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SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
FEBRUARY 3, 2018

Following Memories' Footprints

How Blowflies Stay Cool

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Origin Story for Fast Radio Bursts

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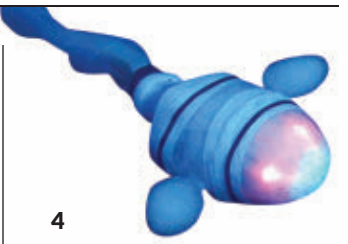

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Departments

COVER Smartphones — a constant companion to most people — have sensors that can disclose all kinds of details about device users. *Sorbetto/iStockphoto, E. Otwell*

CLOCKWISE FROM TOP: SVEN HAUTH; STACY FARINA AND M. GERRINGER/FRIDAY HARBOR LABS/UW; RIISHEDE/ISTOCKPHOTO

Memory remains elusive, but the search continues

In *Theaetetus*, Plato likened memory to a wax tablet, which would adopt the image of whatever was impressed upon it. Aristotle is said to have called memory "the scribe of the soul." Others have viewed memory as a stomach, storehouse or switchboard, while acknowledging that it sometimes seems like a leaky bucket.

St. Augustine and Robert Hooke also thought deeply about memory. But not until the late 1800s did a German psychologist by the name of Hermann Ebbinghaus pioneer the study of memory in an experimental way. To research memory in isolation, Ebbinghaus used himself as a subject. After coming up with a list of nonsense syllables, he memorized series of different lengths, uncovering patterns in the time it takes to learn, relearn and forget.

Well over a century later, memory is far from understood. When former President Barack Obama launched the BRAIN Initiative five years ago (*SN: 2/22/14, p. 16*), the goal was to support technologies that would, in part, "open new doors to explore how the brain records, processes, uses, stores and retrieves vast quantities of information," according to the White House. Today, memory seems to fascinate everyone, and the writers at *Science News* are no exception.

On Page 22, Laura Sanders updates readers on the hunt for the "engram," a term coined early in the 20th century to describe the physical trace a memory leaves in the brain. Neuroscientists have yet to find the engram, but they have new notions — and are revisiting old ones. One of those ideas comes from the work of James Vernon McConnell, who reported some six decades ago that memories could somehow be transferred from one flatworm to another.

Over its near-century of existence, *Science News* has reported regularly on the nature of memory: how to create it, improve it and even, as needed, eliminate it. In 1926, *Science News-Letter* (the precursor to *Science News*) offered a series of mnemonic devices to help readers recall specific information. These "memory rimes" included tricks for units of geologic time, the 12 cranial nerves and the value of pi (three ways). And in 1966, the magazine followed up on the experiments that made McConnell famous as the "flatworm man." Though initially substantiated with RNA extracted from shocked worms and injected into unconditioned ones, the memory transfer findings were questioned by a study the next year. Our pages called it an "antibreakthrough in man's attempt to understand the way memory works." Scientists still don't know what to make of the results.

And so the struggle to understand memory continues. As does the struggle to understand hundreds of other deep topics related to the human mind, the history of life and the evolution of our cosmos. On Page 10, behavioral sciences writer Bruce Bower covers a study in bonobos that might offer insights into the evolution of human cooperation. On Page 13, earth and climate writer Carolyn Gramling revisits the Yellowstone supervolcano, peeking into the workings of our planet. Technology writer Maria Temming's cover story on smartphones (Page 18) raises important questions about how technology transforms our lives.

There's a lot to ponder, and a lot more reporting to do. Now, if I could only remember where I left my blue pencil. — *Elizabeth Quill, Acting Editor in Chief*

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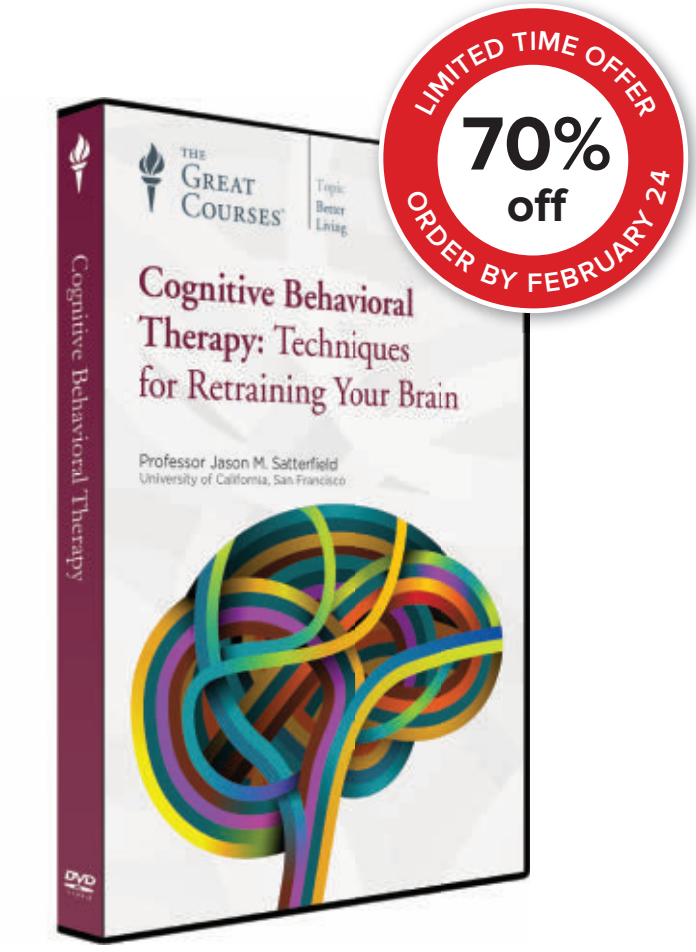

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Excerpt from the February 3, 1968 issue of *Science News*

50 YEARS AGO

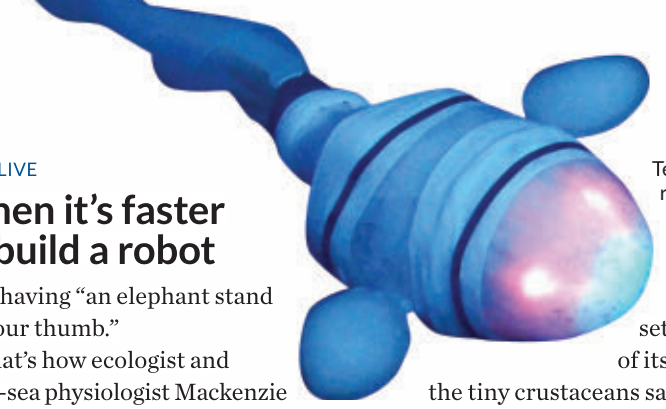
IUDs: approval of a renaissance

In 1929, the German scientist Ernst Grafenberg inserted silver rings into the uteri of 2,000 women, and reported a pregnancy rate of only 1.6 percent. Despite this history, the use of intrauterine devices, or IUDs, was not generally accepted.... A report made public last week by the FDA's Advisory Committee on Obstetrics and Gynecology concludes that ... [IUDs are] safe and effective in blocking contraception.

UPDATE: Early intrauterine devices came in myriad shapes, including a double-S, loops and spirals. One IUD, the spiked Dalkon Shield, was taken off the market in 1974 amid complaints of severe infections. Consumers quickly lost interest. But after companies redesigned the devices in the 1990s, use rose. From 1988 to 2002, just 1.5 percent of U.S. women ages 15 to 44 used an IUD; from 2011 to 2013, use was as high as 7.2 percent. IUDs have been found to be more reliable than contraceptive pills (*SN: 6/30/12, p. 9*).

IT'S ALIVE

When it's faster to build a robot



Tests with this snailfish robot showed what's great about having a body full of watery goo deep underwater.

Like having "an elephant stand on your thumb."

That's how ecologist and deep-sea physiologist Mackenzie Gerringer describes the pressure squeezing down on the deepest known living fish, some eight kilometers below the surface. What may help these small, pale Mariana snailfish survive elephantine squashing, says Gerringer, of the University of Washington's Friday Harbor Labs, is a watery goo bulking up the rump. At least that's what her robot showed.

The snailfish family gets its nickname from the way some shallow-water species endure thundering tides by gripping a rock with a suction cup on the belly and curling up. "Quite cute," Gerringer says, and maybe, if you squint, kind of like a snail.

She and colleagues found the newly named deepest fish in 2014 in the western Pacific Ocean's Mariana Trench and described the species, *Pseudoliparis swirei,* November 28 in *Zootaxa*. To catch specimens, Gerringer and colleagues weighted boxy, mesh-sided traps with steel plates to sink them. The traps took about four hours to fall to the seafloor.

The scientists baited traps with mackerel, which snailfish don't eat. But the fish do eat the underwater amphipods that mob a mackerel feast. Remotely related to garden pill bugs, trench amphipods clean mackerel to the bones. "I certainly wouldn't swallow a live amphipod after seeing what they can do," Gerringer says. A Mariana snailfish, however, has a second set of jaws at the back of its throat that render the tiny crustaceans safe to swallow.

For fish that live at such extreme pressures and temperatures (1° or 2° Celsius), the snailfish don't "look very robust ... or very armored," she says. "You can actually see the brain through the skull."

Skimping on dense muscles and bones may improve snailfish buoyancy and save energy. These deepwater fish also lack the air pockets that give a little lift to some other fish. Such pockets would get squashed to nothing so far down. Instead, these snailfish have inner deposits of a watery goo, more buoyant than muscles and bones and less compressible than air.

The goo also may aid swimming efficiency by offering a cheap shape improvement, Gerringer and colleagues proposed December 6 in *Royal Society Open Science*. To test the idea, she 3-D printed and motorized a robosnailfish. Easier than catching a real one, Gerringer says.

A latex sleeve around the robot tail let her add or subtract water as an approximation of the gelatinous tissue. With an empty sleeve, the wide fish body pinches in to a thin tail, inviting vortices that cause drag, and the roboswimmer struggles. Filling the tail-sleeve created a tapering rear and a faster swimming robosnailfish.

This goo is cheap tissue to grow, says Gerringer. It's mostly water, one thing a fish living underneath eight kilometers of ocean has in abundance. —*Susan Milius*

A Japanese film crew captured images of Mariana snailfish (white) checking out mackerel bait that lures tiny amphipods. The snailfish, here at 8,178 meters deep, eat the mackerel-devouring amphipods.

FROM TOP: STACY FARINA AND M. GERRINGER/FRIDAY HARBOR LABS/UW; JAMSTEC/NHK

SCIENCE STATS

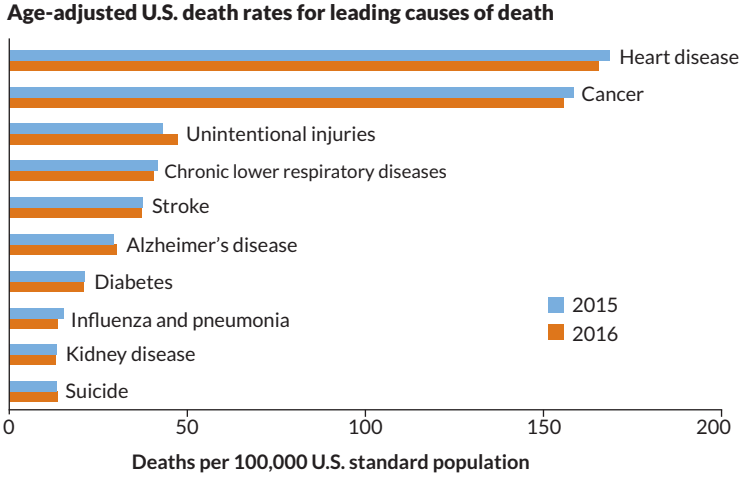
U.S. life expectancy declines again

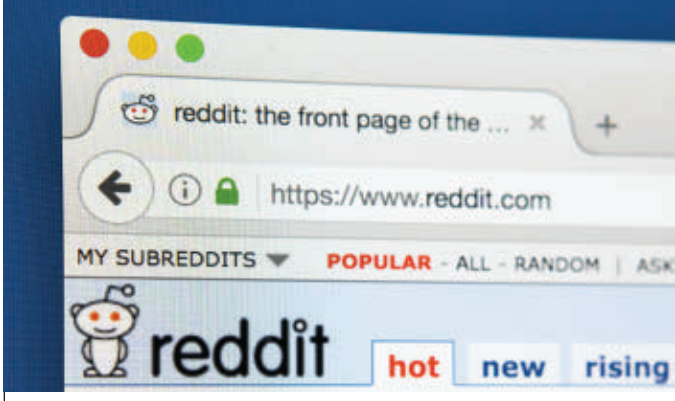
Life expectancy in the United States decreased for the second year in a row in 2016, the first back-to-back drop in more than 50 years.

In 2016, life expectancy at birth was 78.6 years for the U.S. population as a whole. That's 0.1 year less than in 2015. For men, life expectancy decreased from 76.3 years in 2015 to 76.1 years in 2016; women's life expectancy remained the same, at 81.1 years. The new data, from the U.S. Centers for Disease Control and Prevention's National Center for Health Statistics, were published online in a report December 21.

Deaths from the two leading causes, heart disease and cancer, dropped between 2015 and 2016. However, the overall drop in life expectancy is largely a result of an uptick in the age-adjusted death rates for three of the top 10 causes of death: unintentional injuries (including drug overdoses and car crashes), Alzheimer's disease and suicide, the report's authors say. — *Aimee Cunningham*

Difference makers Among the 10 leading causes of death in the United States, age-adjusted death rates rose for three causes from 2015 to 2016, which cut into life expectancy.





THE LIST

How not to kill online conversations

A new computer code can tell whether your next post to an online forum will engage others or fall flat. Computer scientist Qiaozhu Mei of the University of Michigan in Ann Arbor and colleagues trained a machine-learning program on about 63,000 Reddit threads to pick out dialog-enders. — *Maria Temming*

AI's guide to being an online conversationalist

Stay on topic. Posts that repeat words used elsewhere in a thread or use more related terms are less likely to end a conversation.

Share experiences. Comments that include words such as "talked," "heard" or "seen" are likely to encourage further discussion.

Keep it moving. The more time that elapses between a post and a reply, the more likely that reply will go unanswered.

Elaborate. Unlike in-person chats, where long monologues can bore those within earshot, lengthier online posts tend to get more responses.

Be polite. Posts that include words like "Mr." and "Mrs." are more likely to encourage a back-and-forth compared with responses that address people with insulting or intense language, such as curse words or an all-caps "YOU."

FROM LEFT: K.D. KOCHANEK *ET AL*/NCHS 2017; CHRISDORNEY/SHUTTERSTOCK

TEASER

Jazz improvisers score on creativity

Improvisation may give jazz artists a creative boost not seen among musicians more likely to stick to the score. Jazz musicians' brains quickly embrace improvisational surprises, new research on the neural roots of creativity shows.

Neuroscientist Emily Przysinda and colleagues at Wesleyan University in Middletown, Conn., measured the creative aptitudes of 12 jazz improvisers, 12 classical musicians and 12 nonmusicians. The researchers first posed creativity challenges to the volunteers, such as listing every possible use for a paper clip. Volunteers then listened to three different kinds of chord progressions — common ones, some that were a bit off and some that went in wild directions — as the researchers recorded the subjects' brain waves with an electroencephalogram. Afterward, volunteers rated how much they liked each progression.

More so than the other participants, jazz musicians preferred the unexpected riffs, brain waves showed. And the improvisers' faster and stronger neural responses showed that those musicians were more attuned to unusual music and quickly engaged with it. Classical musicians' and nonmusicians' brains hadn't yet figured out the surprising music by the time the jazz musicians had moved on, the researchers report in the December *Brain and Cognition*.

The jazz musicians' striking responses to unexpected chords mirrored their out-of-the-box thinking on the creativity tests. Training to be receptive to the unexpected in a specific area of expertise can increase creativity in general, says cognitive neuroscientist Roger Beaty of Harvard University, who was not involved in the study. — *Kimber Price*

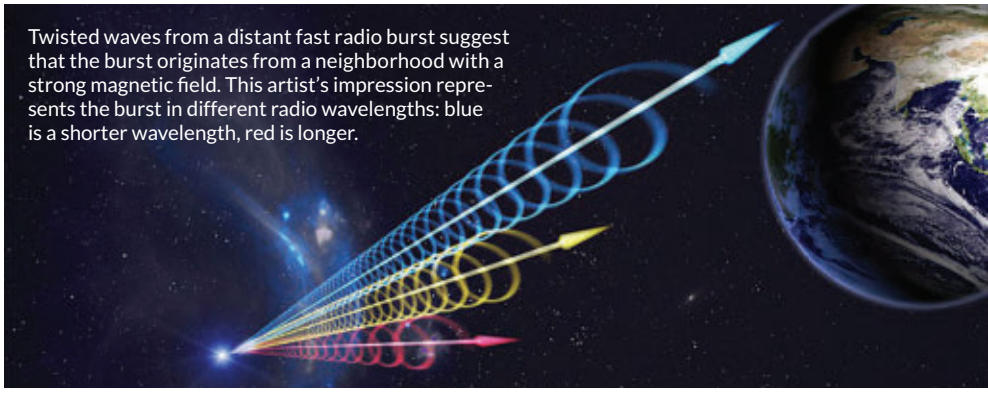
Listen to musical chords played in a creativity test at **bit.ly/SN_jazzbrain**

News

ATOM & COSMOS

Odd blasts traced to neutron star

Repeating fast radio burst shows signature twist



Twisted waves from a distant fast radio burst suggest that the burst originates from a neighborhood with a strong magnetic field. This artist's impression represents the burst in different radio wavelengths: blue is a shorter wavelength, red is longer.

JINGCHUAN YU, BEIJING PLANETARIUM

BY LISA GROSSMAN

Fast radio bursts could come from a turbulent home. At least one source of these bright, brief blasts of radio energy may be a young neutron star assisted by a nearby massive black hole, a new study finds.

"The biggest mystery around fast radio bursts is how such powerful and short-duration bursts are emitted," says Daniele Michilli, an astronomer at the University of Amsterdam. The latest observations, presented January 11, suggest that the bursts are coming from an environment with an unusually strong magnetic field. That field leaves a signature mark on the radio waves, twisting them into spirals, Michilli and colleagues also report in the Jan. 11 *Nature*.

Only a few fast radio bursts have ever been detected, and most appear as one-off events. Few known processes in the universe can explain the bursts. But one, FRB 121102, has been seen repeating over the last decade or so. That repetition let astronomers track the burst to a dwarf galaxy some 2.5 billion light-years away (*SN: 2/4/17, p. 10*).

Now, Michilli and colleagues have shown that the burst's source is embedded in a very strong magnetic field — 200 times stronger than the average magnetic field in the Milky Way.

Using the Arecibo telescope in Puerto Rico, the team measured high-frequency radio waves from 16 distinct repetitions over three two-hour observational runs spanning several months. The bursts were brief; one lasted just 30 microseconds. Whatever emitted that burst must be just 10 kilometers wide, Michilli says.

"To emit a short burst, you need a small region," he says. "Therefore compact objects such as neutron stars are strongly favored by this result."

The team also analyzed the radio waves in a new way, revealing that what looked like individual bursts were actually composed of many smaller sub-bursts, says team member Andrew Seymour, an astronomer at the Universities Space Research Association at Arecibo. That complicates the picture even further. The sub-bursts might be intrinsic to the object that creates them, or they might be the result of the waves passing through blobs of plasma, he says.

Finally, the observations showed that the waves were polarized, all oriented in the same direction. But something had twisted the waves, forcing them to rotate in corkscrews on their way to Earth.

A strong magnetic field is the only phenomenon known to create such a rotation, Michilli says. There are two main hypotheses for the bursts' behavior. One is that the bursts are from a young, energetic neutron star called a magnetar that's sitting inside a shell of magnetized gas, which the magnetar expelled in a supernova explosion. The magnetar emits radio waves, and the shell rotates them.

"If you have young magnetars that have just been born in supernova explosions, only a few decades old, they could be very bursty objects, have very violent youths, and that could give rise to repeating fast radio bursts," says astronomer Brian Metzger of Columbia University, who was not involved in the study.

But to drive such strong magnetic fields, the supernova remnant would have to be a million times brighter than even the brightest remnant in the Milky Way, Michilli notes. Instead, the bursts could come from a young neutron star orbiting the dwarf galaxy's dominant black hole, which probably has 10,000 to 1 million times the mass of the sun, he says.

Such large black holes have strong magnetic fields and make polarized light rotate. And a neutron star sidling up to a black hole is plausible: There's one orbiting the Milky Way's supermassive black hole. This neutron star's radio waves don't come in brief bright bursts, but the waves are twisted, the researchers say.

Michilli's team acknowledges, however, that other exotic explanations may account for the observations. And many questions remain, like whether all fast radio bursts — including the ones that don't repeat — come from such exciting neighborhoods. Also unknown is whether any other bursts have twisted waves at high frequencies — the smoking gun for strong magnetic fields. Measuring the rotation of the waves in FRB 121102 required hacking Arecibo with new hardware that let it detect higher frequencies than before. Maybe previous fast radio bursts that Arecibo observed didn't show the same rotation signature because the telescope wasn't able to measure it yet.

"The prospects are quite good" for figuring out what fast radio bursts are, coauthor Jason Hessels of the University of Amsterdam said in a news conference January 10. New radio observatories should come online in the next few years. He expects to find other repeating bursts, if they exist. "Then we can see if this repeating source is really a complete oddball." ■

ATOM & COSMOS

Dead star trio upholds gravity theory

Ultradense objects conform to principle of general relativity

BY EMILY CONOVER

Observations of a trio of dead stars have confirmed that a foundation of Einstein's gravitational theory holds even for ultradense objects with strong gravitational fields.

The complex orbital dance of the three former stars conforms to a rule known as the strong equivalence principle, researchers reported January 10. That agreement limits theories predicting Einstein's general theory of relativity should fail at some level.

According to general relativity, an object's composition has no impact on how gravity pulls on it: Earth's gravity accelerates a sphere of iron at the same rate as a sphere of lead. That's what's known as the weak equivalence principle. A slew of experiments have confirmed that principle — dating back to Galileo's purported test of dropping balls from the Leaning Tower of Pisa (*SN: 1/20/18, p. 9*).

But the strong equivalence principle is more stringent and difficult to test than the weak version. According to the strong equivalence principle, not only do different materials fall at the same rate, but so does the energy bound up in gravitational fields. That means that an incredibly dense, massive object with a correspondingly strong gravitational field should fall with the same acceleration as other objects.

"We're asking, 'How does gravity fall?'" says astronomer Anne Archibald of the University of Amsterdam, who presented the preliminary result. "That sounds weird, but Einstein says energy and mass are the same." So the energy bound up in a gravitational field can fall just as mass can. If the strong equivalence principle were violated, an object with an intense gravitational field would fall with a different acceleration than one with a weaker field.

To test this theory, scientists measured the timing of signals from a pulsar — a spinning, ultradense collapsed star emitting beams of electromagnetic radiation that sweep past Earth at regular intervals. The pulsar in question, PSR J0337+1715, isn't just any pulsar: It has two companions (*SN: 2/22/14, p. 8*). The pulsar orbits with a type of burned-out star called a white dwarf. That pair is accompanied by another white dwarf, farther away.

If the strong equivalence principle holds, the paired-up pulsar and white dwarf should both fall at the same rate in the gravitational field of the second white dwarf. But if the pulsar, with its intense gravitational field, fell faster toward the outermost white dwarf than the companion white dwarf did, the pulsar's orbit would be pulled toward the outermost white dwarf, tracing a path in the shape of a rotating ellipse.

Scientists can use the timing of a pulsar's signals to deduce its orbit. As a pulsar moves away from Earth, for example, its pulses fall a little bit behind its regular beat. So if J0337+1715's orbit were rotating, signals received on Earth would undergo regular changes in their timing as a result. Archibald and colleagues saw no such variation, which means the pulsar and the companion white dwarf must have had matching accelerations, to within 0.16 thousandths of a percent.

Many physicists expect the strong equivalence principle to be violated on some level. General relativity doesn't mesh well with quantum mechanics, the theory that reigns on very small scales. Adjustments to general relativity that attempt to combine these theories tend to result in a violation of the strong equivalence principle, says Clifford Will, a physicist at the University of Florida in Gainesville who was not involved with the research.

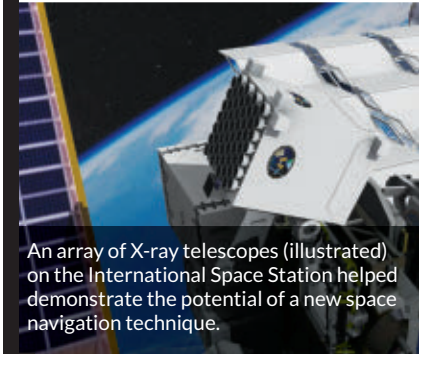
The strong equivalence principle might still fail at levels too tiny for this test to catch. So the door remains open for adjustments to general relativity. But the new measurement constrains many such theories better than any previous test. The result is "really tremendous," Will says. It's "a great improvement in this class of theories ... which is why this triple system is so beautiful." ■

MEETING NOTE

Spaceships could use blinking dead stars to chart the way

Future spacecraft could navigate by the light of dead stars. Using only the timing of radiation bursts from pulsating stellar corpses, an International Space Station experiment pinpointed its location in space. The method is like a stellar version of GPS, scientists with SEXTANT, the Station Explorer for X-ray Timing and Navigation Technology experiment, reported at a news conference January 11.

The dead stars, pulsars, emit beams of radiation that sweep past Earth at regular intervals, like a lighthouse's rotating beams. Those radiation blips could let a spaceship find its location (*SN: 12/18/10, p. 11*). It's similar to how GPS uses the timing of satellite signals to determine the position of your cell phone — and would mean spacecraft would no longer have to use radio telescope communications to find coordinates. That system becomes less accurate the farther a ship travels from Earth.



An array of X-ray telescopes (illustrated) on the International Space Station helped demonstrate the potential of a new space navigation technique.

SEXTANT used an array of 52 X-ray telescopes to measure signals from five pulsars. With those signals, the researchers located SEXTANT's position to within 10 kilometers as it orbited Earth, reported Keith Gendreau of NASA's Goddard Space Flight Center in Greenbelt, Md. — *Emily Conover*

NASA'S GODDARD SPACE FLIGHT CENTER

BODY & BRAIN

Virus fighter linked to pregnancy woes

Immune response to mom's Zika infection harmed fetal mice

BY AIMEE CUNNINGHAM

An immune system mainstay in the fight against viruses may harm rather than help a pregnancy. In Zika-infected mice, this betrayal appears to contribute to fetal abnormalities linked to the virus, researchers report online January 5 in *Science Immunology*. And it could explain pregnancy complications that arise from infections with other pathogens and from autoimmune disorders.

In pregnant mice infected with Zika virus, those fetuses with a docking station, or receptor, for immune system proteins called type I interferons either died or grew more poorly compared with fetuses lacking the receptor. "The type I interferon system is one of the key mechanisms for stopping viral infections," says Helen Lazear, a virologist at the University of North Carolina at Chapel Hill who coauthored an editorial accompanying the study report. "That same [immune] process is actually causing fetal damage, and that's unexpected."

Cells infected by viruses begin the fight against the intruder by producing type I interferons. These proteins latch on to their receptor on the surfaces of neighboring cells and kick-start the production of hundreds of other antiviral proteins.

Akiko Iwasaki, an immunologist at Yale School of Medicine and a Howard Hughes Medical Institute investigator, and her colleagues were interested in studying what happens to fetuses when moms are sexually infected with Zika. The researchers mated female mice unable to make the receptor for type I interferons to males with one copy of the gene needed to make the receptor. This meant that moms would carry some pups with the receptor and some without in the same pregnancy.

Pregnant mice were infected vaginally with Zika at one of two times — either the equivalent of middle or late first trimester in humans. Of fetuses exposed to infection earlier, those with the interferon receptor died; those without it continued developing. For fetuses exposed to infection a bit later in pregnancy, those with the receptor were much smaller than their receptor-lacking counterparts.

Fetuses without the receptor still grew poorly because of the Zika infection, which was expected given the inability to fight the virus. What was striking, Iwasaki says, was that the fetuses able to fight the infection were more damaged and the only ones that died. How the antiviral immune response caused fetal damage is unclear. But the placentas — which, like their fetuses, had the receptor — didn't appear to provide their fetuses with enough oxygen, Iwasaki says.

The researchers also infected pregnant mice that had the type I interferon receptor with a viral mimic — a bit of genetic material that goads the body to begin its antiviral immune response. These fetuses also died early in pregnancy, an indication that perhaps the immune system could cause fetal damage during

MATH & TECHNOLOGY

Artificial cartilage flexes its muscle

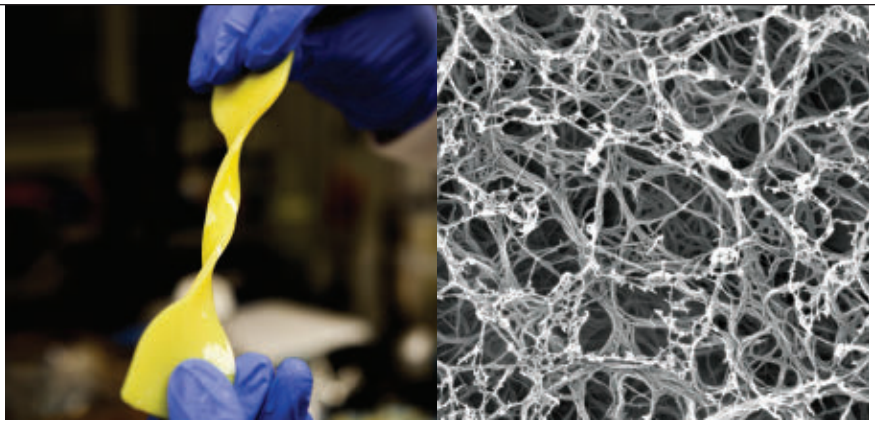
Synthetic material can ferry nutrients like the real tissue

BY MARIA TEMMING

A new kind of artificial cartilage, made with the same type of fiber in bulletproof vests, is proving stronger than others.

The fabricated material mimics the stiffness, toughness and water content of natural cartilage, researchers report in the Jan. 4 *Advanced Materials*. This synthetic tissue could replace the cartilage in a person's body that naturally wears down and heals poorly (*SN: 8/11/12, p. 22*), alleviating joint pain and potentially sparing many people from having to undergo joint replacement surgery.

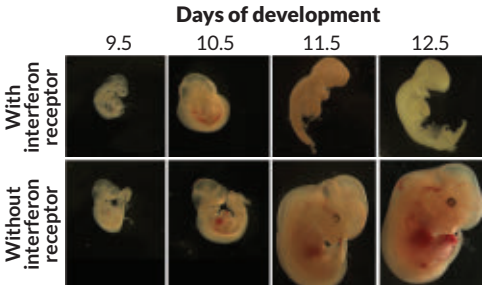
Scientists have been trying to fashion artificial cartilage for decades, says Kara Spiller, a biomedical engineer at Drexel University in Philadelphia who was not involved in the work. But earlier materials were either weaker than the real thing or didn't pack enough water to transport nutrients to surrounding cells.



Synthetic cartilage made mostly from water is strong and resistant to tears thanks to the material's nanofiber and polymer network (scanning electron microscope view, right).

FROM LEFT: JOSEPH XU/MICHIGAN ENGINEERING COMMUNICATIONS & MARKETING; LIZHI XU/KOTOV LAB/UNIV. OF MICHIGAN

The new material is a polymer mixture called a hydrogel that's mostly water and contains nanoversions of the aramid fibers used to fortify bulletproof vests. Nicholas Kotov, a chemist at the University of Michigan in Ann Arbor, and colleagues tested how well their material held its shape when squeezed or stretched, and how easily it broke. Two versions of the hydrogel — one, about 70 percent water and the other, about 92 percent — either matched or



In a new study, mice were infected with Zika virus early in their pregnancies (equivalent to humans' mid–first trimester). After 12.5 days (second trimester), fetuses with a receptor for the immune system proteins type I interferons had died; those without it were still developing.

other viral infections, Iwasaki notes.

Iwasaki and colleagues next added type I interferon to samples of human placental tissue in dishes. After 16 to 20 hours, the tissue developed structures resembling syncytial knots, which are widespread in the placentas of pregnancies with complications such as preeclampsia.

The next step is to figure out which of the many antiviral proteins that are made when type I interferon ignites the immune system are the ones triggering placental and fetal damage, Iwasaki says. ■

exceeded the stiffness and toughness of real cartilage.

The material has many potential uses, Spiller says. "The biggest market is going to be osteoarthritis patients, because most patients with osteoarthritis have no damage to the bone, just damage to the cartilage." Many of the 30 million adults in the United States with osteoarthritis undergo knee or hip replacements. If doctors could simply replace worn-down cartilage with this material, that procedure would carry fewer risks than complete joint replacement. "That would be really huge," Spiller says.

This kind of hydrogel, she adds, could also be used to repair other types of soft tissue often damaged in sports injuries.

It remains to be seen how well the material integrates into the body, says Benjamin Wiley, a chemist at Duke University. Researchers still need to make sure it anchors to bone and doesn't irritate surrounding tissue. ■

L. YOCKEY *ET AL*/*SCIENCE IMMUNOLOGY* 2018

ATOM & COSMOS

White dwarf's inner makeup mapped

Oxygen-rich stellar corpse challenges star evolution theories

BY LISA GROSSMAN

Astronomers have probed the inner life of a dead star. Tiny changes in a white dwarf's brightness reveal that the stellar corpse has more oxygen in its core than expected, researchers report online January 8 in *Nature*. The finding could challenge theories of how stars live and die, and may have implications for measuring the expansion of the universe.

By the end of a sunlike star's life, it has shed most of its gas into space until all that remains is a dense core of carbon and oxygen, the ashes of a lifetime of burning helium (*SN: 4/30/16, p. 12*). That core, plus a thin shellacking of helium, is called a white dwarf.

But the proportion of those elements relative to one another was uncertain. "From theory, we have a rough idea of how it's supposed to be, but we have no way to measure it directly," says astrophysicist Noemi Giammichele, now at the Research Institute in Astrophysics and Planetology in Toulouse, France.

Luckily, some white dwarfs encode their inner nature on their surface. These stars change their brightness in response to internal vibrations. Astrophysicists can infer a star's internal structure from the vibrations, similar to how geologists learn about Earth's interior by measuring seismic waves during an earthquake.

Giammichele and colleagues used data from NASA's Kepler space telescope, which looked for exoplanets by tracking periodic changes in stars' brightness. Kepler also monitored KIC 08626021, a white dwarf about 1,375 light-years away from Earth in the constellation Cygnus, for 23 months. The observations provided the highest-precision data yet on tiny changes in a white dwarf's brightness and, indirectly, its vibrations.

Next, Giammichele borrowed a computer simulation technique from her former life as an aeronautical engineer to figure out how the changes in vibrations related to the makeup of the core. The team ran millions of simulations, looking for one that reproduced the exact light changes that Kepler observed. One simulation fit the data perfectly, showing that the white dwarf had a core of carbon and oxygen with a shell of helium as expected.

But the details were surprising. The core was about 86 percent oxygen by mass, 15 percent greater than physicists had previously calculated. Something about the processes that convert helium to carbon and oxygen or that mix elements in the star's core during its active lifetime must boost the oxygen content.

Four other white dwarfs show a similar trend, says study coauthor and astrophysicist Gilles Fontaine of the University of Montreal. "We certainly will go ahead and analyze many more." If other white dwarfs turn out to be similar, the results will send theorists who study stellar evolution back to the drawing board, he says.

White dwarfs are also thought to be the precursors of type 1a supernovas. These catastrophic stellar explosions were once thought to have the same intrinsic brightness, meaning they appeared brighter or dimmer depending only on their distance from Earth. Measuring their actual distances led to the discovery that the universe is expanding at an accelerating rate (*SN: 8/6/16, p. 10*), which physicists explain by invoking a mysterious substance called dark energy.

More recent observations suggest that these so-called standard candles may not be so standard after all. If the white dwarfs that help create supernovas have varying oxygen contents, that may help explain some of the differences in brightness, Fontaine says.

Accounting for those differences may someday help reveal details of what dark energy is made of, says astrophysicist Alex Filippenko of the University of California, Berkeley. But those implications are a long way off. "Just how much bearing it will have on cosmology remains to be seen," he says. ■

LIFE & EVOLUTION

Bonobos gravitate toward hinderers

Cozying up to unhelpful peers may motivate the 'laid-back' apes

BY BRUCE BOWER

Despite a reputation as mellow apes, bonobos have a thing for bad guys.

Rather than latching on to individuals with a track record of helpfulness, adult bonobos favor obstructionists who keep others from getting what they want. The result may help explain what differentiates humans' cooperative skills from those of other apes, biological anthropologists Christopher Krupenye of the University of St. Andrews in Scotland and Brian Hare of Duke University report online January 4 in *Current Biology*.

By 3 months old, humans do the opposite of bonobos, choosing to align more frequently with helpers than hinderers, previous investigations indicate. Humans, unlike other apes, have evolved to seek cooperative partnerships that make large-scale collaborations possible (*SN: 10/28/17, p. 7*), Krupenye and Hare propose.

"Conducting similar experiments with chimpanzees and other apes is a key next step," Krupenye says. If chimps view hinderers as kindly as bonobos do, that finding would support the duo's proposal about human cooperation, he says.

Bonobos may view those who impede others' actions as socially dominant and thus worth grooming as allies, Krupenye says. Although bonobos readily share food, social pecking orders still affect the animals' behavior.

Bonobos, such as this male living at an African sanctuary, prefer individuals who hinder others over those that help, new tests suggest.

C. KRUPENYE

The researchers showed 24 bonobos four animated videos featuring pairs of colored shapes, most depicted with a pair of eyes. In one video, a circle tries and fails to climb a hill until a "helper" triangle arrives and pushes the circle to the top. In a second video, a circle tries and fails to climb a hill before a "hinderer" square arrives and pushes the circle farther down the hill. In the other two videos, other shapes with eyes push an eyeless, unmoving circle up or down a hill.

After watching the first two videos, bonobos chose between paper cutouts of helper and hinderer shapes placed on top of small apple pieces. The same choice was presented for cutouts of shapes from the last two videos.

Snacks covered by hinderer shapes were chosen about 70 percent of the time by the 14 adult animals. Younger bonobos displayed no strong preference either way. Apes of all ages showed no partiality to either shape that had pushed inanimate circles.

Adult bonobos also reached more often for an apple piece offered by a human they had observed snatch a toy dropped by another person, versus a human seen returning the toy.

In a final experiment, eight of 24 bonobos usually selected apple pieces covered by cutouts of an animated shape that the apes had watched win a contest with another shape to occupy a location. This result suggests that some bonobos' strong preference for dominant individuals partly accounts for the newly reported fondness for hinderers, Krupenye says.

"The notion that bonobos approach the bully because they view that individual as more dominant is a very plausible interpretation," says psychologist Felix Warneken of the University of Michigan in Ann Arbor, who studies cooperative behavior in humans and other apes. ■

MATTER & ENERGY

Search for elusive magnets goes on

Experiments are teasing out new details about monopoles

BY EMILY CONOVER

Magnetic poles are seemingly inseparable: Slice a magnet in half, and you get two smaller magnets, each with its own north and south poles. But exotic magnetic particles that flout this rule may be lurking undetected, some physicists suspect.

The hunt is in full swing for these hypothetical particles, known as magnetic monopoles, which possess a lone north or south pole. Now, two research groups have further winnowed down the particles' possible masses and characteristics.

There's good reason to suspect magnetic monopoles are out there, some physicists suggest. The particles' existence would explain why electric charge is quantized — why it always seems to come in integer multiples of the charge of an electron instead of a continuous range of values.

If even a single magnetic monopole were detected, the discovery would rejigger the foundations of physics. The equations governing electricity and magnetism are mirror images of each other, but there's one major difference between the two phenomena. Protons and electrons carry positive and negative electric charges, respectively, but no known particle has a magnetic charge. A magnetic monopole would be the first, and if one were discovered, electricity and magnetism would finally be on equal footing.

For decades, scientists have searched fruitlessly for magnetic monopoles. Recent work at the Large Hadron Collider, at the particle physics lab CERN in Geneva, has reinvigorated the search. Magnetic monopoles might be produced there as protons slam together at record-high energies of 13 trillion electron volts.

The latest search by particle physicist James Pinfold of the University of Alberta in Edmonton, Canada, and collaborators with the Monopole and Exotics Detector

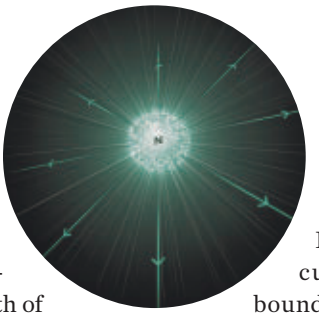
at the LHC, or MoEDAL (pronounced "medal"), found no magnetic monopoles. Still, the work has set some of the most stringent constraints yet on how easily the hypothetical particles may interact with matter, the MoEDAL collaboration reported December 28 at arXiv.org.

Magnetic monopoles may also dwell where magnetic fields are extraordinarily strong and temperatures are high. Under these conditions, pairs of monopoles might form spontaneously. Such extreme environments can be found around a special kind of dead star known as a magnetar, and in the aftermath of collisions of heavy atomic nuclei in particle accelerators. By studying these scenarios, Arttu Rajantie, a MoEDAL collaborator, and physicist Oliver Gould, both of Imperial College London, put new constraints on monopoles' masses.

If magnetic monopoles had relatively small masses, the particles would sap the strength of magnetars' magnetic fields. That fact suggests the particles must be more massive than about 0.3 billion electron volts, about a third of a proton's mass, the researchers calculated in the Dec. 15 *Physical Review Letters*. That estimate depends on another unknown monopole property: the strength of the magnetic charge. The particles have a minimum possible charge. A charge larger than this baseline value would correspond to a minimum mass greater than 0.3 billion electron volts.

A monopole with twice the minimum charge, Rajantie and Gould determined, must be more massive than about 10 billion electron volts, going by data from lead nuclei collisions in the Super Proton Synchrotron, a CERN accelerator smaller than the LHC. Studying similar lead nuclei collisions in the LHC could improve the estimate.

While other experiments have set higher monopole mass limits than the new estimates, those analyses relied on questionable theoretical assumptions, Rajantie says. "These are currently the strongest bounds on the masses of magnetic monopoles that don't rely on assumptions" about how the particles are created, he says.



Physicists are searching for magnetic monopoles (one illustrated), hypothetical particles that have a single north or south magnetic pole.

"Very exciting" results, says Kimball Milton, a theoretical physicist at the University of Oklahoma in Norman, though "not as exciting as if somebody actually found a magnetic monopole."

Even if monopoles do exist, they might be so heavy that they can't be produced by accelerators or recent cosmic processes. The only magnetic monopoles in the universe might be remnants of the Big Bang. A future incarnation of MoEDAL, located on a mountaintop instead of in an accelerator's cavern, could look for such magnetic monopoles that sprinkle down on Earth from space, Pinfold says. ■

DANIEL DOMINGUEZ/CERN

LIFE & EVOLUTION

Blowflies use drool to keep their cool

Dangle, slurp, repeat may help the insects protect their brains

BY SUSAN MILIUS

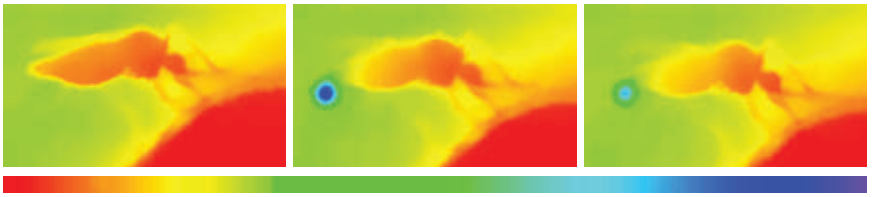
SAN FRANCISCO — Blowflies don't sweat, but they have raised cooling by drooling to a high art.

In hot times, sturdy, big-eyed *Chrysomya megacephala* flies repeatedly release — and then retract — a droplet of saliva, Denis Andrade reported January 4 at the annual meeting of the Society for Integrative and Comparative Biology. This process isn't sweating. Blowfly droplets put the cooling power of evaporation to use in a different way, said Andrade, who studies ecology and evolution at the Universidade Estadual Paulista in Rio Claro, Brazil.

As saliva hangs on a fly's mouthparts, the droplet starts to lose some of its heat to the air around it. When the fly droplet has cooled a bit, the fly then slurps the saliva back in, Andrade and colleagues found. Micro-CT scanning showed the retracted droplet in the fly's throat-like passage near the animal's brain. Temperature-sensitive imaging showed fly bodies cooling during a drool cycle. That cooling may prevent dangerous overheating, Andrade proposed. The same droplet seemed to be released, cooled, drawn back in and then released again several times in a row.

Andrade had never seen a report of this saliva droplet in-and-out before he and a colleague noticed it while observing blowfly temperatures for other reasons. But in 2012, Chloé Lahondère, who studies disease-vector insects, and a colleague described how *Anopheles stephensi* mosquitoes exude a droplet that dangles and cools, but at the insect's rear.

Mosquitoes, which let their body temperatures float with that of their environment, can get a heat rush when drinking from warm-blooded mammals. While drinking, the insects release a blood-tinged urine droplet, which dissipates some of the heat. There's some fluid movement within the droplet, says Lahondère, now at Virginia Tech in Blacksburg, but whether any of the liquid gets recaptured by the body the way fly drool does, she can't say. ■



As an *Anopheles stephensi* mosquito drinks mammal-hot blood (left), the insect releases a droplet of urine (blue dot, middle). The droplet cools the body (paler red-orange, right) before falling and being replaced. Now, researchers have observed a similar cooling mechanism in blowflies, which release a droplet of saliva, then slurp it up after the droplet has had a chance to cool down.

C. LAHONDÈRE AND C.R. LAZZARI/*CURRENT BIOLOGY* 2012

GENES & CELLS

Why not all strep infections are alike

Strains' genetic extras lead to immune reaction diversity

BY LAUREL HAMERS

One person infected with strep bacteria gets a sore throat; another might develop a fatal blood infection. Now, scientists are beginning to pin down why.

Variation between people's immune systems may not be entirely to blame. Instead, extra genes picked up by some pathogens can cause different strains to have different effects on the immune system, even in the same person, scientists report January 11 in *PLOS Pathogens*.

The idea that bacterial strains can behave differently in the body isn't new. But bacteria have exceptionally large amounts of genetic variation, even among members of the same species. So scientists are still trying to figure out how that diversity affects the way the microbes interact with the human immune system.

Every bacterial species has a core set of genes that all its members share. Then there are add-on genes that specific strains have acquired over time, from the environment or other microbes. Some of those genes give bacteria new traits.

Immunologist Uri Sela and colleagues at Rockefeller University in New York City tested how extra genes influenced the way two bacterial species, *Staphylococcus aureus* and *Streptococcus pyogenes*, interact with the immune system.

Different strains of the same species provoked wildly different immune responses in blood samples collected from the same patient, the researchers showed. But the strain-specific responses were consistent across patients. Some strains triggered lots of T cells to be made in every sample; others increased B cell activity. (T cells and B cells are the main weapons of the adaptive immune response, which lets the body build long-lasting immunity against a pathogen.)

In tests of strains missing some of their extra genes, though, T cells didn't respond as strongly as they did to a matching strain with the extra genes. The variation in immune response across strains was coming, at least in part, from differences in these supplementary genes.

In the future, Sela says, information about which strain of a species a patient has could help doctors decide on treatment based on how an illness will unfold.

Microbiologist Alan McNally of the University of Birmingham in England says the study "adds fuel to an active debate" about whether natural selection shapes the genetic add-ons that bacteria maintain. Customization might aid certain strains' survival by letting them provoke distinct immune responses that the strains can overcome. ■

New heat source ID'd for Yellowstone

Sinking tectonic plate helps fuel supervolcano, simulations show

BY CAROLYN GRAMLING

The driving force behind Yellowstone's long and explosive volcanic history may not be as deep as once thought. A new study suggests that instead of a plume of hot mantle that extends down to Earth's core, the real culprit is a subducting tectonic plate that began sinking beneath North America hundreds of millions of years ago.

Computer simulations show that movement of broken-up remnants of the ancient Farallon Plate could be stirring the mantle in a way that fuels Yellowstone, researchers report December 18 in *Nature Geoscience*. "The fit is so good," says study coauthor and geodynamicist Lijun Liu of the University of Illinois at Urbana-Champaign.

The giant supervolcano now beneath Yellowstone National Park, located mostly in Wyoming, has a 17-million-year history — much of it on the move. In that time, the locus of volcanism has moved northeastward from southwestern Idaho to its current location, where the most recent supereruption occurred about 640,000 years ago. These shifting eruptions have created a track of volcanic craters resembling those made by the hot spot that formed the Hawaiian Islands. As a result, scientists have long suspected that a deep plume of magma originating from the core-mantle boundary, similar to the one that fuels Hawaii's volcanoes, is the source of Yellowstone's fury.

But the nature of the Yellowstone plume has been the subject of debate. "Usually with plumes, we can trace them to the core-mantle boundary," says Robert Porritt, a seismologist at the University of Texas at Austin who was not involved in the study. To "see" Earth's structure, seismologists use seismic tomography, a technique that maps the interior using seismic waves generated by earthquakes. Particularly hot or liquid parts of the mantle slow some seismic waves known as shear waves. Tomographic images of mantle plumes such as the one beneath Hawaii show a low–shear velocity region that extends all the way down to the boundary between mantle and core, about 2,900 kilometers below Earth's surface. Such deep plumes are thought to be necessary to provide sufficient heat for the volcanism.

"But at Yellowstone, we don't have that large low–shear velocity thing at the core-mantle boundary," Porritt says. Current images suggest a region of low-velocity material extending at least 1,000 kilometers deep — but whether there is a deeper plume is uncertain.

And the region is tectonically complex. About 200 million years ago, the Farallon Plate to the west began to slide eastward beneath the North American Plate. The Juan de Fuca Plate off the Pacific Northwest coast, one of the last remnants of the Farallon Plate, continues to slide beneath the western United States. Some researchers have suggested that, instead of a deep mantle plume, the flexing and melting of the subducting Juan de Fuca Plate are responsible for Yellowstone's volcanism.

Liu and his colleagues had yet another idea. In 2016, Liu suggested that the sinking ancient Farallon slab was acting like a lid on a deep mantle plume, preventing the plume from rising to the surface (*SN Online: 2/3/16*). "But we kept in mind that the problem was not solved," Liu says. "The heat source [for Yellowstone] was still missing."

The researchers created a sophisticated, supercomputer-driven series of simulations to try to find the best scenario that matches the three known knowns: the current tomographic images of the subsurface beneath the western United States; the volcanic history at Yellowstone as well as in the nearby Basin and Range region; and the movements of the subducting Juan de Fuca Plate since about 20 million years ago.

Yellowstone's volcanism is linked not just to the subducting young Juan de Fuca Plate, but also to the remnants of its older incarnation, the Farallon Plate, the simulations suggest. Those remnants have continued to slide deeper and now lie beneath the eastern United States. This downward dive dragged hot mantle eastward along with it. As the Juan de Fuca Plate began to break up beneath the western United States, the hot mantle rose through the cracks. Some of that hot mantle circulated back to the west across the top of the Juan de Fuca Plate, fueling volcanism in the Basin and Range region. And some of it flowed eastward, feeding Yellowstone's fire. The study doesn't rule out the presence of a deep magma plume, but it suggests that such a plume plays little role in Yellowstone's volcanism.

Porritt says he's intrigued by the idea that the sinking Farallon slab could be driving mantle circulation on such a large scale. However, he says, he isn't convinced that the authors have truly solved the larger mystery of Yellowstone's volcanism — or that a yet-to-be-found deep plume isn't playing a major role. "It's an interesting debate that's going to be raging, hopefully for decades." ■

The heat source for Yellowstone's supervolcano and ongoing hydrothermal activity (Castle Geyser shown) isn't a deep mantle plume, but the downward drag of a subducting tectonic plate stirring up the mantle, researchers argue.

RIISHEDE/ISTOCKPHOTO

Entomologist Jeff Pettis inspects honeybees for signs of colony collapse. He suspects a combination of factors are to blame for the sudden deaths that first made news about a decade ago.

LIFE & EVOLUTION

Questions linger about colony collapse

Scientists have yet to prove cause of sudden honeybee die-offs

BY SUSAN MILIUS

It was one of the flashiest mysteries in the news about a decade ago — honeybee workers were vanishing fast for no clear reason. To this day, that puzzle has never been entirely solved, researchers acknowledge.

And maybe it never will be. Colony collapse disorder, or CCD, as the sudden mass honeybee losses were called, has faded in recent years as mysteriously as it began. It's possible the disappearances could start up again, but meanwhile bees are facing other problems.

CCD probably peaked around 2007 and faded since, says Jeff Pettis, who during the heights of national curiosity was running the Beltsville, Md., honeybee lab for the U.S. Department of Agriculture's research wing. And five years have passed since Dennis vanEngelsdorp, who studies bee health at the University of Maryland in College Park, has seen a "credible case" of colony collapse.

Beekeepers still report some cases, but Pettis and vanEngelsdorp aren't convinced such cases really are colony collapse disorder, a term that now gets used for a slew of things that are bad for bees. To specialists, colony collapse is a specific phenomenon. An apparently healthy colony over the course of days or a few weeks loses much of its workforce, while eggs and larvae, and often the queen herself, remain alive. Also food stores in collapsing colonies don't get raided by other bees as a failing colony's treasures usually do.

"I think I know what happened," says Pettis, now in Salisbury, Md., consulting on pollinator health. His proposed scenario for CCD, like those of some other veterans of the furor, is complex and doesn't rest on a single exotic killer. But so far, no experiment has nailed the proof.

On a suspect's trail

Looking back, Pettis realizes he had heard about what might have been early cases of CCD, described as colonies "just falling apart," for several years before the phenomenon made headlines. Then in November 2006, Pennsylvania beekeeper David Hackenberg, as usual, sent his colonies to Florida for the winter. They arrived in fine shape. Soon after, however, many buzzing colonies had shrunk to stragglers. Yet there were no dire parasite infestations and no dead bee bodies in sight.

"It was, 'OK, something weird just happened,' " remembers Jay Evans of the USDA's honeybee lab in Beltsville. "It looked like a 'flu,' something that kind of swept through miraculously fast."

No single menace, however, could be tightly linked to every sick colony, or only to sick colonies. Varroa mites, small hive beetles, *Nosema* fungi, deformed wing virus, unusual signs of pesticide exposure, for instance — screening techniques at the time just weren't picking up a clear pattern in any of these bee bedevilments.

"People were following this story like crazy," Pettis says. The bees' unexplained plight prompted a national outbreak of amateur entomology. "There were people saying, 'Why aren't you doing more with jet contrails?' There were 'alien abductions.' And the rapture — the bees were being called home."

Entomologists were hounded by the press, not to mention leaned on by politicians and pursued by would-be entrepreneurs. "For me, what made it rewarding," Pettis says, "was that people were learning about the value of pollination."

A Columbia University researcher who had identified pathogens in mysterious human disease outbreaks took a crack at the problem. Ian Lipkin had never worked with bees, but he and his lab collaborated with entomologists and other bee specialists to search for any genetic signature of a pathogen appearing only in collapsing colonies. The approach of searching through mass samples, with their messy traces of gut microbes and random parasites, is now familiar as metagenomics. At the time, this way of searching for pathogens was groundbreaking, says collaborator Diana Cox-Foster, then at Penn State. The resulting paper, in *Science*, pointed to several viruses, especially the previously obscure Israeli Acute Paralysis Virus, or IAPV (*SN: 9/8/07, p. 147*).

That emphasis on IAPV, which got a lot of attention at the time, hasn't held up well. "It's not 100 percent ruled out," Evans says. But the explanation's main problem is shared by other threats proposed as a single cause of CCD. After finding IAPV or another presumed single menace in sick bees in one place, he says, "you could go to other apiaries that were collapsing and not find it, or you could find it in healthier colonies."

As an apiary inspector for Pennsylvania at the time, vanEngelsdorp monitored for signs of collapse in over 200 hives. "We tried to watch it happen but we couldn't," he says. None collapsed. Even finding the sickest bees in collapsing colonies was a challenge. Doomed bees presumably flew off in multiple directions, and birds

STEPHEN AUSMUS/USDA

or other scavengers usually found the bees before scientists could.

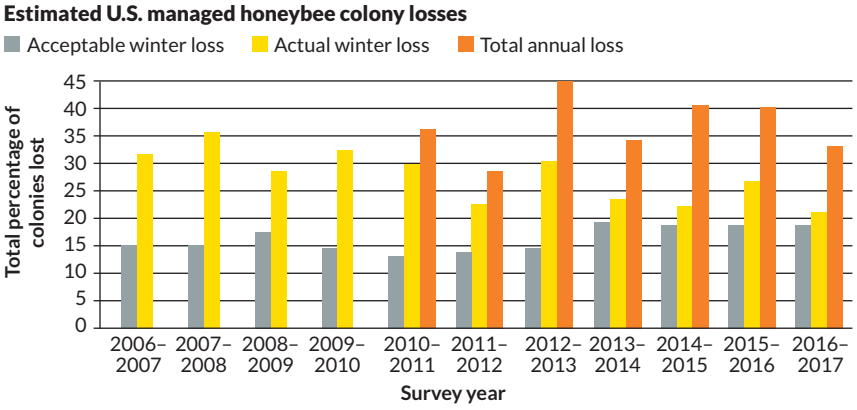
A gang of killers

Pettis now sees the disaster as a two-step process. Various stressors such as poor nutrition and pesticide exposure weakened bees so much that a virus, maybe IAPV, could quickly kill them in droves. Evans, too, sees various stressors mixing and matching. When pressed for his best guess, he says "all of the above."

Cox-Foster has managed to re-create part of the process, the vanishing effect that marked the end for stressed bees. When she infected honeybee colonies in a greenhouse with a virus, the sick bees left the hive but were trapped by the greenhouse walls before dispersing too far to be found. (Of course, this experiment doesn't demonstrate how colonies with no sign of a virus died.)

That tendency for sick bees to leave hives, vanEngelsdorp proposes, could have developed as a hygiene benefit. "Altruistic suicide," as social-insect biologists call it. Flying away from the colony could minimize a sick bee's tendency to pass disease to the rest of the family.

Losing bees Annual U.S. honeybee losses are higher than what beekeepers say is acceptable. Hives can be split so numbers build up again, but the slowdown raises costs of pollination.



Today, hive losses remain high even with CCD waning or gone, according to national surveys by the Bee Informed Partnership, a nonprofit bee health collaboration. Beekeepers typically note that they either expect or can tolerate annual losses between 15 and 20 percent of their total number of colonies. Yet from April 2016 until March 2017, losses across the United States ran at about a third of hives. And that was a so-called good year, the second-lowest loss in the seven years with data on annual losses.

Classic CCD may not be much threat these days, but the "four p's" — poor nutrition, pesticides, pathogens and parasites — are, says Cox-Foster, now at a USDA lab for pollinating insects in Logan, Utah. While honeybees aren't likely to go extinct, these threats to the beekeeping industry boost pollination costs, which could affect food prices.

Coping with the four p's may not fire the imaginations of armchair entomologists. But it's more than enough of a challenge for the bees. ■

GENES & CELLS

Ultrasound keeps tabs on bacteria

Technique could help monitor medicinal microbes in body

BY MARIA TEMMING

Ultrasound can now track bacteria in the body like sonar detects submarines.

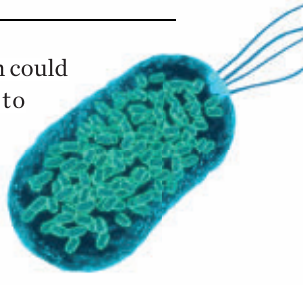
For the first time, scientists have genetically modified microbes to form gas-filled pouches that scatter sound waves to produce ultrasound signals. When these bacteria are injected inside an animal, an ultrasound detector can pick up those signals and reveal the microbes' location, much like sonar waves bouncing off ships at sea, explains study coauthor Mikhail Shapiro, a chemical engineer at Caltech.

This technique, described in the Jan. 4 *Nature,* may help with the monitoring of microbes that could be used to seek and destroy tumors or treat gut diseases.

Repurposing ultrasound, a common tissue-imaging method, to map microbes creates "a tool that nobody thought was even conceivable," says Olivier Couture, a medical biophysicist at the French National Center for Scientific Research in Paris who wasn't involved in the work.

Until now, researchers had tracked disease-fighting bacteria in the body by genetically engineering them to glow green when exposed to ultraviolet light. But that glow provides only blurry views of microbes in deeper tissue, if they can be seen at all. With ultrasound, "we can go centimeters deep and still see things with a spatial precision on the order of a hundred micrometers," Shapiro says.

Shapiro and colleagues engineered a strain of *E. coli* used to treat gut infection to form gas compartments, and injected the bacteria into mice's bellies. Unlike glowing bacteria, which could be pinpointed only to somewhere in a mouse's abdomen, ultrasound images located the gas-filled microbes in the colon. The method also worked for engineered *Salmonella* bacteria, which could be used to deliver drugs to tumor cells.



Microbes made to have gas-filled pouches (illustrated) scatter sound waves, generating ultrasound signals that reveal the microbes' location in the body.

Bacteria that make ultrasound signals can also be designed to help diagnose illness, Shapiro says. For instance, a patient could swallow bacteria engineered to create gas pockets wherever inflammation is sensed. A doctor could then use ultrasound to search for inflamed tissue, rather than perform an invasive colonoscopy. ■

FROM TOP: BEE INFORMED PARTNERSHIP; BARTH VAN ROSSUM FOR CALTECH

MATH & TECHNOLOGY

Prime number sets record

There's a new largest known prime number in town, with a whopping 23,249,425 digits. The figure is calculated by multiplying 2 by itself 77,232,917 times and then subtracting 1. Announced on January 3, the number is almost a million digits longer than the last record-breaking prime.

A prime number can't be divided by anything other than 1 and itself. As numbers get larger, primes become sparse.

After 14 years of searching, Jonathan Pace, an electrical engineer in Tennessee, found the number using software from the Great Internet Mersenne Prime Search. GIMPS is a volunteer-based project seeking ever-higher Mersenne primes, which are found by multiplying the number 2 by itself some number of times and subtracting 1. These primes are easier to find than other types, Pace says: The computer doesn't need to calculate a number's divisors to determine whether it's prime.

Anyone can download the software for free. So you, too, could discover a record-breaking prime number — if you have the patience. — *Laurel Hamers*

EARTH & ENVIRONMENT

Threat of coral bleaching heats up

Corals are in hot water. Severe bleaching is hitting reefs five times as often as in 1980, researchers report in the Jan. 5 *Science*.

Scientists surveyed 100 tropical coral reef locations worldwide, tracking each spot's fate from 1980 to 2016. Initially, only a few locations had experienced bleaching. But by 2016, all but six had suffered a severe event affecting over 30 percent of corals in an area.

Consistently higher tropical water temperatures, the result of climate change, are in part to blame, researchers say. Warm water stresses corals and strips their symbiotic algae, their main food source.

In the past, major bleaching most likely happened when El Niño brought warmer water to the tropics. But sea surface temperatures in tropical areas are now warmer during La Niña (when water is typically cooler) than they were during El Niño events 40 years ago, says study coauthor Terry Hughes of James Cook University in Townsville, Australia. — *Laurel Hamers*

GENES & CELLS

CRISPR gene editor could spark immune reactions in people

Immune reactions against proteins used as molecular scissors might make CRISPR/Cas9 gene editing ineffective in people.

About 79 percent of 34 human blood donors had antibodies against the Cas9 protein from *Staphylococcus aureus* bacteria, Stanford University researchers report online January 5 at bioRxiv.org. About 65 percent of donors had antibodies against *Streptococcus pyogenes* Cas9.

Six of 13 blood donors also had T cells that seek and destroy cells that make *S. aureus* Cas9. The researchers didn't detect any T cells that attack *S. pyogenes* Cas9, but the methods may not be sensitive enough to find these T cells, says study coauthor and stem cell biologist Kenneth Weinberg.

Cas9 is the DNA-cutting enzyme that enables precise gene edits. Antibodies and T cells against the protein could cause the immune system to attack cells carrying it, making gene therapy ineffective.

Immune reactions may be a technical glitch but probably aren't a safety concern for cells edited in lab dishes and not the body, Weinberg says. — *Tina Hesman Saey*

BODY & BRAIN

Protein helps explain why old blood ages young brains

Old blood can prematurely age the brains of young mice, and scientists may now be closer to understanding how. A protein in the cells that form the blood-brain barrier, a mesh of tightly woven cells that protects the brain from harmful factors in the blood, could be partly to blame, experiments in mice suggest.

If something similar happens in humans, methods for blocking the action of the protein may hold promise for treating age-related brain decline.

The preliminary study, reported online January 3 at bioRxiv.org, focused on a form of the VCAM1 protein, which interacts with immune cells in response to inflammation. As mice and humans age, VCAM1 levels in blood rise, Alzheimer's researcher Tony Wyss-Coray of Stanford University and colleagues found.

After injecting young mice behind an eye with plasma from old mice, VCAM1 levels also rose in certain parts of the blood-brain barrier. Young mice also showed signs of brain deterioration, including inflammation and decreased birthrates of new nerve cells. Plasma from young mice had no such effects.

Interfering with VCAM1 may help prevent premature brain aging. Old mice's plasma didn't have strong effects when injected into young mice genetically engineered to lack VCAM1 in certain blood-brain barrier cells. Nor did the plasma affect mice treated with antibodies that blocked the activity VCAM1. Those antibodies also seemed to slow signs of deterioration in the brains of mice that had aged naturally. — *Laura Sanders*

Bleaching removes the algae that feed corals and give them color, turning vibrant reefs barren, like this Indian Ocean reef bleached in 2016. Reefs are now experiencing severe bleaching much more frequently than four decades ago.

KRISTEN BROWN/ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES

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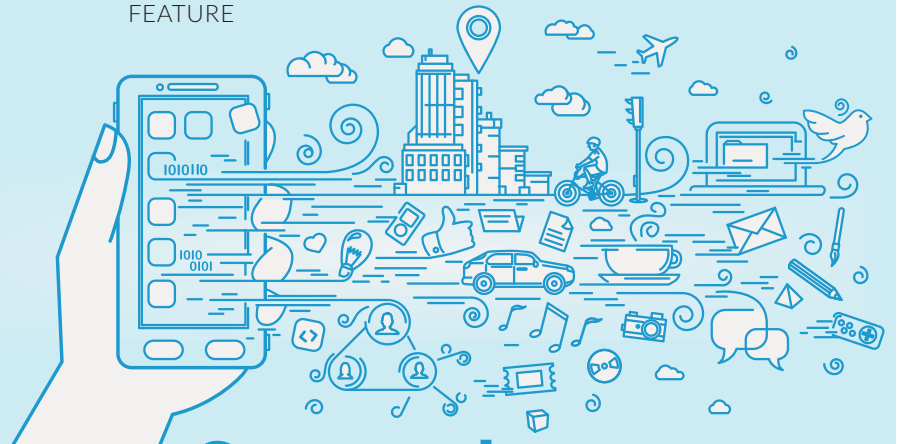
SCIENCE AND TECHNOLOGY



Smartphones Overshare

Devices can divulge a whole lot of info on your comings and goings

By Maria Temming

Consider everything your smartphone has done for you today. Counted your steps? Deposited a check? Transcribed notes? Navigated you somewhere new?

Smartphones make for such versatile pocket assistants because they're equipped with a suite of sensors, including some we may never think — or even know — about, sensing, for example, light, humidity, pressure and temperature.

Because smartphones have become essential companions, those sensors probably stayed close by throughout your day: the car cup holder, your desk, the dinner table and nightstand. If you're like the vast majority of American smartphone users, the phone's screen may have been black, but the device was probably on the whole time.

"Sensors are finding their ways into every corner of our lives," says Maryam Mehrnezhad, a computer scientist at Newcastle University in England. That's a good thing when phones are using their observational dexterity to do our bidding. But the plethora of highly personal information that smartphones are privy to also makes them powerful potential spies.

Online app store Google Play has already discovered apps abusing sensor access. Google recently booted 20 apps from Android phones and its app store because the apps could — without the user's knowledge — record with the microphone, monitor a phone's location, take photos, and then extract the data.

Stolen photos and sound bites pose obvious privacy invasions. But even seemingly innocuous sensor data can potentially broadcast sensitive information. A smartphone's movement may reveal what users are typing or disclose their whereabouts. Even barometer readings that subtly shift with increased altitude could give away which floor of a building you're standing on, suggests Ahmed Al-Haiqi, a security researcher at the National Energy University in Kajang, Malaysia.

These sneaky intrusions may not be happening in real life yet, but concerned researchers in academia and industry are working to head off eventual invasions. Some scientists have designed invasive apps and tested them on volunteers to shine a light on what smartphones can reveal about their owners. Other researchers are building new smartphone security systems to help protect users from myriad real and hypothetical privacy invasions, from stolen PIN codes to stalking.

Message revealed

Motion detectors within smartphones, like the accelerometer and the rotation-sensing gyroscope, could be prime tools for surreptitious data collection. They're not permission protected — the phone's user doesn't have to give a newly installed app permission to access those sensors. So motion detectors are fair game for any app downloaded onto a device, and "lots of vastly different aspects of the environment are imprinted on those signals," says Mani Srivastava, an engineer at UCLA.

For instance, touching different regions of a screen makes the phone tilt and shift just a tiny bit, but in ways that the phone's motion sensors pick up, Mehrnezhad and colleagues demonstrated in a study reported online April 2017 in the *International Journal of Information Security*. These sensors' data may "look like nonsense" to the human eye, says Al-Haiqi, but sophisticated computer programs can discern patterns in the mess and match segments of motion data to taps on various areas of the screen.

For the most part, these computer programs are machine-learning algorithms, Al-Haiqi says. Researchers train them to recognize keystrokes by feeding the programs a bunch of motion sensor data labeled with the key tap that produces particular movement. A pair of researchers built TouchLogger, an app that collects orientation sensor data and uses the data to deduce taps on smartphones' number keyboards. In a test on HTC phones, reported in 2011 in San Francisco at the USENIX Workshop on Hot Topics in Security,

MUSTAFAHACALAKI/ISTOCKPHOTO

TouchLogger discerned more than 70 percent of key taps correctly.

Since then, a spate of similar studies have come out, with scientists writing code to infer keystrokes on number and letter keyboards on different kinds of phones. In 2016 in *Pervasive and Mobile Computing*, Al-Haiqi and colleagues reviewed these studies and concluded that only a snoop's imagination limits the ways motion data could be translated into key taps. Those keystrokes could divulge everything from the password entered on a banking app to the contents of an e-mail or text message.

A more recent application used a whole fleet of smartphone sensors — including the gyroscope, accelerometer, light sensor and magnetism-measuring magnetometer — to guess PINs. The app analyzed a phone's movement and how, during typing, the user's finger blocked the light sensor. When tested on a pool of 50 PIN numbers, the app could discern keystrokes with 99.5 percent accuracy, the researchers reported on the Cryptology ePrint Archive in December.

Other researchers have paired motion data with mic recordings, which can pick up the soft sound of a fingertip tapping a screen. One group designed a malicious app that could masquerade as a simple note-taking tool. When the user tapped on the app's keyboard, the app covertly recorded both the key input and the simultaneous microphone and gyroscope readings to learn the sound and feel of each keystroke.

The app could even listen in the background when the user entered sensitive info on other apps. When tested on Samsung and HTC phones, the app, presented in the *Proceedings of the 2014 ACM Conference on Security and Privacy in Wireless and Mobile Networks*, inferred the keystrokes of 100 four-digit PINs with 94 percent accuracy.

Al-Haiqi points out, however, that success rates are mostly from tests of keystroke-deciphering techniques in controlled settings — assuming that users hold their phones a certain way or sit down while typing. How these info-extracting programs fare in a wider range of circumstances remains to be seen. But the answer to whether motion and other sensors would open the door for new privacy invasions is "an obvious yes," he says.

Tagalong

Motion sensors can also help map a person's travels, like a subway or bus ride. A trip produces an undercurrent of motion data that's discernible from shorter-lived, jerkier movements like a phone being pulled from a pocket. Researchers designed an app, described in 2017 in *IEEE Transactions on Information Forensics and Security*, to extract the data signatures of various subway routes from accelerometer readings.

In experiments with Samsung smartphones on the subway in Nanjing, China, this tracking app picked out which segments of the subway system a user was riding with at least 59, 81 and 88 percent accuracy — improving as the stretches expanded from three to five to seven stations long. Someone who can trace a user's subway movements might figure out where the traveler lives and works, what shops or bars the person frequents, a daily schedule, or even — if the app is tracking multiple people — who the user meets at various places.

Accelerometer data can also plot driving routes, as described at the 2012 IEEE International Conference on Communication Systems and Networks in Bangalore, India. Other sensors can be used to track people in more confined spaces: One team synced a smartphone mic and portable speaker to create an on-the-fly sonar system to map movements throughout a house. The team reported the work in the September 2017 *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*.

> "Sensors are finding their ways into every corner of our lives."
> MARYAM MEHRNEZHAD

"Fortunately there is not anything like [these sensor spying techniques] in real life that we've seen yet," says Selcuk Uluagac, an electrical and computer engineer at Florida International University in Miami. "But this doesn't mean there isn't a clear danger out there that we should be protecting ourselves against."

That's because the kinds of algorithms that researchers have employed to comb sensor data are getting more advanced and user-friendly all the time, Mehrnezhad says. It's not just people with Ph.D.s who can design the kinds of privacy invasions that researchers are trying to raise awareness about. Even app developers who don't understand the inner workings of machine-learning algorithms can easily get this kind of code online to build sensor-sniffing programs.

What's more, smartphone sensors don't just provide snooping opportunities for individual cybercrooks who peddle info-stealing software. Legitimate apps often harvest info, such as search engine and app download history, to sell to advertising companies and other third parties. Those

Observational artillery Along with the familiar camera and microphone, smartphones can pack a slew of other exquisitely sensitive sensors.
SOURCE: M. MEHRNEZHAD *ET AL*/ *INTERNATIONAL JOURNAL OF INFORMATION SECURITY* 2017

Fingerprint/TouchID Scans the user's fingerprint

Proximity Measures the distance of other objects from the phone's touch screen

Light Gauges the light level in the phone's environment

Barometer Measures ambient pressure around the phone

Accelerometer Measures acceleration of the device's movement or vibration

Gyroscope Evaluates degree and direction of a phone's rotation

Magnetism Reports the magnetic field intensity around the phone

Gravity Measures the force of gravity

MUSTAFAHACALAKI/ISTOCKPHOTO, ADAPTED BY E. OTWELL

third parties could use the information to learn about aspects of a user's life that the person doesn't necessarily want to share.

Take a health insurance company. "You may not like them to know if you are a lazy person or you are an active person," Mehrnezhad says. "Through these motion sensors, which are reporting the amount of activity you're doing every day, they could easily identify what type of user you are."

Sensor safeguards

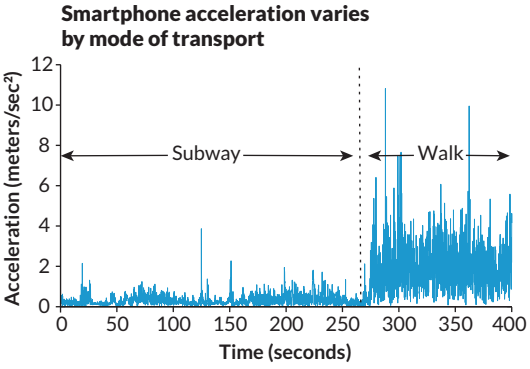
Since it's only getting easier for an untrusted third party to make private inferences from sensor data, researchers are devising ways to give people more control over what information apps can siphon off of their devices. Some safeguards could appear as standalone apps, whereas others are tools that could be built into future operating system updates.

Uluagac and colleagues proposed a system called 6thSense, which monitors a phone's sensor activity and alerts its owner to unusual behavior, in Vancouver at the August 2017 USENIX Security Symposium. The user trains this system to recognize the phone's normal sensor behavior during everyday tasks like calling, Web browsing and driving. Then, 6thSense continually checks the phone's sensor activity against these learned behaviors.

If someday the program spots something unusual — like the motion sensors reaping data when a user is just sitting and texting — 6thSense alerts the user. Then the user can check if a recently downloaded app is responsible for this suspicious activity and delete the app from the phone.

Uluagac's team recently tested a prototype of the system: Fifty users trained Samsung smartphones with 6thSense to recognize their typical sensor activity. When the researchers fed the 6thSense system examples of benign data from daily activities mixed in with segments of malicious sensor operations, 6thSense picked out the problematic bits with over 96 percent accuracy.

Metro motion Subway rides produce smartphone accelerometer readings distinct from other modes of transport. For instance, when a user steps off the train, that jerkier motion involved in walking produces a different signature.

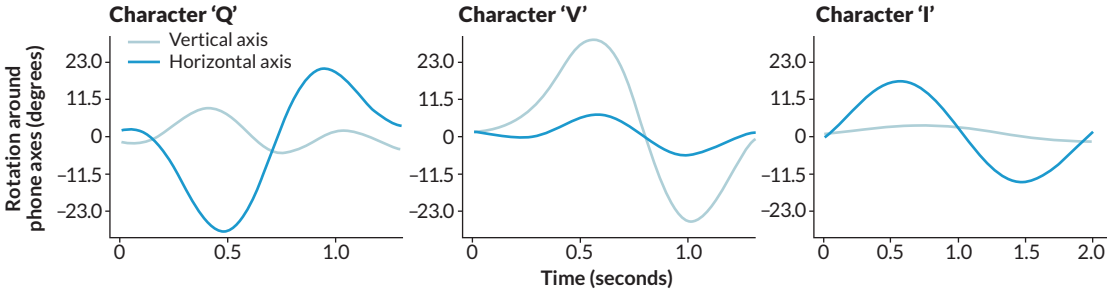


For people who want more active control over their data, Supriyo Chakraborty, a privacy and security researcher at IBM in Yorktown Heights, N.Y., and colleagues devised DEEProtect, a system that blunts apps' abilities to draw conclusions about certain user activity from sensor data. People could use DEEProtect, described in a paper posted online at arXiv.org in February 2017, to specify preferences about what apps should be allowed to do with sensor data. For example, someone may want an app to transcribe speech but not identify the speaker.

DEEProtect intercepts whatever raw sensor data an app tries to access and strips that data down to only the features needed to make user-approved inferences. For speech-to-text translation, the phone typically needs sound frequencies and the probabilities of particular words following each other in a sentence.

But sound frequencies could also help a spying app deduce a speaker's identity. So DEEProtect distorts the dataset before releasing it to the app, leaving information on word orders alone, since that has little or no bearing on speaker identity. Users can control how much DEEProtect changes the data; more distortion begets more

Key tap reveal A gyroscope senses how much and in which direction a smartphone rotates with various key taps. Here, touching "Q" produces more movement around the horizontal axis and "V" yields more vertical rotation.



FROM TOP: J. HUA *ET AL/IEEE TRANSACTIONS ON INFORMATION FORENSICS AND SECURITY 2017*; S. NARAIN *ET AL/PROC. OF THE 2014 ACM CONF. ON SECURITY AND PRIVACY IN WIRELESS AND MOBILE NETWORKS*

privacy but also degrades app functions.

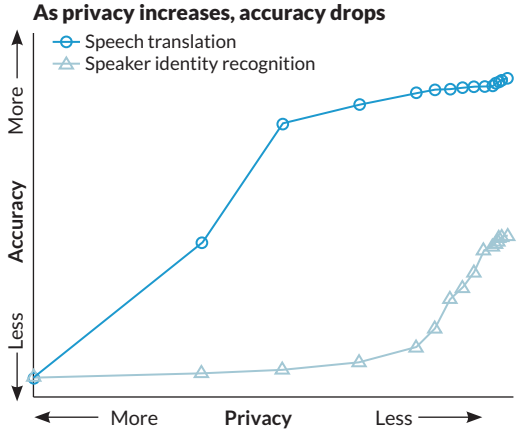
In another approach, Giuseppe Petracca, a computer scientist and engineer at Penn State, and colleagues are trying to protect users from accidentally granting sensor access to deceitful apps, with a security system called AWare.

Apps have to get user permission upon first installation or first use to access certain sensors like the mic and camera. But people can be cavalier about granting those blanket authorizations, Uluagac says. "People blindly give permission to say, 'Hey, you can use the camera, you can use the microphone.' But they don't really know how the apps are using these sensors."

Instead of asking permission when a new app is installed, AWare would request user permission for an app to access a certain sensor the first time a user provided a certain input, like pressing a camera button. On top of that, the AWare system memorizes the state of the phone when the user grants that initial permission — the exact appearance of the screen, sensors requested and other information. That way, AWare can tell users if the app later attempts to trick them into granting unintended permissions.

For instance, Petracca and colleagues imagine a crafty data-stealing app that asks for camera access when the user first pushes a camera button, but then also tries to access the mic when the user later pushes that same button. The AWare system, also presented at the 2017 USENIX Security Symposium, would realize the mic access wasn't part of the initial deal, and would ask the user again if he or she would like to grant this additional permission.

Balancing act Distorting sensor data with the security system DEEProtect curbs the ability of an app, such as a speech-to-text translator, to use sensor readings. But more distortion for more privacy comes with less accuracy.



FROM TOP: G. PETRACCA *ET AL*/*PROC. OF THE 26TH USENIX SECURITY SYMPOSIUM* 2017; C. LIU *ET AL*/ARXIV.ORG 2017

Petracca and colleagues found that people using Nexus smartphones equipped with AWare avoided unwanted authorizations about 93 percent of the time, compared with 9 percent among people using smartphones with typical first-use or install-time permission policies.

The price of privacy

The Android security team at Google is also trying to mitigate the privacy risks posed by app sensor data collection. Android security engineer Rene Mayrhofer and colleagues are keeping tabs on the latest security studies coming out of academia, Mayrhofer says.

But just because someone has built and successfully tested a prototype of a new smartphone security system doesn't mean it will show up in future operating system updates. Android hasn't incorporated proposed sensor safeguards because the security team is still looking for a protocol that strikes the right balance between restricting access for nefarious apps and not stunting the functions of trustworthy programs, Mayrhofer explains.

"The whole [app] ecosystem is so big, and there are so many different apps out there that have a totally legitimate purpose," he adds. Any kind of new security system that curbs apps' sensor access presents "a real risk of breaking" legitimate apps.

Tech companies may also be reluctant to adopt additional security measures because these extra protections can come at the cost of user friendliness, like AWare's additional permissions pop-ups. There's an inherent trade-off between security and convenience, UCLA's Srivastava says. "You're never going to have this magical sensor shield [that] gives you this perfect balance of privacy and utility."

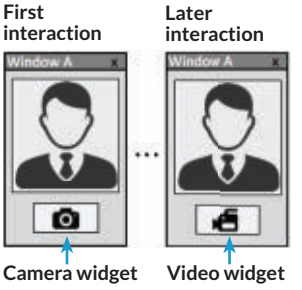
But as sensors get more pervasive and powerful, and algorithms for analyzing the data become more astute, even smartphone vendors may eventually concede that the current sensor protections aren't cutting it. "It's like cat and mouse," Al-Haiqi says. "Attacks will improve, solutions will improve. Attacks will improve, solutions will improve."

The game will continue, Chakraborty agrees. "I don't think we'll get to a place where we can declare a winner and go home." ■

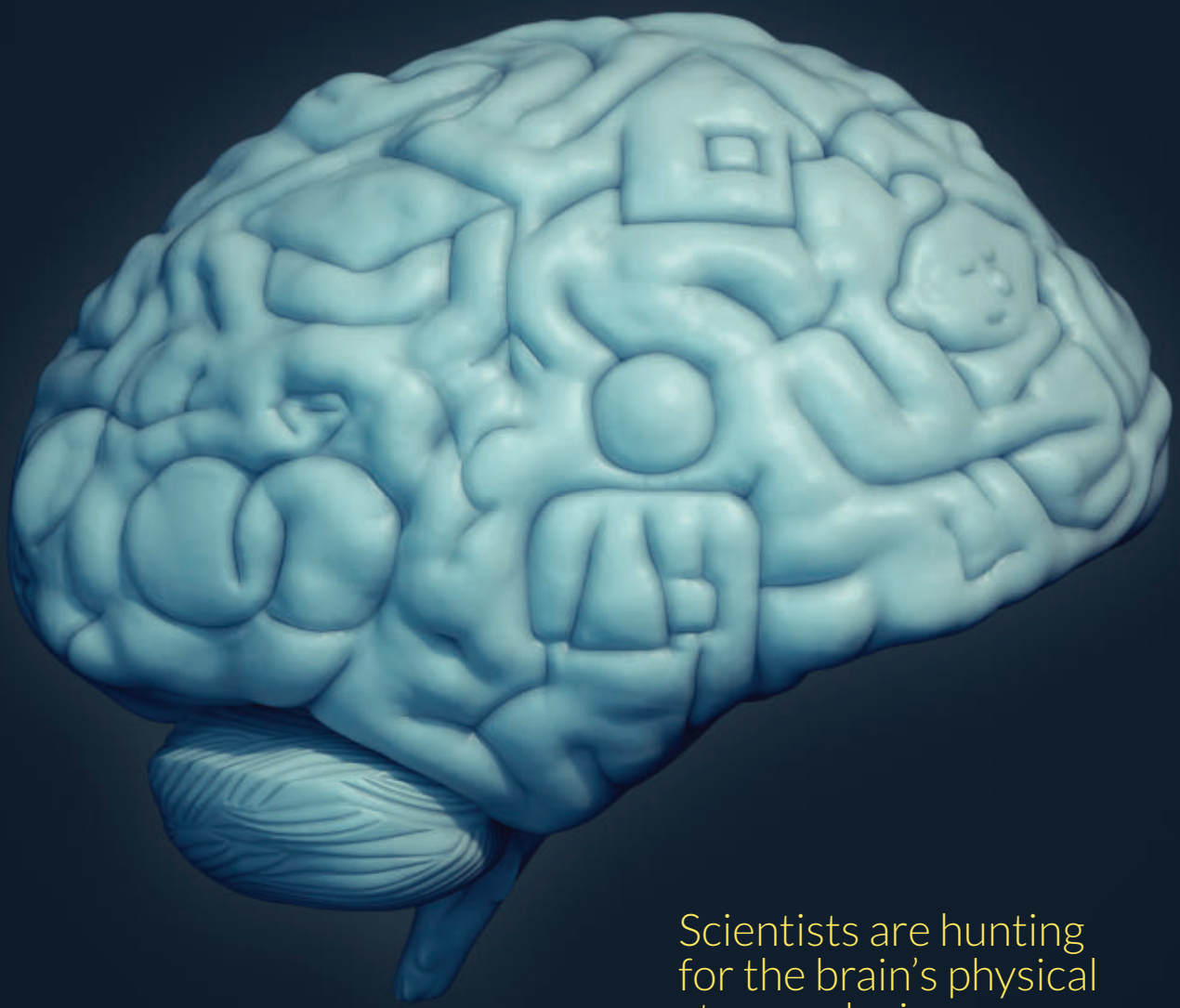
Explore more

- Muzammil Hussain *et al.* "The rise of keyloggers on smartphones: a survey and insight into motion-based tap inference attacks." *Pervasive and Mobile Computing.* January 2016.

Tricky widget A deceptive smartphone app might show the user a camera button several times, then switch to the video camera button, tricking a distracted user into giving the app access to the mic as well as the camera.



TRACES OF memory



Scientists are hunting for the brain's physical storage device

By Laura Sanders

SVEN HAUTH

People tend to think of memories as deeply personal, ephemeral possessions — snippets of emotions, words, colors and smells stitched into our unique neural tapestries as life goes on. But a strange series of experiments conducted decades ago offered a different, more tangible perspective. The mind-bending results have gained unexpected support from recent studies.

In 1959, James Vernon McConnell, a psychologist at the University of Michigan in Ann Arbor, painstakingly trained small flatworms called planarians to associate a shock with a light. The worms remembered this lesson, later contracting their bodies in response to the light.

One weird and wonderful thing about planarians is that they can regenerate their bodies — including their brains. When the trained flatworms were cut in half, they regrew either a head or a tail, depending on which piece had been lost. Not surprisingly, worms that kept their heads and regrew tails retained the memory of the shock, McConnell found. Astonishingly, so did the worms that grew replacement heads and brains. Somehow, these fully operational, complex arrangements of brand-spanking-new nerve cells had acquired the memory of the painful shock, McConnell reported.

In subsequent experiments, McConnell went even further, attempting to transfer memory from one worm to another. He tried grafting the head of a trained worm onto the tail of an untrained worm, but he couldn't get the head to stick. He injected trained planarian slurry into untrained worms, but the recipients often exploded. Finally, he ground up bits of the trained planarians and fed them to untrained worms. Sure enough, after their meal, the untrained worms seemed to have traces of the memory — the cannibals recoiled at the light.

The implications were bizarre, and potentially profound: Lurking in that pungent planarian puree must be a substance that allowed animals to literally eat one another's memories.

These outlandish experiments aimed to answer a question that had been needling scientists for decades: What is the physical basis of memory? Somehow, memories get etched into cells, forming a physical trace that researchers call an "engram." But the nature of these stable, specific imprints is a mystery.

Today, McConnell's memory transfer episode has largely faded from scientific conversation. But developmental biologist Michael Levin of Tufts University in Medford, Mass., and a handful of other researchers wonder if McConnell was onto something. They have begun revisiting those historical experiments in the ongoing hunt for the engram.

Applying powerful tools to the engram search, scientists are already challenging some widely held ideas about how memories are stored in the brain. New insights haven't yet revealed the identity of the physical basis of memory, though. Scientists are chasing a wide range of possibilities. Some ideas are backed by strong evidence; others are still just hunches. In pursuit of the engram, some researchers have even searched for clues in memories that persist in brains that go through massive reorganization.

T. SHOMRAT AND M. LEVIN

Planarian flatworms can remember how to navigate bumpy terrain (shown) in pursuit of food. This memory seems to survive even after a flatworm's head has been lopped off and regrown.

Synapse skeptics

One of today's most entrenched explanations puts engrams squarely within the synapses, connections where chemical and electrical messages move between nerve cells, or neurons. These contact points are strengthened when bulges called synaptic boutons grow at the ends of message-sending axons and when hairlike protrusions called spines decorate message-receiving dendrites.

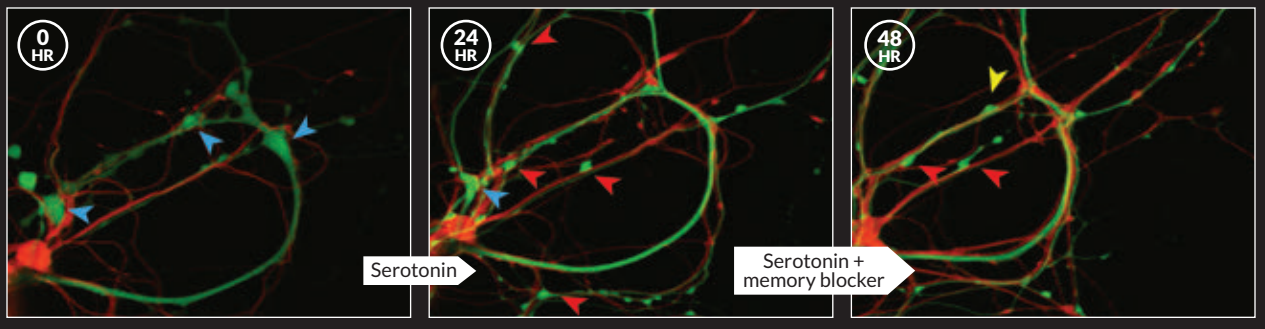
In the 1970s, researchers described evidence that as an animal learned something, these neural connections bulked up, forming more contact points of synaptic boutons and dendritic spines. With stronger connection points, cells could fire in tandem when the memory needed to be recalled. Stronger connections mean stronger memory, as the theory goes.

This process of bulking up, called long-term potentiation, or LTP, was thought to offer an excellent explanation for the physical basis of memory, says David Glanzman, a neuroscientist at UCLA who has studied learning and memory since 1980. "Until a few years ago, I implicitly accepted this model for memory," he says. "I don't anymore."

Glanzman has good reason to be skeptical. In his lab, he studies the sea slug *Aplysia*, an organism that he first encountered as a postdoctoral student in the Columbia University lab of Nobel Prize–winning neuroscientist Eric Kandel. When shocked in the tail, these slugs protectively withdraw their siphon and gill. After multiple shocks, the animals become sensitized and withdraw faster. (The distinction between learning and remembering is hazy, so researchers often treat the two as similar actions.)

After neurons in the sea slugs had formed the memory of the shock, the researchers saw stronger synapses between the nerve cells that sense the shock and the ones that command

Another way In a simplified system of two neurons, researchers used the chemical messenger serotonin to mimic training that leads to a painful memory in a sea slug brain. Some connections came and others went, suggesting these contact points don't actually store the memory.



The axon (green) of a neuron that senses painful signals connects (blue arrows) with dendrites (red) from a neuron that helps the sea slug move. This image was taken before training began.

Twenty-four hours after pain training is mimicked using five pulses of serotonin, new connections (red arrows) form and some preexisting connections (blue arrows) disappear.

When the "memory" is recalled, with one pulse of serotonin, then quickly blocked with a drug, only some of the newly formed connections (red arrows) disappear and new contacts appear (yellow arrow).

the siphon and gill to move. When the memory was made, the synapse sprouted more message-sending bumps, Glanzman's team reported in *eLife* in 2014. And when the memory was weakened with a drug that prevents new proteins from being made, some of these bumps disappeared. "That made perfect sense," Glanzman says. "We expected the synaptic growth to revert and go back to the original, nonlearned state. And it did."

But the answer to the next logical question was a curve ball. If the memory was stored in bulked-up synapses, as researchers thought, then the new contact points that appear when a memory is formed should be the same ones that vanish when the memory is subsequently lost, Glanzman reasoned. That's not what happened — not even close. "We found that it was totally random," Glanzman says. "Completely random."

Research from Susumu Tonegawa, a Nobel Prize–winning neuroscientist at MIT, turned up a result in mice that was just as startling. His project relies on sophisticated tools, including optogenetics. With this technique, the scientists activated specific memory-storing neurons with light. The researchers call those memory-storing cells "engram cells."

In a parallel to the sea slug experiment, Tonegawa's team conditioned mice to fear a particular cage and genetically marked the cells that somehow store that fear memory. After the mice learned the association, the researchers saw more dendritic spines in the neurons that store the memory — evidence of stronger synapses.

When the researchers caused amnesia with a drug, that newly formed synaptic muscle went away. "We wiped out the LTP, completely wiped it out," says neuroscientist Tomás Ryan, who conducted the study in Tonegawa's lab and reported the results with Tonegawa and colleagues in 2015 in *Science*.

And yet the memory wasn't lost. With laser light, the researchers could still activate the engram cells — and the memory they somehow still held. That means that the memory was stored in something that isn't related to the strength of the synapses.

The surprising results suggest that researchers may have been sidetracked, focusing too hard on synaptic strength as a memory storage system, says Ryan, now at Trinity College Dublin. "That approach has produced about 12,000 or so papers on the topic, but it hasn't been very successful in explaining how memory works."

Silent memories

The finding that memory storage and synaptic strength aren't always tied together raises an important distinction that may help untangle the research. The cellular machines that are required for calling up memories are not necessarily the same machines that store memories. The search for what stores memories may have been muddled with results on how cells naturally call up memories.

Ryan, Tonegawa and Glanzman all think that LTP, with its bulked-up synapses, is important for retrieving memories, but not the thing that actually stores them. It's quite possible to have stored memories that aren't readily accessible, what Glanzman calls "occult memories" and Tonegawa refers to as "silent engrams." Both think the concept applies more broadly than in just the sea slugs and mice they study.

Glanzman explains the situation by considering a talented violin player. "If you cut off my hands, I'm not able to play the violin," he says. "But it doesn't mean that I don't know how to play the violin." The analogy is overly simple, he says, "but that's how I think of synapses. They enable the memory to be expressed, but they are not where the memory is."

In a paper published last October in *Proceedings of the National Academy of Sciences,* Tonegawa and colleagues created silent engrams of a cage in which mice received a shock. The mice didn't seem to remember the room paired with the shock, suggesting that the memory was silent. But the memory could be called up after a genetic tweak beefed up synaptic connections by boosting the number of synaptic spines

ALL: SHANPING CHEN, DIANCAI CAI AND D.L. GLANZMAN

specifically among the neurons that stored the memory.

Those results add weight to the idea that synaptic strength is crucial for memory recall, but not storage, and they also hint that, somehow, the brain stores many inaccessible memory traces. Tonegawa suspects that these silent engrams are quite common.

Finding and reactivating silent engrams "tells us quite a bit about how memory works," Tonegawa says. "Memory is not always active for you. You learn it, you store it," but depending on the context, it might slip quietly into the brain and remain silent, he says. Consider an old memory from high school that suddenly pops up. "Something triggered you to recall — something very specific — and that probably involves the conversion of a silent engram to an active engram," Tonegawa says.

But engrams, silent or active, must still be holding memory information somehow. Tonegawa thinks that this information is stored not in synapses' strength, but in synapses' very existence. When a specific memory is formed, new connections are quickly forged, creating anatomical bridges between constellations of cells, he suspects. "That defines the content of memory," he says. "That is the substrate."

These newly formed synapses can then be beefed up, leading to the memory burbling up as an active engram, or pared down and weakened, leading to a silent engram. Tonegawa says this idea requires less energy than the LTP model, which holds that memory storage requires constantly revved up synapses full of numerous contact points. Synapse existence, he argues, can hold memory in a latent, low-maintenance state.

"The brain doesn't even have to recognize that it's a memory," says Ryan, who shares this view. Stored in the anatomy of arrays of neurons, memory is "in the shape of the brain itself," he says.

A temporary vessel

Tonegawa is confident that the very existence of physical links between neurons stores memories. But other researchers have their own notions.

Back in the 1950s, McConnell suspected that RNA, cellular material that can help carry out genetic instructions but can also carry information itself, might somehow store memories.

This unorthodox idea, that RNA is involved in memory storage, has at least one modern-day supporter in Glanzman, who plans to present preliminary data at a meeting in April that suggest injections of RNA can transfer memory between sea slugs.

Glanzman thinks that RNA is a temporary storage vessel for memories, though. The real engram, he suggests, is the folding pattern of DNA in cells' nuclei. Changes to how tightly DNA is packed can govern how genes are deployed. Those changes, part of what's known as the epigenetic code, can be made — and even transferred — by roving RNA molecules, Glanzman argues. He is quick to point out that his idea, memory transfer by RNA, is radical. "I don't think you could find another card-carrying Ph.D. neuroscientist who believes that."

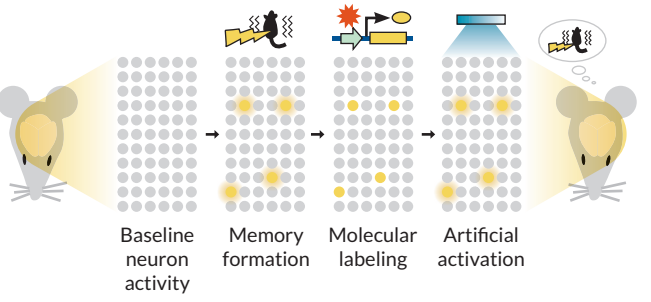
Other researchers, including neurobiologist David Sweatt of Vanderbilt University in Nashville, also suspect that long-lasting epigenetic changes to DNA hold memories, an idea Sweatt has been pursuing for 20 years. Because epigenetic changes can be stable, "they possess the unique attribute necessary to contribute to the engram," he says.

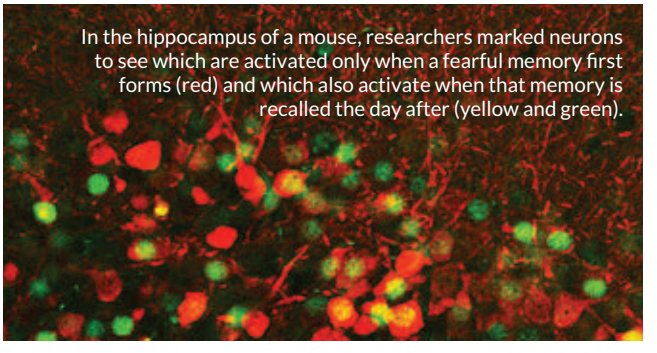
And still more engram ideas abound. Some results suggest that a protein called PKM-zeta, which helps keep synapses strong, preserves memories. Other evidence suggests a role for structures called perineuronal nets, rigid sheaths that wrap around neurons. Holes in these nets allow synapses to peek through, solidifying memories, the reasoning goes (*SN: 11/14/15, p. 8*). A different line of research focuses on proteins that incite others to misfold and aggregate around synapses, strengthening memories. Levin, at Tufts, has his own take. He thinks that bioelectrical signals, detected by voltage-sensing proteins on the outside of cells, can store memories, though he has no evidence yet.

Beyond the brain

Levin's work on planarians, reminiscent of McConnell's cannibal research, may even prod memory researchers to think beyond the brain. Planarians can remember the texture of their terrain, even using a new brain, Levin and Tal Shomrat, now at the Ruppin Academic Center in Mikhmoret, Israel, reported in 2013 in the *Journal of Experimental Biology*. The fact that memory somehow survived decapitation hints that signals outside of the brain may somehow store memories, even if temporarily.

Memory tags Researchers in the MIT lab of Susumu Tonegawa can mark and manipulate the memory-storing neurons in the hippocampus of a mouse brain. When the mouse gets a shock, a smattering of neurons, dubbed "engram cells," become active, somehow storing the memory (yellow circles, second panel). Using genetic techniques, the researchers tweak those cells to respond to blue light (next panel). When a burst of blue light hits (last panel), the mouse remembers the shock. SOURCE: S. TONEGAWA *ET AL*/*NEURON* 2015





In the hippocampus of a mouse, researchers marked neurons to see which are activated only when a fearful memory first forms (red) and which also activate when that memory is recalled the day after (yellow and green).

FROM TOP: C. CHANG; DHEERAJ ROY/TONEGAWA LAB/MIT

Memory clues may also come from other animals that undergo extreme brain modification over their lifetimes. As caterpillars transition to moths, their brains change dramatically. But a moth that had learned as a caterpillar to avoid a certain odor paired with a shock holds onto that information, despite having a radically different brain, researchers have found.

Similar results come from mammals, such as the Arctic ground squirrel, which massively prunes its synaptic connections to save energy during torpor in the winter. Within hours of the squirrel waking up, the pruned synaptic connections grow back. Remarkably, some old memories seem to survive the experience. The squirrels have been shown to remember familiar squirrels, as well as how to perform motor feats such as jumping between boxes and crawling through tubes. Even human babies retain taste and sound memories from their time in the womb, despite a very changed brain.

These extreme cases of memory persistence raise lots of basic questions about the nature of the engram, including whether memories must always be stored in the brain. But it's important that the engram search isn't restricted to the most advanced forms of humanlike memory, Levin says. "Memory starts, evolutionarily, very early on," he says. "Single-celled organisms, bacteria, slime molds, fish, these things all have memory.... They have the ability to alter their future behavior based on what's happened before."

The diversity of ideas — and of experimental approaches — highlights just how unsettled the engram question remains. After decades of work, the field is still young. Even if the physical identity of the engram is eventually discovered and universally agreed on, a bigger question still looms, Levin says.

"The whole point of memory is that you should be able to look at the engram and immediately know what it means," he says. Somehow, the physical message of a memory, in whatever form it ultimately takes, must be translated into the experience of a memory by the brain. But no one has a clue how this occurs.

At a 2016 workshop, a small group of researchers gathered to discuss engram ideas that move beyond synapse strength. "All the rebels came together," Glanzman says. The two-day debate didn't settle anything, but it was "very valuable," says Ryan, who also attended. He coauthored a summary of the discussion that appeared in the May 2017 *Annals of the New York Academy of Sciences*. "Because the mind is part of the natural world, there is no reason to believe that it will be any less tangible and ultimately comprehensible than other components," Ryan and coauthors optimistically wrote.

For now, the field hasn't been able to explain memories in tangible terms. But research is moving forward, in part because of its deep implications. The hunt for memories gets at the very nature of identity, Levin says. "What does it mean to be a coherent individual that has a coherent bundle of memories?" The elusive identity of the engram may prove key to answering that question. ■

Explore more

- Bridget N. Queenan *et al.* "On the research of time past: the hunt for the substrate of memory." *Annals of the New York Academy of Sciences.* May 2017.

Big changes In some creatures, memories can survive massive brain reorganizations, and even complete regrowth. Studying such persistence may provide hints about how memories are stored. SOURCE: D.J. BLACKISTON, T. SHOMRAT AND M. LEVIN/*COMMUNICATIVE & INTEGRATIVE BIOLOGY* 2015

Metamorphosing insects

Neurons' complex shapes get pruned back to just the cell body before the brain transitions into its adult form (monarch caterpillar shown).

Behaviors that survive the change:

- Moths prefer to lay eggs on foods they had eaten as larvae.
- Adult fruit flies continue to avoid an odor that had been paired with a shock they had received as larvae.

Planarian flatworms

Following a head amputation, these worms can regenerate an entire new brain (along with the rest of the head) from their tails.

Behaviors that survive the change:

- Planarians with new heads know to avoid light previously paired with a shock.
- Planarians previously trained on a bumpy surface navigate better than untrained worms.

Arctic ground squirrels

The message-receiving dendrites on neurons shrink way back during winter torpor, then regrow quickly when the animal awakens.

Behaviors that survive the change:

- The squirrels continue to recognize relatives and familiar individuals.
- Previously trained squirrels perform well on leaping and tunnel tasks.

FROM LEFT: PSEUDOPANAX/WIKIMEDIA COMMONS; JUNJI MOROKUMA/LEVIN LAB; IANARE SEVI/WIKIMEDIA COMMONS (CC BY-SA 3.0)

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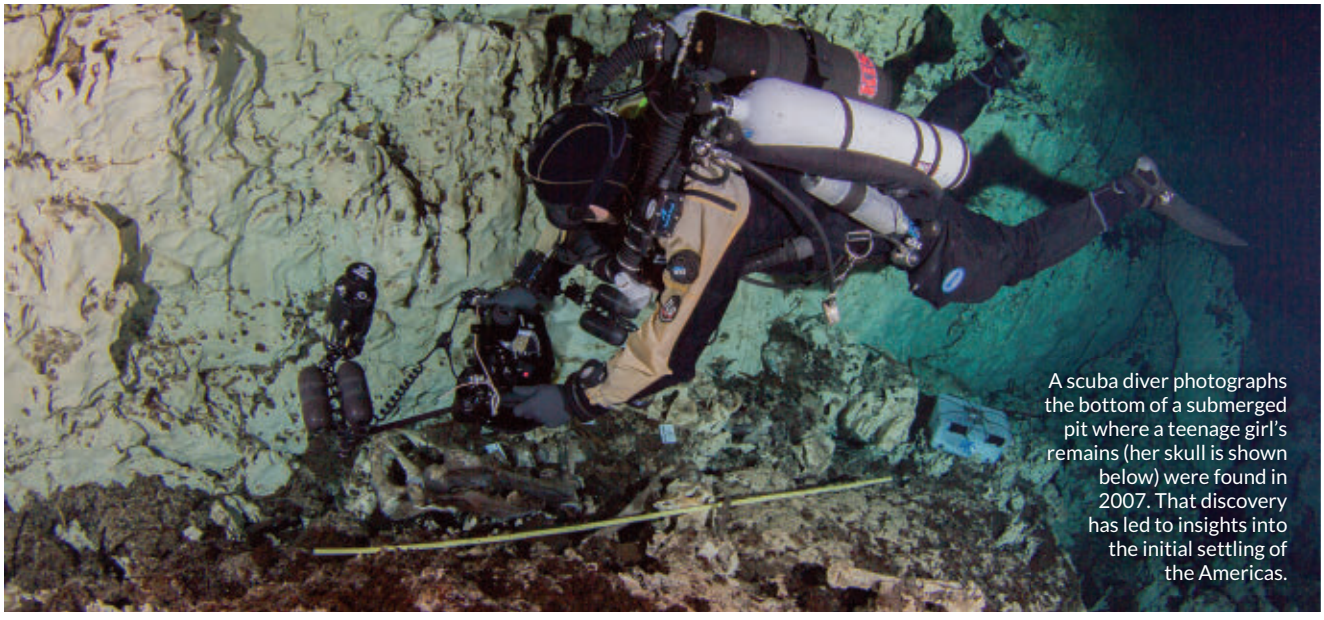


A scuba diver photographs the bottom of a submerged pit where a teenage girl's remains (her skull is shown below) were found in 2007. That discovery has led to insights into the initial settling of the Americas.

TELEVISION

Relive daring search for America's first settlers

A teenage girl climbed into an underground cave around 13,000 years ago. Edging through the ink-dark chamber, she accidentally plunged to her death at the bottom of a deep pit.

Rising seas eventually inundated the cave, located on Central America's Yucatán Peninsula. But that didn't stop scuba divers from finding and retrieving much of the girl's skeleton in 2007.

"First Face of America," a new *NOVA* documentary airing February 7 on PBS, provides a closeup look at two dangerous underwater expeditions that resulted in the discovery and salvaging of bones from one of the earliest known New World residents, dubbed Naia.

The program describes how studies of Naia's bones (*SN: 6/14/14, p. 6*) and of genes from an 11,500-year-old infant recently excavated in Alaska have generated fresh insights into how people populated the Americas. Viewers watch anthropologist and forensic consultant James Chatters, who directed scientific studies of Naia's remains, as he reconstructs the ancient teen's face and charts the lower-body injuries that testify to what must have been a rough life.

In one suspenseful scene, cameras record Chatters talking with scuba divers shortly before the divers descend into the submerged cave to collect Naia's bones. The scientist describes how thousands of years of soaking in seawater have rendered the precious remains fragile. He uses a plaster cast of a human jaw to demonstrate for scuba diver Susan Bird how to handle Naia's skull so that it stays intact while being placed in a padded box. Bird's worried expression speaks volumes.

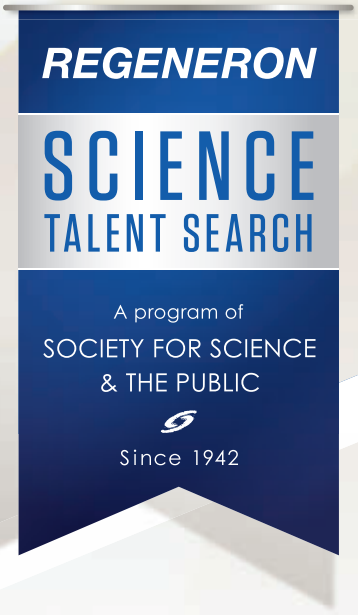
"First Face of America"
PREMIERES FEBRUARY 7
PBS | *NOVA*

"On the day of the dive, there was so much tension, so many people on the verge of freaking out," Bird recalls in the show. When the divers return from their successful mission, collective joy breaks out.

The scene then shifts to a lab where Chatters painstakingly re-creates what Naia looked like. Asian-looking facial features raise questions about how the ancient youth ended up in Central America. That's where University of Alaska Fairbanks anthropologist Ben Potter enters the story. In 2013, Potter and colleagues excavated the remains of two infant girls at an Alaskan site dating nearly to Naia's time. Analysis of DNA recovered from one of the infants, described in the Jan. 11 *Nature*, supports a scenario in which a single founding Native American population reached a land bridge that connected northeast Asia to North America around 35,000 years ago. As early as 20,000 years ago, those people had moved into their new continent, North America. Naia's face reflects her ancestors' Asian roots.

In tracing back how people ended up in the Americas, *NOVA* presents an outdated model of ancient humans moving out of Africa along a single path through the Middle East around 80,000 years ago. Evidence increasingly indicates that people started leaving Africa 100,000 years ago or more via multiple paths (*SN: 12/24/16, p. 25*). That's a topic for another show, though. In this one, Naia reveals secrets about the peopling of the Americas with a lot of help from intrepid scuba divers and state-of-the-art analyses. It's fitting that a slight smile creases her reconstructed face. — *Bruce Bower*

FROM TOP: ALBERTO NAVA; FRANCIS CORDERO RAMIREZ



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NOVEMBER 25, 2017

Past and present

A new year brings new, notable anniversaries in science, math and medicine. In a *Context* blog post, "2018's Top 10 science anniversaries" (*SN Online: 1/5/18*), **Tom Siegfried** recalls helium's discovery 150 years ago, the 100th anniversary of the birth of physicist Richard Feynman (pictured) and more special occasions, "reminders of past achievements and context for appreciating science of the present day." Read more at bit.ly/SN_Anniversaries2018

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Pedal to the universal metal

Some cosmologists hope to explain the universe's accelerating expansion by fully accounting for the universe's lumpiness, ***Emily Conover*** *reported in "Adventures in lumpy space"* (SN: 11/25/17, p. 22).

The universe's accelerating expansion "is apparently based on the observation of objects that are moving away from Earth at speeds that increase as the distance to the object from Earth increases," reader **Tom Phillips** wrote. "But the greater the distance from Earth, the farther back in time the object is being observed. This implies that the universe was expanding faster in the past than at present. What am I missing?"

Phillips isn't alone in his confusion, **Conover** says. "We know that the universe is expanding thanks to the redshift of light from faraway sources. That light looks redder to us (meaning it has longer wavelengths) than it was when originally emitted," she says. "In the case of the expanding universe, the redshift isn't caused by the source moving away from us, but by space itself expanding."

That expansion stretches out light as it travels, giving the light a longer wavelength over time. The farther away a light source is, the longer the light must travel to reach Earth, which means that its light will be more redshifted. The reason cosmologists know that the universe's expansion is accelerating is that sources that are the farthest away are less redshifted than expected, given how long the light has been traveling. "That means at the time long ago when the oldest light was emitted, the universe was expanding more slowly," **Conover** says.

Into the void

By-products of cosmic rays called muons helped scientists uncover a hollow area inside the Great Pyramid of Giza, ***Maria Temming*** *reported in "Hidden void found in Great Pyramid"* (SN: 11/25/17, p. 6).

A few readers on Reddit wondered how scientists could further explore the cavity. "Where to from here?" asked Reddit user **Etrigone**. "I'm assuming we can't get to the void.... Any other techniques to allow for a better idea of what it looks like?"

If the muon detectors were left running in their current locations for many years, researchers could get more precise images and possibly detect smaller structures, says **Mehdi Tayoubi**, cofounder of the Heritage Innovation Preservation Institute in Paris, which led the project. Moving the detectors to other locations around the pyramid could give the team a different view of the void.

Unfortunately, the void is located in a place that is difficult to access from the inside, **Tayoubi** says. A roboticist recently joined the research team, which now hopes to design a robot that would fly inside the pyramid as well as other monuments. Whether Egyptian authorities would allow such a robot to explore the pyramid from the inside is not yet known, the researchers say.

Flushed away

Lessons learned from flushing space toilets might help researchers plan life-hunting missions to icy moons, such as Saturn's Enceladus, ***Lisa Grossman*** *reported in "Space toilets could be a research tool"* (SN: 11/25/17, p. 4).

Online reader **Abhishek** wondered if waste flushed into space could make its way to other celestial bodies like the moon or Mars. If future missions "find residues which date to sometime in the 20th or 21st century, wonder how [the] world will react," **Abhishek** wrote.

There's already human waste on the moon in bags left there by astronauts. But any waste that's ejected from spacecraft in orbit around Earth is too close to the planet to escape the pull of Earth's gravity. "Small objects decay very quickly and enter the atmosphere," says planetary scientist **Ralph Lorenz** of Johns Hopkins University. It takes a lot of energy, **Grossman** adds, for something to leave Earth's orbit. For instance, "rocks from Earth have reached Mars, but only after a major asteroid impact launched them."

MATERIALSCIENTIST/WIKIMEDIA COMMONS

When ultrablack is the new black

Some birds of paradise really know how to work their angles. Tilted, microscopic filaments in some of the showy birds' black feathers make that plumage look much darker than traditional black feathers, researchers report January 9 in *Nature Communications*.

Evolutionary biologist Dakota McCoy of Harvard University and colleagues used scanning electron microscopy and nano-CT scanning to study feather microstructures. The team compared ordinary black feathers, including from the lesser melampitta (*Melampitta lugubris,* top row of SEM images at left) — a close relative of birds of paradise — with superdark plumes from five bird of paradise species (three shown at left, *Ptiloris paradiseus* shown above).

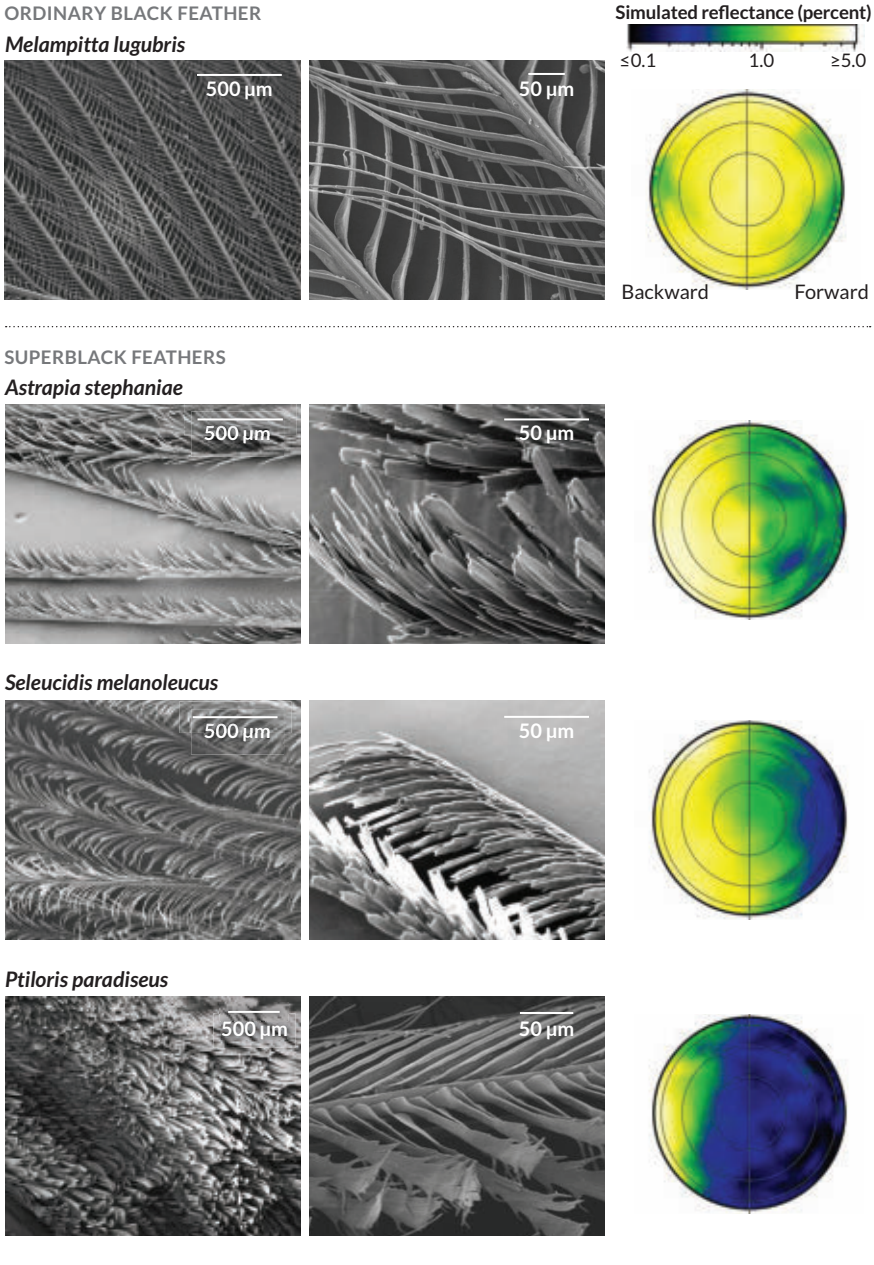
Ultrablack feathers have ragged, spike-studded barbules that curve upward at a roughly 30-degree angle to the tip, the team found. Traditional black feathers are flatter and smoother.

These spikes and grooves scatter incoming light multiple times, allowing for more and more absorption and accentuating feathers' black pigment. Simulations of feathers' light reflectance (circles) showed that the ordinary plume reflects more direct light than the superblack ones do (the darker the color, the more absorbed light). What light the darkest quills do reflect always heads in the same direction, back toward a feather's base and away from where a viewer would be (concentric rings represent viewing angles).

Plumes from *P. paradiseus* were "incredibly efficient" at absorbing light, McCoy says, reflecting "almost no light in most directions." Superblack feathers absorb up to 99.95 percent of direct light, whereas ordinary black feathers absorb up to 96.8 percent.

Ultrablack patches, the team writes, probably evolved to "exaggerate the perceived brilliance of adjacent color patches" during mating displays.

— Ashley Yeager



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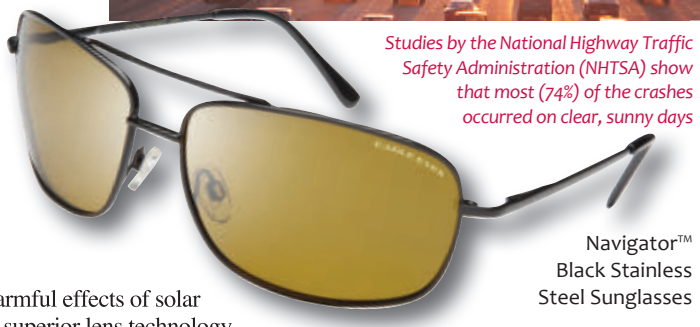

Navigator™ Black Stainless Steel Sunglasses

In the fall and winter, the sun is lower in the sky so it rises and sets at peak travel periods. During the early morning and afternoon rush hours many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle or snowy and icy pavement. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

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

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

Slip on a pair of Eagle Eyes® and everything instantly appears more vivid and sharp. You'll immediately notice that your eyes are more comfortable and relaxed and you'll feel no need to squint. These scientifically designed sunglasses are not just fashion accessories for the summer; they are necessary to protect your eyes from those harmful rays produced by the sun in the winter.

The Only Sunglass Technology Certified by the Space Foundation for UV and Blue-Light Eye Protection. Eagle Eyes® features the most advanced eye protection technology ever created. The TriLenium® Lens Technology offers triple-filter polarization to block 99.9% UVA and UVB—plus the added benefit of blue-light eye protection. Eagle Eyes® is the only optic technology that has earned official recognition from the Space Certification Program for this remarkable technology. Now, that's proven science-based protection.

Certified EAGLE EYES® was developed from original NASA Optic technology and was recently inducted into the Space Foundation Technology Hall of Fame.

The finest optics: And buy one, get one FREE! Eagle Eyes® has the highest customer satisfaction of any item in our 20 year history. We are so excited for you to try the Eagle Eyes® breakthrough technology that we will give you a **second pair of Eagle Eyes® Navigator™ Sunglasses FREE—a $59.95 value!**

That's two pairs to protect your eyes with the best technology available for less than the price of one pair of traditional sunglasses. You get a pair of Navigators with stainless steel black frames and the other with stainless steel gold, plus one hard zipper case and one micro-fiber drawstring cleaning pouch are included. Keep one pair in your pocket and one in your car.

Your satisfaction is 100% guaranteed. If you are not astounded with the Eagle Eyes® technology, enjoying clearer, sharper and more glare-free vision, simply return one pair within 30 days for a full refund of the purchase price. The other pair is yours to keep. No one else has such confidence in their optic technology. Don't leave your eyes in the hands of fashion designers, entrust them to the best scientific minds on earth. Wear your Eagle Eyes® **Navigators** with absolute confidence, knowing your eyes are protected with technology that was born in space for the human race.

Receive the Navigator™ Gold Sunglasses (*a $59.95 value*) **FREE! just for trying the Navigator™ Black**

Navigator™ Gold Stainless Steel Sunglasses

Fit-ons available for $39 +S&H
Black or Tortoise-Shell design

Two Pairs of Eagle Eyes® Navigator™ Sunglasses ~~$119.90~~†

Offer Code Price **$49** + S&P **Save $70.90**

Offer includes one pair each Navigator™ Black and Navigator™ Gold Sunglasses

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