues cut from the bodies of their deceased kin — kin who had been infected by kuru, an incurable and highly transmissible neurological disease.

Cannibals — whether microbes or Methodists — who eat their own relatives can also experience decreases in a

measure of evolutionary success known as inclusive fitness, in which the survival of an individual's genes, whether they're from an offspring or a collateral relative (like a brother or cousin) is the true measure of evolutionary success. A cannibal that consumes its own offspring, siblings or even more distant relatives, removes those genes from the population and reduces its own inclusive fitness. Since this is bad juju, natural selection should favor cannibals that can discriminate between kin and non-kin. In many instances, this is exactly what happens.

Pfennig and his team found that their study subjects could recognize cues associated with their kin that were absent in non-kin.

"Most examples would fall under the heading of 'the armpit effect,'" Pfennig told me. "Here, an individual forms a template for what its kin smell like based on what its own smell is." He used the example of a species of paper wasps that regularly raid the nests of conspecifics to provide food for their own broods. In these species, individuals learn that "if an individual smells like your nest or burrow … you don't eat them."

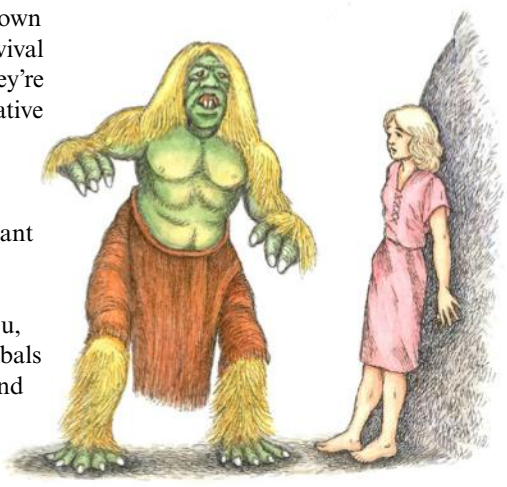
Similarly, tiger salamander larvae are more likely to eat the larvae of unrelated individuals. Pfennig explained that he and his colleagues determined this experimentally by "preventing them from being able to smell."

"How did you do that?" I wondered, envisioning a team of micro-surgeons hovering over a tiny, amphibious patient. Irrigation please, Nurse. Can't you see this patient is dehydrating?

"By applying superglue under their [nostrils]," he replied.

"Oh, right," I said with an uncomfortable laugh, before Pfennig assured me the condition was temporary.

If you're wondering whether or not spadefoot toads avoid eating their kin, Pfennig told me omnivores associate preferentially with their siblings, whereas cannibals generally school only with non-siblings. In close encounters of the bitey kind, cannibal tadpoles release siblings unharmed and consume non-relatives. In the lab, though, apparently all bets are off if the cannibals are deprived of food and then placed in a tank with other tadpoles. In these cases, starvation becomes the great equalizer, and both kin and non-kin are eaten.



I wondered whether H.G. Wells knew about cannibal morphs when he wrote *The Time Machine* in 1895.

DARWINIAN TWIST

I wondered whether H.G. Wells knew about cannibal morphs when he wrote *The Time Machine* in 1895. In Wells' classic novel, the Time Traveler encounters two human species: the child-sized and docile Eloi, and the brutish Morlocks, who raise the Eloi in order to feed upon them. Wells explained the Morlocks' cannibalistic behavior by suggesting that they were once members of a worker class, toiling underground for lazy, upper-class surface-dwellers. The Time Traveler speculates that a food shortage (i.e., an environmental change) forced the subterraneans to alter their diets — at first rats, but ultimately something a bit larger. This behavior resulted in a race of hulking cannibals, feeding on the surface-dwellers, whose own evolutionary path would produce the sheeplike Eloi, pampered, well-fed and eventually slaughtered for food.

Although the Eloi-Morlock relationship was clearly meant to serve as a cautionary tale of the horrors of class distinction, Wells imagined a biological phenomenon remarkably similar to what scientists like Pfennig and his colleagues are working on today.

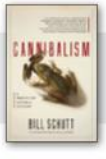
What these scientists hypothesize goes far beyond the realm of cannibalism and into the very mechanisms of evolution itself. Their claim is that the appearance of new traits in a population, generally regarded as a first step toward the evolution of new species, can occur by means other than the accumulation of micromutations (i.e., small-scale or highly localized mutations), the classic mechanism by which new traits, and eventually new species, are thought to appear. Some researchers now believe that given generations, novel traits originating as examples of phenotypic plasticity have the potential to produce separate species.

INNOCENT BUT GORY

In the end, cannibalism makes perfect evolutionary sense. If a population of spiders has lots of males from which a female can choose, then cannibalizing a few of them could increase Charlotte's overall fitness by increasing the odds that she can raise a new batch of spiderlings. On the other hand (and in spiders there are eight of these to choose from), in a population where males aren't plentiful or where the sexes cross paths infrequently, cannibalizing males would likely have a negative impact on a female's overall fitness by decreasing her mating opportunities.

As a zoologist, I find this kind of dichotomy pleasing, since it's logical and appears to be more or less predictable in occurrence. In nature, as far as cannibalism is concerned, I've found no gray areas, no guilt and no deception.

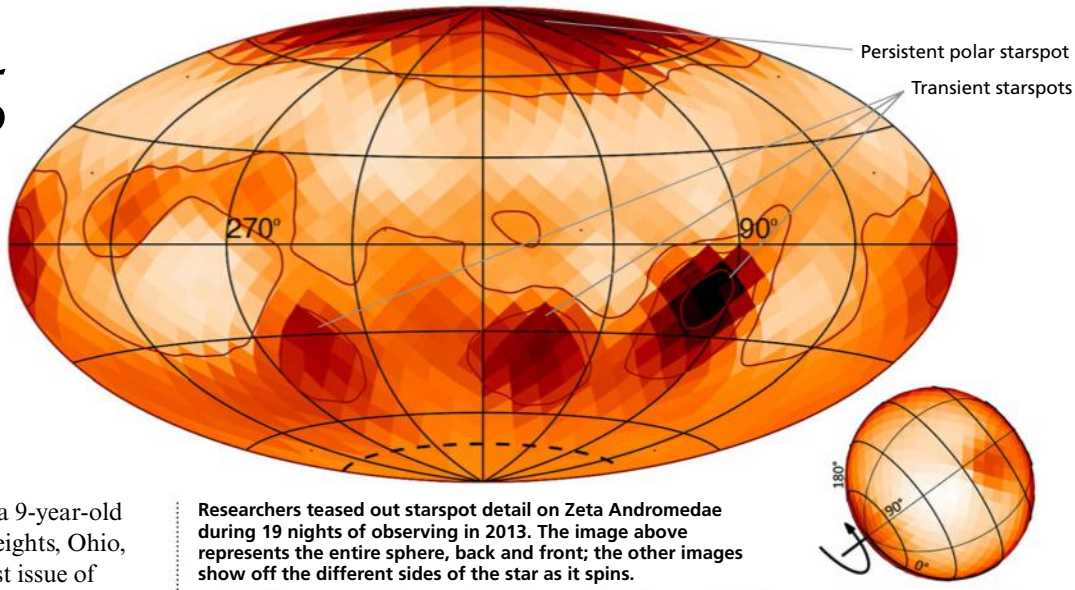
There is only a fascinating variety of innocent — though often gory — responses to an almost equally variable set of environmental conditions: too many kids, not enough space, too many males, not enough food. D



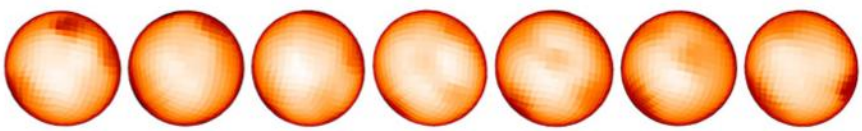
Seeing Stars

Twinkle, twinkle no more — now astronomers can see other stars as living, breathing suns.

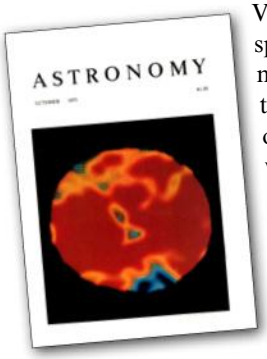
BY **COREY S. POWELL**



Researchers teased out starspot detail on Zeta Andromedae during 19 nights of observing in 2013. The image above represents the entire sphere, back and front; the other images show off the different sides of the star as it spins.



It was 1975. I was a 9-year-old living in Shaker Heights, Ohio, and the cover of the latest issue of *Astronomy* magazine had just blown my young mind. What so captivated me on that day was not one of NASA's new images of Mercury and Venus. They were spectacular, don't get me wrong, but this thing on the cover of the magazine was something else entirely. It was a picture of Betelgeuse — a star. It was totally different from a blurry planet made clearer and more detailed by a passing probe. This was a dot of light decoded, a mathematical point that suddenly had dimension and structure and *reality*. It was almost like magic. I was hooked.



I fell into a lifelong obsession with astronomy, eventually becoming the editor of *Discover*, and waited for more pictures of stars. And waited. And waited some more, for so long that it almost seemed like I had dreamed that astonishing glimpse.

These memories came flooding back last spring when I finally saw a new picture of another star, Zeta Andromedae (And). Unlike the crude reconstruction of Betelgeuse, this was a precision portrait of a stellar surface.

And it was not just a single still, but a whole series of images knit together into a movie. Frame by frame, I could watch cool, dark spots moving along with Zeta And as it rotated; meanwhile, an even larger spot sat anchored at its visible pole. Nobody had ever seen a distant star with such crystalline clarity. And all of this from a distance of more than a quadrillion miles! At last it will be possible to compare our sun directly with other stars, to put models of stellar evolution to concrete tests, to understand the detailed relationships between alien planets and their suns.

I call up Rachael Roettenbacher, the postdoc at the University of Michigan who created this unique stellar portrait, to see if she is as stunned as I am. No — definitely more so. "I'm amazed that this is possible; it's just so fantastic," she says. "I like to look at the movie sometimes just to remind myself that it really happened."


Rachael Roettenbacher

BREAKING THE LIGHT BARRIER

So why did it take so long? Roettenbacher's quick answer is that stars appear exceedingly tiny. Conventional observing techniques still can't bring them into view, not even close.

Consider the case of Betelgeuse, one of the most promising targets for imaging. It is a giant star, one of the night sky's brightest and nearly 1,000 times the diameter of the sun, but so far away that it appears much smaller in the sky than Pluto. In astronomical terms, its angular size is about 50 milliarcseconds, or about half the size of a *single pixel* in the best images from the Hubble telescope. Zeta And appears 20 times smaller yet. When Galileo pointed his spyglass to the heavens in 1609, he regarded the stars

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A dome encloses a 1-meter telescope, one of six that make up the CHARA array on Mount Wilson in California.

as dimensionless points of light. Today that is still essentially true, even at the world's greatest observatories.

Starting in the late 1960s, astronomers saw a possible way forward: a technique called speckle imaging that could reach beyond the normal telescopic limits. The idea is to take a series of high-speed snapshots of a star, freezing the blurring effects of Earth's atmosphere, and then reconstructing the true image from those. Unfortunately, speckle imaging involves a lot of mathematical inference. The Betelgeuse image by Roger Lynds and his team at Kitt Peak National Observatory — the one that got my younger self so worked up — used this technique to show the star's overall size and shape, but it didn't reliably capture any specific surface detail.

The next giant leap was optical interferometry, merging the light beams from two or more telescopes to create, in effect, a single telescope as large as the distance between the two. The payoff is images hundreds of times as sharp as anything from Hubble. Radio astronomers have used a similar approach for many years, with great success, but light waves are more than a million times smaller than radio waves, meaning optical interferometry requires a million times greater accuracy. Promising experiments in the 1970s soon ran into the limits of the hardware and software of the time, and "anything involving optical interferometry fell out of interest for a while," Roettenbacher explains.

With little fanfare, though, a few groups of determined researchers kept advancing toward the stars — albeit at an agonizing, incremental pace. Starting in the late 1980s, a collaboration between the U.S. Navy and the Lowell Observatory began developing the Navy Precision Optical Interferometer (NPOI) in Arizona. Around the same time, at Georgia State University's Center for High Angular Resolution Astronomy (CHARA), astronomer Harold McAlister championed an interferometry machine combining the light from six separate telescopes on California's Mount Wilson. After 16 years of planning and construction, CHARA finally began full operation in 2001. Soon after, John Monnier at the University of Michigan began work on an instrument called MIRC (Michigan InfraRed Combiner) that could convert the merged light to produce meaningful images. He tested it on the nearby star Altair in 2006, and found that he could clearly see how the star's rapid rotation whips it up into a roughly egglike shape.

Roettenbacher read about the Altair results while she was in college at Ohio Wesleyan University. "I remember thinking, 'This is the coolest thing ever.' I was so fascinated that we could [clearly see] stars that aren't the sun," she says. At the time, she had no idea that she'd be doing such things herself.

The wide Y-shaped footprint of the Navy Precision Optical Interferometer in Flagstaff, Ariz.

TOP: HAROLD MCALISTER/CHARA/GEORGIA STATE UNIVERSITY. BOTTOM: PAUL SHANKLAND/U.S. NAVAL OBSERVATORY FLAGSTAFF STATION

71 Year Old Senior Comes Back To Life

"He's coming back to life!" his wife screamed.

Jason had become so frail and tired that he had trouble doing everyday things. Simple things like getting up from the couch and getting up from the bed.

Jason had not always been this way. You see, it started when he was in his 50's and he would start falling asleep on the chair while watching TV, and just taking naps during the day. He started **feeling tired and fatigued, having lower energy, and not wanting to do anything.**

His wife just accepted the fact that he is getting older and that is simply what old people do - fall asleep on the couch. He did not even have the energy to go see his grandkids. Their love life also struggled.

Finally, his wife had had enough and wanted to put an end to this. She researched so many different methods and none of them worked Jason and his wife were invited to a wedding, and his wife actually got him to come along since it was a close cousin's wedding. At the wedding they met a doctor named Rand McClain, who is an expert on the human body. She told him about Jason's struggles and how she has tried everything but nothing has worked. He actually told her **these are the signs of aging, but he does not need to struggle.**

He told her about a simple at-home solution to fix his problems. This solution was a drink that anyone can make. Jason's wife gave him the special drink. About 20 minutes later Jason was up and dancing with everyone and his wife was shocked. She said, "How is he doing this? For years he has been too tired to even get out of his bed was falling asleep early at night. He is acting like he is in his 30's again!"

Dr. McClain explained that his method is actually based on a **technology that was banned by the U.S. Government in 2001. Luckily he has found a "loophole" and is fighting back against the government** to allow everyone to get in better health and fight the signs of aging.

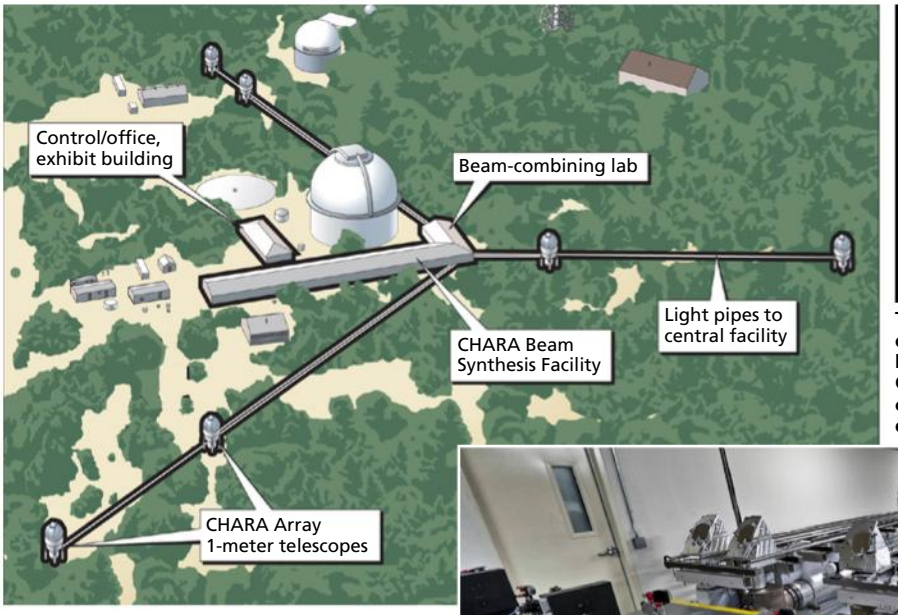
This was **not just a one-time thing for Jason.** He has been using this special at-home method every day and wakes up **with more energy, can get out of his bed easily, has clearer thinking,** and no longer falls asleep on the couch early at night. Jason's wife is also much happier as well because their love life has had a kick start as well! It is now back to how it was when they first got married.

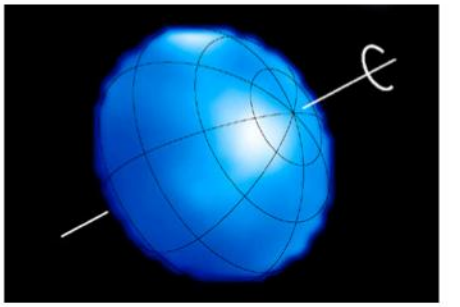
His wife was also curious to see if this method would work for her too. Sure enough this method is also working for her and she is seeing similar results.

You can find out about McClain's breakthrough discovery and how you too can fight the symptoms of aging by going to **www.LCR6.com**

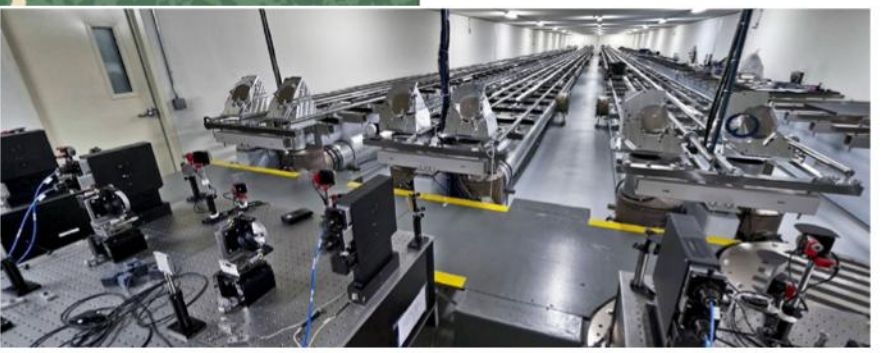
It's even more important that you watch the video if you yourself have been experiencing excessive fatigue, a weaker body, and even foggy thinking, because that could mean what happened to Jason may also happen to you as well.

Of course the government and big pharmaceutical companies are not too pleased with McClain's discovery and may try and take this video down. So we do advise that you watch the video as soon as possible. Watch the shocking presentation here: **www.LCR6.com**





The CHARA observatory layout (left) precisely combines six light sources into one in a long beam lab (below). With the Michigan InfraRed Combiner, astronomers can then tease out details on distant stars, such as Altair (above), which completes a rotation in only nine hours.



But just a few years later she was doing her graduate work at the University of Michigan, slaving away with Monnier to jam beams of light together and zeroing in on Zeta And as the perfect target for a stellar close-up.

THE STARS ARE OURS

What Roettenbacher was attempting required a level of precision well beyond what had come before. With interferometry, there is no point-and-shoot. Getting a clear picture of a star would require a tremendous amount of additional, tedious work.

Zeta And takes 18 days to rotate, so Roettenbacher had to monitor the star for at least 18 nights, all night long. That was the easy part; then came the data processing. Optical interferometry at CHARA requires collecting the light beams from six different telescopes, sifting through multiple gigabytes of data, and then combining the beams to synthesize the kind of image that otherwise would be possible only with an enormous space telescope. Finally, all the processed data get imported into a software program, developed by Monnier, that translates the lightwave information into a picture.

"I don't even want to calculate how much time I've spent doing all that," Roettenbacher laughs. But then came the payoff: "We were just stunned by how incredible the imaging was."

Not only could she see starspots (giant signatures of magnetic activity) on its surface, but she noted that they behaved utterly unlike the spots on the sun. Our star has magnetic symmetry between the northern and southern hemispheres, but Zeta And is oddly lopsided, only showing such activity on one side of its equator. "The theory people are still working on it," Roettenbacher says.

The images and movie of Zeta And presage many more stellar visions soon to come. Roettenbacher is about to observe two more stars that are even smaller, more difficult targets. Engineers are currently outfitting NPOI with four giant 1.8-meter telescopes; in upgraded form, it has the capability to provide even sharper views than CHARA. The VLT Interferometer in Chile, operating since 2000 but only now approaching its full potential, has lower resolution but can see much fainter objects. These instruments will scrutinize the disks where planets form around infant stars, and watch the cataclysmic stellar explosions known as novas.

But for me, Roettenbacher's observation of Zeta And is the singular event, the one that transforms our way of looking at the universe. One of the first things Galileo did with his telescope was observe spots on the sun. Now we have seen spots on another star. We have left the last vestiges of the era of astrology and entered the era of aster-ology: the age of stars as physical, tangible and brilliantly visible things. D

Corey S. Powell**, a contributing editor at* Discover, *also writes for the magazine's Out There blog. Follow him on Twitter:* ***@coreyspowell

CLOCKWISE FROM TOP LEFT: CHARA/GEORGIA STATE UNIVERSITY; MING ZHAO/UNIVERSITY OF MICHIGAN; STEVE GOLDEN/CHARA/GEORGIA STATE UNIVERSITY

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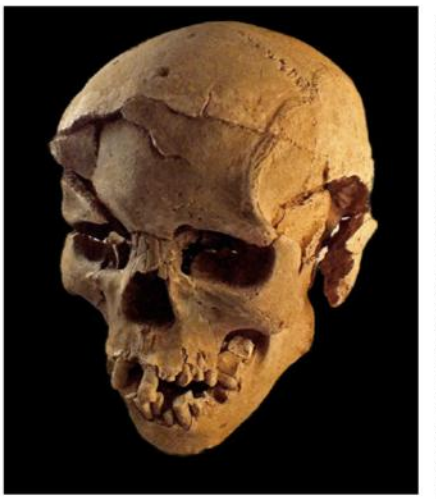
This Means War!

Sites of ancient conflicts reignite a debate over when members of our species first took up arms against each other.

BY **HILLARY WATERMAN**

The skull, though weathered from millennia of brutal heat and scouring sands, is unmistakably human. Unmistakable, too, are the signs of a violent death: massive fractures from the blunt force of a weapon wielded by another human. The shattered cranium is one of several from a site in Kenya known as Nataruk, where, long ago, a band of hunter-gatherers met its end.

Described in *Nature* in 2016, the remains are believed to be among the earliest evidence of human warfare. Although the terrain is arid and desolate now, around 10,000 years ago this was a lagoon near Lake Turkana, surrounded by lush vegetation. In this Eden-like landscape, aggressors captured and massacred at least 27 people: men, women — one of them pregnant — and children.



A digital rendering based on photographs (top) captures the aftermath of a massive Bronze Age battle near Germany's Tollense River. At Kenya's Nataruk site, a fractured skull (above) is a clue to even earlier violent human conflict.

The most complete remains are 12 skeletons found facedown in what was the lagoon. The captors used blunt force trauma to the head to kill, but other fractures — at the neck, ribs, knees, legs and hands — speak to the brutality of the event. A few of the victims were bound before death, and some have arrowheads of stone and obsidian embedded in their bones. Obsidian, a volcanic glass that is relatively rare around Lake Turkana, suggests that the marauders may have come from a different region.

Richard Wrangham, a biological anthropologist at Harvard University

TOP: LAKD M-V, LANDESARCHÄOLOGIE, C. HARTL-REITER. BOTTOM: MARTA MIRAZON LAHR, ENHANCED BY FABIO LAHR

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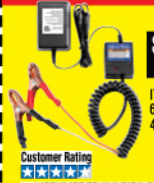
69955
42292 shown



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SUPER COUPON $4.99

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who has studied the evolution of human warfare, says the find at Nataruk shows that violent conflict is ancient and primal, a vestige of our pre-*Homo* ancestry rather than a recent adaptation to life in settled societies. When territories are large and numbers few, Wrangham says, both humans and chimps — the living species nearest our own — generally practice avoidance. After all, open conflict is risky: It's safer to stay in your own backyard and mind your own business. But alpha males of both species can be tempted, as Wrangham puts it, "with dreams of cheap victory." If they perceive an advantage, such as having greater numbers than another group, they will typically launch a surprise attack.

GRAVE TIDINGS

The mass grave at Schöneck-Kilianstädten, on the outskirts of Frankfurt, Germany, may mark the aftermath of one such guerrilla raid. Discovered during construction of a road in 2006, the roughly 7,000-year-old site documents the annihilation of an entire community. Thirteen adults and 13 children were tortured, killed and dumped into the settlement's refuse pit, with arrowheads found among the bones. Archaeologists found no remains of women between the ages of 25 and 40 at the site. That's not at all surprising, says Christian Meyer, an osteoarchaeologist and lead author of a 2015 study of the find: Young women were commonly taken captive.

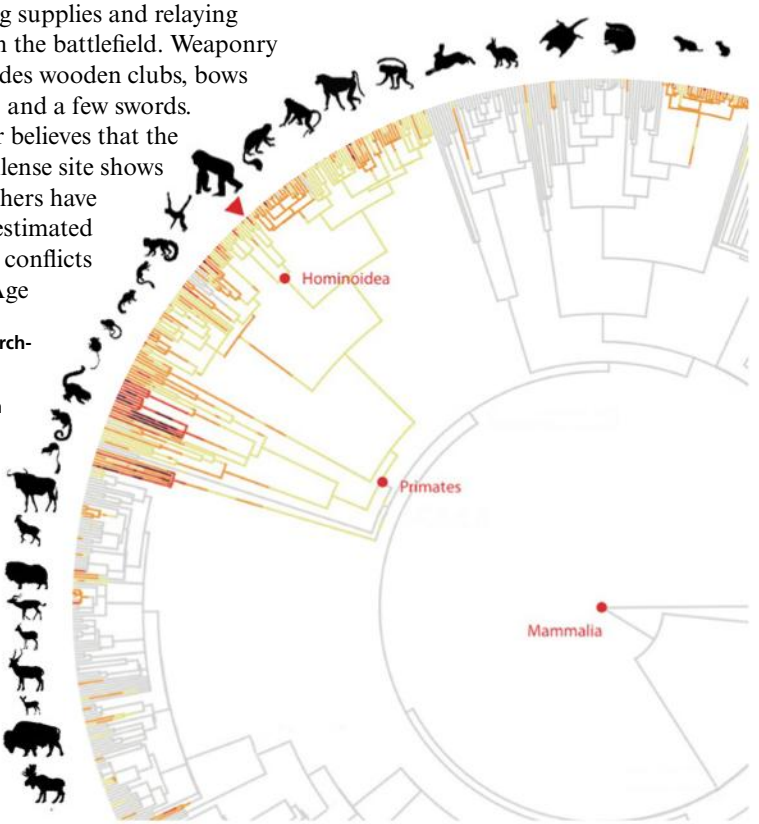
The evidence echoes that of other massacre sites from around the same time, most notably Talheim, some 80 miles south of the Schöneck site, and Asparn-Shletz, just outside Vienna: mass graves with jumbles of shattered bones and pierced skulls, entire communities wiped out. At Schöneck, the lower leg bones of most of the young men showed a nearly identical pattern of blunt force breakage probably made by the Neolithic weapon of choice, the ax-like adze. Meyer speculates this systematic but nonlethal mutilation was symbolic, and could hint at genocide.

Younger than Schöneck by more than 3,500 years, a Bronze Age site in northeastern Germany records an even larger violent event: a massive battle. In 1996, an amateur archaeologist discovered a few human bones and an ancient wooden war club eroding out of the bank of the Tollense River. One arm bone had an arrowhead lodged in it. A formal dig began in 2009, and even though only about 20 percent of the site has been excavated, project director Thomas Terberger and colleagues have identified remains of more than 100 different individuals, including women and children.

Based on these finds, the team estimates that up to 2,000 people may have participated in the conflict. Although researchers believe young men did the fighting, Terberger says women and children likely assisted by providing supplies and relaying messages on the battlefield. Weaponry found includes wooden clubs, bows and arrows, and a few swords.

Terberger believes that the massive Tollense site shows that researchers have long underestimated the scale of conflicts in Bronze Age

Children were not spared during the massacre at Schöneck-Kilianstädten 7,000 years ago: Skulls fractured shortly before death belong to a 3- to 5-year-old (top) and an 8-year-old (above) who perished during the event.



In 2016, researchers modeled intraspecies violence as an evolutionary trait among different mammal lineages. The darker the line, the more violent the species. Humans, indicated by the red triangle within *Hominoidea*, evolved in one of the more murderous bunches.

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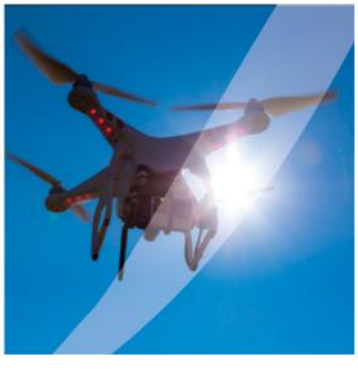

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Up to 2,000 people may have participated in a battle along Germany's Tollense River some 3,500 years ago. Remains include a skull with a massive fracture from a club (left), another skull pierced by a bronze arrowhead (below) and a flint arrowhead embedded in an upper arm bone (bottom). Weapons such as bronze spearheads (right) litter the site.

Europe. "This looks like a community defending itself against invaders," Terberger says. Some of the Tollense bones had chemical traces of millet — a rare crop in northern Europe during the Bronze Age — which could mean the individuals came from the south. The strategic location of the battle (a river crossing) also suggests the aggressors may have been trying to push into new territory.

CONFLICT VS. COLLABORATION

Wrangham and other researchers believe that these sites, Nataruk in particular, support the notion that we dragged our violent nature along with us as we became human. A 2016 paper in *Nature* that looked at evidence for lethal intraspecies violence among all mammals supports this idea. The researchers concluded that individuals are most likely to kill each other when the species is both social and territorial, traits apparent in some apex predator mammals, such as wolves and lions — and humans.

But University of Notre Dame anthropologist Agustín Fuentes, author of *The Creative Spark: How Imagination Made Humans Exceptional*, believes that violence does not define the basis of human nature. He notes that out of some 2,700 human fossils dated from 2 million years ago to roughly 14,000 years ago, only about 2 percent show any evidence of lethal aggression. After that time, says Fuentes, we see a definite uptick in numbers of sites with clear evidence of aggression and homicide — in fact, it doubles. The incident at Nataruk, he says, was well within this time frame. The apparent surge in violence and aggression coincided with humans beginning to settle and create societies with a shared sense of group identity. And with that came a new category and natural foil: the outsider.

In evolutionary terms, the trait we call aggression is a complex cocktail of genes, hormones, learned behavior and culture. Each of these elements on its own performs some task that helped us succeed as a species. These ingredients can combine in different ways and with other elements to form a variety of behaviors, some of which are constructive, and some of which are not.

According to Fuentes, war and other destructive capabilities are merely the flip side of the same uniquely human faculty that has enabled us to coexist peacefully, to innovate, to travel in space and shape our world. "We are," Fuentes says, "both the potentially nicest and the potentially cruelest species on the planet." D

Hillary Waterman *is a science writer based in Maine.*

CLOCKWISE FROM TOP LEFT: LAKD M-V, LANDESARCHÄOLOGIE/S. SUHR (2); V. MINKUS, S. SUHR

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Rain

BY **GEMMA TARLACH**

Raindrops that fell 2.7 billion years ago left fossilized imprints.

1 Rain reigns over us: It's the main way liquid water, necessary for all earthly life-forms, disperses across the planet. **2** But a 2015 study in *Nature Geoscience* concluded Earth's early rain was made of iron. More than 4.5 billion years ago, bits of space rock vaporized upon impact with our still-forming planet, rose up in plumes of rock and iron, and then fell back down as rain. **3** Water-based rain dates back to at least the late Archaean Eon: Researchers have found fossilized raindrop imprints in 2.7 billion-year-old volcanic tuff in South Africa. **4** Acid rain, while still water, leaves a different kind of imprint on many surfaces, corroding metal and eroding limestone and marble. The term, coined in the mid-19th century, typically refers to precipitation with a pH of less than 5.2. **5** Normal rain, by the way, is still slightly acidic, with a pH of about 5.6. The pH value of rainfall varies slightly due to factors such as season and climate. **6** Acid rain can occur naturally after volcanic eruptions, forest fires and other events that release sulfur dioxide into the atmosphere. The compound dissolves in rainwater and oxidizes into sulfuric acid. **7** Unnatural acid rain poses larger environmental threats, such as deforestation. Since the Industrial Revolution, fossil fuel burning has released sulfate and nitrate ions — both acid rain precursors — into the atmosphere at unprecedented levels. **8** Today, the northeastern U.S. sees the most acid rain in the country because of density of both people and industry, as well as prevailing winds. **9** Acid rain is bad enough, but on Saturn's moon Titan, the rain is made of methane. Nobody is singing in the rain there. **10** On Saturn itself, as well as Jupiter, droplets of helium rain may fall from the gas giants' outer layers toward the interior, according to research published in 2010 in *Physical Review Letters*. **11** But nowhere on Earth, Saturn or anywhere else has it rained cats and dogs. There's a flood of theories about the origin of the popular saying, which was first recorded in the mid-17th century. **12** Some etymologists think the phrase refers to dead animals washed into the streets after a downpour. But others see a possible corruption of the Old English word for waterfall, *catadupe*, which makes more sense than falling Fidos and Fluffys. **13** It rains some serious *catadupe* in Cherrapunji, India. The weather station there holds the world record for the heaviest 48-hour rainfall (more than 98 inches), set in 2014. **14** Cherrapunji also holds a long-standing record for highest rainfall in a 12-month period: 86 feet, 10 inches, set back in 1860-1861. **15** The folks in Cherrapunji might be tired of it, but many people enjoy petrichor, the scent that often follows rainfall. Two Australian researchers coined the term back in the 1960s. **16** A U.S.-based team working at about the same time identified geosmin, a byproduct of soil bacteria, as the source of earthy notes in the distinctive smell. **17** Researchers discovered the likely mechanism behind petrichor only in 2015: A study in *Nature Communications* found that the average raindrop hits a porous surface with enough force to trap air bubbles at point of impact. The bubbles then rise and pop, releasing aerosols, including geosmin. **18** Many people find the sound of rain as pleasant as its smell, but a 2016 study determined it's also possible to measure rainfall amounts over oceans by monitoring the sound of droplets hitting the waves. **19** And quantifying oceanic rainfall, notoriously difficult to do, is important: 80 percent of the planet's precipitation lands there. **20** Since Earth's water cycle is essentially evaporation from the surface, condensation in the upper atmosphere and precipitation (gravity sending that condensation back down), those little droplets are really just going home. D

When it rains, it pours in the Indian town of Cherrapunji, which since 1861 has held the world record for rainiest 12-month period.

Discover *senior editor* ***Gemma Tarlach*** *only wants to see you laughing in the purple rain.*

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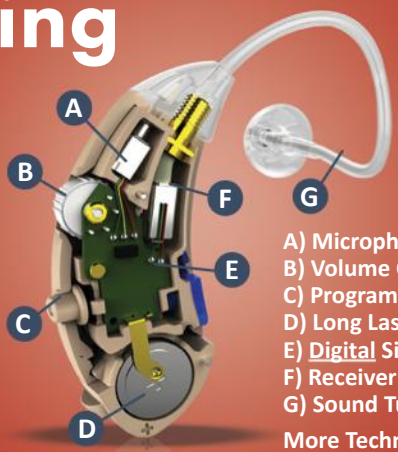

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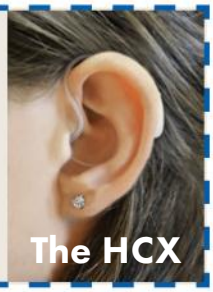
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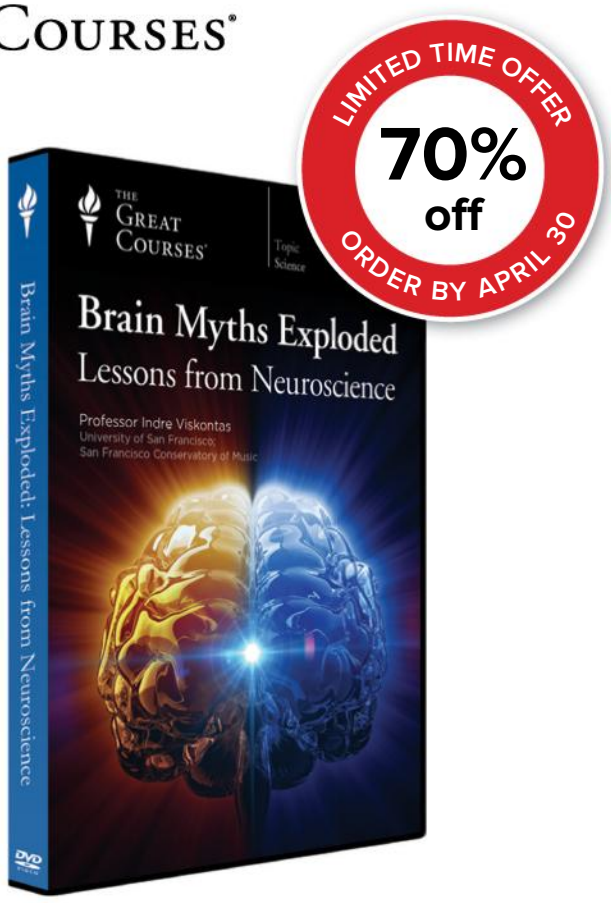

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