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SCIENCE NEWS M
SOCIETY FOR SCIENCE
MAY 28, 2016

Math and Mental Illness

Snow-Making Bacteria

Goldilocks Worlds Nearby

Sleep Secrets

Seeing Oddly

Animals that are all eyes and other twists in vision evolution

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Science News e-books tackle time and space

COVER With compound eyes and diverse photoreceptors, the peacock mantis shrimp sees things differently. © *Mike Veitch/Alamy Stock Photo*

CLOCKWISE FROM TOP: S. JOHNSEN/DUKE UNIV.; COURTESY OF MIKOLAJ BAKALARZ/BIGGER BANG COMMUNICATIONS; P.R. GRANT

Math offers new view of brain and its disorders

Of the many disorders that can afflict the brain, schizophrenia and autism are among the most inscrutable. The long scientific searches to explain their causes have turned up many clues and inspired various theories. But no clear answers have emerged.

A new way of thinking about these disorders has begun to show promise, as Laura Sanders reports on Page 18. This approach conceptualizes the brain as a fantastic guessing machine that combines information from the senses with expectations based on past experience. Interpreting the external world in this way can be described precisely (and therefore can be tested and explored in a rigorous way) with the use of a mathematical expression known as Bayes' theorem.

Many scientists now suspect that in schizophrenia, autism and perhaps other disorders, the guesses the brain makes about the external world get derailed — either because of trouble integrating sensory information with expectations, or from failure to adjust expectations based on new information.

Other sorts of problems in the brain have little to do with interpreting reality, but rather reflect the detrimental impact of toxic substances. Lead's destructive influence in the brain, for instance, is clear and well-documented. Other metals may also pose problems. On Page 14, Sanders explores the current controversy over iron. Iron plays a crucial role in the transport of oxygen in the blood, but too much iron in the brain may be unhealthy; some experts suspect excessive iron contributes to Parkinson's disease. Others argue that iron starvation is actually the problem for cells in the part of the brain affected by Parkinson's. That issue has proved difficult to resolve, and researchers are deeply divided — even though clinical trials based on one side of the argument are now under way.

Brain researchers are concerned not only with diseases but also with normal healthy functions, such as sleep. On Pages 8–9, Sanders, Tina Hesman Saey and Sarah Schwartz report several new sleep-related findings: a major role for ion concentrations in the process of awakening or falling asleep; the brain's strategy for staying alert when sleeping in a strange place; and new evidence from lizards relevant to the evolution of human sleep patterns.

Interest in the brain is not a strictly modern phenomenon. Bruce Bower's story on Page 12 details new findings about 4,000- to 6,000-year-old skulls in southwestern Russia with rather large holes carved into them. Whether ancient people in this region were trying to peer more closely at the brain, taking part in a religious ritual or attempting some kind of therapeutic surgery is unclear. The scientist who led the team that analyzed the skulls contends that the holes are in the wrong place for a medical intervention and were cut in skulls that were otherwise healthy. Some speculate that the holes might have prepared people for a new, perhaps spiritual role in the group. Apparently, most survived the procedure. While the intent may never be known, those skulls do suggest that people have long been interested in examining the brain to find answers — be they about mental illness, other diseases or even spiritual quests. — *Eva Emerson, Editor in Chief*

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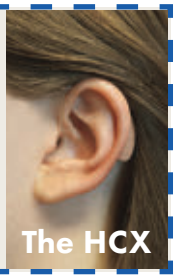
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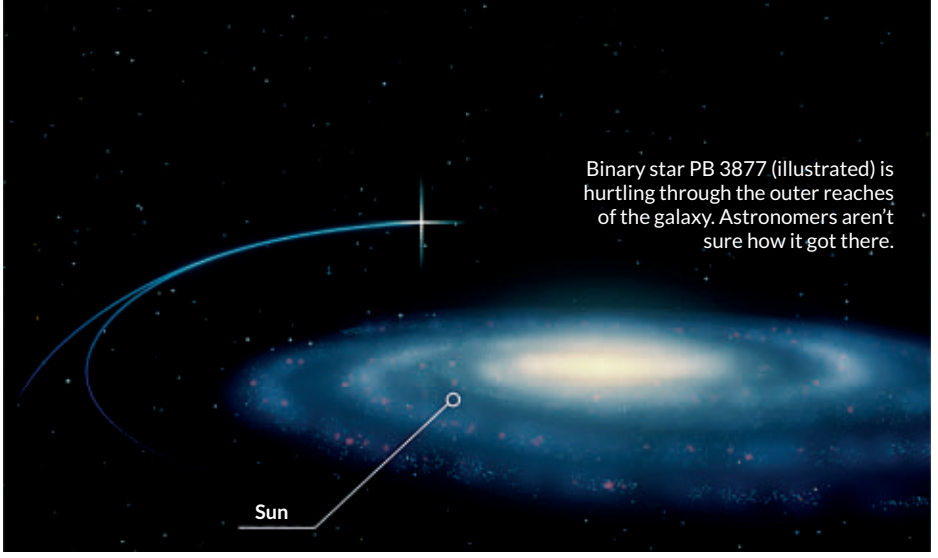
Excerpt from the May 21, 1966 issue of *Science News*

50 YEARS AGO

Growth hormone mapped

Discovery of the complete chemical structure of the human growth hormone has been reported.... The discovery marks a major advance toward understanding how the powerful growth-promoting substance works and increases the chances for its eventual synthesis in the laboratory.... Some 5,000 fresh human pituitary glands were required to achieve the results.

UPDATE: In 1979, researchers produced a synthetic human growth hormone in the lab, using bacteria equipped with human hormone genes. Six years later, the synthetic growth hormone was approved for medical use; distribution of growth hormone collected from human pituitary glands had been halted after infected product was linked to Creutzfeldt-Jakob disease, a fatal brain-wasting disorder. Today, doctors use synthetic growth hormone to treat growth hormone deficiency, which can stunt growth in children. Because synthetic growth hormone can build muscle and trim body fat, it is prohibited as a doping agent by many sports organizations.



Binary star PB 3877 (illustrated) is hurtling through the outer reaches of the galaxy. Astronomers aren't sure how it got there.

HOW BIZARRE

What sent two stars racing out of the Milky Way?

Something catapulted a pair of stars from the outer rim of our galaxy, but astronomers aren't sure what. A binary star known as PB 3877 is rocketing away at about 2 million kilometers per hour — possibly fast enough to escape the galaxy's gravitational pull — and all the usual explanations for such speedy stars fall short. Astrophysicist Péter Németh of the University of Erlangen-Nuremberg in Germany and colleagues report the discovery in the April 10 *Astrophysical Journal Letters*.

Many galactic escapees get kicked out after a close brush with the supermassive black hole in the Milky Way's center. But PB 3877, first noticed in 2011 and currently about 18,000 light-years away in the constellation Coma Berenices, has been nowhere near that behemoth. A supernova could be responsible; it has happened before (*SN Online: 3/5/15*). But PB 3877 is two stars traveling together. A supernova would have torn the two apart. Németh and colleagues propose that the duo may be left over from a smashup between the Milky Way and a smaller galaxy. If that's the case, then there might be others like PB 3877 lurking in the galactic outskirts. — *Christopher Crockett*

THE -EST

Bear bone rewrites human history in Ireland

In a bit of Irish luck, archaeologists have found evidence of the Emerald Isle's earliest known humans. A brown bear's kneecap excavated in 1903, featuring stone tool incisions, pushes back the date that humans set foot in Ireland by as many as 2,500 years.

Radiocarbon dating at two independent labs places the bone's age between about 12,800 and 12,600 years old, say Marion Dowd of the Institute of Technology, Sligo in Ireland and Ruth Carden of the National Museum of Ireland in Dublin. Melting glaciers and milder temperatures in northwestern Europe at that time made it easier for humans to reach Ireland by boat to hunt game, at least for several weeks at a time, the researchers propose in the May 1 *Quaternary Science Reviews*.

Stone-tool marks on a brown bear's kneecap provide the earliest evidence of humans in Ireland, between about 12,800 and 12,600 years ago.

Until now, the oldest signs of people on Ireland came from a hunter-gatherer camp that dates to about 10,290 years ago.

Carden discovered the brown bear's kneecap while studying bones that had been packed away in boxes in the 1920s, after the bones' 1903 discovery at Ireland's Alice and Gwendoline Cave. — *Bruce Bower*

FROM TOP: THORSTEN BRAND; JAMES CONNOLLY

SCIENCE STATS

With easy e-cig access, teen vaping up

In 2013, nearly three times as many U.S. high school students smoked cigarettes as vaped electronic cigarettes. By 2015, the trend reversed. Nearly twice as many vaped as smoked, a new study finds. For middle school students, the preference for vaping over smoking cigarettes was even stronger (2.3-fold).

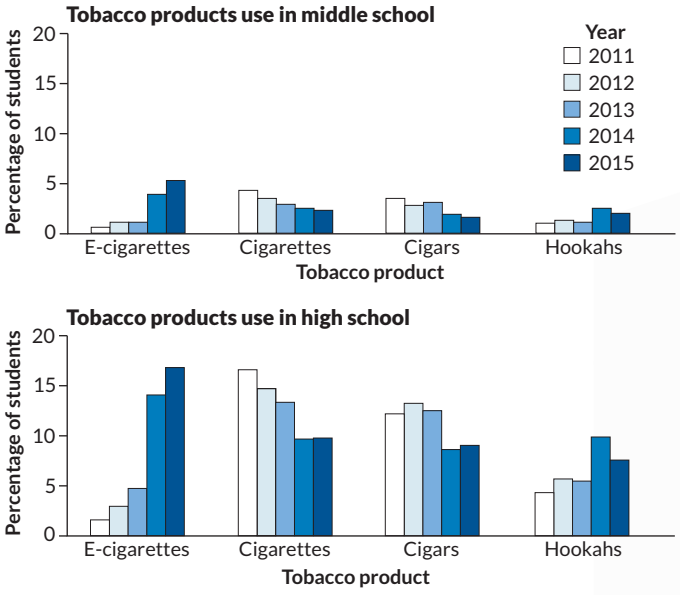
Federal researchers analyzed data from the National Youth Tobacco Survey and found that some 2.39 million U.S. high school kids vaped in 2015. Fewer high schoolers, about 1.37 million, smoked cigarettes, the researchers report in the April 15 *Morbidity and Mortality Weekly Report*.

Since 2011, teen use of tobacco products has fallen for all categories but two: e-cigarettes and hookahs (although even hookah use has dropped since 2014). In fact, the federal researchers conclude, the steep growth in vaping seems to be keeping overall teen tobacco use stable.

The vast majority of U.S. states have banned sales of vaping supplies to minors, according to the National Conference of State Legislatures. Yet "minors do not face any significant barrier in purchasing liquid nicotine over the Internet" to vape in e-cigs, a second new study shows.

Last summer, Dmitriy Nikitin of the University of California, Irvine and his colleagues recruited three teens to buy e-liquids from 120 different U.S. online vaping-supply vendors. Only four stores did not sell e-liquids to the 16- and 17-year-olds. "I was really blown away," Nikitin says. His team published its findings online March 19 in *Nicotine & Tobacco Research*.

Some of the stores packaged their e-liquids with child-friendly bonuses: toy frogs, stickers, little green army men or candy such as SweeTarts. On May 5, the U.S. Food and Drug Administration announced sweeping new regulations for e-cigs, hookahs and other tobacco products. — *Janet Raloff*



SOURCE: T. SINGH *ET AL*/*MMWR* 2016

Pseudomonas syringae bacteria can freeze water at above-freezing temperatures. The microbes are often used to help make artificial snow for ski slopes.

MYSTERY SOLVED

Bacteria use cool trick to make ice

Scientists have discovered how one microbe plays it cool.

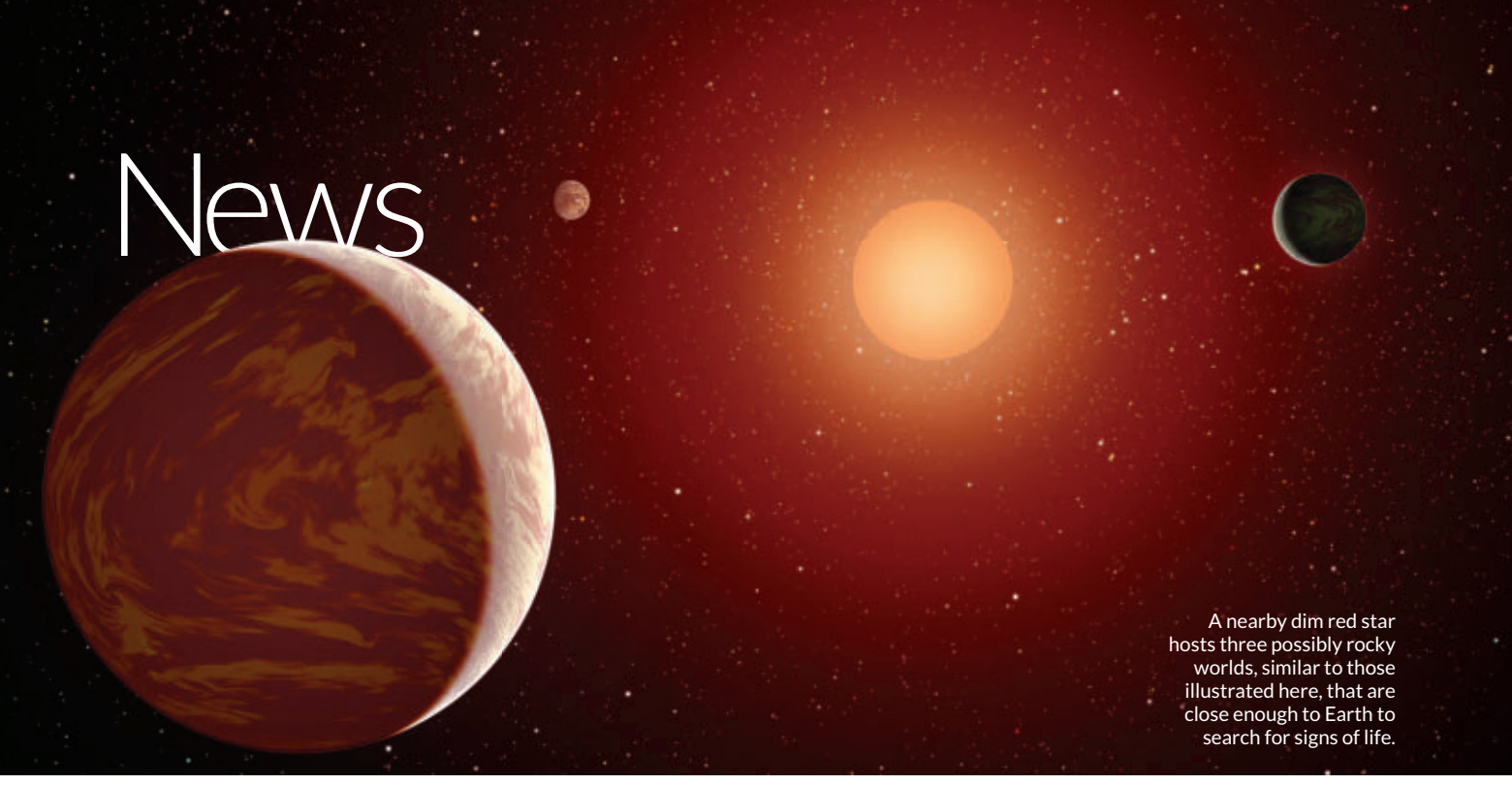
Until now, it was a mystery how *Pseudomonas syringae* turns water into ice at temperatures above a normal freezing point. The bacterium pulls off its cool trick by rearranging nearby water molecules, researchers in the United States and Germany report April 22 in *Science Advances*. This chill ability makes the microbe useful in churning out artificial snow at ski resorts.

Researchers knew that a particular protein on the microbe's membranes was somehow responsible for making ice form. The team found that this ice nucleation protein, inaZ, acts as a mold for ice crystals. Alternating water-repelling and water-attracting parts of the protein tug nearby water molecules into an orderly, icelike arrangement. Once set in an ice-promoting formation, water molecules can quickly disperse heat energy.

This alignment process becomes more prominent as water temperatures drop toward 5° Celsius, a degree above the freezing point of the water the team used in the experiment (which contained a heavy form of hydrogen). Outside the lab, *P. syringae* can crystallize water at around –2° C, several degrees above the temperature at which ice crystals commonly form.

Understanding how *P. syringae* bacteria freeze water could inform science beyond the slopes. In gardens, the bacteria can wreak havoc on frost-sensitive plants. And ice-forming microbes play an important role in climate by affecting patterns of cloud formation and precipitation, the researchers say.
— *Sarah Schwartz*

CLOCKWISE FROM TOP: MR. GREEN/SHUTTERSTOCK; TUDOR CATALIN GHEORGHE/SHUTTERSTOCK; E. OTWELL



A nearby dim red star hosts three possibly rocky worlds, similar to those illustrated here, that are close enough to Earth to search for signs of life.

JPL-CALTECH/NASA

ATOM & COSMOS

Exoplanet trio could harbor life

Worlds orbiting cool star are good place to look for aliens

BY CHRISTOPHER CROCKETT

Three Earth-sized planets orbiting a star practically next-door might be a good place to hunt for alien life — or at least to check out some worlds that are different from anything in our solar system.

The planets orbit a dim, cool star just 39 light-years away in the constellation Aquarius. Each is outside or possibly on the edge of the star's habitable zone — where average temperatures are just right for liquid water. But there could be niche locales on these worlds where alien life might thrive, Michaël Gillon, an astrophysicist at the University of Liège in Belgium and colleagues report online May 2 in *Nature*.

On the two inner planets, a year lasts just a couple of days. Data on the third world are sparse; it could take anywhere from 4.5 to 72.8 days to trek around its sun. The star, designated 2MASS J23062928−0502285, is about the size of Jupiter — about one-tenth as wide as our sun — and about 3,200 degrees Celsius cooler than the sun. Such runts make up about 15 percent of the stars in the galaxy, though astronomers had not found planets around one before. All three planets were discovered as periodic dips in starlight in late 2015 using TRAPPIST, a telescope at La Silla Observatory in Chile.

If anything does crawl or grow on these worlds, it bathes in mostly infrared light. The innermost planets receive several times as much energy from their star as Earth does from our sun, which technically puts them outside the star's habitable zone (*SN: 4/30/16, p. 36*). But the planets are huddled up so close to the star that gravity might keep one side of the planets permanently facing the star, creating a temperate zone along the line where day turns to night, the researchers say.

Faint red stars such as this one are the best place to look for warm rocky planets, says Nicolas Cowan, an astronomer at McGill University in Montreal. Planets, even small ones, are easier to see around these dim bulbs than they are around sunlike stars. NASA's planet-hunting Kepler space telescope has already shown that planets exist around similar stars, but those are too far away to investigate further. "This [study] finds a nearby example," Cowan says.

Being nearby is important for studying the atmospheres of such worlds, or learning whether they have atmospheres at all. They may not. Red dwarf stars take a long time to form; planets arise while their sun is still a puffy, temperamental ball of contracting gas. "That might bake off all the water and the atmosphere," Cowan says. Astronomers won't know, though, until they point some big telescopes toward these worlds.

The Hubble Space Telescope might be able to get a crude look. But NASA's James Webb Space Telescope, scheduled to launch in 2018, could gaze at these planets and measure how much starlight is being absorbed by molecules in their atmospheres. If there is an atmosphere, James Webb could look for such gases as oxygen and methane (*SN: 4/30/16, p. 32*). On Earth, at least, those gases are produced by plants and microbes.

Whether or not life has found a home on these worlds, all offer a peek at unfamiliar environments. The two planets closest to the star, for instance, are bombarded with more energy than Venus, notes Lisa Kaltenegger, an astronomer at Cornell University. "How would Venus evolve if you heat it up even more?" she asks. "We don't have such planets in our own solar system, so it is really interesting to find out what such planets can be like." ■

GENES & CELLS

One gene governs finch beak size

Galápagos bird's postdrought molecular evolution detailed

BY TINA HESMAN SAEY

Natural selection can sometimes work one gene at time, a new study of Darwin's finches suggests.

Variants of one gene had a major effect on rapid changes in beak size after a drought, researchers report in the April 22 *Science*. The finding may help explain how Darwin's finches evolved into 18 species in an evolutionarily speedy 1 million to 2 million years.

Medium ground finches (*Geospiza fortis*, shown) shifted from big beaks to small ones after a drought. Most of that shift was traced to big- and small-beak variants of a gene called *HMGA2*.

A drought that struck the Galápagos island of Daphne Major in 2004 and 2005 put adaptation of some of Darwin's iconic finches on fast-forward. Competition for scarce seeds pitted medium-sized ground finches (*Geospiza fortis*) with big beaks against large ground finches (*G. magnirostris*) with big beaks. Big-beaked medium ground finches lost that contest. They died in large numbers, but medium ground finches with small beaks survived by eating small seeds. As a result, medium ground finches on the island tended to have smaller beaks after the drought than before.

Genetic variants of the *HMGA2* gene control beak size in the birds, evolutionary geneticist Leif Andersson and colleagues now report. Birds with large-beak varieties of the gene were at a strong disadvantage during the drought, the researchers find.

The study takes "arguably the most elegant story in evolutionary biology and then fills in the nitty-gritty molecular details," says Hopi Hoekstra, an evolutionary biologist at Harvard University. While the researchers don't know precisely how the gene influences beak size, the work may help scientists better understand the genetic underpinnings of evolution, she says. "This is a beautiful and big first step."

> The study takes "arguably the most elegant story in evolutionary biology and then fills in the nitty-gritty molecular details."
>
> **HOPI HOEKSTRA**

Andersson, of Uppsala University in Sweden, teamed with Princeton University's Peter and B. Rosemary Grant, who have been documenting changes in populations of Darwin's finches for decades. The researchers previously discovered that a gene called *ALX1* controls whether beaks are blunt or pointy (*SN: 3/7/15, p. 7*). But beak shape didn't seem to play a role in surviving the drought, the team found. Instead, beak size changed.

Andersson's group narrowed the search for the gene controlling beak size to a stretch of DNA that contains *HMGA2* and three other genes. The researchers can't rule out that the other genes also affect beak size but say *HMGA2* is the gene most strongly associated with the trait. It accounts for almost 30 percent of the shift in beak size during the drought, Andersson says. HMGA2 protein is known to help regulate how other genes are turned on or off. In humans and mice, the gene is associated with height, face development and other traits.

Birds that have two copies of the large-beak variant of the gene have big beaks, while two copies of the small-beak variant produce little beaks. Birds with one of each have intermediate-sized beaks. The small-beak variant was found 61 percent of the time in finches that survived the drought, but only 37 percent of the time in birds that died.

It's unusual for a single gene to have such a strong effect on survival, says plant ecologist Thomas Givnish of the University of Wisconsin–Madison. Researchers have documented many cases in which multiple genes each affect a trait a little bit. Genes with big effects may explain rapid evolutionary shifts.

Small-beak variants of *HMGA2* aren't new changes brought on by the drought, Andersson says. The variant has been around for a long time, perhaps 1 million years or more, and may have come from interbreeding with tree finches, the researchers find.

Interbreeding between species is proving to be a powerful evolutionary force, says Daniela Palmer, an evolutionary biologist at the University of Chicago. Researchers are documenting more and more examples of interbreeding influencing evolution of organisms as diverse as butterflies and humans (*SN: 3/5/16, p. 18*), she says. "Hybridization contributes major genetic variation to shape adaptation." ■

P.R. GRANT

BODY & BRAIN

Ions, not neurons, may oversee sleep

Potassium spike in brain initiates eye-opening jolt, study finds

BY TINA HESMAN SAEY

To rewrite an Alanis Morissette song, the brain has a funny way of waking you up (and putting you to sleep). Isn't it ionic? Some scientists think so.

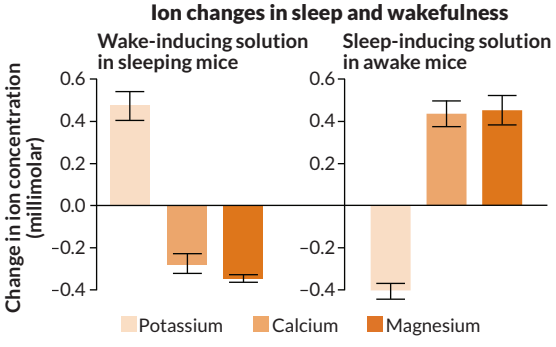
Changes in ion concentrations, not nerve cell activity, switch the brain from asleep to awake and back again, researchers report in the April 29 *Science*. Scientists knew that levels of potassium, calcium and magnesium ions bathing brain cells changed during sleep and wakefulness. But they thought neurons — electrically active cells responsible for most of the brain's processing power — drove those changes.

Instead, the study suggests, neurons aren't the only sandmen or roosters in the brain. "Neuromodulator" brain chemicals, which pace neuron activity, can directly wake the brain or lull it to sleep by changing ion concentrations.

Scientists hadn't found this direct connection between ions and sleep and wake before because they were mostly focused on what neurons were doing, says neuroscientist Maiken Nedergaard, who led the study. She got interested in sleep after her lab at the University of Rochester in New York found a drainage system that washes the brain during sleep (*SN: 11/16/13, p. 7*). When measuring changes in the fluid between brain cells, Nedergaard and colleagues realized that ion changes followed predictable patterns: Potassium ion levels are high when mice (and presumably people) are awake and drop during sleep. Calcium and magnesium ions follow the opposite pattern; they are higher during sleep and lower when mice are awake.

In the study, Nedergaard's group administered a "wake cocktail" of neuromodulator chemicals to mouse brains. Levels of potassium ions floating between brain cells increased rapidly after the treatment. That ion change happened even when the researchers added tetrodotoxin to stop neuron activity. The results suggest that the brain chemicals — norepinephrine, acetylcholine, dopamine, orexin and histamine — directly affect ion levels with no help from neurons. Exactly how the chemicals manage ion levels still isn't known.

Similar changes happen under anesthesia. When awake mice were anesthetized, potassium ion levels in their brains dropped sharply, while levels of calcium and magnesium rose. As mice awoke from anesthesia, potassium



Stirring slumber When scientists infuse a cocktail of eye-opening chemicals into the brains of sleeping mice (left), levels of potassium ions rise while calcium and magnesium ion concentrations fall. But a nightcap of sleep-inducing brain chemicals pumped into awake mice (right) causes potassium ion concentrations to plummet, while calcium and magnesium ion levels rise.
SOURCE: F. DING *ET AL*/*SCIENCE* 2016

BODY & BRAIN

Left brain stands guard while asleep

Vigilance in unfamiliar places may serve as safety measure

BY LAURA SANDERS

Away from home, people sleep with one ear open.

In unfamiliar surroundings, part of the left hemisphere keeps watch while the rest of the brain is deeply asleep, scientists report in the May 9 *Current Biology*. The results help explain why the first night in a hotel isn't always restful.

Some aquatic mammals and birds sleep with half a brain at a time, a trick called unihemispheric sleep. Scientists have believed that humans, however, do not show any such asymmetry in their slumber.

Yuka Sasaki of Brown University in Providence, R.I., and colleagues looked for signs of asymmetry on the first night that young, healthy people came into their sleep lab. Usually, scientists toss the data from the inaugural night because the sleep is so disturbed, Sasaki says. But she and her team thought that some interesting sleep patterns might lurk within that fitful sleep. "It was a little bit of a crazy hunch," she says, "but we did it anyway."

During a deep sleep stage known as slow-wave sleep, a network of nerve cells in the left side of the brain showed less sleep-related activity than the corresponding network on the right side. Those results suggest that the left side of the brain is a lighter sleeper. "It looked like the left hemisphere and the right hemisphere did not show the same degree of sleep," Sasaki says. This imbalance disappeared on the second night of sleep.

This more vigilant brain system is the left hemisphere's default mode network, a collection of nerve cells active when the brain isn't doing anything in particular. It's not clear how this network keeps watch during sleep, or if it works alone.

The left side of the brain reacted faster to quiet sounds on the first night of sleep, further experiments revealed. Tones played to the right ear, which sends sounds to the brain's left hemisphere, were more likely to rouse sleeping people than tones played to the left ear. And response times were faster on the

M. TELFER

ion levels rose quickly. But calcium and magnesium levels took longer to drop. As a result, the mice "are totally confused," Nedergaard says. "They bump into their cages, they run around and they don't know what they are doing."

Those results may help explain why people are groggy after waking up from anesthesia; their calcium and magnesium ion levels haven't yet returned to "awake" levels, says Amita Sehgal, a sleep researcher at the Perelman School of Medicine at the University of Pennsylvania.

Learning more about how ions affect wakefulness and sleep may eventually lead to a better understanding of sleep, consciousness and coma, Nedergaard says.

But, says neuroscientist Chiara Cirelli of the University of Wisconsin–Madison, practical implications of the new work, such as improved sleep drugs, are probably far in the future. How researchers will make use of the new finding is not yet known, she says, "but just knowing this is certainly very eye-opening." It would be interesting, she adds, to find out what happens to ion concentrations during REM sleep, when neurons are as active as they are when a person is awake. ■

first night than the second.

Because the experiment tested only the first slow-wave sleep session of the nights, the scientists don't know whether the left hemisphere keeps watch all night long. Further experiments are needed to see if the right side ever takes a turn, Sasaki says.

This alertness make sense, says sleep researcher Jerome Siegel of UCLA. "Sleep is only adaptive if it doesn't produce risks that outweigh its benefits," he says. And safe sleep often entails keeping an eye on the environment. A more general version of this vigilance probably happens in familiar places, too, Siegel says, pointing to the old saw that a parent can sleep through a thunderstorm but awaken to a baby's whimpers. ■

BODY & BRAIN

Dragons sleep like mammals, birds

Brain activity of lizards shows signs of two-state slumber

BY SARAH SCHWARTZ

Lizards might snooze like humans do.

Sleeping lizards appear to share distinctive brain activity patterns with sleeping birds and mammals, researchers report in the April 29 *Science*. If true, the results suggest that human sleep patterns evolved by around 300 million years ago in a common ancestor of birds, mammals and reptiles.

During sleep, mammal and bird brains alternate between two states of activity. In deep slow-wave sleep, recordings of the brain's electrical activity show sparse bursts of big, slow waves. During rapid eye movement, or REM, sleep, brain waves appear small and fast, like those of an awake brain. REM sleep is usually accompanied by quickly twitching eyes.

"The prevailing view has been that REM and slow-wave sleep are limited to mammals and birds," says study coauthor Gilles Laurent, a neuroscientist at the Max Planck Institute for Brain Research in Frankfurt. Many researchers think that birds and mammals separately evolved this similar sleep pattern, Laurent says. So when he and his colleagues monitored dozing Australian dragons (*Pogona vitticeps*), they were surprised to find familiar patterns.

"We saw this two-state sleep in the lizard, which we definitely did not expect," says study coauthor Mark Shein-Idelson, also of the Max Planck Institute for Brain Research.

While sleeping, this Australian dragon shows brain wave patterns similar to those of slumbering birds and mammals.

STEPHAN JUNEK/MPI FOR BRAIN RESEARCH

While exhibiting REM-like brain waves, the dragons' eyes flicked, a convincing sign that lizards sleep like mammals, Shein-Idelson says. Probes implanted in the dragons' brains revealed hundreds of cycles of alternating slow-wave–like and REM-like sleep each night. Lizards' sleep cycles were simple and speedy, though — each around 80 seconds on average, compared with up to an hour and a half in humans, Laurent says.

But some scientists say more evidence is required to prove that the dragons are truly experiencing two-state sleep.

"It is possible that the dragons were immobile with eyes closed — but awake," says John Lesku, a comparative sleep researcher at La Trobe University in Melbourne, Australia. REM brain activity looks similar to that of an awake brain. Neuroscientist Niels Rattenborg of the Max Planck Institute for Ornithology in Seewiesen, Germany, points out that eye movements and limb twitching in REM sleep can also be hard to distinguish from brief awakenings. Additional evidence — showing that it's difficult to rouse a lizard during apparent REM sleep — would support the case that the dragons are truly snoozing, Rattenborg says.

Laurent says that sleeping lizards did show other signs of sleep, including reduced muscle activity and low heart rate, and could often be moved without waking. And the team observed gradual changes in brain wave patterns, such as increasing sleep cycle length over the course of a night, which would be unexpected if the lizards were constantly waking up.

If lizards do experience REM and slow-wave sleep, two-state sleep probably stems from a common ancestor of all reptiles, birds and mammals that lived some 320 million to 300 million years ago, Laurent says. An even older creature could be the true founder of two-state sleep, he adds. But to support this idea, researchers would need to find such sleep patterns in more distant relatives, such as fish or amphibians. ■

MATTER & ENERGY

Even quantum information is physical

Erasing qubits emits heat, as predicted by Landauer's principle

BY EMILY CONOVER

Information may seem ethereal, given how easily we forget phone numbers and birthdays. But scientists say information is physical, and if a new study is correct, that's true in quantum systems, too.

Although pages of text or strings of bits seem easily erased with the press of a button, the act of destroying information has a tangible physical impact, according to a principle proposed in 1961 by physicist Rolf Landauer. Deleting information is associated with an increase in entropy, or disorder, resulting in the release of a certain amount of heat for each erased bit.

This principle has been verified experimentally for systems that follow the familiar laws of classical physics. But the picture has remained fuzzy for quantum mechanical systems, in which particles can be in multiple states at once and their fates may be linked through the spooky process of quantum entanglement.

Now a team of scientists reports in the April *Proceedings of the Royal Society A* that Landauer's principle holds even in that wild quantum landscape. "Essentially what they've done is test [this principle in] a very detailed and quantitative way," says physicist John Bechhoefer of Simon Fraser University in Burnaby, Canada. "And they're showing that this works in a quantum system, which is a really important step." Testing Landauer's principle in the quantum realm could be important for understanding the fundamental limits of quantum computers, Bechhoefer says.

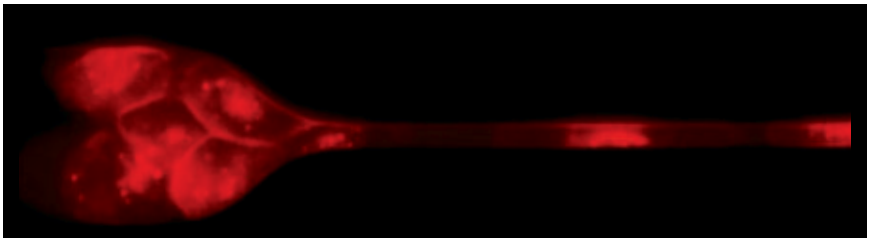
To verify Landauer's principle, the researchers used a system of three qubits — the quantum version of the bits found in a typical computer — made from trifluoroiodoethylene, a molecule that has three fluorine atoms. The nuclei of these atoms have a quantum property known as spin. That spin can be clockwise or counterclockwise, serving the same purpose as a 0 or 1 for a standard bit.

The first qubit, called the "system," contains the information to be erased. According to Landauer's principle, when the information is erased, heat will be generated and energy will flow to the second qubit, known as the "reservoir." Just as computer scientists can perform operations on bits (adding or subtracting numbers, for instance), the researchers could apply operations to the fluorine qubits by using pulses of radio waves to tweak the state of the nuclear spins.

But making measurements of quantum systems is tricky, says team leader Lucas Céleri, a physicist at Federal University of Goiás in Brazil. "In a quantum world, every time you measure the system, you interact with it," thereby changing it. So the team used a work-around. The third qubit was coupled to the reservoir and could measure the heat generated without mucking up the qubits of interest.

When the researchers erased information, heat was generated as expected from Landauer's principle. They looked at the average of multiple measurements, because quantum fluctuations mean that any single trial won't necessarily conform to the principle. "It's a very nice demonstration of Landauer's principle in a quantum system, cleverly conceived and well carried out," says quantum physicist Seth Lloyd of MIT.

But some researchers suggest more work is needed. In a traditional test of Landauer's principle, the reservoir would not be a single qubit but a large "heat bath" of many particles, physicists Jukka Pekola of Aalto University in Finland and Jonne Koski of ETH Zurich wrote in an e-mail. The study's authors therefore had to account for additional entropy introduced as a result of their single-particle reservoir. To perform a more conventional test of Landauer's principle at the quantum level, Pekola and Koski say, the researchers need to investigate a qubit that interacts with a reservoir consisting of more particles. ■



S.H. AU *ET AL*/*PNAS* 2016

GENES & CELLS

Clusters of cancer cells move single file

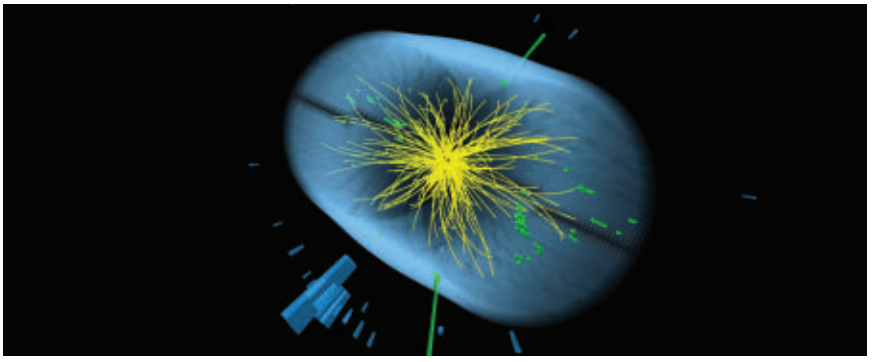
In narrow blood vessels, tumor cells go marching one by one.

By unfolding into a cellular chain, clusters of cancer cells can slide through capillary tubes less than 10 micrometers wide, Sam Au of Harvard Medical School and colleagues report in the May 3 *Proceedings of the National Academy of Sciences*. The cells pass through the tubes in single file, each squeezing into an oblong shape and clinging to a neighbor or two (as shown with the human breast cancer cells, bright red, above). After arriving in roomier quarters, the cells regroup into round clumps, the scientists report.

Cancer cell clumps that break off tumors and travel through the blood spread cancer more efficiently than single cells. But many scientists thought the clusters were unable to squeeze through the narrowest blood vessels.

In experiments, breast and prostate cancer cells used this single file strategy to travel through lab-made tubes, tubes lined with human cells, and blood vessels of live zebrafish. — *Sarah Schwartz*

Watch cancer cells squeeze through capillaries at **bit.ly/SN_cancerclumps**



Hints of a possible new particle that decays into two photons show up in proton collisions at the Large Hadron Collider, as in an event (illustrated) seen by the CMS detector.

CMS/CERN

ATOM & COSMOS

Hints of new particle baffle physicists

Hundreds of papers attempt to explain unexpected LHC data

BY EMILY CONOVER

Physicists may soon know if a potential new subatomic particle is something beyond their wildest dreams — or doesn't exist at all.

Hints of the new particle emerged last December at CERN's Large Hadron Collider outside Geneva. Theorists attempting to explain the existence of the particle, assuming that it's not a statistical fluke, are now beginning to converge on the most likely explanations.

"If this thing is true, it's huge. It's very different than what the last 30 years of particle physics looked like," says theoretical physicist David Kaplan of Johns Hopkins University.

The speculation was triggered by a subtle wiggle in data from two LHC experiments, ATLAS and CMS. The bump in the data suggests a new particle that decays into two photons (*SN: 1/9/16, p. 7*). But what that particle might be is unclear — its properties don't line up with scientists' expectations.

"I'm not aware of anybody who'd predicted the existence of such a particle," says theoretical physicist John Ellis of King's College London. "There's a dish on the table that nobody can remember ordering."

More than 300 papers posted online at arXiv.org take a shot at explaining the potential particle's origins, and on April 12, *Physical Review Letters* published four papers, selected to give a sense of the kinds of theories that could explain the observations.

One of the most plausible explanations, scientists say, is that the particle is a composite, made up of smaller constituents, much like protons and neutrons are made of quarks. The strong nuclear force binds quarks in these nucleons; the new particle would be composed of quarklike particles held together by a new type of strong force. "That's the model that works the best with the data," says theoretical physicist Kathryn Zurek of Lawrence Berkeley National Laboratory in California.

The particle could also be similar to the Higgs boson — which was discovered at the LHC in 2012 (*SN: 7/28/12, p. 5*) — but with a mass six times as large. Still other theories propose that the possible new particle is a graviton, which is believed to transmit the force of gravity. The biggest constraint on devising a theory, or model, to explain the new particle's origins is that it has so far revealed itself in only one type of decay, producing two photons. If it decays to two photons, says theoretical physicist Matthew Buckley of Rutgers University in Piscataway, N.J., "you might expect that it also goes to other things, and the fact that we don't see that makes it difficult for many models to be right."

Additionally puzzling is that the particle doesn't seem to easily solve any of the major mysteries of particle physics. It doesn't provide an obvious explanation for dark matter, an unidentified substance that makes up more than 80 percent of the matter in the universe. And it doesn't easily explain a persistent puzzle known as the hierarchy problem, which is related to the mass of the Higgs. According to theory, physicists would naïvely expect the Higgs to have an enormously large mass, but for unknown reasons, it is found at a much lower scale.

Many physicists had pinned their hopes for solving these problems on a theoretical concept called supersymmetry, which proposes that each known particle has a heavier partner. But although theorists have concocted supersymmetric explanations for the new possible particle, it doesn't seem to fit easily into that box, either. "This thing doesn't smell like supersymmetry," says Caltech experimental particle physicist Maria Spiropulu, who is also affiliated with CMS.

The lack of simple explanations makes some physicists more skeptical that the particle really exists. They think it's more likely just a blip that will disappear with more data. "If it had been something that was confidently expected in some well-motivated scenario like supersymmetry, then I think people would be a lot more confident about its reality," Ellis says.

Updated analyses presented by ATLAS and CMS in March strengthened the case slightly, making physicists more optimistic that the hints will hold up with more data. Notably, Spiropulu says, the first signs of the long-sought Higgs boson showed up in a similar fashion before they were confirmed. So, she says, theoretical physicists have a license to be excited and speculate. "It is expected that they will run amok," she says.

After a few months on hiatus, the LHC experiments resumed taking data in early May. So scientists expect answers by this summer, when more data could provide additional details — or make the hints of a new particle evaporate. ■

HUMANS & SOCIETY

Ancient surgery had ritual purpose

Skull cutting 6,000 years ago was not medical treatment

BY BRUCE BOWER

Surgery has some surprisingly ritual roots.

Between around 6,000 and 4,000 years ago, skilled surgeons in southwestern Russia cut holes, many the size of a silver dollar or larger, out of the backs of people's skulls. But the risky procedure wasn't performed for medical reasons: These skull surgeries fulfilled purely ritual needs, a new study suggests. And those on the cutting end of the procedure usually lived.

Skulls of 13 people previously excavated at seven ancient sites in this region contain surgical holes in roughly the same spot, in the middle of the back of the head, say archaeologist Julia Gresky of the German Archaeological Institute in Berlin and her colleagues. That's a particularly dangerous location for this kind of skull surgery, also known as trepanation, the scientists report online April 21 in the *American Journal of Physical Anthropology*. It's not an area of the skull typically targeted in ancient trepanations, which go back roughly 11,000 years in West Asia.

"There may have been an original medical purpose for these trepanations, which over time changed to a symbolic treatment," Gresky says.

Archaeologist Maria Mednikova of the Russian Academy of Sciences in Moscow agrees that skulls in Gresky's new study probably represent cases of ritual trepanation. She previously examined some of the same skulls. Trepanation may have been used in some ancient cultures as part of a rite of passage for people taking on new social roles, Mednikova speculates.

Carving a center hole in the back of people's heads was a potentially fatal procedure. Surgeons would have needed to know precisely how deep to scrape or grind bone to avoid penetrating a blood-drainage cavity for the brain. They also had to know how to stop potentially fatal bleeding of veins nicked during surgery. The procedure must have been performed as fast as possible to minimize bleeding, the researchers suspect.

Yet 11 of 13 skull openings show signs of healing and bone regrowth, indicating that these individuals survived the operation and often lived for years after. The researchers identify six males and six females in the skull sample. One specimen's sex couldn't be determined from skull features.

> "There may have been an original medical purpose for these trepanations, which over time changed to a symbolic treatment."
>
> JULIA GRESKY

Most individuals died between ages 20 and 40. One female with a layer of bone that had regrown from the inside border of a trepanation hole died between ages 14 and 16, suggesting her skull surgery had occurred as young as age 10, the researchers estimate.

CT scans, X-rays and analyses of bone surfaces produced no evidence of injuries or brain tumors that could have motivated surgery. Ancient skull surgery intended as a medical treatment often involved holes on the side of the head, near fractures from some type of blow (*SN Online: 4/25/08*). It's impossible to determine from bones whether trepanations were aimed at treating chronic headaches, epilepsy, psychological problems or difficulties attributed to evil spirits.

Other evidence, in addition to the risky and unusual location of trepanation holes, points to ritual skull surgeries in southwestern Russia, Gresky says. Many of these individuals were interred according to special customs, suggesting they ranked high in their societies. For instance, the skulls of seven people buried in a pit at one site had been grouped together near bundled fragments of limb bones in a special display. Incisions on the limb bones indicate that bodies had been dismembered after death before being ritually buried. Of the seven skulls, five display surgical openings at the back of the head. Another contains possible scrapes from a partial trepanation, Mednikova says. Partial trepanations were probably intentional rather than unfinished, with their own cultural significance, she says.

Trepanation holes on the sides of another six skulls found at the same Russian sites were probably made to treat medical conditions, Gresky says. Surgical openings on several of these skulls are located near bone fractures.

Rituals and meanings attached to ancient trepanations in southwestern Russia will remain mysterious, predicts Mednikova. "We don't know the myths and religions of tribes that lived there 6,000 years ago." ■

J. GRESKY

An almost 6,000-year-old human skull from southwestern Russia contains a large opening at the back of the head created by cutting away bone with a sharp instrument. Researchers suspect many skull surgeries at that time in this part of Russia were done for ritual reasons.

BODY & BRAIN

How ketamine really fights depression

In mice, drug's metabolite eases symptoms without side effects

BY LAURA SANDERS

Ketamine, a drug that has shown promise in quickly easing depression in people, doesn't actually do the job itself. Instead, depression relief comes from one of the drug's breakdown products, a study in mice suggests. The results, published online May 4 in *Nature*, identify a potential depression-fighting drug that works quickly but without ketamine's serious side effects or potential for abuse.

The discovery "could be a major turning point," says neuroscientist Roberto Malinow of the University of California, San Diego. "I'm sure that drug companies will look at this very closely."

Depression is a pernicious problem with few good treatments. Traditional antidepressants don't work for everyone, and when the drugs do work, they can take weeks to kick in. Ketamine, developed in the 1960s as a sedative and now used by veterinarians to knock out animals, can ease depression in minutes, not weeks, small studies show.

The new study suggests that a metabolite of ketamine — not the drug itself — fights depression. Inside the body, ketamine gets converted into a slew of related molecules. One of these molecules, called (2R,6R)-hydroxynorketamine, is behind the benefits, neuropharmacologist Todd Gould of the University of Maryland School of Medicine in Baltimore and colleagues find.

On its own, a single dose of (2R,6R)-HNK reduced signs of depression in mice, restoring their drive to search for a hidden platform in water, to try to escape a shock and to choose sweet water over plain. A type of ketamine that couldn't be broken down easily into HNKs didn't ease signs of depression.

Ketamine comes with serious side effects — hallucinations, floating sensations and clumsiness, for example. And at high enough doses, the drug is an anesthetic. But (2R,6R)-HNK may avoid these problems, experiments on mice movement indicate. And since ketamine has already been used to treat depression, Gould says, the breakdown product has been inside people with no apparent ill effects. He and colleagues plan to test the metabolite in clinical trials of people with depression. ■

EARTH & ENVIRONMENT

Failure spurred current El Niño

False start's stored-up heat led to record 2015–16 event

BY THOMAS SUMNER

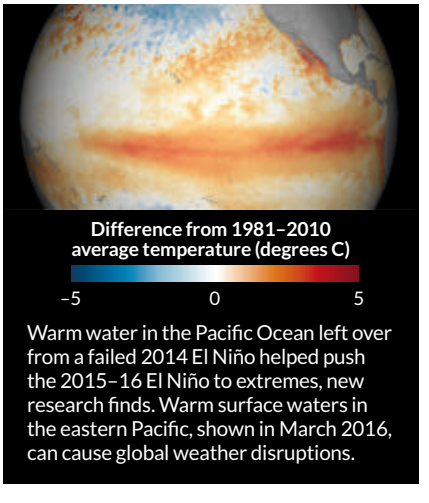
The historic El Niño event currently shaking up Earth's weather rose like a phoenix from the hot remains of a failed 2014 El Niño, new research suggests.

In 2014, the scientific community buzzed about the possibility of a supersized El Niño as warm Pacific Ocean water sloshed eastward. That July, however, large winds pushed westward and halted the budding El Niño (*SN: 11/1/14, p. 6*). Those same winds also prevented the release of stored-up ocean heat, researchers report in a paper to be published in *Geophysical Research Letters*. In March 2015, that lingering heat gave the 2015–16 El Niño a jump start toward the extreme, the researchers propose.

The ongoing El Niño is among the three strongest on record. Such a once-in-a-generation event would have been less likely without the failed 2014 El Niño, says study coauthor Michael McPhaden, a physical oceanographer at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle.

"In a sense, we dodged a bullet in 2014," he says. "But that was short-lived, because the conditions that shut that developing El Niño down set up the big one in 2015."

El Niños typically form every two to seven years when Pacific winds shift a large, near-surface pool of warm water eastward. That warm water then rises to the surface and releases its heat into the atmosphere, causing global shifts in storms, precipitation and temperatures.



Warm water in the Pacific Ocean left over from a failed 2014 El Niño helped push the 2015–16 El Niño to extremes, new research finds. Warm surface waters in the eastern Pacific, shown in March 2016, can cause global weather disruptions.

NOAA ENVIRONMENTAL VISUALIZATION LAB

The fizzled 2014 El Niño followed by a colossal event in 2015–16 is very unusual, McPhaden says. He and climate scientist Aaron Levine, also at the Pacific Marine Environmental Laboratory, wondered if the sequence of events was a coincidence. The pair looked at decades of El Niño climate data and ran computer simulations of various hypothetical El Niño events.

Under typical ocean conditions, the chances of a 2015–16 El Niño of any strength are about 27 percent, the researchers estimate. The remnant heat from the failed 2014 El Niño increased those odds to about 40 percent. Having a failed El Niño the previous year stacks the deck in favor of an El Niño. But it "isn't a guarantee," Levine says. Strong El Niños also require strong winds, he says.

Forecasting those winds is tricky because the winds and warm water "are all part of the same system," says climate scientist Kevin Trenberth of the National Center for Atmospheric Research in Boulder, Colo. Ocean heat can cause atmospheric changes that can influence the winds. The new work gives insights, he says, "but it is far from complete." ■

BODY & BRAIN

Role of iron in Parkinson's debated

Data conflict on whether too much or too little metal raises risk

BY LAURA SANDERS

Iron, says aging expert Naftali Raz, is like The Force. It can be good or bad, depending on the context. When that context is the human brain, though, scientists wrangle over whether iron is a dark force for evil or a bright source of support.

Some iron is essential for the brain. On that, scientists agree. But recent studies suggest that too much iron, and the chemical reactions that ensue, can be dangerous, especially to nerve cells in the vulnerable brain area that deteriorates with Parkinson's disease.

Writing in the April issue of *Brain*, analytical neurochemist Dominic Hare and collaborator Kay Double argue that the chemical messenger dopamine teams up with iron to form a "toxic couple" that destroys nerve cells, or neurons. This troublesome duo, with its resulting chemical products, is particularly dangerous in the substantia nigra, the dopamine-rich part of the brain damaged in Parkinson's, Hare, of the University of Technology Sydney, and Double, of the University of Sydney, propose.

Yet other work raises the possibility that those neurons die from too little iron, rather than too much.

"There are a lot of surprises in this field," says iron biologist Nancy Andrews of Duke University.

The idea that too much iron is dangerous captivates many researchers. "All of life is a chemical reaction," Hare says, "so the start of disease is a chemical reaction as well."

And as Raz points out, reactions involving iron are both life-sustaining and dangerous. "Iron is absolutely necessary for conducting the very fundamental business in every cell," says Raz, of Wayne State University in Detroit. It helps produce energy-storing ATP molecules. And that's a dirty job, throwing off dangerous free radicals that can cause cellular mayhem as energy is made.

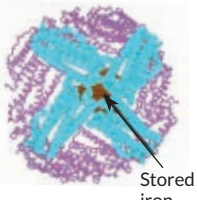
But those free radicals are not the most worrisome aspect of iron, Hare believes. "The reaction that is much more dangerous is the reaction you get when iron and dopamine come together."

Dopamine has a number of breakdown products, and one of these, produced by interactions with iron, is 6-hydroxydopamine, a compound that "sounds innocuous, but it's very damaging," Hare says. "There are essential chemicals that you don't want to put together." Like gas and an open flame, dopamine and iron are best kept apart.

When protective coatings that surround and protect dopamine deteriorate, or when iron levels rise, cells can be harmed by these unintended chemical reactions. And because the substantia nigra is awash in both dopamine and iron, neurons there may be exposed to an extra-large dose of 6-hydroxydopamine.

But as evidence accumulates about the dangers of excess iron, other scientists argue that it's a lack of iron — not too much — that endangers substantia nigra neurons.

This part of the brain is packed with iron, but that abundance may be deceiving, says Tracey Rouault of the National Institutes of Health in Bethesda, Md. She argues that the substantia nigra is a natural iron reservoir that simply stores the essential element for use. "People who don't get Parkinson's also have iron in those areas," she says. "No one to my satisfaction has proven that the iron is excessive."



A spherical protein called ferritin can store iron safely in an interior pocket, keeping the element from reacting with other compounds inside cells.

What's more, those elevated iron levels seen in the substantia nigra of people with Parkinson's may not be in the neurons themselves. Instead, iron may be packed inside scavenger immune cells called microglia, which gobble up damaged debris. "Our eyes are fooling us," Rouault says. Neurons that appeared to be overfed with iron may actually be starving.

Evidence of this starvation diet comes from experiments by Andrews, the Duke iron biologist, and colleagues. They genetically engineered mice to lack a protein that ferries iron into substantia nigra neurons. Without enough iron, dopamine-making neurons slowly withered, first losing their connections to other cells before dying. Movement problems accompanied this neural destruction, Andrews and colleagues reported in the March 29 *Proceedings of the National Academy of Sciences*. "If they can't get iron in to begin with, they're going to have a problem," Andrews says.

Even in the midst of an environment teeming with iron, it seems that neurons might not be getting enough — "the opposite of what people have been saying," Andrews says. She points to a study that found that people who gave blood frequently in a five-year span, and as a result may have been iron-depleted, had a higher risk of Parkinson's. Still, more work is needed to show that a functional iron deficit is behind neural damage in

Diseases related to iron overload in the brain

Disease	Disease gene	Clinical features
Pantothenate kinase-associated neurodegeneration (PKAN)	*PANK2*	Childhood-onset dystonia and spasticity
Fatty acid hydroxylase-associated neurodegeneration (FAHN)	*FA2H*	Trouble speaking, gait abnormalities, dystonia and parkinsonism
Neuroferritinopathy	*FTL*	Abnormal gait late in disease

Too much iron These three genetic diseases belong to a small group of disorders marked by excess iron in the brain. Rare cases like these may help clarify iron's role in other disorders such as Parkinson's disease. SOURCE: T.A. ROUAULT/*NATURE REVIEWS NEUROSCIENCE* 2013

T.A. ROUAULT/*NATURE REVIEWS NEUROSCIENCE* 2013

Parkinson's, she acknowledges.

These iron contradictions come in part from the complexity of the brain itself. Iron can pile up in places other than in neurons, and the element exists in many forms, some of which are more reactive than others. What's more, techniques to measure iron in a living brain don't provide the resolution needed to see clearly what's going on.

Meanwhile, other lines of evidence continue to suggest that too much iron is in fact hazardous. Some experiments indicate that high iron levels, which are known to increase with age, may damage myelin, the insulating material that protects nerve fibers, for instance. In elderly people, high-iron, low-myelin brains are more likely to come with poorer memory performance, Tineke Steiger of the University of Lübeck in Germany and colleagues reported in the March 23 *Journal of Neuroscience*. Because myelin itself is iron-rich, its demise could lead to even more buildup of iron, increasing the damage, Steiger says.

Some scientists, convinced of iron's dangers, are pursuing a Parkinson's therapy that strips the brain of excess iron. Their hope is that they can stop dangerous reactions by sopping up iron in the substantia nigra early enough to slow or prevent Parkinson's progression.

Neurologist and neuroscientist David Devos of the University of Lille, University Hospital Center and France's National Institute of Health and Medical Research is testing this approach. In a small pilot study, he and colleagues found that an iron-slurping chelator called deferiprone may have promise. Nineteen people who took the drug — already used to treat rare diseases caused by too much iron — had lower iron levels in their substantia nigra after six months on the drug.

More important, these people also showed slight improvements in movement, Devos and colleagues reported in 2014 in *Antioxidants & Redox Signaling*. The researchers have just enrolled their first two patients in what will be a much larger trial in Europe. In that trial, participants will begin the chelating treatment soon after their Parkinson's diagnosis, a design that Devos hopes will protect vulnerable neurons before they are irrevocably damaged.

Skeptics such as Andrews don't have confidence in this approach. "If the problem is a neuronal deficit, you could make it worse," she says. But Hare politely disagrees. "Science is science, and people disagree a lot. We try to disprove other people's theories," he says. "I think the evidence there is big enough to test it." ■

BODY & BRAIN

Words' meanings mapped in brain

Language comprehension spreads all across cortex

BY MEGHAN ROSEN

Language pops up everywhere in the brain.

All across the wrinkly expanse of the brain's outer layer, a constellation of regions handles the meaning of language, scientists report in the April 28 *Nature*.

One region that responds to *family*, *home* and *mother*, for example, rests in a tiny chunk of tissue on the right side of the brain, above and behind the ear. That region and others were revealed by an intricate new map that charts the location of hundreds of areas that respond to words with related meanings.

Such a detailed map hints that humans comprehend language in a way that's much more complicated than previously thought, says Stanford University neuroscientist Russell Poldrack. "These data suggest we need to rethink how the brain organizes meaning."

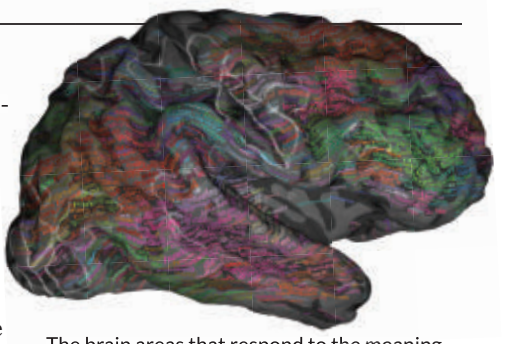
Scientists knew that different concepts roused action in different parts of the brain, says study coauthor Jack Gallant, a neuroscientist at the University of California, Berkeley. But people generally thought that big hunks of the brain each dealt with different concepts separately: one region for concepts related to vision, for example, another for concepts related to emotion. And conventional wisdom said the left hemisphere was most important.

Previous studies had tested just single words or sentences, and made only rough estimates of where meaning showed up, Gallant says. That's like looking at the world's countries in Google maps, instead of zooming in to the street view.

So he and colleagues mapped the activity of some 60,000 to 80,000 pea-sized regions across the cerebral cortex in seven people who lay in a functional MRI machine and listened to stories from *The Moth Radio Hour*.

Gallant's team used a computer program to decipher the meaning of every one- to two-second snippet of the stories and then cataloged where 985 concepts showed up. Meanings conveyed by different words didn't just engage the left hemisphere, but instead switched on groups of nerve cells spread across the brain's surface. After mapping where meaning was represented, the researchers figured out where individual words might show up. Often, the same word appeared in different locations; the word *top* turned up in a spot with clothing words and in an area related to measurements.

One day, Gallant says, the work could potentially help those with ALS or locked-in syndrome to communicate — by decoding a person's thoughts. But that's just one piece of the puzzle, he says. Researchers would also need to devise a portable method for measuring brain activity, unlike MRI machines. ■



The brain areas that respond to the meaning of words speckle much of the cerebral cortex, the wrinkly outer layer of the brain.

ALEXANDER HUTH, PYCORTEX SOFTWARE BY JAMES GAO, MARK LESCROART AND A. HUTH

EARTH & ENVIRONMENT

Lead levels in drinking water vary seasonally

Lead contamination in drinking water can change with the seasons. Tracking lead levels in water pipes over nearly two years, researchers discovered three times as much dissolved lead and six times as much undissolved lead in summer than in winter. The finding could help improve water testing, says study coauthor Sheldon Masters, an environmental engineer at Virginia Tech and Corona Environmental Consulting in Philadelphia.

Masters and colleagues analyzed water contamination data collected from pipes in Washington, D.C., and Providence, R.I., and tested the dissolvability of lead in different water conditions. In many homes and lab tests, the amount of lead leaching into water rose as water temperature increased.

For pipes in Washington, for instance, average wintertime dissolved lead levels were 3.6 parts per billion, compared with 10.8 ppb during summer. Average undissolved lead concentrations varied from 7.6 ppb in winter to 48.4 ppb in summer. Each 1 degree Celsius rise in water temperature boosted dissolved lead levels by about 17 percent and lead particles by about 36 percent, the researchers report online April 14 in *Environmental Science & Technology*. Washington water temperature varied from about 5° to 30° C. Seasonal variations in lead were smaller than those expected from temperature changes alone, since other factors such as the amount of organic matter in water can also influence lead levels.

Some water systems could meet the regulatory standard of less than 15 ppb in winter while exceeding that threshold during warmer months, the researchers warn. — *Thomas Sumner*

LIFE & EVOLUTION

Baby titanosaur was mini-adult

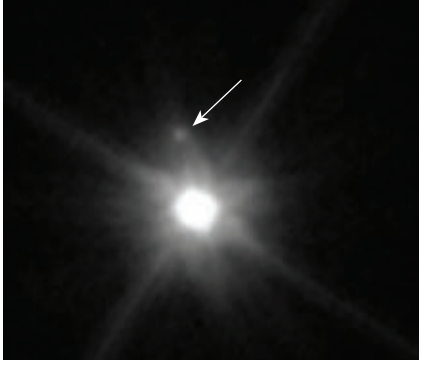
A baby titanosaur looked a lot like a grown-up — and it probably acted like one, too.

The (relatively) tiny fossils of a roughly 1- to 2-month-old dinosaur, *Rapetosaurus krausei*, discovered in what is now Madagascar, suggest that babies and adults had similar limb proportions, researchers report in the April 22 *Science*. That's a sign that the babies were precocious, or didn't require a lot of parental care, says study coauthor Kristi Curry Rogers, a vertebrate paleontologist at Macalester College in St. Paul, Minn. After hatching, she says, the tiny titanosaur may have been more self-reliant than babies of other dinosaur species.

Just weeks after birth, a titanosaur called *Rapetosaurus krausei* was about the size of a dog (left). The baby dino had similar limb proportions to an adult (right), suggesting that youngsters didn't require much care.

A lack of very young titanosaur specimens has made it tough to understand the enormous dinosaurs' growth patterns. Curry Rogers and colleagues estimate that when newly hatched, the baby weighed 3.4 kilograms — about as much as a newborn human. But within just a few weeks, the dinosaur's weight shot up to 40 kilograms, closer to a 12-year-old boy's.

During the growth spurt, all of the baby's limbs grew at about the same rate, the team calculated using data from microscopic images and CT scans. Those data plus features of the bones' tissue point toward a life that, though cut short by starvation, was both active and independent. — *Meghan Rosen*



ATOM & COSMOS

Tiny moon orbits dwarf planet

In the backwaters of the solar system lies the dwarf planet Makemake. The tiny world has an even tinier moon, NASA announced April 26. The moon was spotted in Hubble Space Telescope images as a smudge orbiting Makemake (shown above, arrow points to moon).

Researchers estimate that the moon, temporarily dubbed S/2015 (136472) 1, is about 160 kilometers wide; its home world is about 1,400 kilometers across. The satellite appears to trek around Makemake once every 12 days or more. The moon's motion can help researchers determine the mass of Makemake, one of the largest known bodies in the Kuiper belt. — *Christopher Crockett*

LIFE & EVOLUTION

Prions may help plants remember

Prions — which show their dark side in mad cow disease — may occur in plants as a form of memory.

Prions are proteins that change shape and shift tasks, and then trigger other proteins to make the same change. Inheriting prions lets cells "remember" and replicate a shift in form and function. A protein called luminidependens, which is connected with flowering, shows signs of these shapeshifter powers, researchers report online April 25 in the *Proceedings of the National Academy of Sciences*.

Susan Lindquist of the Whitehead Institute for Biomedical Research in Cambridge, Mass., and colleagues tested plant proteins for prion power by swapping bits of them into yeast prions. Luminidependens, found in the common lab plant *Arabidopsis thaliana*, fit the criteria, and may be the first botanical protein shown to act like a prion. Prion-like memory might be useful in such tasks as keeping track of winter's chill. — *Susan Milius*

FROM TOP: NASA, ESA, A. PARKER AND M. BUIE/SWRI; R. MARTIN AND K. CURRY ROGERS

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MISGUIDED MATH

Faulty Bayesian reasoning may explain some mental disorders

By Laura Sanders

From within the dark confines of the skull, the brain builds its own version of reality. By weaving together expectations and information gleaned from the senses, the brain creates a story about the outside world. For most of us, the brain is a skilled storyteller, but to spin a sensible yarn, it has to fill in some details itself.

"The brain is a guessing machine, trying at each moment of time to guess what is out there," says computational neuroscientist Peggy Seriès.

Guesses just slightly off — like mistaking a smile for a smirk — rarely cause harm. But guessing gone seriously awry may play a part in mental illnesses such as schizophrenia, autism and even anxiety disorders, Seriès and other neuroscientists suspect. They say that a mathematical expression known as Bayes' theorem — which quantifies how prior expectations can be combined with current evidence — may provide novel insights into pernicious mental problems that have so far defied explanation.

Expectations
People have assumptions about the world, which are either inborn or learned early in life. For example:

- Light comes from above.
- Noses stick out.
- Objects move slowly.
- Background images are uniformly colored.
- Other people's gazes are directed at us.

Bayes' theorem "offers a new vocabulary, new tools and a new way to look at things," says Seriès, of the University of Edinburgh.

Experiments guided by Bayesian math reveal that the guessing process differs in people with some disorders. People with schizophrenia, for instance, can have trouble tying together their expectations with what their senses detect. And people with autism and high anxiety don't flexibly update their expectations about the world, some lab experiments suggest. That missed step can muddy their decision-making abilities.

Given the complexity of mental disorders such as schizophrenia and autism, it is no surprise that many theories of how the brain works have fallen short, says psychiatrist and neuroscientist Rick Adams of University College London. Current explanations for the disorders are often vague and untestable. Against that frustrating backdrop, Adams sees great promise in a strong mathematical theory, one that can be used to make predictions and actually test them.

"It's really a step up from the old-style cognitive psychology approach, where you had flowcharts with boxes and labels on them with things like 'attention' or 'reading,' but nobody having any idea about what was going on in [any] box," Adams says.

Applying math to mental disorders "is a very young field," he adds, pointing to *Computational Psychiatry*, which plans to publish its first issue this summer. "You know a field is young when it gets its first journal."

A mind for math

Bayesian reasoning may be new to the mental illness scene, but the math itself has been around for centuries. First described by the Rev. Thomas Bayes in the 18th century, this computational approach truly embraces history: Evidence based on previous experience, known as a "prior," is essential to arriving at a good answer, Bayes argued. He may have been surprised to see his math meticulously applied to people with mental illness, but the logic holds. To make a solid guess about what's happening in the world, the brain must not rely just on current input from occasionally unreliable senses. The brain must also use its knowledge about what has happened before. Merging these two streams of information correctly is at the heart of perceiving the world as accurately as possible.

> "The brain is a guessing machine, trying at each moment of time to guess what is out there."
> PEGGY SERIÈS

Bayes figured out a way to put numbers to this process. By combining probabilities that come from prior evidence and current observations, Bayes' formula can be used to calculate an overall estimate of the likelihood that a given suspicion is true. A properly functioning brain seems to do this calculation intuitively, behaving in many cases like a skilled Bayesian statistician, some studies show (*SN: 10/8/11, p. 18*).

This reckoning requires the brain to give the right amount of weight to prior expectations and current information. Depending on the circumstances, those weights change. When the senses falter, for instance, the brain should lean more heavily on prior expectations. Say the mail carrier comes each day at 4 p.m. On a stormy afternoon when visual cues are bad, we rely less on sight and more on prior knowledge to guess that the late-afternoon noise on the front porch is probably the mail carrier delivering letters. In certain mental illnesses, this flexible balancing act may falter.

People with schizophrenia often suffer from hallucinations and delusions, debilitating symptoms that arise when lines between reality and imagination blur. That confusion can lead to hearing voices that aren't there and believing things that can't possibly be true. These departures from reality could arise from differences in how people integrate new evidence with previous beliefs.

There's evidence for such distorted calculations. People with schizophrenia don't fall for certain visual illusions that trick most people, for instance. When shown a picture of the inside of a hollowed-out face mask, most people's brains mistakenly convert the image to a face that pops outward off the page. People with schizophrenia, however, are more likely to see the face as it actually is — a concave mask. In that instance, people with schizophrenia give more weight to information that's coming from their eyes than to their expectation that noses protrude from the rest of the face.

People easily fall for this illusion, seeing the hollow face on the right as protruding out, like the one on the left. People with schizophrenia aren't as easily fooled.

To complicate matters, the opposite can be true, too, says neuropsychologist Chris Frith of the Wellcome Trust Centre for Neuroimaging at University College London. "In this case, their prior is too weak, but in other cases, their prior is too strong," he says.

In a recent study, healthy people and those who recently began experiencing psychosis, a symptom of schizophrenia, were shown confusing shadowy black-and-white images. Participants then saw color versions of the images that were easier to interpret. When shown the black-and-white images again, people with early psychosis were better at identifying the images, suggesting that they used their prior knowledge — the color pictures — to truly "see" the images. For people without psychosis, the color images weren't as much help. That difference suggests that the way people with schizophrenia balance past knowledge and present observations is distinct from the behavior of people without the disorder. Sometimes the balance tips too far — in either direction.

In a talk at the annual Computational and Systems Neuroscience meeting in February in

Where there's smoke
18th century English clergyman Thomas Bayes formulated a way to calculate the likelihood of an event based on prior knowledge (in this example, the probability of a dangerous fire).

Dangerous fires are rare (1 percent), but since you live next to a Peruvian chicken restaurant, smoke is fairly common (20 percent). Almost all fires come with smoke (95 percent). You see smoke out of your window. Is it time to evacuate?

$$P(\text{Fire}|\text{Smoke}) = \frac{P(\text{Fire})\,P(\text{Smoke}|\text{Fire})}{P(\text{Smoke})} = \frac{(1\%)\,(95\%)}{20\%} = 4.75\%$$

Probability that there is a dangerous fire when you see smoke

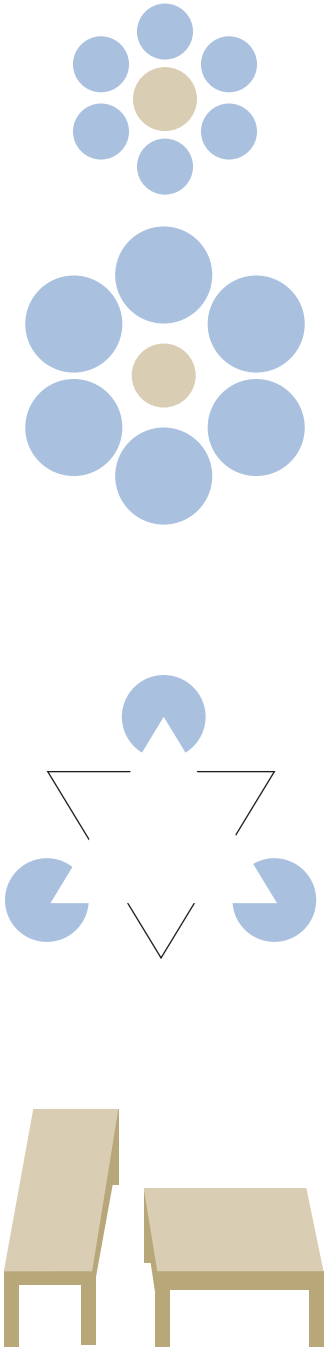
Probability of dangerous fire

Probability of seeing smoke if there is a fire

Probability of seeing smoke

In this case, smoke means dangerous fire 4.75 percent of the time.

E. PELLICANO AND D. BURR/*TRENDS IN COGNITIVE SCIENCES* 2012



Mind games Prior expectations lead most people to incorrectly think that the brown dots (top) are different sizes, that large triangles exist between the blue Pac-Man shapes (middle) and that the table tops have different areas. People with autism or schizophrenia are less susceptible to such visual illusions.

Salt Lake City, Seriès described the results of a different visual test: A small group of people with schizophrenia had to describe which way a series of dots were moving on a screen. The dots moved in some directions more frequently than others — a statistical feature that let the scientists see how well people could learn to predict the dots' directions. The 11 people with schizophrenia seemed just as good at learning which way the dots were likely to move as the 10 people without, Seriès said. In this situation, people with schizophrenia seemed able to learn priors just fine.

But when another trick was added, a split between the two groups emerged. Sometimes, the dots were almost impossible to see, and sometimes, there were no dots at all. People with schizophrenia were less likely to claim that they saw dots when the screen was blank. Perhaps they didn't hallucinate dots because of the medication they were on, Seriès says. In fact, very early results from unmedicated people with schizophrenia suggest that they actually see dots that aren't there more than healthy volunteers.

Preliminary results so far on schizophrenia are sparse and occasionally conflicting, Seriès admits. "It's the beginning," she says. "We don't understand much."

The research is so early that no straightforward story exists yet. But that's not unexpected. "If 100 years of schizophrenia research have taught us anything, it's that there's not going to be a nice, simple explanation," Adams says. But using math to describe how people perceive the world may lead to new hunches about how that process goes wrong in mental illnesses, he argues.

"You can instill expectations in subjects in many different ways, and you can control what evidence they see," Adams says. Bayesian theory "tells you what they should conclude from those prior beliefs and that evidence." If their conclusions diverge from predictions, scientists can take the next step. Brain scans, for instance, may reveal how the wrong answers arise. With a clear description of these differences, he says, "we might be able to measure people's cognition in a new way, and diagnose their disorders in a new way."

Now vs. then

The way the brain combines incoming sensory information with existing knowledge may also be different in autism, some researchers argue. In some cases, people with autism might put excess weight on what their senses take in about the world and rely less on their expectations. Old observations fit with this idea. In the 1960s, psychologists had discovered that children with autism were just as good at remembering nonsense sentences ("By is go tree stroke lets") as meaningful ones ("The fish swims in the pond"). Children without autism struggled to remember the non sequiturs. But the children with autism weren't thrown by the random string of words, suggesting that their expectations of sentence meaning weren't as strong as their ability to home in on each word in the series.

Another study supports the notion that sensory information takes priority in people with autism. People with and without autism were asked to judge whether a sight and a sound happened at the same time. They saw a white ring on a screen, and a tone played before, after or at the same time. Adults without autism were influenced by previous trials in which the ring and tone were slightly off. But adults with autism were not swayed by earlier trials, researchers reported in February in *Scientific Reports*.

This literal perception might get in the way of speech perception, Marco Turi of the University of Pisa in Italy and colleagues suggest. Comprehending speech requires a listener to mentally stitch together sights and sounds that may not arrive at the eyes and ears at the same time. Losing that flexibility could make speech harder to understand.

A different study found that children with autism perceive moving dots more clearly than children without autism (*SN Online: 5/5/15*). The brains of people with autism seem to prioritize incoming sensory information over expectations about how things ought to work. Elizabeth Pellicano of University College London and David Burr of the University of Western Australia in Perth described the concept in 2012 in an opinion paper in *Trends in Cognitive Sciences*. Intensely attuned to information streaming in from the senses, people with autism experience the world as "too real," Pellicano and Perth wrote.

New data, however, caution against a too-simple explanation. In an experiment presented in New York City in April at the annual meeting of the Cognitive Neuroscience Society, 20 adults with and without autism had to quickly hit a certain key on a keyboard when they saw its associated target on a screen. Their job was made easier because the targets came in a certain sequence. All of the participants improved as they learned which keys to expect. But when the sequence changed to a new one, people with autism faltered. This result suggests that they learned prior expectations just

E. OTWELL

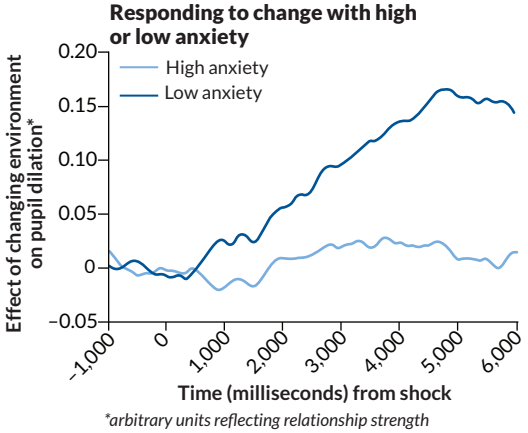
fine, but had trouble updating them as conditions changed, said cognitive neuroscientist Owen Parsons of the University of Cambridge.

Distorted calculations — and the altered versions of the world they create — may also play a role in depression and anxiety, some researchers think. While suffering from depression, people may hold on to distorted priors — believing that good things are out of reach, for instance. And people with high anxiety can have trouble making good choices in a volatile environment, neuroscientist Sonia Bishop of the University of California, Berkeley and colleagues reported in 2015 in *Nature Neuroscience*.

In their experiment, people had to choose a shape, which sometimes came with a shock. People with low anxiety quickly learned to avoid the shock, even when the relationship between shape and shock changed. But people with high anxiety performed worse when those relationships changed, the researchers found. "High-anxious individuals didn't seem able to adjust their learning to handle how volatile or how stable the environment was," Bishop says.

Scientists can't yet say what causes this difficulty adjusting to a new environment in anxious people and in people with autism. It could be that once some rule is learned (a sequence of computer keys, or the link between a shape and a shock), these two groups struggle to update that prior with newer information.

This rigidity might actually contribute to anxiety in the first place, Bishop speculates. "When something unexpected happens that is bad, you wouldn't know how to respond," and that floundering "is likely to be a huge source of anxiety and stress."



Stress shutdown People with higher levels of anxiety (light blue) learned less from shocks (measured by changes in pupil size) when the environment changed than people with low anxiety (dark blue).

SOURCE: MICHAEL BROWNING *ET AL*/*NATURE NEUROSCIENCE* 2015

BOTH: M. TELFER

Random words

Want fetch come go film has do say

Sentence

The nurse has come to fetch the boy

Memory test In a 1967 study, children with autism were just as good at remembering nonsense strings of words as they were at remembering sentences. The results suggest that they had weaker expectations about meaningful sentences.

Recalculating

"There's been a lot of frustration with a failure to make progress" on psychiatric disorders, Bishop says. Fitting mathematical theories to the brain may be a way to move forward. Researchers "are very excited about computational psychiatry in general," she says.

Computational psychiatrist Quentin Huys of the University of Zurich is one of those people. Math can help clarify mental illnesses in a way that existing approaches can't, he says. In the March issue of *Nature Neuroscience*, Huys and colleagues argued that math can demystify psychiatric disorders, and that thinking of the brain as a Bayesian number cruncher might lead to a more rigorous understanding of mental illness. Huys says that a computational approach is essential. "We can't get away without it." If people with high anxiety perform differently on a perceptual test, then that test could be used to both diagnose people and monitor how well a treatment works, for instance.

Scientists hope that a deeper description of mental illnesses may lead to clearer ways to identify a disorder, chart how well treatments work and even improve therapies. Bishop raises the possibility of developing apps to help people with high anxiety evaluate situations — outsourcing the decision making for people who have trouble. Frith points out that cognitive behavioral therapy could help depressed people recalculate their experiences by putting less weight on negative experiences and perhaps breaking out of cycles of despondence.

Beyond these potential interventions, simply explaining to people how their brains are working might ease distress, Adams says. "If you can give people an explanation that makes sense of some of the experiences they've had, that can be a profoundly helpful thing," he says. "It destigmatizes the experience." ■

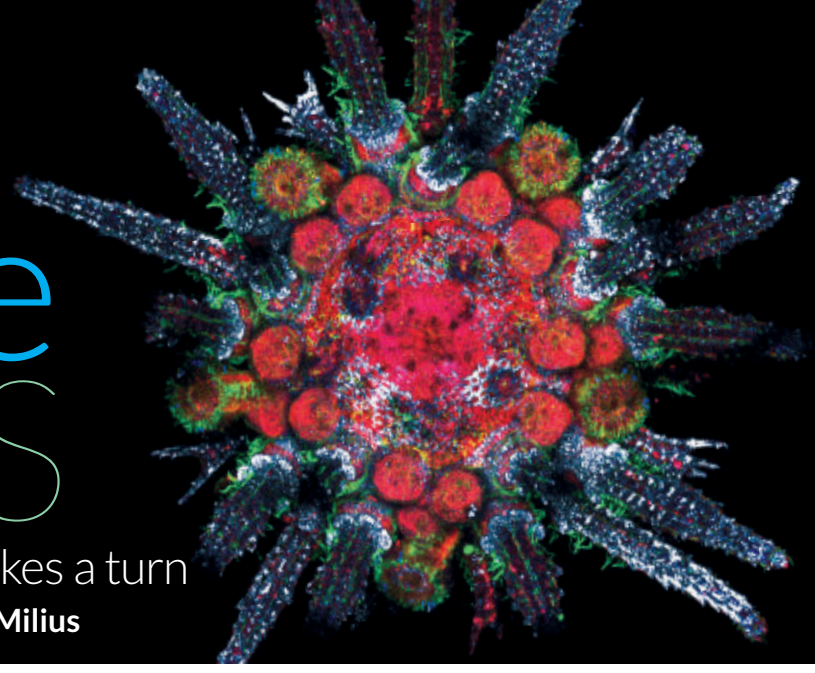
Explore more

- Q. Huys, T. Maia and M. Frank. "Computational psychiatry as a bridge from neuroscience to clinical applications." *Nature Neuroscience*. March 2016.

Strange VISIONS

The study of animal sight takes a turn toward the bizarre

By Susan Milius



A lab image of a juvenile purple sea urchin (*Strongylocentrotus purpuratus*) — without obvious eyes — shows an abundance of light-detecting proteins, such as c-opsins (red).

FROM TOP: E.M. ULLRICH-LÜTER *ET AL/INTEGR. COMP. BIOL.* 2013; © HOPPENRATH *ET AL.*, LICENSEE BIOMED CENTRAL LTD. 2009 (CC BY 2.0)

It sounds like a riddling trick: How can an animal with no eyes still see? But it's a serious scientific question — the trickiest kind of riddle.

Sea urchins don't have anything that people recognize as an eye, says Sönke Johnsen of Duke University. Urchin bodies are mobile pincushions in purples and pinks to browns and blacks, bristling with a mix of spiky spines and soft, stretchy tube feet.

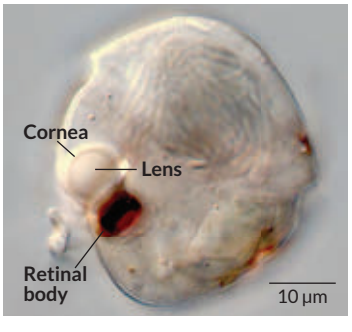
Yet at times urchins act as if they "see" large-enough somethings in their world, even if the how and what of their visual systems have been hard to pin down. "Maddening," Johnsen says. "They almost always have what looks like purposeful behavior, but you can't quite put your finger on it because there's something so alien about them."

Thus 21st century science has come to take seriously the idea that an urchin doesn't have an eye, but *is* an eye. Earth may be home to creatures whose whole bodies serve as big eyeballs crawling on a thousand tiny, soft feet.

This crawling-eyeball hypothesis illustrates a surge of interest in exotic vision. For decades, a few vertebrates (including humans, goldfish and cats) plus fewer insects (mostly honeybees) dominated vision research. No more. "We're not just focusing on eyes that look like our eyes," Johnsen says.

More recent investigations explore eyeballs in creatures too small to have brains to use them, skin with a light-sense of its own, vision in scallops and octopuses and in butterflies that, via the twists of evolution, developed eyes on their heads as well as light sensors on their rumps. Looking into such a wide array of strange eyes or almost-eyes reveals how evolution has solved the basic problem of extracting information from light in an extraordinary variety of ways.

"What it means to be an eye is so much broader than we originally thought," Johnsen says. In all this diversity, who's to say an urchin can't be its own spiny eyeball? The idea has been challenging to test, with brainstorms bumping against frustrations. Years of research delved into parts of the idea, and then a burst of discovery about genes for opsins, the main light-catching molecules in animal vision, changed the rules. Through it all, urchins continue to be maddening wonders.



What looks a bit like a vertebrate eye, with cornea, lens and light-catching retinal body, evolved in a tiny single-cell warnowiid (*Proterythropsis* shown).

Eye icon

The eye has held a special place in biology since Victorian eyeballs caught sight of, and possibly squinted skeptically at, Chapter VI in *On the Origin of Species*. Under "Difficulties of the Theory," Charles Darwin chose the eyeball as an example of "organs of extreme perfection and complications." To imagine that such a marvel arose by mere evolutionary happenstance, he wrote, "seems, I freely confess, absurd in the highest degree."

Of course he doesn't really allow this alleged absurdity to ding his lifework's theory. He immediately proposes a way for extreme perfection to start simple: The building blocks of a fancy eye, he points out, could themselves in their simple form "be useful to any animal under changing conditions of life." Minimal light-sensitive cells might not manage even the blurriest image, but could sense big changes such as day turning to night.

Darwin's absurd eyeball was presumably a camera-style belonging to a vertebrate. (Light enters through a cornea and lens, which focus it on the "film," the swath of light-sensitive photoreceptor cells at the back.) Current research excursions far beyond vertebrate eyeballs are taking the ideas in Chapter VI to new places.

A paper published last year in *Nature*

traced the origin of the simpler parts of a camera-style structure, the parts that Darwin thought must have been useful in themselves. The structure, however, was not in a human or even an animal but in single-celled marine plankton.

A microscopic lens-and-film structure, an ocelloid as it's called, peers out cyclopslike from one side of certain predatory warnowiids. Flicking a little flagellum tail sends a warnowiid corkscrewing through the ocean, the ocelloid scanning as the cell turns.

The diameter of the film in the plankton's microcamera is tiny even compared with the wavelengths of light it receives, says study coauthor Gregory Gavelis of the University of British Columbia in Vancouver. The view through such an "eye," if "you were to project it on a screen, would probably look like one pixel," he says.

Simpler sensitive spots let other microbes swim toward, or flee, light according to their needs. So Gavelis wonders if warnowiids do something more complex with their ocelloid. That single pixel could be useful, he speculates, if it detected some quirk of light, maybe polarization, reflecting off prey.

Even at this scale, Darwin was correct about eye components evolving from simpler structures that had their own uses. The main clear bulge that serves as lens and cornea in warnowiids evolved from what were once mitochondria, vital power stations in the cell. And the swath of photoreceptors that act as film in the camera came from a stolen chloroplast, a nugget that had transformed sunlight into carbohydrates to feed some ancient red alga.

Scaling up to actual animals finds new and odd examples of eye parts useful in their simplified form, even in animals that also have complex image-forming eyes.

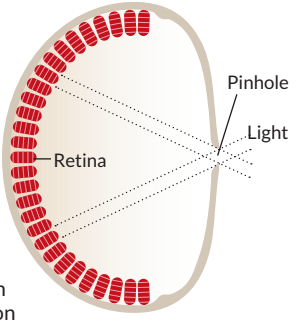
Octopuses stare out of camera-style eyes that are remarkably like vertebrates'. But octopus skin also has photoreceptors that detect light and then cue color changes, Todd Oakley and Desmond Ramirez of the University of California, Santa Barbara reported in 2015 in the *Journal of Experimental Biology*. Shifting color can communicate or camouflage. Exposure to light can trigger waves of yellow and brown even in bits of skin completely detached from the octopus — no connection to a brain needed (*SN: 6/27/15, p. 10*).

Backup sensors for awkward body parts might explain eyespots in Asian swallowtail butterflies (*Papilio xuthus*). They flap pale, stained-glass wings, and their insect-style, compound eyes can outdo human vision to detect ultraviolet or polarized light. Despite these capable eyes, both males and females of the species have eyespots, the most basic of light-sensing organs — just a cluster of photoreceptors — on their genitals.

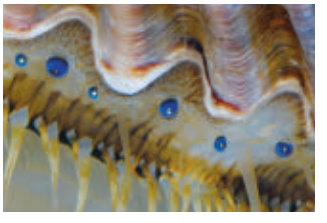
The genital eyespots may help with basic butterfly positioning, suggests Kentaro Arikawa of the Graduate University for Advanced Studies in Hayama, Japan. In his tests, males that had their eyespots removed fumbled during mating as if having trouble orienting themselves. Spotless females had a different problem. They mated and found leaves on which to lay their eggs, as they normally do. But without feedback from eyespots,

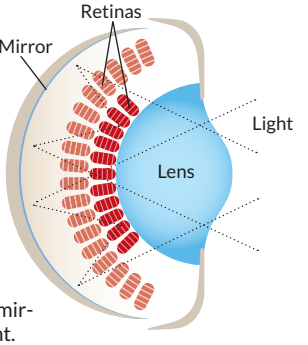
Oddball eyes

The familiar vertebrate eyeball with a lens focusing light on a retina is just one of 10 basic kinds of visual organs that have evolved in animals. Here are four underwater standouts.

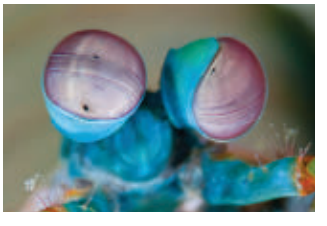


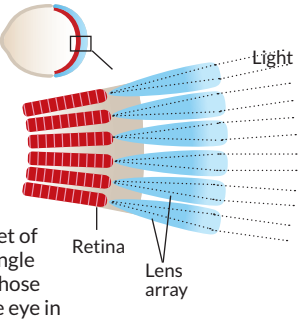
Nautilus This invertebrate relative of squids doesn't use a lens. The tiny eye opening restricts light entry much as a pinhole allows an image to form on film inside the simplest cameras.



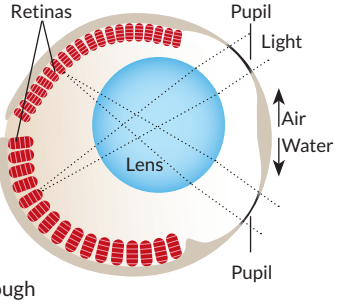


Scallop The tiny eyes rimming the body of a scallop look like vertebrate eyes, but in the 1960s, researchers showed that it's not the lens but the mirror at the rear that's focusing the light.





Mantis shrimp Each clear outer facet of this compound eye sends light to a single photosensitive structure. A zone of those structures (band across middle of the eye in image) holds the color-detecting sensors.



Four-eyed fish These are vertebrate eyes with special features handy for swimming at the surface. Light from the airy world enters through a different opening and registers on a separate retina than light from water below.

SOURCES: NAUTILUS AND FISH: T.W. CRONIN *ET AL/VISUAL ECOLOGY* PRINCETON UNIV. PRESS, 2014; D.I. SPEISER, E.R. LOEW, AND S. JOHNSEN/*J. EXPT. BIOL.* 2011; T.W. CRONIN

the females failed to actually lay any eggs, Arikawa reported in 2001.

Simple parts can be reworked in different combinations for lots of eye diversity. Giant clams, sometimes larger than a soup tureen, watch for danger with many tiny pinhole cameras punctuating the lips of their mantle. So-called four-eyed fish double each of their two eyes, one half better tuned to seeing above water and the other better for below the surface.

Scallops at first glance look as if they have vertebrate eyes, a rim of dozens of mini-marble eyeballs, some sky-blue with a dark spot of pupil. Scallops and people have eyed each other for millennia, but not until the 1960s did Michael Land of the University of Sussex in England demonstrate that the mirrored surface at the back of the mollusk's eyeball does most of the image focusing, as does the lens in a vertebrate eye.

Scallop eyes have a "squishy" lens that makes only minor adjustments as light streams in and hits the eyeball's inner mirror, says Daniel Speiser of the University of South Carolina in Columbia. As the light bounces forward again, the mirror's curve focuses it mainly on one of two retinas stacked well within the eyeball. After more than a decade of puzzling over what a second retina might do in scallop eyes, Speiser says "they remain confounding." But their focusing mirror beat Newton's reflecting telescope by millennia.

Inscrutable urchins

Where urchins fit in this parade of animal vision remains to be seen.

To be a crawling eyeball in the best sense of the term means detecting not just light but also where it comes from. "If you just have a ball, the ball can't really see," Johnsen says. Its own bulk might shade light on one side from reaching the other, but that's not much use for pinpointing light direction. To detect objects or form images, an eye needs more detailed information about where light is and isn't. Some structure has to restrict the incoming light for the photoreceptors. Putting together multiple bits of visual information is what yields an image.

Johnsen credits J.D. Woodley, then at the University of the West Indies in Jamaica, as an early source of the idea that urchins are roving eyeballs with an outer surface that is generally sensitive to light. What made an urchin's bun-shaped body able to locate where light comes from, he proposed, was shading from its many spines. In 1982, during a talk at the International Echinoderm Conference in Tampa, Fla., Woodley suggested that for any patch of urchin body, the forest of spines would allow only restricted shafts of light to penetrate. "It's like being down a well," Johnsen says. "You can only look up."

Experimenting with urchins and their echinoderm relatives is notoriously difficult. "You can have this whole group of animals that will do something that makes a lot of sense. But then you test them a few days later, or test a different batch, and you get a totally different answer," he says.

Nevertheless, Johnsen and his students built "a glorified wading pool" with a glass bottom raised enough for a person to slide underneath and look up at urchins moving on the bottom. "Like watching paint dry," he says. "They're painfully slow."

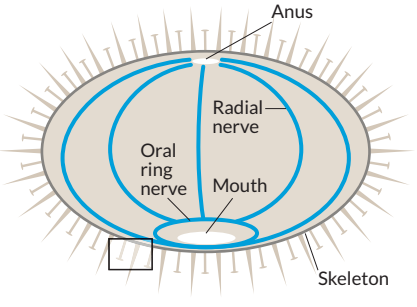
To give urchins a read-the-letters eye test, student Erin Blevins fastened various circles of black plastic one at a time to the pool's wall and released an urchin in the center. Two species of burrow-dwelling *Echinometra* urchins didn't seem to notice spots covering a small part, only 16 or 26 degrees, of the 360-degree view. But a larger, 33-degree spot drew urchins toward it, possibly by mimicking the dark entrance to a burrow, she and Johnsen reported in 2004. These urchins may not be great at resolving details, but they do more than just tell day from night.

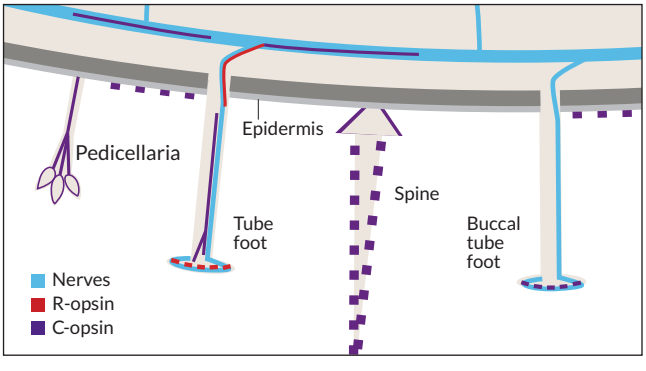
Testing another piece of Woodley's idea about spines, a later student, Divya Yerramilli, and Johnsen considered spine density. They hypothesized that urchins with dense spines might resolve details better than those with sparser coverings. The more tightly packed spines, in theory, would divide the light-sensitive urchin surface into a greater number of little areas with narrow views, a bit like more pixels reducing blur on a computer screen.

The two reported just that in 2010. Densely spined purple urchins (*Strongylocentrotus purpuratus*) detected a smaller spot than the more loosely spined species in earlier experiments. In the pool, the urchins detected a 10-degree black spot and tended to creep toward it or away. (The mix of retreat and advance may mean the spot was scary ... or inviting, hard to tell with alien minds.)

These results fit with the notion of spines shading the urchin surface, but they didn't prove that's what makes the vision work. "Figuring it out from there gets a little tougher,"

The details A sea urchin (schematic, right) has no centralized brain, just large nerves (blue) that connect to a ring around its mouth. However, its outer surface (below), with defensive spines, tube feet and pedicellariae grippers, has two kinds of light-detecting opsin proteins.

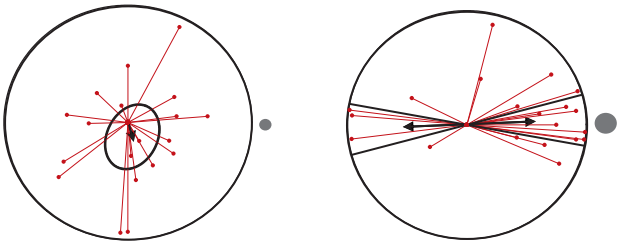




SOURCE: E.M. ULLRICH-LÜTER *ET AL/INTEGR. COMP. BIOL.* 2013

E. OTWELL

Seeing spots In a lab test for vision, purple urchins crawled from the center of a pool in random directions (left) as if they didn't see the small spot on the outer wall. With a larger spot, most urchins noticed, either approaching it or fleeing (right).



Johnsen says. "You have to do something gruesome like take the little spines off and the urchins sort of like — die."

Opsins everywhere

Then advances in automated genetic analysis led to a rush of discoveries of opsin molecules that told a twistier urchin story.

Opsins are the proteins that make animal eyes possible. People also have other light-sensing molecules, such as the cryptochromes that surge and fade to keep the body's day-night rhythms. But opsins are the celebrity molecules that let photoreceptors in the retinas of humans and other animals see.

The various opsins lie embedded in cell membranes and share the basic structure of a cluster of seven dangling curlicues. A naked opsin isn't of much use for vision, but its superpower is the ability to maintain a connection with a catcher's mitt of a molecule called a chromophore. The mitt absorbs a photon of light and unkinks itself into a longer, straighter form. That shape change triggers the attached opsin to change shape too, which sets off the biochemical cascade that ends up with a brain seeing, say, a carrot in all its orangeness. In humans and most other animals, chromophores are forms of retinal, derived from vitamin A, abundant in those showy carrots.

A sea urchin close-up shows surface spines as well as darker, stretching tube feet possibly involved in vision.

Thanks to DNA studies, the growth in sheer numbers of opsin forms being discovered is "explosive," says Thomas Cronin of the University of Maryland, Baltimore County. In 2012, Cronin's then-student Megan Porter and their colleagues published a family tree of the proteins' evolutionary relationships, created by using 889 opsins. "Probably the number of opsins that have been sequenced since then is 50 percent to 100 percent higher," Cronin says.

"We're at this point where we have all this information about the opsins that exist," says Porter, now at the University of Hawaii at Manoa. "But for a lot of these, we don't know what they're doing."

Some might not have anything to do with light at all. Opsins appear in sperm of mice and men, Michael Eisenbach of the Weizmann Institute of Science in Rehovot, Israel, and colleagues wrote last year in *Scientific Reports*. The opsins are sensitive to heat and may help sperm navigate their way by temperature, the researchers propose. If so, sperm opsins do it splendidly. A single sperm reacts to a difference of less than 0.0006 degrees Celsius across its body length. Rather than crawling eyeballs, sperm might just be swimming thermometers.

Urchins 2.0

Esther Ullrich-Lüter's opsin search was all about sea urchins when she worked in Maria Ina Arnone's lab at the Anton Dohrn Zoological Station in Naples, Italy. A big international collaboration had unveiled the majority of genes for the purple sea urchin in 2006, confirming that the animal without obvious eyes had genes for light-catching opsins. In fact, urchins have genes for at least eight different opsins.

With the genes' sequences in hand, Ullrich-Lüter could do molecular studies to locate them in the urchin body. This project started looking for particular opsin forms in urchin larvae (which are easy to get). After a year of slow progress, the researchers added adults as test subjects. In a what-if whim born of frustration, Ullrich-Lüter tested the adult tube feet. Bingo.

The soft extendible foot projections rise among the spines over the whole body of the urchin. At the tips of the feet and in a cavity at the base of each foot were concentrations of rhabdomeric opsins, which are vital to invertebrate vision, Ullrich-Lüter and the Arnone team reported in 2011. But these r-opsins were not scattered across the urchin surface, which would have supported the spine-shading idea. Ullrich-Lüter instead proposed that opsins in the little cavities at the bases of the tube feet would be shaded enough to detect light direction.

Plowing forward, the researchers uncovered a whole second visual system in the urchin, based on a different set of opsins. Ciliary opsins, or c-opsins, were scattered all over the urchin surface, Ullrich-Lüter and colleagues reported in 2013. "We thought, oh my god, this could be the reason for this long-proposed dermal light sense," she says. But it wasn't that simple.

The same study found c-opsins on the spines and tube feet too. If the spines themselves perceive light, she asks, how could they offer shading? Ullrich-Lüter and collaborators at Lund University in Sweden continue to study the puzzling animals. Her best bet is that the cavities around the feet are the key to urchin vision. Johnsen's current opinion: "Tough to say."

There may indeed be eyes in the maddening urchins. But it's going to take more science to see them. ■

Explore more

- Thomas W. Cronin *et al. Visual Ecology*. Princeton University Press, 2014.

FROM TOP: D. YERRAMILLI AND S. JOHNSEN/*J. EXP. BIOL.* 2010; JERRY KIRKHART/FLICKR (CC BY 2.0)

TELEVISION

Stephen Hawking finds the inner genius in ordinary people

It's hard to believe that it took reality television this long to get around to dealing with space, time and our place in the cosmos.

In PBS' *Genius by Stephen Hawking*, the physicist sets out to prove that anyone can tackle humankind's big questions for themselves. Each of the series' six installments focuses on a different problem, such as the possibility of time travel or the likelihood that there is life elsewhere in the universe. With Hawking as a guide, three ordinary folks must solve a series of puzzles that guide them toward enlightenment about that episode's theme. Rather than line up scientists to talk at viewers, the show invites us to follow each episode's trio on a journey of discovery.

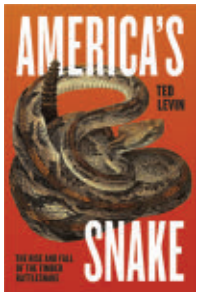
By putting the focus on nonexperts, *Genius* emphasizes that science is not a tome of facts handed down from above but a process driven by curiosity. After working through a demonstration of how time slows down near a black hole, one participant reflects: "It's amazing to see it play out like this."

The show is a fun approach to big ideas in science and philosophy, and the enthusiasm of the guests is infectious. Without knowing what was edited out, though, it's difficult to say whether the show proves Hawking's belief that anyone can tackle these heady questions. Each situation is carefully designed to lead the participants to specific conclusions, and there seems to be some off-camera prompting.

By playing catch while on a bare-bones carousel, participants in *Genius* discover the Coriolis effect.

Genius by Stephen Hawking
PREMIERES MAY 18
PBS

But the bigger message is a noble one: A simple and often surprising chain of reasoning can lead to powerful insights about the universe, and reading about the cosmos pales next to interacting with stand-ins for its grandeur. It's one thing, for example, to hear that there are roughly 300 billion stars in the Milky Way. But to stand next to a mountain of sand where each grain represents one of those stars is quite another. "I never would have got it until I saw it," says one of the guests, gesturing to the galaxy of sand grains. "This I get." — *Christopher Crockett*



America's Snake
Ted Levin
UNIV. OF CHICAGO, $35

BOOKSHELF

The life and times of an American icon, the timber rattlesnake

Turns out, it *is* possible to be a lucky snakebite victim. Depending on the circumstances (and the snake's mood, presumably), a timber rattlesnake may choose to strike its prey with only one fang and to pump out little or no venom when it does so. Far from being mindless, hair-triggered biting machines, timber rattlers don't always strike — even when stepped on.

In *America's Snake*, zoologist and snake enthusiast Ted Levin thoroughly recounts the anatomical marvels of the timber rattlesnake (*Crotalus horridus*) from head to tail. For instance, the snake — promoted by Benjamin Franklin as a symbol of the nascent United States, hence the book's title — has heat-sensitive pits on its snout that can sense temperature differences as small as 0.001 degrees Celsius. Tail muscles can shake the namesake rattle almost 90 times per second, uninterrupted, for hours.

But this delightful book is at its best when it delves into the weird world of the people associated with this species, including the scientists who study and seek to protect it, the property developers and suburban gardeners who revile it, and the poachers and bounty hunters who have decimated its populations.

Once found in at least 31 states, including all of the original 13 colonies, the timber rattler is now either extinct or endangered in several states, largely thanks to the vagaries of its life cycle and habits, Levin notes. In the Northeast, for instance, the snake's preferred habitat is steep rocky outcrops of south-facing terrain; winter chill forces the snakes to spend much of their lives in dens. Females typically don't breed until they're at least 6 years old and then just once every three to six years after that. And although a timber rattler can live more than 40 years, the fact that it usually returns each fall to the den in which it was born means that once a den's location is known, the snake and its den mates are vulnerable to poachers.

America's Snake is a tour of all senses. Levin's descriptions of his field trips include the slick feel of rain-moistened rocks; the bitter, acidic taste of acorns; and the gunpowder-like smell generated by boulders grinding against one another in a rockslide. — *Sid Perkins*

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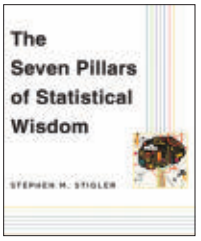
To find *Genius* airdates, visit **www.pbs.org/genius-by-stephen-hawking**



The Seven Pillars of Statistical Wisdom
Stephen M. Stigler
HARVARD UNIV., $22.95

BOOKSHELF

Despite misuses, statistics still has solid foundation

In many realms of science today, "statistical wisdom" seems to be in short supply. Misuse of statistics in scientific research has contributed substantially to the widespread "reproducibility crisis" afflicting many fields (*SN: 4/2/16, p. 8*; *SN: 1/24/15, p. 20*). Recently the American Statistical Association produced a list of principles warning against multiple misbeliefs about drawing conclusions from statistical tests. Statistician Stephen Stigler has now issued a reminder that there is some wisdom in the science of statistics. He identifies seven "pillars" that collectively provide a foundation for understanding the scope and depth of statistical reasoning.

Stigler's pillars include methods for measuring or representing aggregation (measures, such as averages, that represent a collection of data); information (quantifying it and assessing how it changes); likelihood (coping with probabilities); intercomparison (involving measures of variation within datasets); regression (analyzing data to draw inferences); design (of experiments, emphasizing randomization); and residual (identifying the unexplained "leftovers" and comparing scientific models).

His approach is to identify the historical origins of these seven key pillars, providing some idea of what they are and how they can assist in making sense of numerical data. His explanations are engaging but not thorough (it's not a textbook), and while mostly accessible, his writing often assumes a nontrivial level of mathematical knowledge. You'll have to cope with expressions such as $L(\Theta)=L(\Theta)|X$ and $Cov(L,W)=E\{Cov(L,W|S)\}+Cov(E\{L|S\}, E\{W|S\})$ every now and then.

While Stigler defends statistics from some of the criticisms against it — noting, for instance, that specific misuses should not be grounds for condemning the generic enterprise — he acknowledges that some issues are still a source of concern, especially in the new era of "big data" (*SN: 2/7/15, p. 22*). Using common statistical tests when many comparisons are made at once, or applying tests at multiple stages of an experimental process, introduces problems that the seven pillars do not accommodate. Stigler notes that there is room, therefore, for an eighth pillar. "The pillar may well exist," he writes, "but no overall structure has yet attracted the general assent needed for recognition." — *Tom Siegfried*

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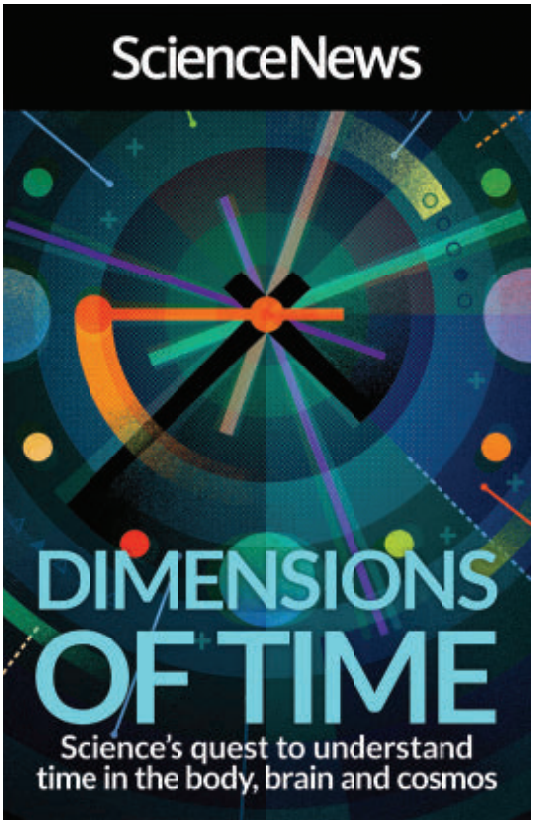
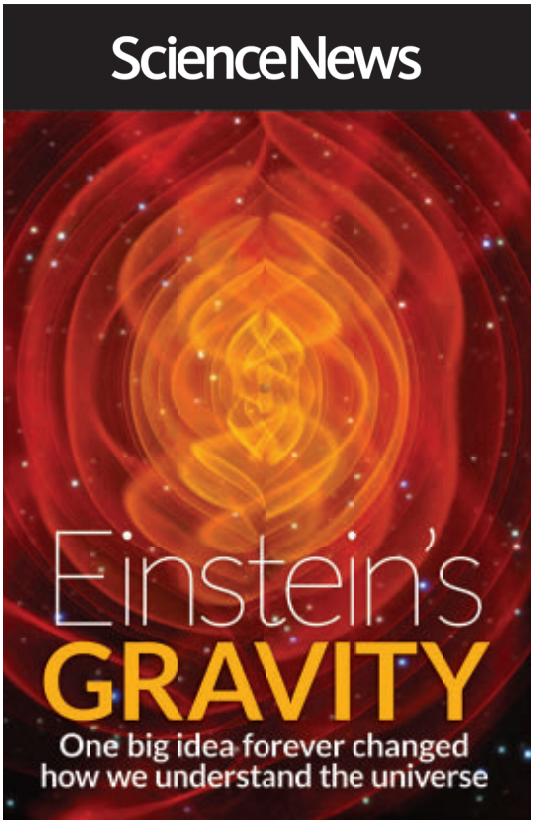


Dimensions of Time covers all aspects of a concept that is familiar to all of us but hard to explain scientifically — **time**. Included are stories about the most precise clocks, the body's circadian rhythms and how our brains track time. Among the enduring questions explored in the book: Is time fundamental? Why does time flow just one way? And are there time travelers among us?



The release of *Einstein's Gravity* follows the announcement of the breakthrough detection of **gravitational waves** by the Advanced Laser Interferometer Gravitational–Wave Observatory. This e-book includes the full history of that search, and also covers the early reactions to general relativity and the tests that have confirmed the theory again and again. An impressive attempt to explain the theory using only one-syllable words dates to the 1920s.

"Time and gravity — and the human attempt to understand them — have persistently been among the most fascinating topics in science for the last century. Our new e-books explore the key concepts and players in this ongoing search for knowledge."

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SOCIAL MEDIA

Pendant play

Researchers in England found an 11,000-year-old engraved shale pendant that is one of the county's oldest known artworks, **Bruce Bower** reported in "Ancient engraved pendant found in England" (*SN: 4/2/16, p. 18*). Noticing its resemblance to a guitar pick, Facebook readers pondered the pendant's true origins.

"That is not a pendant. That is an ancient electric guitar pick. Probably from the Fendorian civilization."
Carlos Casillas

"I do believe you are mistaken. The intricate lines moving to the center do lend themselves more to the Gibsonian peoples, possibly of the Stratocastrian tribe."
Mike Smock

"Now to find the 11,000-year-old electric guitar."
Pandu Sarijadi

"And a cave painting of Slash."
Rachel Bradley

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Zapping Zika

As Zika virus spreads, researchers are racing to find Zika-carrying mosquitoes' Achilles' heel, ***Susan Milius*** *reported in "Science versus mosquito" (*SN: 4/2/16, p. 30*). Some approaches include genetic sterilization so mosquitoes can't reproduce and infecting them with bacteria to decrease their disease-spreading power.*
One reader had another suggestion. "Maybe we could just secure some wilderness areas for birds and bats," **Kurt Feierabend** wrote on Facebook. "Let the feasting begin."

"Some bats and birds do eat mosquitoes, but *Aedes aegypti* mosquitoes, which are Zika carriers, typically dwell in or around people's houses — not an easy hunting ground for predators," says **Meghan Rosen**, who also reported on the virus for this special report (*SN: 4/2/16, p. 26*). The mosquitoes lay eggs in water though, so predatory fish and crustaceans could serve as a type of biological control. But, according to the U.S. Centers for Disease Control and Prevention, that option may not be practical. *Ae. aegypti* larvae can also develop in dog bowls, plant saucers and rain splash left in crumpled plastic bags, **Milius** notes.

Wandering baby Jupiter

As proto-Jupiter moved through the solar system, it may have absorbed so much planet-building material that it reduced the number of planets that could form near the sun, ***Christopher Crockett*** *reported in "Jupiter could have formed near sun," (*SN: 4/2/16, p. 7*).*
"Over what time span would this have occurred, and are any of our planets currently moving in or out?" asked online reader **Mark S**.

If Jupiter formed close to the sun, it spent only about 100,000 years in the inner solar system, well before the rocky planets started to form, **Crockett** says. "Researchers suspect that the outer planets danced around quite a bit during their formative years. All the sun's worlds are now, fortunately, staying put for the foreseeable future," he says.

Addicted to microbes

*In "Microbes and the mind" (*SN: 4/2/16, p. 22*),* ***Laura Sanders*** *reported on the surprising ways in which gut microbes influence depression, anxiety and other mental disorders. But it's not a one-way street. "Our behavior can influence the microbiome right back," she wrote.*
Reader **George Szynal** wondered how addiction to drugs, alcohol and other substances may influence microbes and vice versa. "Can treatments of microbiome enhance and aid the recovery of addicted persons?" he asked.

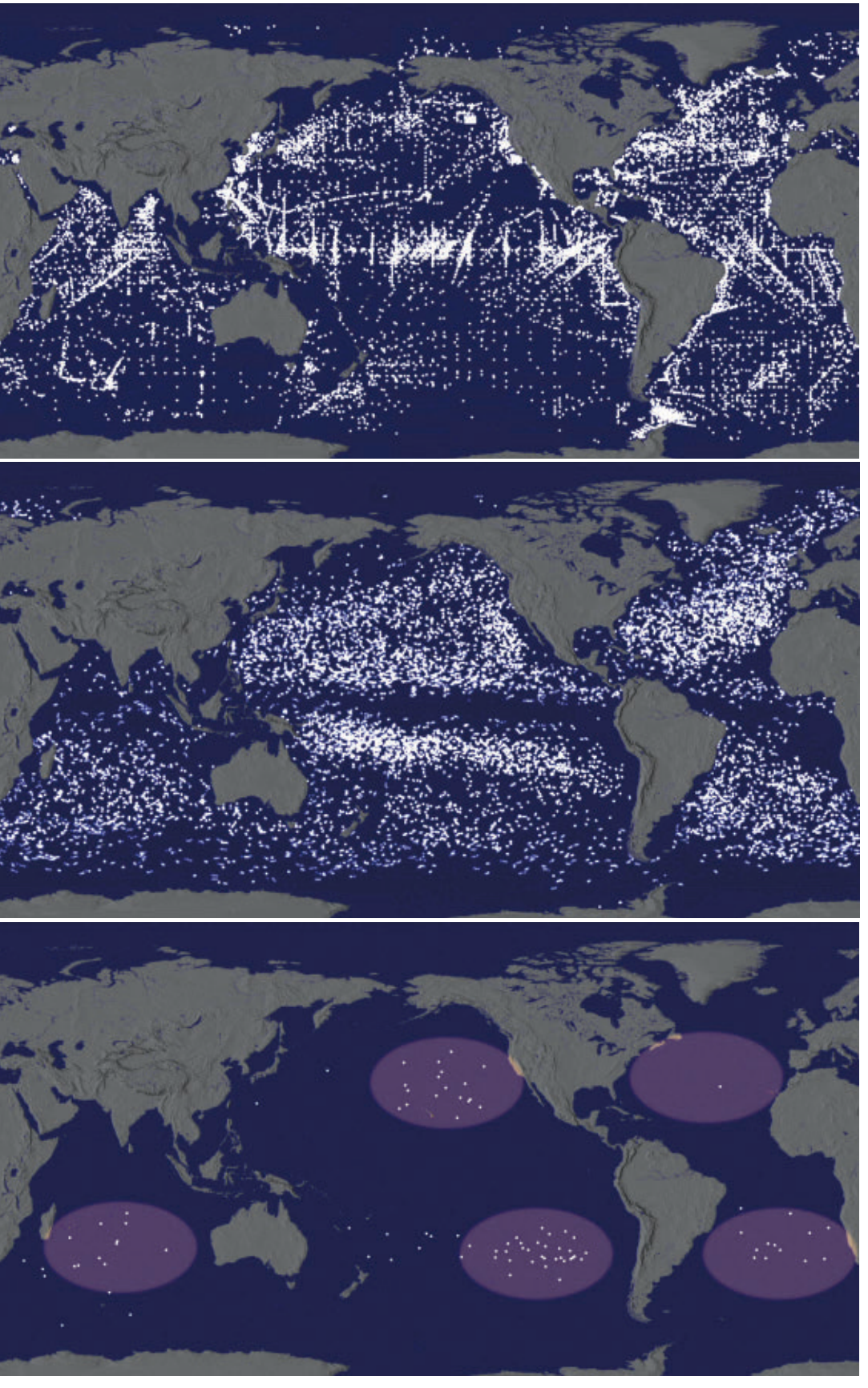
"That's a fascinating idea, but so far, little research has been done on this question," **Sanders** says. "Alcohol disorders have been linked to changes in the gut microbiome, and smoking has been linked to differences in mouth bacteria. But until scientists figure out whether those microbe changes are consequences or causes of the addictions, we won't know whether changing the microbes could help people kick the habits," she says.

Water rising

Without a sharp decrease in carbon dioxide emissions, rapid melting of the Antarctic ice sheet could raise sea levels by 60 meters by the end of the century, ***Thomas Sumner*** *reported in "Tipping point for ice sheet looms" (*SN: 4/2/16, p. 10*).*
In addition to melting ice sheets, reader **Carolyn Lawson** asked if human depletion of groundwater also contributes to sea level rise.

About 80 percent of groundwater losses end up in the oceans, according to a recent study in *Nature Climate Change*. Simulations showed that groundwater contributed about 0.02 millimeters of sea level rise annually in 1900 and increased to around 0.27 millimeters annually by 2000. "Current sea level rise is about 3 millimeters per year, so that's a pretty large chunk," **Sumner** says. "Unfortunately, Earth's groundwater reserves are disappearing. It's unclear whether the groundwater contribution to sea level rise will continue to increase indefinitely."

HARRY ROBSON



Buoy ballet tracks ocean motion

Garbage in, garbage out. But where does all that garbage go? In the oceans, floating bits of debris — everything from plastic bags to Legos — tend to ride along ocean currents to a common destination: one of five major whirling ocean gyres, also known as the ocean garbage patches. Researchers recently got a new look at these gyres thanks to a visualization that combined 35 years' worth of data on another thing humans drop into the oceans: scientific buoys. The visualization was a finalist in the Data Stories competition sponsored by the American Association for the Advancement of Science. The winners were announced May 5.

Free-floating buoys, released by the National Oceanic and Atmospheric Administration, track temperature, saltiness and other ocean properties. Experts at NASA's Scientific Visualization Studio combined the movements of more than 17,000 buoys to illustrate the motions of the oceans. The buoys start off scattered across the oceans (top), with some in neat lines that follow the paths of buoy-deploying research vessels. From this chaos, the buoys begin to migrate into clusters (center). Over time, most drop off the grid and disappear, but some buoys eventually end up in one of the ocean garbage patches (bottom, shaded ovals).

The garbage patches aren't floating landfills of intact soda bottles and yogurt cups. The gyres are instead speckled with tiny plastic bits smaller than grains of rice, as many as 100,000 per square kilometer. All that plastic can end up in fish and serves as a foundation for microbe colonies (*SN: 2/20/16, p. 20*).

— Thomas Sumner

NASA SCIENTIFIC VISUALIZATION STUDIO

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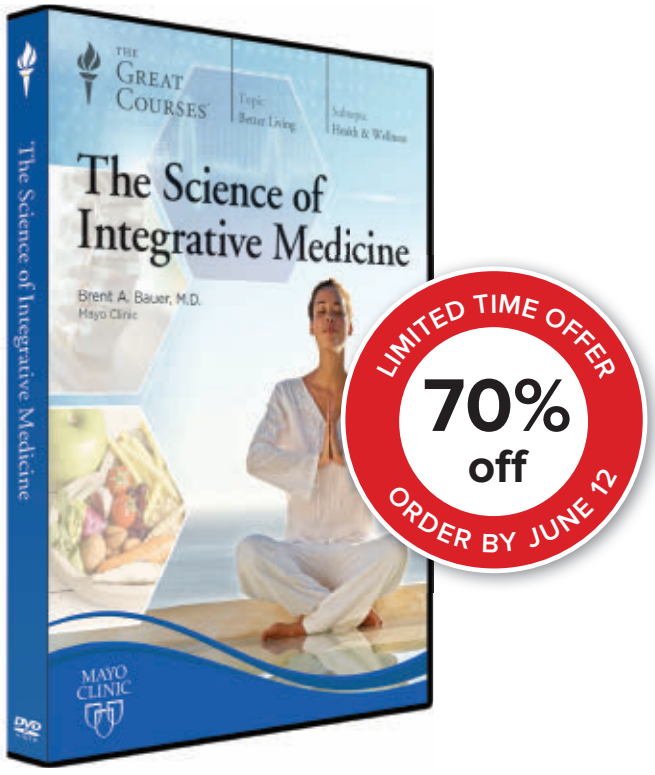

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