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SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE &
APRIL 30, 2016

Every Diamond Has Its Flaw

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SOCIETY UPDATE
Highlights from *Science News for Students*

COVER With no evidence of life on other planets (yet), humans have been left to imagine what other beings might look like. *The Red Dress*

CLOCKWISE FROM TOP: KATHIE THOMAS-KEPRTA/NASA JOHNSON SPACE CTR.; M. KORNMESSER/ESO; L. SCOTT MILLS RESEARCH PHOTO

Trying to find ET and our place in the universe

Toddlers, I know from experience, believe themselves to be very, very special — the center, in fact, of the entire universe. With maturity, however, most of us learn that we are not quite as special as we thought. Other people are important, too.

It's similar with Earthlings in general. As humans have learned about the size of the cosmos (and our not-so-central place in it), we have grappled with weighing our specialness against the possible existence of alien beings on other worlds. Given the amazing diversity of life on Earth, it makes sense that life here is just one example from a cosmic multitude. If so, the next question becomes whether we can find the others.

That quest is at the heart of this special issue, which explores our long fascination with the idea of extraterrestrial life and then examines more practical matters, such as how to go about searching for it. We already monitor radio signals with projects like SETI. So far, we've heard nothing. We have sent rovers to Mars to dig in the soil. So far, we have found nothing that resembles a living thing. But we persist in the search.

That persistence has deep roots in human history, as Tom Siegfried describes in his essay on Page 24. Originally, the question of whether life exists on other worlds was linked to questions of divine power. But in the 20th century, the search for aliens became an issue of logic and probabilities. Siegfried reports on new ideas about why, even if they're out there, we haven't yet heard from them.

In contrast to the superintelligent, high-tech aliens that inhabit film and TV, most scientists expect aliens to be some form of microbial life — perhaps not even carbon-based. On Page 28, Tina Hesman Saey discusses the latest thinking about what alien life might look like, and the challenges we may face in recognizing it even if we do encounter it. Telling such life from nonlife is not trivial, even on Earth, Saey reports. Desert varnish, a dark stain on earthly rocks, may be made by living things that have so far escaped detection. Finding signs of past or present life on another planet will be even more difficult. But the possibility of life as we do not know it energizes the debate about how to find ET, and a broader discussion about what counts as living.

The broader search for ET assumes alien life (and a planet) similar to Earth's. On Page 32, Christopher Crockett discusses new and existing tools that exoplanet hunters can use to peer at faraway worlds. Analyses of exoplanet atmospheres might reveal signatures of life, hints, if not proof, of ET. Geoscientists have also gotten in on the action, trying to understand what planetary processes make Earth habitable, and, in so doing, helping to identify livable worlds in space. Thomas Sumner, on Page 36, reveals new findings about alternatives to Earth's carbon cycle, plate tectonics and other processes that could keep exoplanets temperate and inform the hunt for other life-forms.

It is our obsession with aliens, and whether they exist or not, that motivates much of our search for Earth-like planets and even the exploration of our solar system. And that obsession stems from a deeper, innate curiosity about whether Earth is special or just one of a billion. — *Eva Emerson, Editor in Chief*

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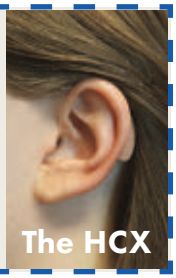

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Excerpt from the April 30, 1966 issue of *Science News*

50 YEARS AGO

Bacterium effective when dusted on plants

The successful agent for destroying pesty insects, the microscopic bacterium, *Bacillus thuringiensis*, is most effective when it is dusted onto tobacco or other plants.... The bacteria are now recommended for use against tobacco budworms and hornworms. From known results ... they look promising as biological control agents.

UPDATE: *Bacillus thuringiensis*, or Bt, is still used to combat agricultural pests. Different strains of the bacterium target different insects; one strain can even kill mosquito larvae in water. Organic farmers dust or spray Bt on crops and consider it a natural insecticide. In conventional farming, Bt DNA is often inserted into a plant's genome, creating genetically modified crops that make their own pesticide (*SN: 2/6/16, p. 22*). In 2015, 81 percent of U.S. corn and 84 percent of U.S. upland cotton contained Bt genes.

Baby-doll eyes on the dark form of Europe's cave-dwelling olm salamander (above) look almost ordinary compared with the atrophied eyes of white olms (below).

IT'S ALIVE

What's odd about a dark, big-eyed salamander

Normal is the new strange for the world's largest cave salamanders.

Biologists are thinking deep thoughts about why some of Europe's olm salamanders living in darkness have (gasp!) skin coloring and eyes with lenses.

Most salamanders, of course, have skin pigments and grow adult eyes like other vertebrates. But after eons of cave life, olms (*Proteus anguinus*) have become mostly pinkish-white beasts, about 30 centimeters head to tail, that spend long lifetimes (maybe 70 years) slinking in cold, subterranean water.

Living at 11 to 12° Celsius, olms don't mature sexually until about age 11 for males and 14 for females. Even then, they never really grow up, staying in water like giant larvae and keeping such youthful features as neck fluff gills into old age. "They look a little creepy, especially if you look at the skull," says Stanley Sessions of Hartwick College in Oneonta, N.Y. Their blunt heads have no real upper jaw, and their adult eyes start to form but then regress to nubbins buried under skin.

Long, skinny white olms, which keep their red gill tufts even after sexual maturity, wriggle like eels to swim through cave streams.

These salamanders live frugally. They can go more than a year without eating. (Lilijana Bizjak Mali of the University of Ljubljana in Slovenia says a lab-dwelling olm survived even after more than 10 years without food.) Females take six- to 12-year breaks between laying eggs, which "develop extraordinarily slowly," Sessions says. Recently laid olm eggs in Slovenia's Postojna Cave took about seven weeks to start forming a nervous system; a common spotted salamander takes about one.

Among extreme cave-lifers, the oddballs are the more normal-looking salamanders (for now, called subspecies *parkelj*), with dark skin and better-developed eyes. For decades, biologists treated these curios as remnants of the most ancient olms that haven't shed all their daylight ways. But rather than putting the dark salamanders at the base of the genealogical tree of olms, a genetic analysis places them higher among more recent, pale lineages.

"This forces you to consider that the black one probably evolved from white ancestors by reversing cave adaptations," Sessions says. In evolution, "weirder things have happened." — *Susan Milius*

BOTH: DOMIN DALESSI

THE -EST

Quasar has wildest whip

When visiting the center of a galaxy nicknamed J0230, pack a sturdy, windproof jacket. Prepare for a galactic hurricane with winds whipping at about 200 million kilometers per hour. At that speed, nearly 20 percent of the speed of light, a trip around the Earth would take 0.7 seconds. These are the fastest known winds around a quasar, a blazing disk of detritus surrounding a supermassive black hole, researchers report in the March 21 *Monthly Notices of the Royal Astronomical Society*. The winds are about 625,000 times as fast as the highest sustained winds in any hurricane seen on Earth.

625,000×
as fast

Speed of the winds around a quasar in constellation Cetus compared with the highest sustained winds seen in any of Earth's hurricanes

Winds at the center of a quasar, like the one illustrated here, are fastest on record.

These quasar winds get their speed from the intense radiation emitted by the disk, which glows as bright as roughly 22 trillion suns. The light comes from gases slamming together as they orbit a black hole with 2.2 billion times as much mass as the sun. Despite its relatively tiny volume of space, the quasar can launch winds that are powerful enough to shape its entire home galaxy. Star-forming factories throughout the galaxy can get shut down as gases are flung into intergalactic space.

Winds from the quasar, which sits in the constellation Cetus, best the previous record holder, quasar PG 2302+029, by about 14 million kilometers per hour. — *Christopher Crockett*

MYSTERY SOLVED

True nature of 'Tully monster' revealed

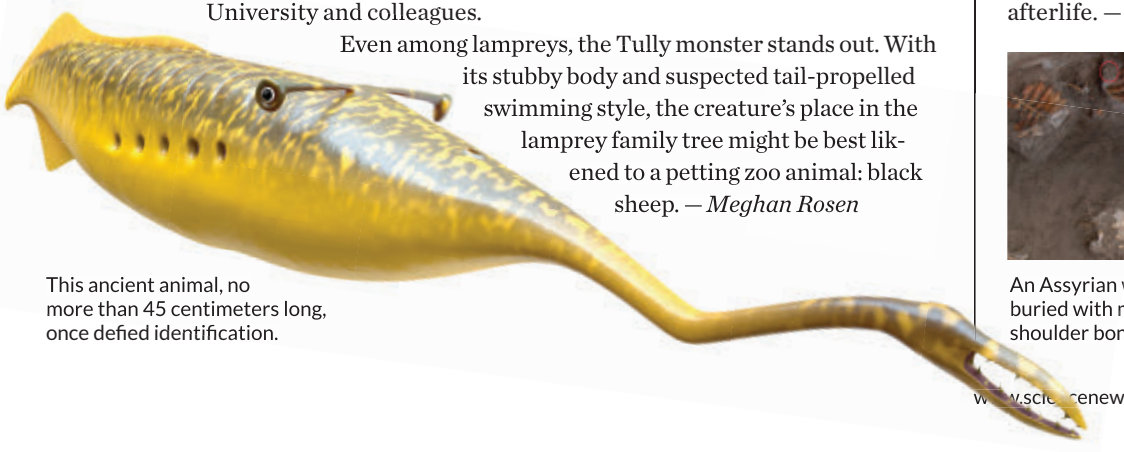
If some of the most bizarre zoo animals merged into one cartoonish creature, it might look something like the "Tully monster."

Fossils of *Tullimonstrum gregarium*, a soft-bodied animal that lived 300 million years ago in what is now Illinois, feature wide-set eyes like a hammerhead shark's, a nose like an elephant's and a mouth that could pass for a crab claw with teeth. For more than 50 years, the weird wonder has stymied scientists debating its identity.

Now, an analysis of more than 1,200 museum specimens, reported online March 16 in *Nature*, says the Tully monster was a vertebrate (not a slug, or a worm or an arthropod). A long, thin tube running down the creature's back was not part of the gut, as some scientists had suggested, but a notochord, a structural hallmark of vertebrates.

The creature was probably an ancestor of lampreys, jawless fish that can latch onto prey like a vacuum cleaner hose with teeth, say study coauthor Victoria McCoy of Yale University and colleagues.

Even among lampreys, the Tully monster stands out. With its stubby body and suspected tail-propelled swimming style, the creature's place in the lamprey family tree might be best likened to a petting zoo animal: black sheep. — *Meghan Rosen*



This ancient animal, no more than 45 centimeters long, once defied identification.

HOW BIZARRE

Turtles were part of Assyrian burial

Ancient Assyrians sent their dead to the afterlife with fearsome companions: turtles. Excavations of a burial pit in southeastern Turkey revealed skeletons of a woman and a child, plus 21 turtles, a team led by archaeologist Rémi Berthon of France's National Museum of Natural History in Paris reports in the February *Antiquity*.

The burial is part of an Assyrian site called Kavuşan Höyük that dates to between 700 and 300 B.C. The turtle bonanza included shells from one spur-thighed tortoise (*Testudo graeca*) and three Middle Eastern terrapins (*Mauremys caspica*), plus bones from 17 Euphrates soft-shelled turtles (*Rafetus euphraticus*). Butchering marks on the *R. euphraticus* bones suggest the turtles were eaten in a funerary feast, write Berthon and colleagues.

Back then, turtles were not a regular meal in Mesopotamia. Turtle bones, however, were thought to ward off evil. The abundance of *R. euphraticus* turtles, an aggressive species, in this burial pit indicates that the deceased had high social status.

To ancient Assyrians, the team writes, these ferocious reptiles probably represented eternal life and served as psychopomps — mythical guides to the afterlife. — *Helen Thompson*

An Assyrian woman and child were buried with many turtles (*R. euphraticus* shoulder bones circled in red).

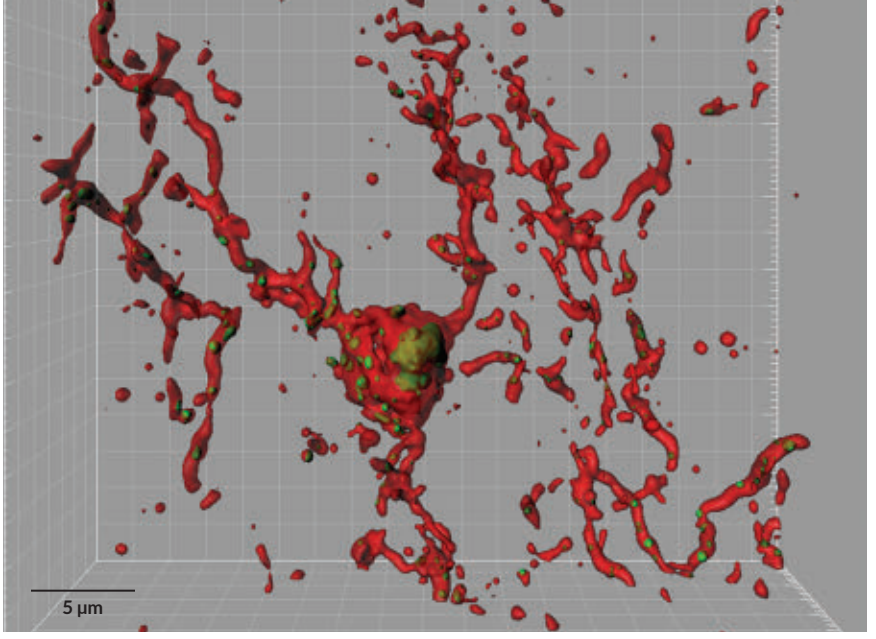
CLOCKWISE FROM TOP: M. KORNMESSER/ESO; R. BERTHON *ET AL/ANTIQUITY* 2016; PAUL MAYER/FIELD MUSEUM OF NATURAL HISTORY

BODY & BRAIN

Synapses lost in early Alzheimer's

Overactive immune cells point to path to fight brain disease

BY LAURA SANDERS



In this 3-D reconstruction, a microglial cell (red) engulfs synapses (green) in a mouse's hippocampus after an injection of the Alzheimer's-related protein amyloid-beta.

In the early stages of Alzheimer's disease, an overzealous set of proteins and cells begins to chew away at the brain's nerve cell connections, a study in mice suggests.

That finding, described online March 31 in *Science*, adds to a growing body of research that implicates the same process that shapes the young brain by culling unused connections, called synaptic pruning, in disorders when it occurs later in life (*SN: 11/30/13, p. 22*). The new work pins the loss of synapses, which connect nerve cells, on particular immune system molecules and a notorious Alzheimer's-linked protein.

By uniting these multiple strands of evidence, the study may help explain the earliest steps in Alzheimer's march of neural destruction. "No one has put it together in quite this way," says neuropathologist John Trojanowski. If the same process happens in humans, the new results may point to ways to slow or stop Alzheimer's, says Trojanowski, of the Pearlman School of Medicine at the University of Pennsylvania.

A curious observation led to this new view of neural whittling. A protein called C1q was packed around synapses in the brains of young mice genetically engineered to show signs of Alzheimer's. And in these mice, C1q was most abundant in brain areas known to suffer synapse losses as Alzheimer's takes hold.

C1q is a member of the complement cascade, a group of immune system proteins that calls in microglial cells to gobble up synapses or cells. This pruning is essential as the brain develops. But these neural gardeners seem to spring back into action in the early stages of Alzheimer's, neuroscientist Beth Stevens of Boston Children's Hospital and Harvard University and colleagues found. And that reactivation seems to be helped along by the Alzheimer's-related protein amyloid-beta.

In the brains of healthy, nonaltered mice, injections of oligomeric A-beta, the form thought to be the most dangerous, caused C1q levels to rise. Along with this increase, synapses were destroyed, the team found. But A-beta injections didn't harm synapses in mice lacking C1q, showing that C1q and A-beta are both needed for excessive pruning. Exactly how the two proteins work together isn't clear, Stevens says, but "they are definitely there at the right time and the right place."

Complement proteins and microglia are known to be active in late-stage Alzheimer's, when the inflamed brain is packed with sticky gobs of A-beta. But the new results suggest that the synapse-pruning pathway is active much earlier in the disease process, long before A-beta plaques form. "The story is extremely compelling and tight in Alzheimer's mouse models," says neurologist Scott Small of Columbia University.

There are reasons to think that a similar process happens in people. Autopsy studies by neurobiologist Stephen Scheff of the University of Kentucky in Lexington and colleagues, for instance, have turned up fewer synapses in the brains of people with mild cognitive impairment — thought to be an early stage of Alzheimer's. The cause of that synapse loss could certainly be explained by changes in complement proteins or microglia, Scheff says.

Any therapy to target this pruning process would depend on identifying people at risk not already showing symptoms. So far, there are no good tests to spot excessive oligomeric A-beta in the brain, says neurologist Sam Gandy of Mount Sinai Medical Center in New York City. "Oligomers are invisible," he says.

But if screening methods are developed, then the prospect of stopping Alzheimer's by protecting synapses is appealing, Small says. A drug that could prevent C1q or its partners from targeting synapses for destruction might halt the damage, for instance. "It's easier to cure a sick cell than a dead cell," he says.

Overactive synaptic pruning may be behind other brain disorders, Stevens suspects. She and her colleagues recently implicated a different complement cascade protein in schizophrenia (*SN: 2/20/16, p. 7*). "This may be a pathway that is dysregulated and playing a role in synapse loss in a host of neurological diseases, not just one," she says. Stevens and several coauthors are involved with a company that is developing a drug to block C1q. ■

S. HONG *ET AL*/*SCIENCE* 2016

HUMANS & SOCIETY

Hobbits died out earlier than thought

Disappearance coincided with *Homo sapiens*' arrival in region

BY BRUCE BOWER

Hobbits disappeared from their island home nearly 40,000 years earlier than previously thought, new evidence suggests.

This revised timeline doesn't erase uncertainty about the evolutionary origins of these controversial Indonesian hominids. Nor will the new evidence resolve a dispute about whether hobbits were a distinct species, *Homo floresiensis*, or small-bodied *Homo sapiens*.

Hobbits vanished about 50,000 years ago from Liang Bua Cave on Flores, an island situated between Borneo and Australia's northern coast, say archaeologist Thomas Sutikna of the University of Wollongong in Australia and colleagues.

Cave sediment dating to about 12,000 years ago, which lies just above soil that yielded *H. floresiensis* remains, provided an initial estimate of when these diminutive hominids died out. But that sediment washed into the cave long after *H. floresiensis* was gone, covering much older, hobbit-bearing soil, the researchers report online March 30 in *Nature*.

Using the initial age estimate, scientists had previously concluded that hobbits survived for tens of thousands of years after *H. sapiens* passed through Indonesia and reached Australia around 50,000 years ago. It now appears that hobbits instead hit an evolutionary dead end around that time, Sutikna's group says.

A partial skeleton of *Homo floresiensis* (skull shown) dates to at least 71,500 years ago, not 18,000 years ago.

The centerpiece of hobbit finds, a partial skeleton, comes from an individual who lived well before then, the scientists add. Measurements of the decay of radioactive elements in an arm bone from the partial skeleton indicate that the find dates to between 86,900 and 71,500 years ago. Until now, researchers suspected these bones were only about 18,000 years old.

Based on the new dates, "there was possibly no overlap or interactions between *H. floresiensis* and *H. sapiens* on Flores," says Richard Potts, a paleoanthropologist at the Smithsonian Institution in Washington, D.C.

Hobbits disappeared before the earliest skeletal evidence of humans on Flores, says paleoanthropologist and study coauthor Matthew Tocheri of Lakehead University in Thunder Bay, Canada. *H. sapiens* bones on Flores date to around 11,000 years ago. That undermines a controversial argument that the partial hobbit skeleton belonged to a human with a developmental disorder (*SN: 11/18/06, p. 330*), Tocheri says.

Paleoanthropologist Russell Ciochon of the University of Iowa in Iowa City agrees. *H. floresiensis* probably descended from a large-bodied Asian *Homo erectus* group that reached Flores roughly 1 million years ago, he says. On islands, large-bodied mammals tend to become smaller, presumably in response to limited food sources and other factors.

But in a joint e-mail to *Science News*, two researchers who regard hobbits as humans — and the partial hobbit skeleton as displaying signs of Down syndrome — stick to their guns. Regardless of the new dates, hobbit bones fall within the range of skeletal sizes and shapes observed in people today, assert Robert Eckhardt of Penn State and Maciej Henneberg of the University of Adelaide in Australia. *H. sapiens* could have reached Flores and nearby islands at the time Sutikna's group says hobbits were alive (*SN: 2/6/16, p. 7*), the researchers claim.

New work at Liang Bua Cave on Flores suggests that controversial hominids known as hobbits disappeared about 50,000 years ago.

It's not known whether humans or other hominids, such as Denisovans (*SN Online: 3/17/16*), reached Flores more than 50,000 years ago at a time of lowered sea levels and possible drought on the island, Potts says. If they did, intruding species might have pushed an already reeling hobbit population to extinction.

Liang Bua Cave excavations also suggest that other Flores animals, including vultures, giant marabou storks and an extinct elephant relative, vanished around the same time that hobbits did.

Annual excavations from 2007 through 2014 clarified how sediment accumulated in the cave. A thick sediment deposit containing hobbit remains had substantially eroded before being covered by sediment layers that washed into the cave starting about 20,000 years ago. Techniques for dating sediment, rock, volcanic ash and bone indicated that hobbits' skeletal remains range in age from 100,000 to 60,000 years ago. Stone tools probably made by hobbits date to around 190,000 to 50,000 years ago.

Liang Bua Cave preserves a late slice of *H. floresiensis* life on an island probably reached by toolmaking hobbit ancestors around 1 million years ago (*SN: 6/3/06, p. 341*), Tocheri says.

Researchers don't know what happened during the roughly 800,000 years between hobbit ancestors' arrival and hobbits' last evolutionary stages. "If there was a book that chronicled the evolutionary history of *H. floresiensis*, we would have only a few tattered and torn pages with the rest missing," Tocheri says. ■

FROM TOP: SMITHSONIAN DIGITIZATION PROGRAM OFFICE, LIANG BUA TEAM; © CARL BENTO/AUSTRALIAN MUSEUM

ATOM & COSMOS

Faint gravity waves in LIGO's future

New analysis finds better prospects for spotting weak ripples

BY EMILY CONOVER

A conspicuous "chirp" heralded the first detection of gravitational waves. But some future measurements could be more like hushed murmurs.

Scientists may soon tease out a faint gravitational wave signal from black hole collisions too distant to detect directly, scientists with LIGO, the Advanced Laser Interferometer Gravitational-Wave Observatory, report in the April 1 *Physical Review Letters*. This detection could come in as few as three years.

When LIGO detected the stretching and squeezing of space generated by a pair of merging black holes, scientists were wowed (*SN: 3/5/16, p. 6*). The signal stood out well above spurious bumps and wiggles in the data, which are ever-present in LIGO's sensitive detectors. The signal rose swiftly in frequency; when converted to sound waves, it was reminiscent of a bird's chirp — a hallmark of the black holes' inward-spiraling cosmic dance.

But such obvious swells are outnumbered by a sea of smaller ripples. With these ripples, "you're looking at black holes which are much farther away," says LIGO spokesperson Gabriela González of Louisiana State University.

LIGO is not sensitive enough to detect these waves outright. But by comparing the data recorded by LIGO's separate detectors — one in Louisiana and one in Washington state — scientists could identify patterns revealing the presence of the background waves. Such a measurement would allow scientists to compare black hole populations of different ages and could help nail down the conditions under which black hole pairs form.

"My honest opinion was, 'I'm going to be lucky if we see this result in my lifetime,'" says physicist Emanuele Berti of the University of Mississippi, who is not involved with LIGO. He has changed his tune: "Nature was good to us, and now we think that we're going to be able to see them pretty soon."

That's because new estimates of the rate of such black hole mergers are higher than expected. Using models of binary black hole populations combined with LIGO data, scientists find that LIGO could be sensitive to nearly 2,000 such black hole mergers a year. ■

EARTH & ENVIRONMENT

Diamond origins debate settled

Older gems, younger crystals formed in similar conditions

BY THOMAS SUMNER

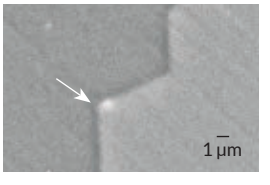
Even top-caliber diamonds aren't perfect. And their imperfections are finally settling a debate about the origins of the gem-quality diamonds used in jewelry.

Previously, scientists knew only how impurity-ridden fibrous diamonds form. Those diamonds crystallize inside fluid pockets deep in the Earth that contain compounds called carbonates. Carbonate-containing impurities inside fibrous diamonds provide clues about the diamonds' origins. Gem diamonds typically don't contain these impurities, so scientists argued over whether the gems form under different conditions.

After an exhaustive hunt, geochemists have at last found microscopic impurities in gem-quality diamonds. The flaws suggest that most pretty and ugly diamonds form from the same kinds of carbonate-containing fluids, the researchers report in the June 1 *Earth and Planetary Science Letters*. The result may also offer insights into the history of plate tectonics.

The work "gives us the first strong constraint on how gem diamonds grow," says Thomas Stachel, a petrologist at the University of Alberta in Canada who was not part of the research. "It seems diamond formation is less diverse than we thought."

Diamonds are made of carbon atoms. At the pressures and temperatures found in the deep Earth, these carbon atoms can form a crystal structure. Rising magma then carries the crystals to the surface.



Microscopic bits of trapped material (arrow) helped scientists identify the origins of gem-quality diamonds.

B.M. JABLON AND O. NAVON/*EARTH AND PLANETARY SCIENCE LETTERS* 2016

The type of diamonds prized for jewelry formed as early as 3.5 billion years ago. Fibrous diamonds date back only a few million years and formed more quickly. That quick creation trapped bits of surrounding material inside the crystal structure. Those inclusions suggest that these diamonds formed from the carbon atoms in carbonate-containing fluids.

Brooke Matat Jablon and Oded Navon, both geochemists at Hebrew University in Jerusalem, hunted for inclusions in gem diamonds. The researchers found what they were looking for in diamonds that are symmetrical across a central boundary. As these diamonds grew, a microscopic inclusion would sometimes become trapped along the boundary. Using a beam of electrons, the researchers identified 32 inclusions in eight of 30 diamonds. Twenty of those inclusions were the same kinds of carbonate-bearing fluids found in fibrous diamonds.

The work suggests that while fibrous diamonds and gem diamonds differ in age and price, they share common origins. "We can quiet a debate that has been raging in the field for a long time," Jablon says.

The finding also suggests that Earth has maintained the same diamond-forming conditions for billions of years, Stachel says. Carbonates are carried into Earth's depths when tectonic plates sink into the interior. If ancient diamonds formed from carbonates, then plate tectonics could have already been active by 3.5 billion years ago, he says. ■

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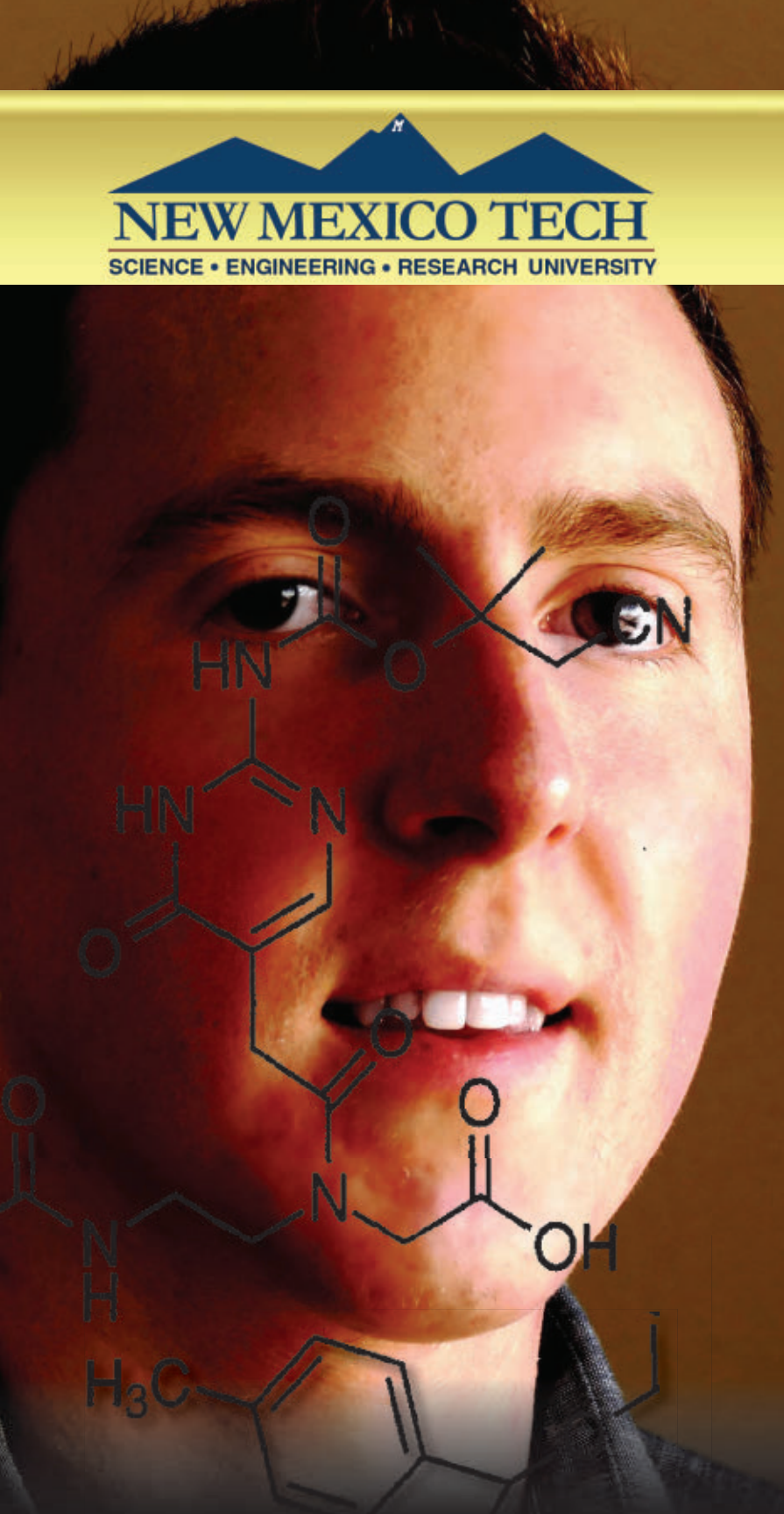

KEVIN REED

Chemical Engineering

A project I'm working on is a collaboration between the Chemical Engineering and Mechanical Engineering departments. The mechanical engineers are trying to develop a mechanoluminescent system that can be used for impact detection. Essentially, when a structure is hit or bent, a polymer coat along the surface will produce light at the impact spot, letting us know that it has been significantly damaged. Inside the polymer are special particles that produce light when they undergo stress. Current challenges are producing enough light to be seen and also characterizing the polymer systems. I'm co-leading the chemical engineering team and as chemical engineers, we are working to develop particles that will work well with the mechanical engineers' system.

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GENES & CELLS

Structure of Zika virus mapped

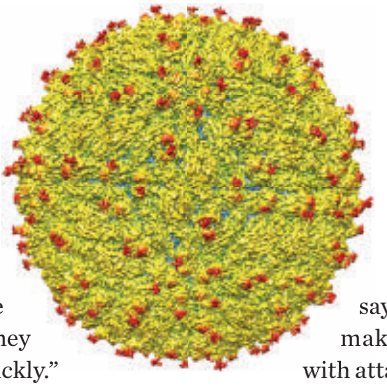
3-D image may provide clues to how to fight infection

BY MEGHAN ROSEN

Zika now has a face to go with the name.

New microscopy images of the virus reveal a bumpy, golf ball–shaped structure, similar to that of the dengue and West Nile viruses, researchers report online March 31 in *Science*. It's the first time scientists have gotten a good look at Zika, the infamous virus that has invaded the Americas and stoked fears that it is causing birth defects and a rare autoimmune disease (*SN: 4/2/16, p. 26*).

Cracking Zika's structure is like getting the blueprints of an enemy's base: Now scientists have a better idea of where to attack. "This certainly gives us great hope that we will be able to find a vaccine or antiviral compounds," says study coauthor Michael Rossmann of Purdue University in West Lafayette, Ind.



Sugars (shown in red in this 3-D reconstruction) poking out from the shell of Zika virus possibly help it infect neural stem cells.

Researchers have been racing to solve Zika's structure, says UCLA microbiologist Hong Zhou. "I was trying to work on the same thing myself," he says. "I was impressed they were able to do it so quickly."

Rossmann and colleagues imaged a strain of Zika collected from a patient during a 2013–2014 outbreak in French Polynesia. The strain is nearly identical to the one now spreading through Latin America (*SN: 4/16/16, p. 16*).

The team used a technique called cryo-electron microscopy to create a 3-D picture of Zika. It's a pretty sharp image, says coauthor Devika Sirohi, also of Purdue. She and colleagues can even make out sugars protruding from the virus' surface.

These sugars, which look like little doorknobs, hang from proteins in Zika's shell. The knobs may help Zika attach to — and infect — human cells. Zika's knobs don't look exactly like those of related viruses. The sugar-decorated proteins "fold a little differently," Sirohi says. That might let Zika make different contacts with attachment sites on cells, called receptors. These differences could explain why Zika infects cells not typically targeted by dengue or West Nile.

One of the receptors targeted by Zika could be AXL, a protein on the surface of neural stem cells, researchers propose in a separate study published online March 30 in *Cell Stem Cell*. Zika is thought to preferentially infect these early-development brain cells, and it could use AXL as an entry point, Arnold Kriegstein of the University of California, San Francisco and colleagues suggest.

Exactly what role subtle structural differences play in Zika's infection ability is "only speculation at this point," Sirohi says. The team plans to test how tweaking the virus's knobby regions affects Zika's virulence. ■

BODY & BRAIN

Cancer killers send signal of success

Nanoparticles deliver drug, then give real-time feedback

BY SARAH SCHWARTZ

New cancer-fighting nanoparticles deliver results — and status reports.

Tiny biochemical bundles carry chemotherapy drugs into tumors and light up when surrounding cancer cells start dying. Doctors could use future iterations of these lab-made particles to monitor the effects of cancer treatment in real time, researchers report online March 29 in the *Proceedings of the National Academy of Sciences*.

"This is the first system that allows you to read out whether your drug is working or not," says study coauthor Shiladitya Sengupta, a bioengineer at Brigham and Women's Hospital in Boston.

Each roughly 100-nanometer-wide particle consists of a drug and a fluorescent dye linked to a coiled molecular chain. Before the particles enter cells, the dye is tethered to a "quencher" molecule that prevents it from lighting up. When injected into the bloodstream of a mouse with cancer, the nanoparticles accumulate in tumor cells and release the drug, which activates a protein that tears a cancer cell apart. This cell-splitting protein not only kills the cell, but also severs the link between the dye and the quencher, allowing the nanoparticles to glow under infrared light.

Previous techniques could track drugs entering tumors but not the efficacy of the drugs, says study coauthor Ashish Kulkarni, a bioengineer at Brigham and Women's and Harvard Medical School.

The team tested the nanoparticles in mice that each had two tumors: one resistant to the drug and one responsive to it. Drug-sensitive tumors glowed around five times as intensely as the resistant tumors. Results were swift, with tumors lighting up in eight to 12 hours.

These nanoparticles are a proof of concept, Sengupta says. Next steps include redesigning the nanoparticles using clinically approved materials and dyes that would be easier to track in the human body with the use of MRI.

Still, such imaging chemicals can be toxic, which could pose a problem for the nanoparticle design, says cancer nanotechnologist Mansoor Amiji of Northeastern University in Boston. Dyes should be cleared from the body as quickly as possible, while the drug they're paired with might take weeks to work. But detecting drug performance in real time is important, Amiji says. "There's tremendous need, especially as we think about personalizing cancer therapies." ■

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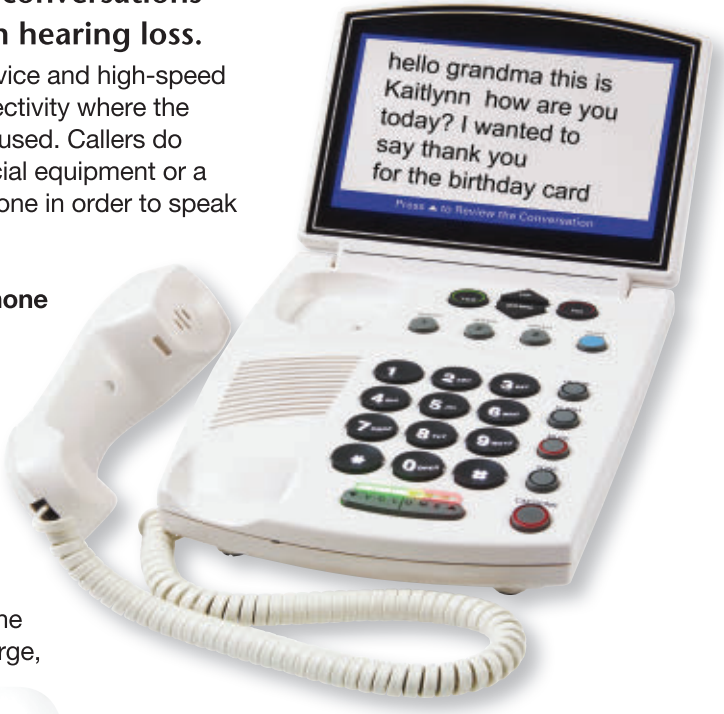

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LIFE & EVOLUTION

Snowshoe hare's new No. 1 threat

Shorter winters pose a bigger problem than loss of forest

BY SUSAN MILIUS

For Wisconsin's snowshoe hares, climate change now ranks as an even bigger menace than the bulldozing, paving and other destructive things that people have done to northern forests.

For snowshoe hares, climate change along the southern boundary of their range has become a worse menace than conservationists' usual concern, habitat destruction.

Habitat loss as humans reshape landscapes has loomed for decades as the main conservation problem for a lot of wildlife. It's still important, says climate change ecologist Benjamin Zuckerberg of University of Wisconsin–Madison. But along the southern boundary of the snowshoe hares' range, climate change bringing skimpy snow cover has surpassed direct habitat loss as a threat, Zuckerberg and colleagues say online March 30 in the *Proceedings of the Royal Society B*.

North America's *Lepus americanus* hares may be especially sensitive to climate change. "Almost everything about them screams adaptation to seasons of extensive snow cover," says study coauthor Jonathan Pauli, also at UW–Madison. The hares have outsized snowshoe feet, thick fur and an annual molt from brown to snow-white. Getting out of sync with the snow turns camouflage into a come-on for predators (*SN Online: 1/26/16*). Bad years mean "a lot of white hares on brown backgrounds," Pauli says.

To see how the hares have fared, the researchers looked for signs of the animals at 199 sites in Wisconsin during the winters of 2012–2013 and 2013–2014. Many of these locations came from a rather anecdotal 1945 study and a more systematic one in 1979 to 1980. Satellite images showed not much change in the overall amount of hare-suitable forest since the 1980s, but snow cover averages have declined. When the researchers analyzed their data, shifts in snow cover duration did a better job of explaining the retreat of the hares' southern boundary than forest cover did.

Snow cover has powerful effects on hares. For each 7.41 days that snow blankets the landscape, snowshoe hare populations become four times as likely to survive, the researchers found.

If the hares dwindle from a place, the loss may ripple through the ecosystem. "Snowshoe hares are central, really central, to prey species," Pauli says. Lynx, great horned owls, coyotes and many

ATOM & COSMOS

Odd white dwarf offers peek at core

Something stripped unusual dead star of hydrogen and helium

BY CHRISTOPHER CROCKETT

White dwarfs — the exposed cores of dead stars — are the last place astronomers expected to find a nearly pure oxygen atmosphere. Yet that's exactly what recently turned up, providing a rare peek inside the core of a massive star and raising questions about how such an oddball could have formed.

Most stars die by gently casting the bulk of their gas into space, leaving behind a dense, hot core. Heavy elements such as carbon and oxygen sink to the core's center while hydrogen and helium float to the surface. But a newly discovered white dwarf, about 1,200 light-years away in the constellation Draco, has no hydrogen or helium at its surface. Its atmosphere is dominated by oxygen, researchers report in the April 1 *Science*.

"We only found one, so it is a rare event," says study coauthor Kepler de Souza Oliveira Filho, an astronomer at the Federal University of Rio Grande do Sul in Porto Alegre, Brazil. But, he says, "every theory must be able to explain all events, even the rare ones."

Hydrogen and helium blanket most white dwarfs, hiding what lies beneath. Here, astronomers have "a window into the core of a star that we didn't have before," says Patrick Dufour, an astrophysicist at the University of Montreal.

While oxygen dominates this white dwarf's atmosphere, neon and magnesium come in second and third — a clue that the original star was much bigger than the sun. Big stars can crank up their core temperatures high enough to fuse progressively heavier elements. A star between about six and 10 times as massive as the sun ends up with a core of mostly oxygen, neon and magnesium — precisely what Filho and colleagues found. But there's a problem: Such a white dwarf should be heavier than the sun, and this newly discovered misfit appears to have about half as much mass.

A nearby stellar companion could have siphoned gas off the dying star, the researchers suggest. Thermonuclear excavation during the star's endgame could also lead to an underweight white dwarf. If enough hydrogen piled up on the core, it might have triggered a runaway nuclear explosion that shaved off the white dwarf's outer layers.

Dufour says the idea is plausible, but he's skeptical. "It could work," he says,

L. SCOTT MILLS RESEARCH PHOTO

more species dine on them. And regardless of any ecosystem role, hares are remarkable in their own right. "It's hard for me, a person living in Wisconsin, to imagine these northern conifer forests without snowshoe hares," Pauli says.

To prevent such a loss, reducing greenhouse gas emissions is important, but so is creating "climate-resilient landscapes," Zuckerberg says. For snowshoe hares, that landscape might bristle with abundant, thick plant growth, full of hiding places for too conspicuous, out-of-season-sync hares, he suggests.

White furry animals may not be the only ones that will have to cope with a shift in the balance of threats. "In a number of cold-associated butterflies, and also birds, it is becoming clear that climate change is beginning to surpass land use as the primary driver of extinction at the trailing edges of the species' range," says ecologist Tom Oliver of the University of Reading in England. And the threats of climate change and land-use upsets can intensify each other. "We appear to be entering a worrying time," Oliver says. ■

"but I doubt it would leave a low-mass white dwarf."

In 2007, Dufour and colleagues reported a similar strange sighting: several white dwarfs whose atmospheres were loaded with carbon instead of hydrogen and helium. Those also appeared to be missing mass, he says, though the problem was found to lie not with the stars but with the mass estimates. The white dwarfs are heavier than initially thought, and Dufour now suspects that each one arose from a collision between two white dwarfs.

It's too early to draw strong conclusions from a single oxygen-laden white dwarf. "There are lots of open questions before we can say that this changes our view of white dwarf evolution," Dufour says. "This white dwarf might only be a freak.... Although often in science, it's the exception that makes you understand a great deal later on." ■

ADAPTED BY J. HIRSHFELD

EARTH & ENVIRONMENT

Sea level rise forecast doubles

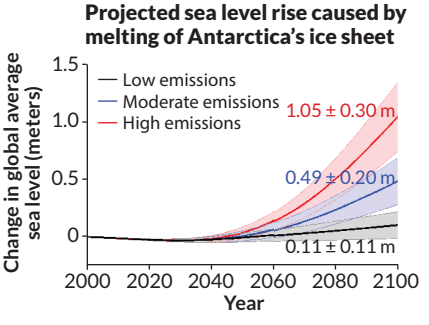
By 2100, Antarctic melt could boost oceans by over a meter

BY THOMAS SUMNER

Antarctica's meltdown could spur sea level rise well beyond current predictions. New simulations suggest that Antarctic melting alone will raise global sea levels by about 64 to 114 centimeters by 2100, scientists report in the March 31 *Nature*.

Adding Antarctic melt to other sources of sea level rise, such as the expansion of warming seawater and melting Greenland ice, the scientists predict that sea levels will rise 1.5 to 2.1 meters by the end of the century. That's as much as double previous predictions that didn't incorporate mechanisms that can expedite the Antarctic ice sheet's collapse, though uncertainties remain, says study coauthor David Pollard, a paleoclimatologist at Penn State.

Predicting future sea level rise requires understanding how the oceans rose in the past. Scientists often glean ancient sea level rise by reconstructing the locations of ancient coastlines. But these coastlines can be a slippery target: Forces such as tectonic activity can cause Earth's surface to rise and fall, obscuring the effects of past sea level rise. Depending on how much uplift obfuscated ancient sea level records — ranging from no uplift to massive uplift — the new prediction of 21st century sea level rise can differ by 35 centimeters or more.



On the rise Antarctica could contribute over a meter of sea level rise by 2100, researchers say. One simulation looked at how the continent's ice sheet would fare under three different greenhouse gas emissions scenarios.
SOURCE: R.M. DECONTO AND D. POLLARD/*NATURE* 2016

"I really would be happier if we had the luxury of doing the research on this without bothering the public until we have 95 percent confidence in an answer," says Penn State glaciologist Richard Alley, who was not involved in the study. "Any single forecast is notably uncertain, but if we continue warming the world rapidly, the most likely outcome is a major event of large and rapid sea level rise."

Two warm periods, one about 125,000 years ago and another about 3 million years ago, were particularly useful for Pollard and geoscientist Robert DeConto of the University of Massachusetts Amherst. Those bouts of warming shrank Earth's ice sheets and boosted sea levels by several meters. Pollard and DeConto used these sea level records to fine-tune a computer simulation of how climate change affects the Antarctic ice sheet. The researchers then applied their calibrated simulation to current climate conditions and projected sea level rise thousands of years into the future.

Assuming that no action is taken to curb greenhouse gas emissions, the simulation predicts that Antarctic melting will accelerate around 2050 as rising temperatures destabilize keystone glaciers in West Antarctica. After 2100, Antarctica's contribution to sea level rise will exceed 4 centimeters a year — more than 10 times the current rate from all sources.

Such sea level rise would reshape most coastlines, and the waters would rise even higher as time goes on, Pollard predicts. "Sea levels won't peak until around 3,000 to 4,000 years from now," he says. At that point, melted Antarctic ice will have raised global sea level by about 20 meters.

The consequences of this long-term sea level rise will be dire, says Maureen Raymo, a marine geologist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y. "I haven't seen anyone mention the long, slowly unfolding refugee crisis that will only get worse as hundreds of millions [of people] are displaced worldwide," she says. ■

BODY & BRAIN

Hippocampus makes 'social' maps

Brain structure is not limited to tracking physical locations

BY LAURA SANDERS

Cells in a brain structure known as the hippocampus are cartographers, drawing mental maps of physical space. But new studies show that this seahorse-shaped hook of neural tissue can also keep track of social space, auditory space and even time, deftly mapping these various types of information into their proper places.

"The hippocampus is an organizer," says Howard Eichenbaum, a neuroscientist at Boston University.

Neuroscientist Rita Tavares described details of one of these new maps April 2. Brain scans had previously revealed that activity in the hippocampus is linked to movement through social space. In an experiment reported last year in *Neuron*, people went on a virtual quest to find a house and job by interacting with a cast of characters. Through these social interactions, the participants formed opinions about how much power each character held, and how kindly they felt toward him or her. These judgments put each character in a position on a "social space" map. Activity in the hippocampus was related to this social mapmaking, Tavares and colleagues found.

It turns out that this social map depends on the traits of the person who is drawing it, said Tavares, of the Icahn School of Medicine at Mount Sinai in New York City. People with more social anxiety tended to give more power to characters they interacted with. What's more, these people's social space maps were smaller overall, suggesting that they explored social space less. Tying these behavioral traits to the hippocampus may lead to a greater understanding of social behavior — and how this social mapping may go awry in psychiatric conditions, Tavares said.

The work emphasizes that the hippocampus is not just a mapper of space, Tavares said. Instead, it is a mapper of relationships.

Other research, discussed at a meeting in February, revealed a role for the hippocampus in building a different sort of map — a map of sounds. Stationary rats were trained to "move" through a soundscape of different tones, pushing a joystick to change the sounds to reach a target tone. As the rats navigated this auditory world, nerve cells in the hippocampus were active in a way that formed a map, Princeton University neuroscientist Dmitriy Aronov reported in Salt Lake City at the annual Computational and Systems Neuroscience meeting.

Cells in the hippocampus can also map time, Eichenbaum has found (*SN: 12/12/15, p. 12*). All of these types of information are quite different, but Eichenbaum argues that they can all be thought of as memories — another mental arena in which the hippocampus plays an important role. Organizing these memories into a sensible structure may be the big-picture job of the hippocampus, he says. "What's being tapped in all of these studies is that we are looking at a framework, whether it's a physical spatial framework, a social space framework, a pitch framework or a time framework." ■

MEETING NOTES

Forgetting can be hard work for the brain

Sometimes forgetting can be harder than remembering. When people force themselves to forget a recently seen image, select brain activity is higher than when they try to remember that image.

Forgetting is often a passive process, one in which the memory slips out of the brain, Tracy Wang of the University of Texas at Austin said April 2. But in some cases, forgetting can be deliberate.

Twenty adults saw images of faces, scenes and objects while a functional MRI scanner recorded their brains' reactions to the images. If instructed to forget an image just after seeing it, people were less likely to remember that image later. Researchers used the scan data to build a computer model that could infer how strongly the brain responded to each particular kind of image. In the ventral temporal cortex, a part of the brain above the ear, brain patterns elicited by a particular image were stronger when a participant was told to forget the sight than when instructed to remember it.

These results show that intentional forgetting isn't a passive process — the brain has to actively work to wipe out a memory on purpose. — *Laura Sanders*

Lip-readers 'hear' silent words

Lip-readers' minds seem to "hear" the words their eyes see being formed. And the better a person is at lipreading, the more neural activity there is in the brain's auditory cortex, scientists reported April 4.

Previous studies involving simple sentences or single words have found that auditory brain areas are active during lipreading, said Satu Saalasti of Aalto University in Finland. In contrast, Saalasti and colleagues studied lipreading in more natural situations. Twenty-nine people who can hear read the silent lips of a person who spoke for eight minutes in a video. The participants, who had no lipreading experience, varied widely in their comprehension of the eight-minute story.

In the best lip-readers, activity in the auditory cortex was quite similar to that evoked when the story was read aloud, brain scans revealed. The results suggest that lipreading success depends on a person's ability to "hear" the words formed by moving lips, Saalasti said. — *Laura Sanders*

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BODY & BRAIN

Fear takes many paths in brain

Drug elicits anxiety in people without working amygdalae

BY LAURA SANDERS

In a pair of twin sisters, a rare disease has damaged the brain structures commonly believed necessary to feel fear. But an injection of a drug can nevertheless make them anxious.

The results of that experiment, described in the March 23 *Journal of Neuroscience*, add to evidence that the amygdalae, small, almond-shaped structures tucked deep in the brain, aren't the only bits of the brain that make a person feel afraid. "Overall, this suggests multiple different routes in the brain to a common endpoint of the experience of fear," says cognitive neuroscientist Stephan Hamann of Emory University in Atlanta.

The twins, called B.G. and A.M., have Urbach-Wiethe disease, a genetic disorder that destroyed most of their amygdalae. Despite this, the twins showed fear after inhaling air laden with extra carbon dioxide (an experience that can create the sensation of suffocating), an earlier study showed (*SN: 3/23/13, p. 12*). Because carbon dioxide affects a wide swath of the body and brain, scientists turned to a more specific cause of fear that stems from inside the body: They injected a drug called isoproterenol, which can set the heart racing and make breathing hard. Sensing these bodily changes provoked by the drug can cause anxiety.

"If you know what adrenaline feels like, you know what isoproterenol feels like," says study coauthor Sahib Khalsa, a psychiatrist and neuroscientist at the Laureate Institute for Brain Research in Tulsa, Okla.

After injections of isoproterenol, both twins felt shaky and anxious. B.G. experienced a full-blown panic attack, an effect of the drug that afflicts about a quarter of people who receive it, Khalsa says. In a second experiment, researchers tested the women's ability to judge their bodies' responses to the drug. While receiving escalating doses, the women rated the intensity of their heartbeats and difficulty breathing. A.M., the woman who didn't have a panic attack, was less accurate at sensing the drug's effects on her body than both her sister and healthy people, researchers found.

It's not clear why the twins responded differently, Khalsa says. Further experiments using brain scans may help pinpoint neural differences that could be behind the different reactions. ■

LIFE & EVOLUTION

Beetle moms repress mates' sex drive

Chemical emitted by females makes males focus on parenting

BY SARAH SCHWARTZ

For burying beetles, parenting is a real turnoff.

While caring for larvae, a mother burying beetle (*Nicrophorus vespilloides*) releases a chemical compound that limits her mate's urge to breed. The antiaphrodisiac lets beetle dads focus on childcare, researchers report March 22 in *Nature Communications*.

"We were surprised to discover such a chemical communication system that helps to resolve — at least in part — conflicts between both parents," says study coauthor Sandra Steiger of the University of Ulm in Germany.

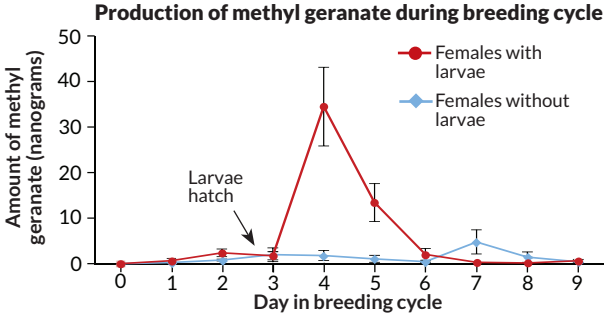
Burying beetles lay eggs on dead animals. For a few days after hatching, larvae beg their parents for predigested food. Previous work showed that beetles refrain from sexual activity — and that females release a gas — during this period.

In the new study, researchers determined that this gas is a compound called methyl geranate. Mother beetles release the gas while caring for a begging brood, producing more if they have more larvae. (Female beetles physically separated from larvae produce little to no methyl geranate.) The compound acts as a buzzkill for males; as females produce more, males make fewer attempts to mate.

Methyl geranate may benefit larvae by allowing attentive parenting, the researchers say. Mating would distract from tending to larvae, which grow and survive better with parental care. The female "can give the signal to the male: 'OK, now it's time to focus on caring and forget about sex,'" says behavioral ecologist Stephen Trumbo of the University of Connecticut in Waterbury.

Adults could benefit too. While caring for young, a female undergoes a hormonal shift that makes her less fertile, the team found. Mating attempts during this time are more likely to be a waste of energy.

Trumbo says the study provides a rare glimpse into how male and female invertebrates coordinate childcare. "It can benefit both the male and female, because they're going to achieve higher reproductive success if their mating behavior and parental behavior is well-coordinated and well-timed." ■



Mood killer While tending larvae, a mother burying beetle produces increased amounts of methyl geranate (red line), which reduces a father's urge to mate. Females physically separated from larvae produce little methyl geranate (blue line).

SOURCE: K.C. ENGEL *ET AL/NATURE COMMUNICATIONS* 2016

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ATOM & COSMOS

Ribose could have formed in space

Key sugar in RNA found in lab-made 'interstellar' ices

BY CHRISTOPHER CROCKETT

Ribose, the sugar in RNA, might form on ice grains irradiated by ultraviolet light in stellar nurseries such as the Carina Nebula, part of which is seen in this Hubble Space Telescope image.

Joni Mitchell was right: We are stardust. One of the essential ingredients for life might have formed in space and then rained down on a young Earth, researchers suggest in the April 8 *Science*.

The simple sugar ribose — a crucial piece of the molecular machinery inside cells — can form on a blend of ices that have been blasted with ultraviolet radiation, chemist Cornelia Meinert of the University Nice Sophia Antipolis in France and colleagues report. These ices are common to comets and are thought to coat grains of interstellar dust that swirl around young stars.

"This is an amazing result," says Conel Alexander, a planetary scientist at the Carnegie Institution for Science in Washington, D.C. Researchers have been looking at irradiated ices for years, he says, but have never seen ribose show up. Ribose is part of the backbone of RNA, a molecule that helps carry out the instructions encoded in genes. RNA is found in all life on Earth and might have been a precursor to DNA billions of years ago.

Other pieces of biological machinery have been found in space or produced in a lab before. Last year, researchers created uracil, cytosine and thymine — three of the molecular letters in DNA's and RNA's genetic alphabets — in a simulated space environment. Researchers have also found amino acids, which link together to form proteins, in meteorites. And in 2014, astronomers detected isopropyl cyanide, a molecule that resembles amino acids, in a gas cloud near the center of the galaxy (*SN: 11/1/14, p. 7*). A decade earlier, scientists reported finding the simple sugar glycoaldehyde in the same cloud (*SN: 10/9/04, p. 237*).

Meinert and colleagues cooled water, ammonia and methanol, which are ices found in comets, to –195° Celsius inside a vacuum chamber. To simulate the radiation from a young star, the researchers exposed the ice to ultraviolet light. After warming the cosmic goop back to room temperature, they found that a cornucopia of organic molecules — about 55 in all, including ribose — had formed on the ice.

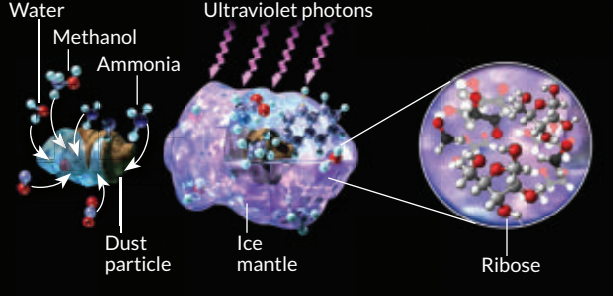
The results aren't too surprising, says Reggie Hudson, an astrochemist at NASA's Goddard Space Flight Center in Greenbelt, Md. Researchers have long suspected that sugars could form on interstellar ice, and the underlying chemistry has been understood for 155 years, he says. But no one had actually done the experiment before.

One of the challenges is that the compounds that formed are also common contaminants. People carry many of the sugars around in their bodies. And one of the molecules that turned up is ethylene glycol, a type of antifreeze. Any of these could have been inadvertently introduced to the experiment. But the researchers used methanol ice that contained a variety of carbon known as carbon-13; any contaminants would have carried the slightly lighter carbon-12. By seeing carbon-13 in the ribose and other sugars, the researchers knew chemical reactions in the ice, and not uninvited interlopers, were responsible for the results.

Hudson also notes — as do the study's authors — that it's hard to tell whether the molecules formed when the ices were cold or as the samples warmed up. But both Hudson and Meinert say that warm conditions aren't foreign to interstellar ice grains. Young stars will periodically warm up their surrounding belts of debris. And grains that fall to Earth will heat up as they pummel the planet. Ribose, instead of forming in space, might have formed as the ingredients were delivered to Earth.

No one has seen ribose in comets and asteroids yet, but a few upcoming missions might get a chance to look. Japan's Hayabusa2 spacecraft is on course to pilfer material from asteroid 162173 Ryugu; NASA's OSIRIS-REx mission, meanwhile, will launch in September to bring back pieces of asteroid Bennu. ■

Ribose recipe
One way to make ribose and other sugars in space is to coat an interstellar dust grain in water, methanol and ammonia ices, then bake under ultraviolet light from a young star.



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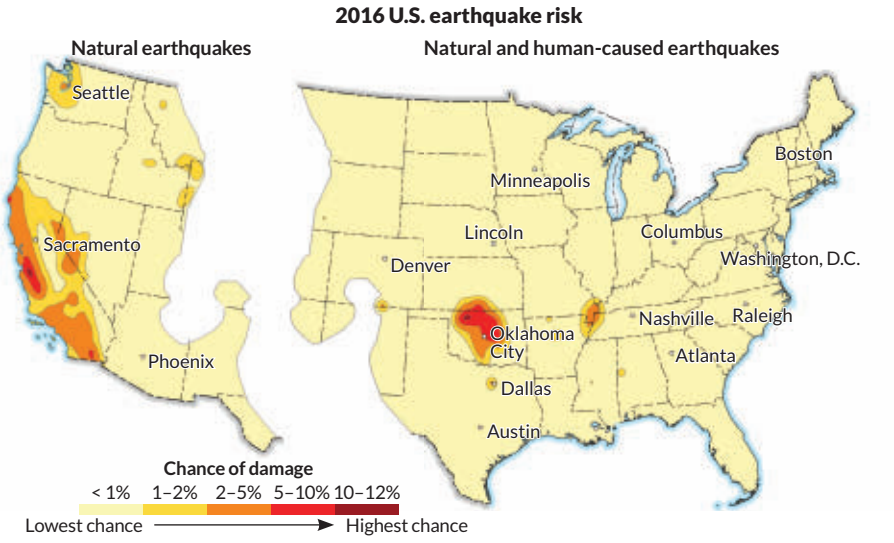

EARTH & ENVIRONMENT

Quake risk high in parts of central United States

Northern Oklahoma is just as susceptible to a damaging earthquake this year as the most quake-prone areas of California. That's because quakes are no longer just a natural hazard, the U.S. Geological Survey says. In its quake hazards forecast released March 28, the agency for the first time included the effects of artificially triggered seismicity. The map above shows which areas are most prone to quake damage of any severity (the far left portion of the map shows just the risks from natural earthquakes).

An increased risk in the central United States largely stems from sites where fluids, such as fracking wastewater, are injected underground (*SN: 8/9/14, p. 13*). Rising fluid pressure can unclamp faults and unleash quakes (*SN: 7/11/15, p. 10*). From 1973 to 2008, an average of 24 potentially damaging quakes rattled the central United States annually. From 2009 to 2015, an uptick in fracking helped that number skyrocket to 318 annual quakes on average, with 1,010 temblors in 2015 alone.

Induced quakes haven't been as powerful as their natural counterparts, but the potential for more powerful shakes exists, scientists warn. — *Thomas Sumner*

ATOM & COSMOS

Companion star could have triggered supernova

Debris from a cosmic explosion bumped into a neighboring star, a new study reports, suggesting that the surviving star might be responsible for its partner's demise.

Astronomers suspect that such explosions, called type 1a supernovas, are the detonation of a white dwarf, the dense core left behind after some stars die. What pulls the trigger is up for debate. Two white dwarfs could spiral together and explode. Or one white dwarf could siphon gas off a companion star until the white dwarf gains so much mass that it blows up.

The type 1a supernova in the new study was discovered in 2012 in a galaxy about 50 million light-years away in the constellation Virgo. Astronomers noticed more blue light coming from the supernova than expected. The excess probably came from gas that was compressed and heated as the shock wave ran into another star, Howie Marion of the University of Texas at Austin and colleagues report in the April 1 *Astrophysical Journal*. The observation is the first strong evidence that some normal type 1a supernovas have orbiting companions and supports the idea that some white dwarfs eat until they explode. — *Christopher Crockett*

LIFE & EVOLUTION

Lethal bat disease moves west

A sick bat caught by hikers not far from Seattle on March 11 has now been confirmed as the first case west of the Rockies of the deadly bat disease white-nose syndrome.

First noticed in North America in the winter of 2006–2007, the disease exterminated some whole colonies of hibernating bats on the East Coast, though some species have proved less susceptible. White-nose syndrome has now swept from coast to coast, the U.S. Geological Survey confirmed March 31.

As of mid-April, the USGS' National Wildlife Health Center has confirmed only the one case, in a little brown bat (*Myotis lucifugus*) found near North Bend, Wash. Genetic testing identified it as a little brown bat most likely from the West instead of an accidental hitchhiker, Jeremy Coleman of the U.S. Fish and Wildlife Service said at a news conference. — *Susan Milius*

MATTER & ENERGY

Machine makes drugs on demand

A new refrigerator-sized factory can rapidly pump out a diverse assortment of drugs on demand.

Researchers designed the system to offer a speedy alternative to large-scale pharmaceutical production. Rejiggering chemical inputs and the device's collection of tanks and tubes allowed the team to produce four different drugs: an anesthetic (lidocaine), an antihistamine (Benadryl), an antianxiety medication (Valium) and an antidepressant (Prozac). The self-contained system was equipped to mix, heat, pump and purify ingredients into hundreds or thousands of doses of pharmaceutical-grade compounds. Making each medication took roughly 12 to 48 hours, an international team of researchers reports in the April 1 *Science*.

For now, the device makes only liquid medications. But the work is a step toward overcoming limitations of cumbersome drug-making supply chains by developing automated tools that make medications on demand (*SN: 8/22/15, p. 22*). — *Sarah Schwartz*

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LIFE & EVOLUTION

Ancient snake wore green

An ancient snakeskin preserves signs of the bright green coloration of its wearer, researchers report online March 31 in *Current Biology*.

The fossilized skin (right) of an 11.2-million- to 8.7-million-year-old snake from Spain contains remnants of pigment cells. By comparing the cells' shapes and architectures with those of modern snakes, the researchers identified cellular structures linked to green, yellow, brown, black and creamy hues.

Previous reconstructions of ancient colors have been limited to the reds, browns and blacks of melanin pigment, but this is an unusual case. Calcium phosphate in the rock allowed for exceptional preservation of the snake's skin layers, opening the door to reconstructing green and yellow colors in the fossil record. — *Helen Thompson*

Calcium phosphate helped prevent the degradation of cellular structures linked to yellow and green coloration in skin tissue (cream color patches) in this fossilized snake.

MATH & TECHNOLOGY

Cyborg beetles walk the walk

Resistance may soon be futile. With machine implants worthy of a *Star Trek* villain, a new breed of beetle takes walking instructions from its human overlords.

Hirotaka Sato and his colleagues at Nanyang Technological University in Singapore inserted electrodes into flower beetles (*Mecynorrhina torquata*) to stimulate specific leg muscle groups. By altering the order of electrical zaps, the team could control a beetle's gait. Changing the duration of the electrical signals also altered speed and step length, Sato and colleagues report in the March *Journal of the Royal Society Interface*.

Scientists have already made cyborg insects that can fly, scuttle and crawl, but controlling things like speed could allow biobots to do more complex tasks. Cyborg insects provide a more energy-efficient and easier-to-assemble alternative to plain old robots (*SN: 3/8/14, p. 18*) and double as a means to study insect locomotion, the researchers argue. — *Helen Thompson*

Electrodes enabled researchers to control this beetle's speed and walking gait.

LIFE & EVOLUTION

Ant antennae provide chemical ID

Ant antennae don't just receive chemical signals — they send signals, too.

Colonies of ants communicate through chemical cues produced all over their bodies. Studies have shown that ants use their antennae to identify their own nest mates and potential invaders. But antennae also produce the key compounds that ants use to tell friend from foe, researchers in Australia report in the March 30 *Proceedings of the Royal Society B*.

Antennae from Australian meat ants (*Iridomyrmex purpureus*) contain a different chemical cocktail than what is found on ants' heads, legs or abdomens, the team found. When a worker ant's antennae were removed or dipped in a solution that washed away signaling chemicals, ants from a different colony couldn't identify the intruder. The unaltered ants brushed the invader with their own antennae, and then acted as though the impostor was one of their own. — *Sarah Schwartz*

HUMANS & SOCIETY

Marijuana linked to financial woes

Financial health takes a hit among people who smoke a lot of marijuana from adolescence into young adulthood, even if they don't get hooked on the drug, researchers say.

The more years that individuals smoke pot four or more days a week, the more likely they are to experience serious money problems, say social epidemiologist Magdalena Cerdá of the University of California, Davis and colleagues. Cash woes include defaulting on credit card payments, struggling to pay for food and rent and going on welfare.

In a representative sample of 947 New Zealanders studied from birth to age 38, adult economic and social problems — including a fall from middle-class status, stealing money at work and domestic violence — occurred about equally among regular marijuana and alcohol users, the scientists report online March 22 in *Clinical Psychological Science*. Of 29 persistent pot smokers who grew up in middle-class families, 15 experienced downward social mobility, versus only 23 of 160 middle-class peers who never used marijuana.

Participants who consistently qualified as dependent on marijuana after age 18 encountered the worst money troubles over time, even exceeding those of peers with alcoholism.

These findings don't prove that regular pot smoking caused Kiwis' financial difficulties, the investigators caution. But the association between marijuana and money troubles remained after accounting for childhood poverty, IQ, teenage delinquency and depression, impulsiveness, self-reported motivation to succeed in life, pot-related criminal convictions and abuse of alcohol and other drugs on top of frequent marijuana use. — *Bruce Bower*

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To an ancient question, no reply

Special Report: In Search of Aliens

People have contemplated the possibility of extraterrestrial life since medieval times. We're still looking for answers today. What would aliens look like? Where should we look to find them? Why are we so obsessed? *Science News* writers explore these questions and more in this special report.

Wonder about civilizations on other worlds goes back centuries

By Tom Siegfried

For beings that are supposedly alien to human culture, extraterrestrials are pretty darn common.

You can find them in all sorts of cultural contexts, from comic books, sci-fi novels and conspiracy theories to Hollywood films and old television reruns. There's Superman and Doctor Who, E.T. and Mindy's friend Mork, Mr. Spock, Alf, Kang and Kodos and My Favorite Martian. Of course, there's just one hitch: They're all fictional. So far, real aliens from other worlds have refused to show their faces on the real-world Earth — or even telephone, text or tweet. As the Italian physicist Enrico Fermi so quotably inquired during a discussion about aliens more than six decades ago, "Where is everybody?"

Scientific inquiry into the existence of extraterrestrial intelligence still often begins by pondering Fermi's paradox: The universe is vast and old, so advanced civilizations should have matured enough by now to send emissaries to Earth. Yet none have. Fermi suspected that it wasn't feasible or that aliens didn't think visiting Earth was worth the trouble.

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The Allen Telescope Array, a suite of radio antenna dishes in California, has been seeking signals from alien life since 2009, so far without success.

Others concluded that they simply don't exist. Recent investigations indicate that harsh environments may snuff out nascent life long before it evolves the intelligence necessary for sending messages or traveling through space.

In any event, Fermi's question did not launch humankind's concern with visitors from other planets. Imagining other worlds, and the possibility of intelligent life-forms inhabiting them, did not originate with modern science or in speculative fiction. In the ancient world, philosophers argued about the possibility of multiple universes; in the Middle Ages the question of the "plurality of worlds" and possible inhabitants occupied the deepest of thinkers, spawning intricate and controversial philosophical, theological and astronomical debate. Far from being a merely modern preoccupation, life beyond Earth has long been a burning issue animating the human race's desire to understand itself, and its place in the cosmos.

Other worlds, illogical

From ancient times Earth's place was widely regarded to be the center of everything. As articulated by the Greek philosopher Aristotle, the Earth was the innermost sphere in a universe, or world, surrounded by various other spheres containing the moon, sun, planets and stars. Those heavenly spheres, crystalline and transparent, rotated about the Earthly core comprising four elements: fire, air, water and earth. Those elements layered themselves on the basis of their essence, or "nature" — earth's natural place was at the middle of the cosmos, which was why solid matter fell to the ground, seeking the inaccessible center far below.

On the basis of this principle, Aristotle deduced the impossibility of other worlds. If some other world existed, its matter (its "earth") would seek both the center of its world and of our world as well. Such opposite imperatives posed a logical contradiction (which Aristotle, having more or less invented logic, regarded as a directly personal insult). He also applied further reasoning to point out that there is no space (no void) outside the known world for any other world to occupy. So, Aristotle concluded, two worlds cannot both exist.

Some Greeks (notably those advocating the existence of atoms) believed otherwise. But Aristotle's view prevailed. By the 13th century, once Aristotle's writings had been rediscovered in medieval Europe, most scholars defended his position.

But then religion leveled the philosophical playing field. Fans of other worlds got a chance to make their case.

In 1277, the bishop of Paris, Étienne Tempier, banned scholars from teaching 219 principles, many associated with Aristotle's philosophy. Among the prohibited teachings on the list was item 34: that God could not create as many worlds as he wanted to. Since the penalty for violating this decree was excommunication, Parisian scholars suddenly discovered rationales allowing multiple worlds, empowering God to defy Aristotle's logic. And since Paris was the intellectual capital of the European world, scholars elsewhere followed the Parisian lead.

While several philosophers asserted that God could make many worlds, most intimated that he probably wouldn't have bothered. Hardly anyone addressed the likelihood of alien life, although both Jean Buridan in Paris and William of Ockham in Oxford did consider the possibility. "God could produce an infinite [number of] individuals of the same kind as those that now exist," wrote Ockham, "but He is not limited to producing them in this world."

In the 1400s, Nicholas of Cusa (left) contended that Earth was one of a multitude of worlds. Later, Giordano Bruno (right) suggested the existence of an infinity of worlds populated by intelligent life.

FROM LEFT: HISTORIOGRAF/WIKIMEDIA COMMONS; FRANKFURT AND LEIPZIG, 1715/WIKIMEDIA COMMONS

Populated worlds showed up more prominently in writings by the renegade thinkers Nicholas of Cusa (1401–1464) and Giordano Bruno (1548–1600). They argued not only for the existence of other worlds, but also for worlds inhabited by beings just like, or maybe better than, Earth's humans.

"In every region inhabitants of diverse nobility of nature proceed from God," wrote Nicholas, who argued that space had no center, and therefore the Earth could not be central or privileged with respect to life. Bruno, an Italian friar, asserted that God's perfection demanded an infinity of worlds, and beings. "Infinite perfection is far better presented in innumerable individuals than in those which are numbered and finite," Bruno averred.

Burned at the stake for heretical beliefs (though not, as often stated, for his belief in other worlds), Bruno did not live to see the triumph of Copernicanism during the 17th century. Copernicus had placed the sun at the hub of a planetary system, making the Earth just one planet of several. So the existence of "other worlds" eventually became no longer speculation, but astronomical fact, inviting the notion of otherworldly populations, as the prominent Dutch scientist Christiaan Huygens pointed out in the late 1600s. "A man that is of Copernicus' opinion, that this Earth of ours is a planet ... like the rest of the planets, cannot but sometimes think that it's not improbable that the rest of the planets have ... their inhabitants too," Huygens wrote in his *New Conjectures Concerning the Planetary Worlds, Their Inhabitants and Productions*.

A few years earlier, French science popularizer Bernard le Bovier de Fontenelle had surveyed the prospects for life in the solar system in his *Conversations on the Plurality of Worlds*, an imaginary dialog between a philosopher and an uneducated but intelligent woman known as the Marquise.

"It would be very strange that the Earth was as populated as it is, and the other planets weren't at all," the philosopher told the Marquise. Although he didn't think people could live on the sun (if there were any, they'd be blinded by its brightness), he sided with those who envisioned inhabitants on other planets and even the moon.

"Just as there have been and still are a prodigious number of men foolish enough to worship the Moon, there are people on the Moon who worship the Earth," he wrote.

From early modern times onward, discussion of aliens was not confined to science and philosophy. They also appeared in various works of fiction, providing plot devices that remain popular to the present day. Often authors used aliens as stand-ins for evil (or occasionally benevolent) humans to comment on current events. Modern science fiction about aliens frequently portrays them in the role of tyrants or monsters or victims, with parallels to real life (think Flash Gordon's nemesis Ming the Merciless, a 1930s dictator, or the extraterrestrials of the 1980s film and TV show *Alien Nation* — immigrants encountering bigotry and discrimination). When humans look for aliens, it seems, they often imagine themselves.

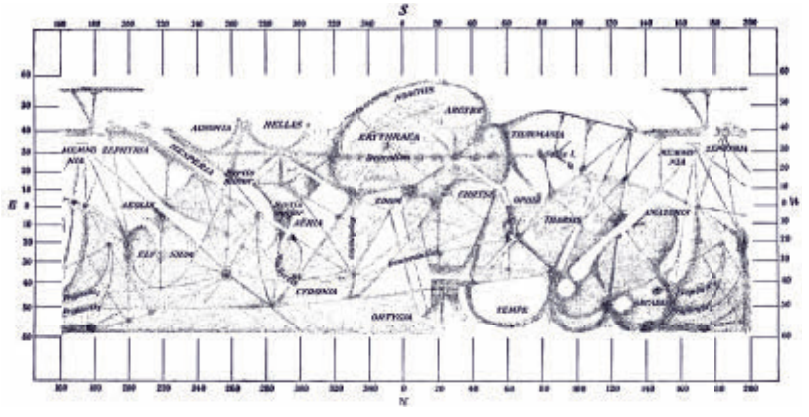
No one any longer doubts that planets are plentiful. But still there's been not a peep from anyone living on them.

Serious science

While aliens thrived in fiction, though, serious scientific belief in extraterrestrials — at least nearby — diminished in the early 20th century, following late 19th century exuberance about possible life on Mars. Supposedly a network of lines interpreted as canals signified the presence of a sophisticated Martian civilization; its debunking (plus further knowledge about planetary environments) led to general agreement that finding intelligent life elsewhere in the solar system was not an intelligent bet.

On the other hand, the universe had grown incredibly vaster than the early Copernicans had imagined. The sun had become just one of billions of stars in the Milky Way galaxy, which in turn was only one of billions of other similar galaxies, or "island universes." Within a cosmos so expansive, alien enthusiasts concluded, the existence of other life *somewhere* seemed inevitable. In 1961, astronomer Frank Drake developed an equation to gauge the likelihood of extraterrestrial life's existence; by the 1990s he estimated that 10,000 planets possessed advanced civilizations in the Milky Way alone, even before anybody really knew for sure that planets outside the solar system actually existed.

But now everybody does. In the space of the last two decades, conclusive evidence of exoplanets, now numbering in the thousands, has reconfigured the debate and sharpened Fermi's original paradox. No one any longer doubts that planets are plentiful. But still there's been not a peep from anyone living on them, despite years of aiming radio telescopes at the heavens



In his book *Astronomy for Amateurs*, French astronomer Camille Flammarion depicted a network of lines seen on the surface of Mars; those lines had been interpreted as canals indicating an intelligent civilization, a conclusion later decisively debunked.

C. FLAMMARION, *ASTRONOMY FOR AMATEURS*

in hope of detecting a signal in the static of interstellar space.

Maybe such signals are just too rare or too weak for human instruments to detect. Or possibly some cosmic conspiracy is at work to prevent civilizations from communicating — or arising in the first place. Or perhaps civilizations that do arise are eradicated before they have a chance to communicate.

Or maybe the alien invasion has merely been delayed. Fermi's paradox implicitly assumes that other civilizations have been around long enough to develop galactic transportation systems. After all, the universe, born in the Big Bang 13.8 billion years ago, is three times as old as the Earth. So most analyses assume that alien civilizations had a head start and would be advanced enough by now to go wherever they wanted to. But a new paper suggests that livable galactic neighborhoods may have developed only relatively recently.

In a young, smaller and more crowded universe, cataclysmic explosions known as gamma-ray bursts may have effectively sterilized otherwise habitable planets, Tsvi Piran and collaborators suggest in a paper published in February in *Physical Review Letters*.

A planet near the core of a galaxy would be especially susceptible to gamma-ray catastrophes. And in a young universe, planets closer to the galactic edge (like Earth) would also be in danger from gamma-ray bursts in neighboring satellite galaxies. Only as the expansion of the universe began to accelerate — not so long before the birth of the Earth — would galaxies grow far enough apart to provide safety zones for life.

"The accelerated expansion induced by a cosmological constant slows the growth of cosmic structures, and increases the mean inter-galaxy separation," Piran and colleagues write. "This reduces the number of nearby satellites likely to host catastrophic" gamma-ray bursts. So most alien civilizations would have begun to flourish not much before Earth's did; those aliens may now be wondering why nobody has visited them.

Still, the radio silence from the sky makes some scientists wonder whether today's optimism about ET's existence will go the way of the Martian canal society. From one sobering perspective, aliens aren't sending messages because few planets remain habitable long enough for life to develop an intelligent civilization. One study questions, for instance, how likely it is that life, once initiated on any planet, would shape its environment sufficiently well to provide for lasting bio-security.

In fact, that study finds, a wet, rocky planet just the right distance from a star — in the Goldilocks zone (see Page 36) — might not remain habitable for long. Atmospheric and geochemical processes would typically drive either rapid warming (producing an uninhabitable planet like Venus) or quick cooling, freezing water and leaving the planet too cold and dry for life to survive, Aditya Chopra and Charles Lineweaver conclude in a recent issue of *Astrobiology*. Only if life itself alters these processes can it maintain a long-term home suitable for developing intelligence.

Throughout the 20th century, extraterrestrial life of various levels of intelligence, benevolence or malevolence has been popular in fictional forms from comic books to TV shows to films.

"Feedback between life and environment may play the dominant role in maintaining the habitability of the few rocky planets in which life has been able to evolve," wrote Chopra and Lineweaver, both of the Australian National University in Canberra.

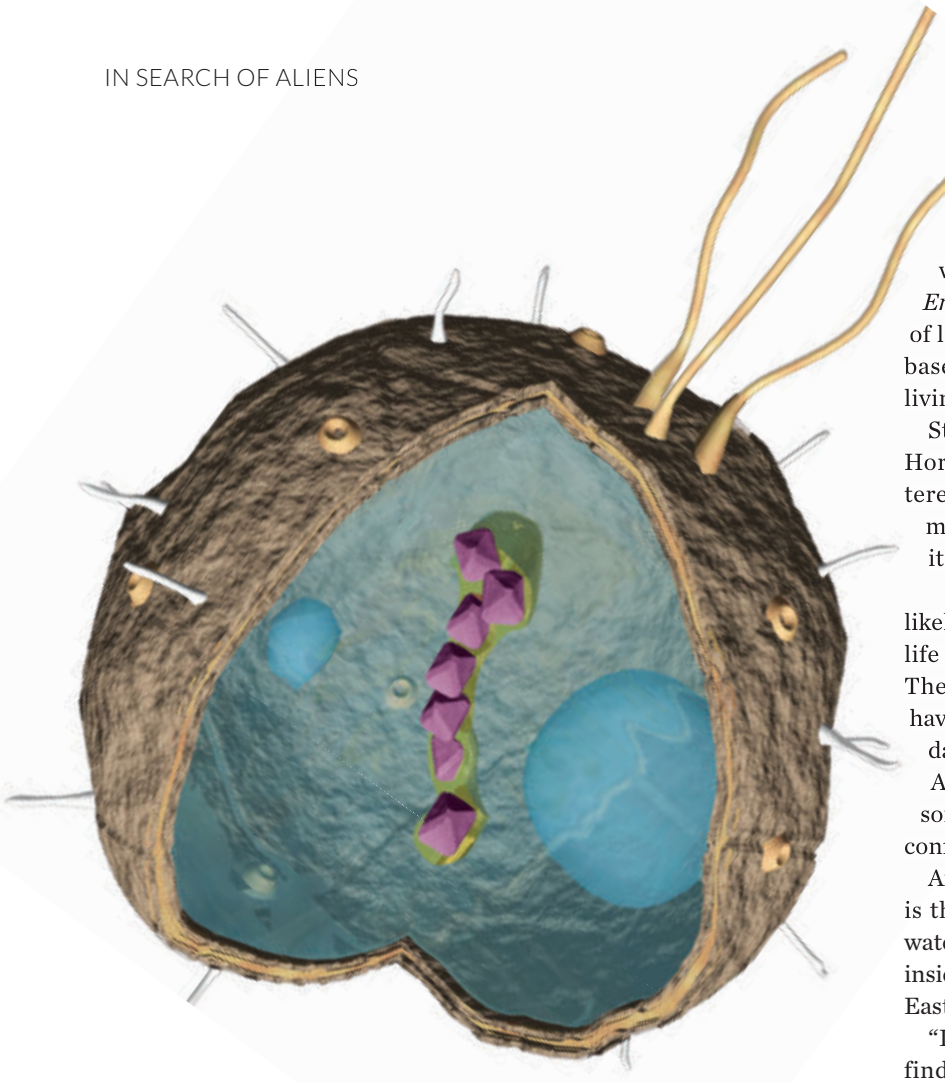
Yet even given such analyses — based on a vastly deeper grasp on astronomy and cosmology than medieval scholars possessed — whether real aliens exist remains one of those questions that science cannot now answer. It's much like other profound questions also explored in medieval times: What is the universe made of? Is it eternal? Today's scientists may be closer (or not) to answering those questions than were their medieval counterparts. Nevertheless the answers are not yet in hand.

Maybe we'll just have to pose those questions to the aliens, if they exist, and are ever willing to communicate. And if those aliens do arrive, and provide the answers, humankind may well discover how medieval its understanding of the cosmos still is. Or perhaps the aliens will be equally clueless about nature's deepest mysteries. As Fontenelle's philosopher told the Marquise: "There's no indication that we're the only foolish species in the universe. Ignorance is quite naturally a widespread thing." ■

Explore more

- Michael J. Crowe. *The Extraterrestrial Life Debate, 1750–1900*. Dover Publications, 2011.
- SETI Institute: www.seti.org

CLOCKWISE FROM TOP LEFT: UNIVERSAL PICTURES/WIKIMEDIA COMMONS; AVON PERIODICALS/DIGITALCOMICMUSEUM.COM; JUNIOR BOOKS, INC/ DIGITALCOMICMUSEUM.COM



Will we know ET when we see it?

The search for alien life requires an open mind

By Tina Hesman Saey

In a 1967 episode of *Star Trek*, Captain Kirk and crew investigated the mysterious murders of miners on the planet Janus VI. The killer, it turned out, was a rock monster called the Horta. But the *Enterprise*'s sensors hadn't registered any signs of life in the creature. The Horta was a silicon-based life-form, rather than carbon-based like living things on Earth.

Still, it didn't take long to determine that the Horta was alive. The first clue was that it skittered about. Spock closed the case with a mind meld, learning that the creature was the last of its kind, protecting its throng of eggs.

But recognizing life on different worlds isn't likely to be this simple, especially if the recipe for life elsewhere doesn't use familiar ingredients. There may even be things alive on Earth that have been overlooked because they don't fit standard definitions of life, some scientists suspect.

Astrobiologists need some ground rules — with some built-in wiggle room — for when they can confidently declare, "It's alive!"

Among the researchers working out those rules is theoretical physicist Christoph Adami, who watches his own version of silicon-based life grow inside a computer at Michigan State University in East Lansing.

"It's easy when it's easy," Adami says. "If you find something walking around and waving at you, it won't be that hard to figure out that you've found life." But chances are, the first aliens that humans encounter won't be little green men. They will probably be tiny microbes of one color or another — or perhaps no color at all.

By definition

Trying to figure out how to recognize those alien microbes, especially if they are very strange, has led scientists to propose some basic criteria for distinguishing living from nonliving things. Many researchers insist that features such as active metabolism, reproduction and Darwinian evolution are de rigueur for any life, including extraterrestrials. Others add the requirement that life must have cells big enough to contain protein-building machines called ribosomes.

But such definitions can be overly restrictive. A list of specific criteria for life may give scientists tunnel vision, blinding them to the diversity of living things in

A Martian microbe, envisioned by planetary geologist Kathie Thomas-Keprta, would need a tough outer wall to withstand the elements and magnetic crystals to help it navigate.

K. THOMAS-KEPRTA/NASA JOHNSON SPACE CTR.

the universe, especially in extreme environments, says philosopher of science Carol Cleland of the University of Colorado Boulder. Narrow definitions will "act as blinkers if you run into a form of life that's very different."

Some scientists, for instance, say viruses aren't alive because they rely on their host cells to reproduce. But Adami disagrees. "There's no doubt in my mind that biochemical viruses are alive," he says. "They don't carry with them everything they need to survive, but neither do we." What's important, Adami says, is that viruses transmit genetic information from one generation to another. Life, he says, is information that replicates.

Darwinian evolution should be off the table, too, Cleland says. Humans probably won't be able to tell at a quick glance whether something is evolving, anyway. "Evolvability is hard to detect," she says, "because you've got a snapshot and you don't have time to hang around and watch it evolve."

Cell size restrictions may also squeeze minuscule microbes out of consideration as aliens. But a cell too tiny to contain ribosomes may still be big enough if it uses RNA instead of proteins to carry out biochemical reactions, says Steven Benner, an astrobiologist at the Foundation for Applied Molecular Evolution in Alachua, Fla. Cells are thought necessary because they separate one organism from another. But layers of clay could provide the needed separation, Adami suggests. Cleland postulates that life could even exist as networks of chemical reactions that don't require separation at all.

Such fantastical thinking can loosen the grip of rigid criteria limiting scientists' ability to recognize alien life when they see it. But they will still need to figure out where to look.

Up close and personal

With the discovery in recent years of more than a thousand exoplanets far beyond the solar system, the odds favoring the existence of extraterrestrial life in the cosmos are better than ever. But even the most powerful telescopes can't detect microscopic organisms directly. Chances of finding microbial life are much higher if scientists can reach out and touch it, which means looking within our solar system, says mineralogist Robert Hazen, of the Carnegie Institution for Science in Washington, D.C.

"You really need a rover down on its hands and knees analyzing chemicals," Hazen says. Rovers are sampling rocks on Mars (*SN: 5/2/15, p. 24*) and the Cassini probe has bathed in geysers spewing from Saturn's icy moon Enceladus (*SN: 10/17/15, p. 8*). Those mechanical explorers and others in the works may send back signs of life.

But those signs are probably going to be subtle, indirect "biomarkers." It may be surprisingly difficult to tell whether those biomarkers are from animals, vegetables, microbes or minerals, especially at a distance.

"We really need to have life be as obvious as possible," says astrobiologist Victoria Meadows, who heads the NASA Astrobiology Institute's Virtual Planetary Laboratory at the University of Washington in Seattle. By obvious, she partly means Earth-like and partly means that no chemical or geologic process could have produced a similar signature.

> "You really need a rover down on its hands and knees analyzing chemicals."
> **ROBERT HAZEN**

Some scientists say life is an "I'll know it when I see it" phenomenon, says Kathie Thomas-Keprta, a planetary geologist. But life may also be in the eye of the beholder, as Thomas-Keprta knows all too well from studying a Martian meteorite. She was part of a team at the NASA Johnson Space Center in Houston that studied a meteorite designated ALH84001 (discovered in Antarctica's Allan Hills ice field in 1984).

In 1996, a team led by Thomas-Keprta's late colleague David McKay claimed that carbonate globules embedded in the meteorite resembled microscopic life on Earth. The researchers found large organic molecules with the carbonate, indicating that they formed at the same time. Thomas-Keprta also identified tiny magnetite crystals overlapping the globules that closely resemble crystals formed by "magnetotactic" bacteria on Earth. Such bacteria use chains of the crystals as a compass to guide them as they swim in search of nutrients. The researchers believed that they were looking at fossils of ancient Martians.

Other researchers disagreed. The globules and crystals could have formed by chemical or geologic processes, not biology, critics said. Since then, the claim of fossilized Martian life has been widely dismissed.

Surely, recognizing something that is still alive, rather than dead and turned to rock, would be much simpler. But don't bet on it, Cleland says. There may even be strange forms of life on Earth — a shadow biosphere — that people have overlooked.

A brick-sized meteorite from Mars called ALH84001 (top) contained what looked to some scientists like fossils of bacteria (bottom).

FROM TOP: JSC/NASA; NASA

Desert varnish

One bit of evidence for shadow terrestrials is "desert varnish," the dark stains on the sunny sides of rocks in arid areas. Odd, communal lifeforms could be sucking energy from the rocks and building the varnish's hard outer crust, Cleland suggests. Some scientists, for instance, think manganese-oxidizing bacteria or fungi might be responsible for concentrating iron and manganese oxides to create the stains. Unknown microbes may cement the metals with clay and silicate particles to produce the varnish's shellac. Scientists have tried and failed to re-create desert varnish in the lab using fungi and bacteria.

Critics say that varnishes form too slowly — over thousands of years — to be a microbial process and that oxidizing manganese doesn't generate enough energy to live on. Desert varnish is most likely a product of physical chemistry, they say.

But that criticism shows bias, Cleland responds. "We have an assumption that life on Earth has a pace," she says. Shadow life may grow far more leisurely, making it hard for scientists to classify it as alive.

One way to determine whether the varnish has a biological or geologic origin is to measure isotope ratios, Cleland says. Isotopes are forms of elements with differing numbers of neutrons in the nuclei of their atoms. Lighter isotopes, with fewer neutrons, are favored by some biochemical reactions.

"Life is lazy," says Cleland. "It doesn't want to haul around an extra neutron." Concentrations of lighter isotopes could signal the handiwork of living organisms, she notes.

Mineral distortions

To find life, and classify it correctly, look for the odd thing out, suggests Hazen, who is looking for messages in minerals. Minerals on Earth are unevenly distributed, he and colleagues have determined. There are 4,933 recognized minerals on the planet. Hazen and colleagues mapped the locations of 4,831 of them and found that 22 percent exist in only one location (*SN Online: 12/8/14*). Close to 12 percent occur in only two places, the researchers reported last year in *The Canadian Mineralogist*.

One reason for the skewed distribution is that evolving life has used local resources and concentrated them into new minerals. Take for example hazenite, named for Hazen. The phosphate mineral is produced only by microbes living in California's Mono Lake. Actions of other species in other places on Earth have combined with the planet's geology to make Earth's mineralogy unique, Hazen wrote with colleagues last year in *Earth and Planetary Science Letters*.

> "Everybody is aware of the pitfalls of experiments conducted at a 100-million-mile distance by robots."
> STEVEN BENNER

Finding similarly distorted distributions of minerals on other planets or moons could indicate that life exists, or once existed, there. Hazen has advised NASA on how rovers might identify mineral clues to life on Mars.

But determining whether something is unusual might not be as easy as it sounds. Scientists don't yet know enough about the environment of Mars, Benner says. "Every rover has given us surprises." He'd like to see a manned fact-finding mission, which he says might lead to a better understanding of the Red Planet and speed up the search for life there.

Mars was once wet (*SN Online: 10/8/15*) and still has occasional running water (*SN: 10/31/15, p. 17*). That and other mounting evidence that the Red Planet was once capable of supporting life led Benner to hypothesize in 2013 that Mars may have seeded life on Earth. Whether that hypothesis holds may depend on finding Martians, but Benner doesn't seem worried.

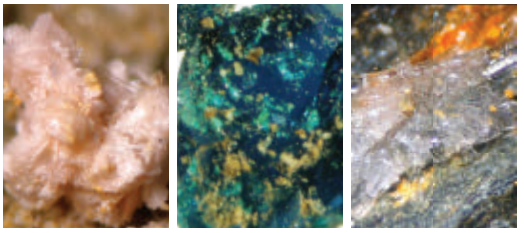
"I think I would be surprised now if they don't find life on Mars," he says. Once the announcement is made, researchers will begin fighting over whether the Martians are real, he predicts. "It will be a good-natured fight because everybody wants to find life, but everybody is aware of the pitfalls of experiments conducted at a 100-million-mile distance by robots."

Manned missions could easily reach Mars to confirm a find, says Dirk Schulze-Makuch, an astrobiologist at Washington State University in Pullman. "If you have a human with a microscope and the microbe is wiggling and waving back, that's really hard to refute," he jokes.

But humans and even probes may have a harder time spotting life on more distant or exotic locales, such as the moons of Jupiter and Saturn. Europa,

Desert varnish, which tints rocks a burnt orange or black (left, Angel Arch, Canyonlands National Park, Utah), may be produced by unknown living organisms. Silicates make desert varnish shiny (right, central Australia).

FROM LEFT: SARA A. FINKE/FLICKR (CC BY 2.0); MARK MARATHON/WIKIMEDIA COMMONS



Coskrenite-(Ce) Hoganite Levinsonite-(Y)

Some minerals like these form from decaying biomatter. Others require the action of microbes. The presence of such minerals could signal life.

Enceladus and Titan are frigid places barely kissed by the sun's energetic rays, but that doesn't mean they are devoid of life, Schulze-Makuch says. ET hunters are particularly attracted to Europa and Enceladus because liquid oceans slosh beneath their icy crusts. Liquid water is thought to be necessary for many of the chemical reactions that could support life, so it's one of the primary things astronomers look for.

Going for the less obvious

But water is actually a terrible solvent for forming complex molecules on which life could be based, Schulze-Makuch says. Instead, he thinks, really alien aliens might have spawned at hot spots deep in the hydrocarbon lakes of Saturn's biggest moon, Titan. There, "you could make something very intriguing. Whether you can get all the way to life, we don't know," he says. If he sent a probe to that moon, he would first look for large macromolecules similar to the DNA, RNA and proteins that Earth life uses, but with a Titanic twist.

He has been studying a natural asphalt lake in Trinidad to learn more about what life in Titan's lakes might be like. Last July in the journal *Life*, he and colleagues laid out the physical, chemical and physiological limits that life on Titan would bump up against.

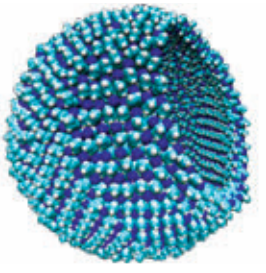
Perhaps the biggest challenge for Titanic life is the extreme cold, says chemical engineer Paulette Clancy of Cornell University. Frosty Titan is so cold that methane — a gas on balmy Earth — is a viscous, almost-freezing liquid, and water "would be like a rock," she says. Under those conditions, organisms with Earth-like chemistry wouldn't stand a chance.

For one thing, the membranes that hold in a cell's guts on Earth wouldn't work on Titan. Membranes are made of twin sheets of chainlike molecules each with an oxygen-containing head and a long tail of fatty acids. "On Titan," says Clancy, "long chains would be a disadvantage because they would be frozen in place," making membranes brittle. Plus, Titan has no free oxygen to form the molecules' traditional heads.

But Clancy and her Cornell colleagues, chemical engineer James Stevenson and astronomer Jonathan Lunine, simulated experiments under Titan-like conditions. (Molecules that would be stable on Titan would fall apart on Earth, so the researchers had to do computer experiments instead of synthesizing the molecules in a lab.) Short-tailed acrylonitrile molecules with nitrogen-containing heads could spontaneously create stable bubbles called azotosomes, the researchers reported last year in *Science Advances*. The bubbles are similar to cell membranes.

"Azo" is a prefix that the researchers use to refer to the presence of nitrogen atoms. It's also Greek for "without life." The word's meaning "would be ironic if life on Titan were based ... on nitrogen," Clancy says.

Like desert varnish, life on Titan may have unfamiliar pacing that could prevent Earthlings from determining whether azotosomes or other membranous bubbles found in that moon's methane oceans actually harbor life. With little solar radiation to stimulate evolution and frigid temperatures to slow chemical reactions, life on Titan may be really poky, Schulze-Makuch says. He imagines that Titanic life-spans may stretch to millions of years, with organisms reproducing or even breathing only once every thousand years. Scientists may need to measure metabolic reactions instead of generation times to determine whether something is living on Saturn's frigid satellite.



Life on Titan could exist within nitrogen-containing structures called azotosomes, some experts suggest.

Clancy hopes to explore what types of metabolism Titan's chemistry might allow. Neptune's icy moon Triton, which is covered in a thin veneer of nitrogen and methane and has nitrogen-spewing geysers, may also be a candidate for new and exciting biochemistry, she says.

With so many options out there, Clancy predicts that there are several planets or moons with life on them. "That we have the lock on the way life decided to develop, I think, is unlikely."

Many other researchers are also optimistic that life is out there to find. "I think life is a cosmic imperative," Hazen says. Someday, astrobiologists may come face-to-face with ET. Maybe they will even recognize it when they see it. ■

Explore more

- Dirk Schulze-Makuch *et al*. "The physical, chemical and physiological limits of life." *Life*. July 17, 2015.

COSKRENITE AND LEVINSONITE: JASON B. SMITH; HOGANITE: MARCUS J. ORIGLIERI; AZOTOSOME: JAMES STEVENSON

Putting Eyes on EXOPLANETS

Finding signs of life is hard, but new telescopes will soon begin searching

By Christopher Crockett

Our galaxy is teeming with planets. Over the last 25 years, astronomers have cataloged about 2,000 worlds in 1,300 systems scattered around our stellar neighborhood. While most of these exoplanets look nothing like Earth (and in some cases, like nothing that orbits our sun), the bonanza of alien worlds implies a tantalizing possibility: There is a lot of real estate out there suitable for life.

We haven't explored every corner of our solar system. Life might be lurking beneath the surface of some icy satellites or in the soil of Mars. For such locales, we could conceivably visit and look for anything wriggling or replicating (see Page 28). But we can't travel (yet) to worlds orbiting remote suns dozens of light-years away. An advanced alien civilization might transmit detectable radio signals, but primitive life would not be able to announce its presence to the cosmos.

At least not intentionally.

On Earth, life alters the atmosphere. If plants and critters weren't around to keep churning out oxygen and methane, those gases would quickly vanish. Water, carbon dioxide, methane, oxygen and ozone are examples of "biosignatures," key markers of a planet crawling with life as we know it. Setting aside questions about how recognizable alien life might be, detecting biosignatures in the atmosphere of an exoplanet would give astronomers the first strong clue that we are not alone.

Biosignatures aren't proof of thriving ecosystems. Ultraviolet light from a planet's sun can zap water molecules and create a stockpile of oxygen; seawater filtering through rocks can produce methane. "We'll never be able to say 100 percent that a

DAVID CURTIS

planet has life," says Sarah Rugheimer, an astrophysicist at the University of St. Andrews in Scotland. But astronomers hope that, given enough information about an exoplanet and the star it orbits, they can build a case for a world where sunlight and geology aren't enough to explain its chemistry — one where life is a viable possibility. Finding a planet similar to Earth is probably still decades away, but thanks to a couple of upcoming telescopes, astronomers might be on the verge of spying on habitable worlds around nearby stars.

NASA's Transiting Exoplanet Survey Satellite, or TESS, will launch in 2017 on a quest to detect many of the exoplanets that orbit the stars closest to us. One year later, the James Webb Space Telescope will launch and peek inside some of these newfound atmospheres. With their powers combined, TESS and James Webb could identify nearby planets that are good candidates for life. These worlds will probably be quite different from Earth — they'll be a bit larger and orbit faint, red suns — but some researchers hope that a few will offer hints of alien biology.

Exoplanets don't give up their secrets easily; they are distant, tiny and snuggled up to blazing stars. With some exceptions, current telescopes can't directly see exoplanets, so astronomers use other means to infer their existence. In rare cases, a remote solar system is oriented so that its planets pass between their sun and Earth, an event known as a transit. During a transit, the star temporarily dims as a planet blocks some of its light.

Transits are powerful tools; not only can they help reveal a planet's density — a way to distinguish gas planets from solid ones — but they also can allow astronomers to inventory the molecules floating in an exoplanet's atmosphere. During a transit, molecules in the planet's atmosphere absorb certain wavelengths of the star's light, leaving a chemical fingerprint. By deciphering that fingerprint, researchers can deduce the chemical makeup of an alien world.

Pushing Hubble

Astronomers so far have used the transit technique primarily with space-based telescopes such as the Hubble Space Telescope to investigate the atmospheres of more than 50 exoplanets, most of them worlds the size of Jupiter and Neptune (*SN: 11/15/14, p. 4*). The puffy atmospheres of giant planets are easier to detect than the relatively slim atmospheres of small rocky worlds. As tools have improved, researchers have started to check out super-Earths, planets that are smaller than Neptune but larger than ours. Though no such planets exist in our solar system, they appear to be one of the most common types in the galaxy.

Only three super-Earths have come under telescope scrutiny so far: GJ 1214b, HD 97658b and 55 Cancri e. These worlds are nothing like Earth. Two of them orbit dim, red suns, all of them whip around their stars in a few days (or even hours) and none are in the coveted habitable zone — the region around a star where a planet's temperatures are just right for liquid water (see Page 36). Around GJ 1214b and HD 97658b, astronomers found no signs of molecules absorbing starlight, leading researchers to conclude that both worlds are blanketed in clouds or haze (*SN Online: 1/2/14*).

In February, researchers reported signs of hydrogen cyanide on 55 Cancri e. If confirmed, it would be the first detection of any molecule in the atmosphere of a super-Earth. "These are very challenging measurements, at the limit of [the Hubble Space Telescope's] capabilities," cautions Heather Knutson, an astrophysicist at Caltech. "We're still learning about the performance of the telescope at this level of precision."

Astronomers will undoubtedly try to squeeze more information out of similar worlds. But, says Kevin France, an astrophysicist at the University of Colorado Boulder, "we've pushed Hubble about as far as we can." And Hubble won't be around forever (*SN: 4/18/15, p. 18*). To continue sniffing around in exoplanet atmospheres, researchers are looking toward Hubble's successor, the James Webb Space Telescope.

James Webb "is going to be a revolution in astronomy," says Jonathan Lunine, an astrophysicist at Cornell University. The infrared observatory boasts a mirror 2.7 times as wide as Hubble's. James Webb will seek out the first generation of stars, track how galaxies grow and — most relevant to the search for life — poke around in planetary atmospheres.

Analyzing the atmospheres of planets the size of Neptune and Jupiter should be a breeze for James Webb. These large planets block enough light to make transits readily detectable, and the fluffy atmospheres are easier to measure. Super-Earths, which are smaller with thin atmospheres, are more challenging, but James Webb should be able to investigate a few. Although replicas of Earth are beyond even James Webb's capabilities, there will be plenty for the observatory to do. "Even if we can't get biosignatures on planets the size of Earth, we're going to find out so much about the nature of exoplanets," Lunine says. "It's

Eyes on the sky Over the next decade, several telescopes will join existing observatories in the hunt for exoplanets and hints of alien life.

Hubble NASA's orbiting telescope has started examining the atmospheres of large exoplanets and a few super-Earths.

Spitzer This infrared NASA observatory sees heat radiating from some exoplanets and can build crude weather maps.

Kepler NASA's premier planet hunter found more than 1,000 exoplanets in its first four years.

TESS NASA's next exoplanet telescope, set to launch next year, will spend two years scouring 200,000 stars for the closest planets to our solar system.

CHEOPS A European Space Agency telescope will launch in 2017 to learn more about the size and density of known exoplanets.

James Webb A NASA infrared telescope, set to launch in 2018, could detect biosignatures in atmospheres of nearby super-Earths.

WFIRST-AFTA Another NASA infrared telescope, scheduled to debut in the 2020s, could sniff around in exoplanet atmospheres.

PLATO An ESA mission planned for 2024 aims to monitor up to 1 million stars for planets similar to Earth.

going to open up a huge number of doors."

The trouble with an Earth-like world is that it doesn't transit often and both the planet and its atmosphere are tiny. It's the same kind of problem an alien group would experience trying to detect us. When viewed from afar, Earth blocks less than 0.01 percent of the sun's light, and only a few percent of that is due to the atmosphere. To an alien astronomer, Earth crosses the sun once a year for, at most, 13 hours. And that's assuming the aliens live in the right part of the galaxy to witness an Earth transit (see Page 44). Telescopes operated by the bulk of the Milky Way's citizens will never line up with both the sun and Earth.

Focus on M dwarfs

The odds of finding life improve if astronomers focus their efforts on M dwarfs, which make up about three-quarters of the stars in the galaxy. The dim red orbs are small, so a transiting planet blocks a relatively large fraction of the star's light, making transits easier to detect. Habitable worlds also transit more frequently. To sustain liquid water, a planet must huddle close to one of these cool stars to stay warm. An orbit in the habitable zone of an M dwarf is much shorter than a comparable trip around the sun. Rather than wait for a year between transits, astronomers might have to wait for only a few weeks or months. Plus, a planet on a cozy orbit is more forgiving when it comes to getting the viewing geometry just right to see a transit.

> "There's no reason why a planet around an M star couldn't be like Earth."
>
> LISA KALTENEGGER

There are potential downsides to M dwarfs. Most of the light they radiate is infrared, so photosynthesis on orbiting planets would be very different compared with photosynthesis on Earth. There's no guarantee that biosignatures from vegetation that thrives on infrared light would look anything like those from local varieties. Many M dwarfs also emit occasional blasts of ultraviolet radiation — blasts made even more dangerous because any habitable planet sits close to the star. Habitable worlds need to be so close, in fact, that the star's gravity might prevent the planet from rotating, which could give rise to extreme climate differences between day and night. Recent research, though, indicates that none of these issues are necessarily deal breakers (*SN: 2/7/15, p. 7*). "There's no reason why a planet around an M star couldn't be like Earth," says Lisa Kaltenegger, an astrophysicist at Cornell.

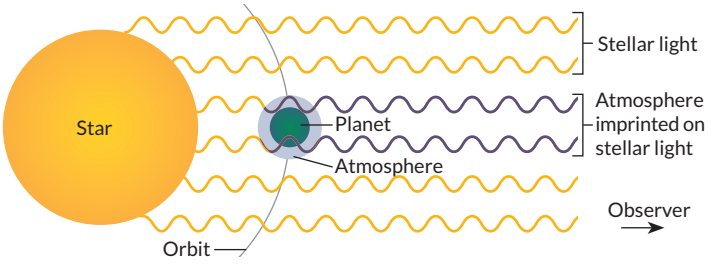
James Webb should be able to poke around in the atmospheres of a few habitable super-Earths around M dwarfs, though it's going to need some targets first (*SN: 5/17/14, p. 6*). NASA's premier planet hunter, the Kepler space telescope, (*SN: 12/27/14, p. 20*) found 1,039 exoplanets during its four-year primary mission, with 4,706 additional candidates awaiting confirmation. But most of Kepler's finds are too distant for James Webb. That's where TESS comes in. It will catalog all the short-period transiting worlds around the sun's nearest neighbors. "Those are the ones that astronomers even decades from now are going to want to focus on," says George Ricker, an MIT astrophysicist and principal investigator for the TESS mission.

Unlike Kepler, which gazed in one direction at 150,000 stars, TESS will spend two years monitoring 200,000 stars all around the sky. To cover that much ground, TESS will stare at one spot for about 27 days before moving onto a new patch. That's not great for finding Earth twins on year-long orbits, but it's good for finding worlds in the habitable zones of M dwarfs.

Based on Kepler's results, astrophysicist Peter Sullivan, then at MIT, and colleagues calculated in 2015 that TESS should discover about 1,700 exoplanets. Of these, more than 500 could be less than twice the size of Earth, of which about 50 would lie in the habitable zones of their host stars. But picking biosignatures, or any signatures, out of those atmospheres is going to be difficult. Estimates vary, but James Webb will need roughly 200 hours to study one super-Earth around a nearby M dwarf, and those hours count only when the planet is passing in front of its star.

There's a debate happening right now over how hard to chase that dream, Caltech's Knutson says. Given its sluggish pace, James Webb might get to look at only a couple of habitable super-Earths. Astronomers could lavish large amounts of time on one or two systems that might not even pan out. Or they could focus telescope resources on Neptunes, Jupiters or hot super-Earths, where researchers can amass a lot of other data about a wide variety of worlds. While James Webb might get lucky and spy some biosignatures, the dream of finding another planet like Earth will probably have to wait a few decades for a larger observatory to come along.

Searching in starlight The atmosphere of a planet in another solar system can leave a chemical fingerprint on the light from its sun, which might reveal hints of alien biological activity.

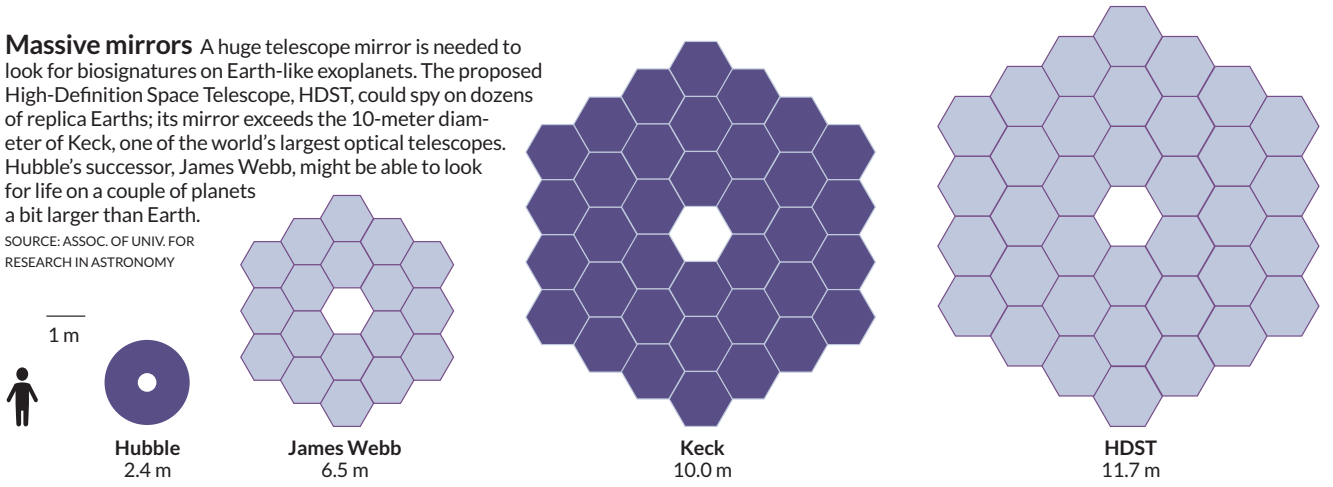


E. OTWELL

Snapping a pic

The transit technique is powerful but inefficient. From our vantage point, most planets don't transit their suns, and those that do transit only once every orbit.

"To really give us the best probability of detecting life, we need to build a telescope that can do direct detection," Rugheimer says. Direct detection requires snapping a picture of an exoplanet and looking for biosignatures such as oxygen and methane imprinted on light reflecting off its surface. Since this technique doesn't require alignments between planets

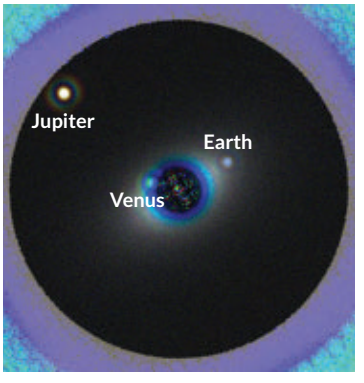


Massive mirrors A huge telescope mirror is needed to look for biosignatures on Earth-like exoplanets. The proposed High-Definition Space Telescope, HDST, could spy on dozens of replica Earths; its mirror exceeds the 10-meter diameter of Keck, one of the world's largest optical telescopes. Hubble's successor, James Webb, might be able to look for life on a couple of planets a bit larger than Earth.
SOURCE: ASSOC. OF UNIV. FOR RESEARCH IN ASTRONOMY

and suns, it can, in principle, work for any world around any star. But to catch an Earth 2.0, astronomers are going to need a bigger telescope.

Consider again those aliens who are looking for us. They would struggle to see Earth even if they set up camp 4.2 light-years away at the star next door, Proxima Centauri (an M dwarf, by the way). It's like trying to see the head of a quilting pin 28 meters to the right of a basketball while standing about 7,500 kilometers away — roughly the distance from Honolulu to Pittsburgh. And the basketball is 10 billion times as bright as the pin.

No observatories come close to being able to capture an image of an Earth-like planet around a sunlike star. But astronomers are thinking about what it would take. One idea is to put a gigantic mirror in space equipped with a device that can block the light of the star, such as the High-Definition Space Telescope proposed by the Association of Universities for Research in Astronomy. To see a few dozen Earth twins and characterize their atmospheres, that telescope would need a mirror 12 meters across. That's bigger than any optical telescope currently on the ground and has 25 times the light-collecting area of Hubble.



The High-Definition Space Telescope wouldn't need transits to detect biosignatures in an exoplanet atmosphere (simulation shows what our system would look like 44 light-years away).

Such an observatory "would be a huge undertaking relative to what we've done in space before," Lunine says. "But relative to other programs this country has undertaken, it's not."

One of the keys to success with the high-definition telescope is a coronagraph, a disk that blocks the light from any star the telescope points at. Many telescopes already use coronagraphs, especially spacecraft designed to look at the sun. James Webb will be outfitted with a coronagraph, though not one designed to search for other Earths.

The downside to a coronagraph is that it requires exceptional control of light that enters the telescope, which complicates the design. Other proposals to detect Earth-like planets, such as the NASA-commissioned Exo-S concept, use a starshade, a separate spacecraft shaped, appropriately, like the petals of a sunflower. The starshade flies tens of thousands of kilometers away from the telescope and maintains perfect alignment to prevent starlight from hitting the mirror (*SN: 7/12/14, p. 11*).

Since a starshade is free-floating and does all the light-suppression work, it should be able to partner up with any telescope, even a relatively small one already in use. But no one has attempted formation flying in space at this scale. And every time astronomers want to look at a new star, the starshade would have to move around the telescope to maintain alignment, which could take days or weeks. All that movement will require fuel, which limits how many stars astronomers can search.

Today these missions and others like them exist only in papers and PowerPoint slides posted online. The concepts, the fruits of a community-wide brainstorming session on how to allocate funding in the 2030s and beyond, will require massive financial and logistical resources, but some astronomers think it will be worth it once TESS and James Webb can point to where the nearest habitable locales might be. "Once we know where the potential habitable worlds are in our sky, I hope that will change a lot of people's curiosity," Kaltenegger says. "I would want to know if there are other habitable worlds. I wouldn't want to just guess."

Everyone agrees that finding a world teeming with life elsewhere in the galaxy is going to be exceptionally difficult. "Maybe nature needs to be on our side," says Mark Clampin, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Md. "But it won't stop people from trying very hard. And we'll probably make a lot of discoveries along the way." ■

Explore more

- Julianne Dalcanton *et al.* "From cosmic birth to living Earths: the future of UVOIR space astronomy." arXiv:1507.04779. July 28, 2015.

FROM TOP: E. OTWELL; L. PUEYO, M. N'DIAYE/STSCI

Where to look? The hunt for extraterrestrial life has long focused on planets at a just-right distance from alien stars, where liquid water can exist on a planet's surface.

THINKING OUTSIDE THE GOLDILOCKS ZONE

Earth scientists reimagine the sweet spot for habitable planets

By Thomas Sumner

Just how fantastical a planet can be and still support recognizable life isn't just a question for science fiction. Astronomers are searching the stars for otherworldly inhabitants, and they need a road map. Which planets are most likely to harbor life? That's where geoscientists' imaginations come in. Applying their knowledge of how our world works and what allows life to flourish, they are envisioning what kind of other planetary configurations could sustain thriving biospheres.

You don't necessarily need an Earth-like planet to support Earth-like life, new research suggests. For decades, thinking about the best way to search for extraterrestrials has centered on a "Goldilocks" zone where temperatures are "just right" for liquid water, a key ingredient for life, to wet the surface of an Earth doppelgänger. But now it's time to think outside the Goldilocks zone, some scientists say. Unearthly mechanisms could keep greenhouse gas levels in check and warm planets in the coldest outer reaches of a solar system. Life itself could even play a starring role in a planet's enduring habitability.

"It's an exciting time," says Harvard planetary scientist Robin Wordsworth. "There's still a ton for us to learn about the way different planets behave. The Goldilocks zone is just a very rough guide, and we need to keep an open mind."

Currency of life

When it comes to habitable planets, water continues to be the currency of life. Too close to a star and all the water on a planet evaporates; too far and the planet is an icy snowball. The Goldilocks zone marks the region between those two extremes, where water can stay liquid. Every known organism requires liquid water at some point during its life cycle. Extraterrestrial life could be completely unlike anything seen on Earth, of course, but "we've got to start looking somewhere," says Colin

NICOLLE RAGER FULLER

Goldblatt, a planetary scientist at the University of Victoria in Canada. "At least we know what Earth life looks like."

With the assumption that water is king, astronomers search for wet planets using powerful telescopes (see Page 32). The search is limited by what the telescopes can see in a planet's atmosphere, however. Life-supporting liquid water could hide under the surface, for example, inside Jupiter's icy moon Europa (*SN: 10/4/14, p. 10*). And any subterranean life, which typically wouldn't alter the atmosphere, would probably be undetectable. Even with rovers roaming Mars, scientists can't tell for certain whether Martian groundwater hosts life (*SN: 12/26/15, p. 26*). For alien life to be observable from afar, liquid water would have to be at the surface, not just concealed belowground.

With liquid surface water as a must-have for hunting extraterrestrials, astronomers estimated the extent of the habitable region more than 50 years ago. Early research confined the Goldilocks zone for our own solar system to a narrow band — one estimate placed it from 0.95 times to 1.01 times Earth's average distance from the sun. But then scientists realized the surprising influence of Earth's built-in temperature control system: the carbon cycle, the process by which carbon travels from the atmosphere into the Earth and back out to the atmosphere.

The carbon cycle controls how much heat-trapping carbon dioxide is in the atmosphere. Rainfall weathers exposed rocks, causing a chemical reaction that pulls CO_2 from the air and into the oceans and eventually underground via plate tectonics. Volcanoes, meanwhile, spew CO_2 into the atmosphere. This cycle keeps the planet's temperatures from getting too extreme.

If the climate ever gets too cold, the carbon cycle could boost CO_2 to compensate. For instance, if temperatures drop and rainfall slows, the lack of weathering will allow CO_2 to build up in the atmosphere. And as volcanoes continue belching up additional CO_2, temperatures will rise and rainfall will rise. And if things get so hot that glaciers melt and rainfall increases, the planet will cool as weathering accelerates and draws down more CO_2 from the atmosphere. Plants and other organisms also play roles in drawing in CO_2 or releasing it into the air.

This balancing act could help keep planets within a comfortable range for life, expanding the habitable zone to as wide as 0.5 to 2.0 times Earth's distance from the sun, though these numbers are hotly contested. Thanks to the carbon cycle, Earth might still be habitable even if pushed out to Mars' orbit, says Penn State geoscientist James Kasting.

Rocky recycling

Not every planet tucked safely inside the habitable zone is necessarily life-friendly. Venus and Mars are within the habitable zone by some definitions, but neither boasts a livable surface climate. More than location is at play. Other factors such as plate tectonics may make a planet right or wrong for life. Plate tectonics is an important piece in the temperature-controlling carbon cycle, as the shifting and sinking plates that cover Earth's surface carry carbon into Earth's interior that later erupts from volcanoes. Some scientists propose that planets akin to Venus and Mars that lack the conditions for plate tectonics should be crossed off the "explore list" (*SN: 1/23/16, p. 8*).

Lindy Elkins-Tanton, a planetary scientist at Arizona State University in Tempe, disagrees. On exoplanets, other processes could do the job of plate tectonics, she said last December at an American Geophysical Union meeting in San Francisco. "We're too Earth-centric in our notion of how you can create a planetary carbon cycle," she says. "What else can we consider?"

One alternative could be the churning of a planet's outer layers in a way that doesn't require giant shifting slabs. The deepest part of a terrestrial planet's outermost shell becomes denser as pressures increase with depth. Rising molten rock from the planet's hot interior can also add density and heat to the bottom of the shell, making the rock runnier and denser. Even just a 1 percent density change could produce globs of material dense enough to sink deeper into the planet, carrying carbon along for the ride, Elkins-Tanton proposes.

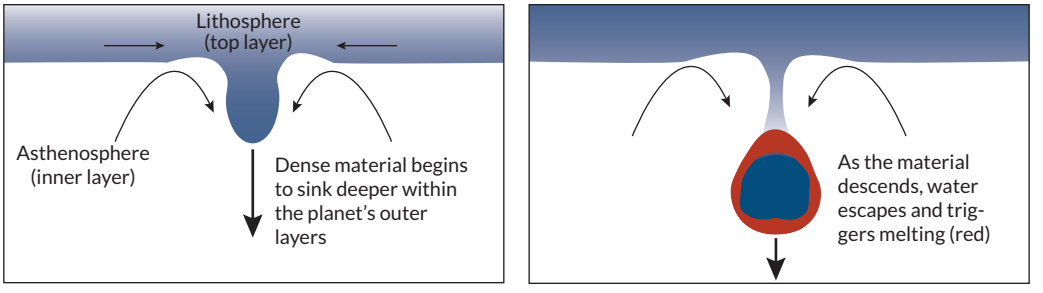
As the material sinks, it releases some water like a squeezed sponge. This carbon-containing water then seeps back toward the surface. Water loosens the bonds that hold rocks together, which lowers a rock's melting point. If enough water accumulates, molten magma pools form and fuel volcanic eruptions. Together, these mechanisms could substitute for plate tectonics in the carbon cycle, Elkins-Tanton says. True, the process would be much slower than plate tectonics, but it could keep some planets' climates livable, her simulations show.

Hot air

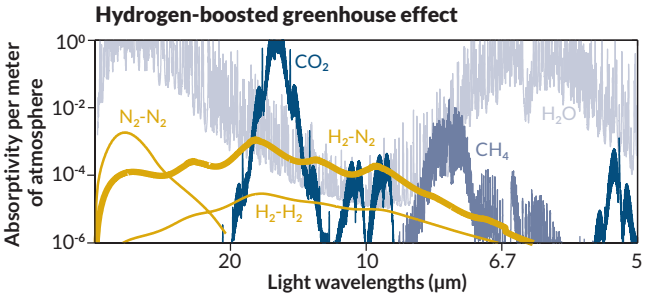
Of course, the carbon cycle matters only if CO_2 is the main driver of the atmospheric blanket that keeps a planet cozy enough for life-sustaining liquid water. Plenty of other greenhouse gases, such as ozone or nitrous oxide, could keep exoplanets temperate. One, however, would be particularly potent: hydrogen.

Drop the base

Geologic forces can churn a planet's outer layers without plate tectonics, research suggests. Density changes can cause large drops of carbon-carrying material to fall deeper into a planet's interior, releasing water that fuels volcanism, sending carbon back into the planet's atmosphere.



L. ELKINS-TANTON/ARIZONA STATE UNIV.



Hot hydrogen Collisions between hydrogen and nitrogen molecules in early Earth's atmosphere could have allowed hydrogen molecules to absorb a wider variety of light wavelengths (H_2-N_2). This effect would curb the amount of heat lost, warming the planet, new research suggests.

Earth used to have a lot more hydrogen in its atmosphere. In 2013, Wordsworth and planetary scientist Raymond Pierrehumbert, now at the University of Oxford, proposed that hydrogen could have kept Earth warm back when the sun was cool. They were attempting to resolve the faint young sun paradox (*SN: 5/4/13, p. 30*).

Early in Earth's history, about 3.8 billion years ago, the sun shined 20 to 30 percent less brightly than it does now. Keeping the young planet warm posed a problem. Wordsworth and Pierrehumbert proposed that hydrogen, when combined with abundant nitrogen in the atmosphere, could serve as a paradox-resolving greenhouse gas. When hydrogen and nitrogen molecules collide in the air, the hydrogen molecules start wobbling differently. This wobbling increases the range of light wavelengths that hydrogen molecules absorb, amplifying the greenhouse effect. Hydrogen escaped from Earth's atmosphere over time. But on larger rocky planets with stronger gravitational pulls, that hydrogen would stick around, Wordsworth says.

With enough hydrogen and nitrogen, a planet can keep warm far outside of the CO_2-based Goldilocks zone, Wordsworth says. Planets as far away from their sun as Pluto is to ours could stay above freezing. Even rogue planets alone in the cosmos with no parent star might keep warm enough to support life (*SN: 4/4/15, p. 22*).

The problem, however, is that these planets would need something akin to a carbon cycle to fine-tune hydrogen concentrations and prevent temperatures from getting too hot or too cold. Worse yet, at least on Earth, enterprising microbes feast on any available hydrogen for energy. Emerging lifeforms could gorge on an exoplanet's hydrogen, essentially eating the very thing keeping the planet warm enough for life. Those planets therefore might not stay habitable long enough for advanced life to evolve, Wordsworth says.

The inhabitance paradox

The hungry microbes might actually be good for hydrogen-wrapped planets, planetary scientist Dorian Abbot of the University of Chicago proposed at the AGU meeting in December. Higher temperatures make enzymes work faster and microbes more active. If temperatures rose, the hydrogen-chomping microbes would draw more hydrogen from the atmosphere and cool the planet. And if temperatures fell too far, microbe activity would fall and hydrogen levels would stabilize.

The ability of life, like those microbes, to fundamentally alter the climate and chemistry of its home planet poses a new paradox, Goldblatt said at the same meeting. Whether or not a planet is habitable could sometimes depend on whether life has already made itself at home there. He calls it the inhabitance paradox; the idea is an extension of the Gaia hypothesis, the proposal that organisms alter their surroundings to maintain a habitable environment. In other words, life could be a requirement for life.

The paradox showcases just how complex the hunt for habitable planets has become, Goldblatt says. "There are many other ways to support life — we just don't know what they are yet," he says. "Our imagination is limited to our experience. We're going to observe other planets and see things we never have imagined." ■

Swing shifts

The Goldilocks zone marks the boundary where planets can exist without permanently slipping into a frigid or scorching wasteland. But even in the zone, extreme temperatures can happen, Kristen Menou proposed last year in *Earth and Planetary Science Letters*. While some scientists say life could exist outside the habitable zone, he thinks the habitable zone itself isn't entirely life-friendly.

Menou, an astrophysicist at the University of Toronto, ran climate simulations mimicking the conditions on hypothetical exoplanets just within the outer edge of the habitable zone. The planets receiving slightly less solar heat than Earth were vulnerable to extreme climate swings. Within tens of millions of years, these planets can cycle between frigid temperatures as low as around −63° Celsius and blistering heat of about 57° C. While such worlds briefly host liquid surface water, they spend as much as 99.2 percent of their time frozen. Unstable planets start appearing farther than about 1.25 times Earth's distance from the sun, the simulations show.

These capricious planets could eventually stabilize to have a habitable climate, but only if advanced plant life emerges first, Menou says. Plants boost the carbon cycle by absorbing and releasing CO_2, a process that helps regulate temperatures. Unfortunately, swinging climates would be inhospitable for the long-term evolution required to develop advanced plants, Menou says. "For complex life, these planets would look very threatening." Plants may never evolve, making the planets unlikely candidates for complex life. — *Thomas Sumner*

Explore more

■ Lindy Elkins-Tanton. "What makes a habitable planet?" *Eos*. April 16, 2013.

R. WORDSWORTH AND R. PIERREHUMBERT/*SCIENCE* 2013

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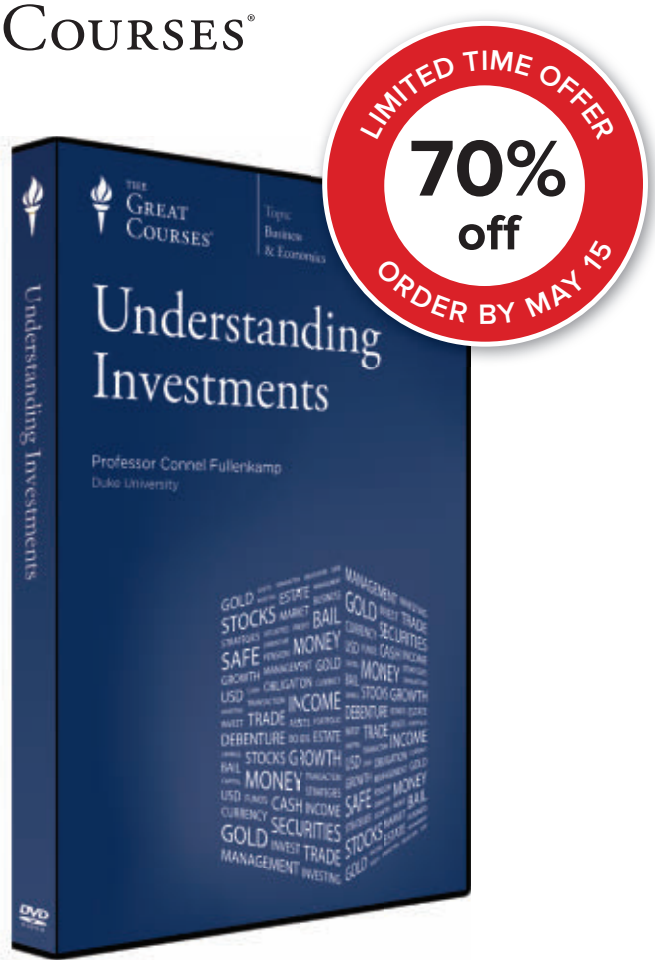

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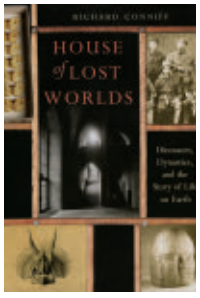

House of Lost Worlds
Richard Conniff
YALE UNIV., $35

BOOKSHELF

Renowned museum repeatedly changed views of Earth's past

A century and a half ago, a young paleontologist named Othniel Charles Marsh persuaded his uncle, philanthropist George Peabody, to give Yale University $150,000 for a museum of natural history. And so Yale's Peabody Museum was born, an institution that has repeatedly upended how people understand Earth's past. In *House of Lost Worlds*, Richard Conniff tells the story of the Peabody through the curious characters connected to it.

Marsh is arguably the best known, for his fossil-collecting rivalry with Edward Drinker Cope (the infamous Bone Wars) and as the discoverer (or describer) of *Stegosaurus*, *Brontosaurus, Triceratops* and *Allosaurus*, to name a few. Other characters include James Dwight Dana, who Conniff calls "the Linnaeus of the geological world"; G. Evelyn Hutchinson, the father of modern ecology; and Hiram Bingham III, who brought Machu Picchu to public attention in the 1910s (and is thought, by some, to have been the inspiration for Indiana Jones). The book is celebration, not exposé, but Conniff still conveys the researchers' full personalities, including their competitive natures, along with academic squabbling.

Squeezed in throughout is the story of the building itself — perpetually undersized and often underappreciated — yet, as Conniff seems to remind us, the place where the soul of the science resides. As Hutchinson said, the museum "began to play a great part in my life as soon as I stepped into it."

Conniff doesn't go so far as to suggest that the museum makes the man (and, through no fault of Conniff's, most of the leading characters are men). But he views the Peabody as a rich repository of knowledge. Its walls enclose over 150 years of insights built on discoveries built on insights, ad infinitum. Without the artifacts brought back from Machu Picchu (later returned to Peru after a bitter battle), anthropologists wouldn't have redefined the site as an estate for Incan emperors. It was Marsh's studies of dinosaurs, and horses, that positioned the Peabody to teach evolution when others were attacking it. And the first reconstruction of a feathered dinosaur's colors (*SN: 2/27/10, p. 9*) depended on a fossilized squid left mostly unnoticed in the Peabody for over a century.

Throughout the book, Conniff emphasizes the discoveries yet to be made and the pleasure of finding out something new. "Please," he invites readers, "step inside." — *Elizabeth Quill*

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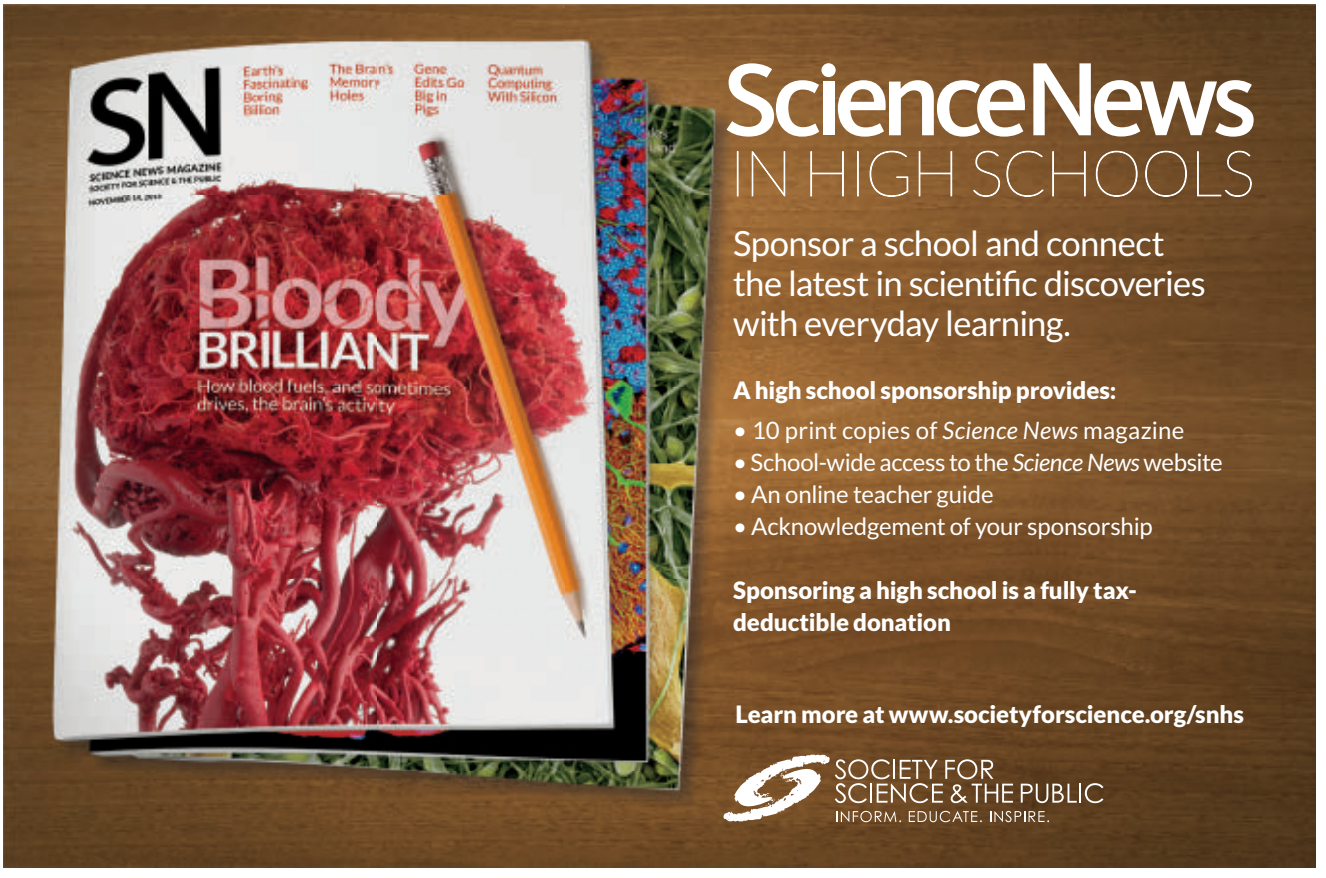

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Reported by J. Page

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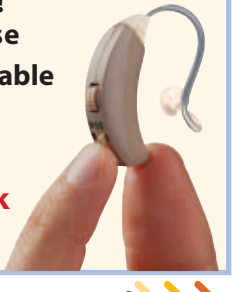

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When smartphones go to school

Almost three-quarters of U.S. teens use smartphones. Some 90 percent of those send texts—typically 30 per day. Many teens also browse the Internet on their mobile devices. This can be a distraction. But not always, new data show. When used in class to do research that's "on task," cellphones can actually improve a teen's performance. Attending to social media, texting and other distractions, however, can harm performance, other research shows. The challenge, such studies find, is to avoid using smartphones for tasks that conflict with schoolwork. — *Kathiann Kowalski*

Read more: **student.societyforscience.org/smartphone-teen**

Making ultradiamonds

Scientists suspected that if a meteorite smashed into Earth hard enough (as one did to make the crater pictured, right), it could change a type of soft, pure carbon into lonsdaleite, a mineral harder than diamond. Now, scientists have confirmed that this can happen. And they didn't have to dodge an incoming space rock to do it. They used a high-energy laser. Its beam slamming into graphite created pressures close to 2 million times those typical on Earth's surface. The resulting "ultradiamond" can, if found on Earth's surface, point to really violent blasts in the past. — *Beth Geiger*

Read more: **student.societyforscience.org/diamonds**

Dirty air may pose obesity risk

Air pollution is bad for our lungs. It may not be great for our waistlines either, concludes a new study. On really bad days, the air in China's capital city of Beijing (shown at left) can host more than 10 times as many tiny pollutant particles as the World Health Organization says people should be allowed to breathe. Rats exposed to this unfiltered Beijing air gained more weight, and were unhealthier overall, than were rats allowed to breathe cleaner air typical of U.S. cities. And, one scientist adds: "It is highly likely that this is happening in humans." — *Ashley Yeager*

Read more: **student.societyforscience.org/pollution-obesity**

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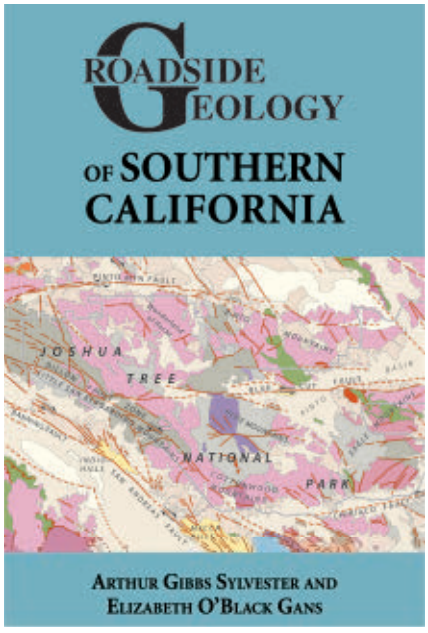

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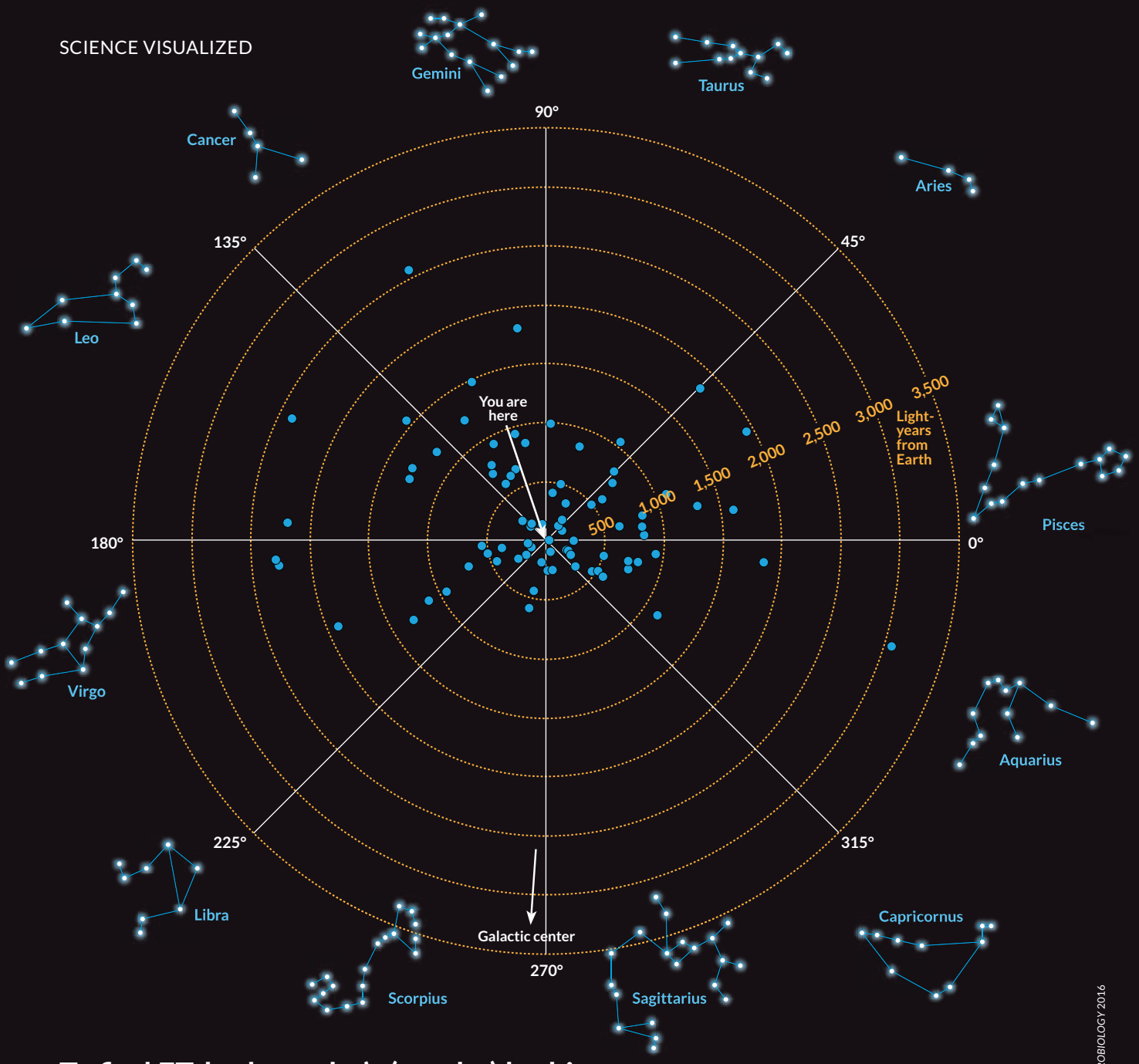

To find ET, look at who's (maybe) looking at us

As Earth whips around the sun, it casts a shadow into the galaxy. If that shadow passes over cosmic neighbors that host reasonably intelligent aliens, they would see Earth the same way NASA's Kepler space telescope sees some of them: as a periodic dip in the light from our sun. If we want to listen for alien radio broadcasts, those are the parts of the sky we should tune into, argue astronomers René Heller of the Max Planck Institute for Solar System Research in Göttingen, Germany, and Ralph Pudritz of McMaster University in Hamilton, Canada.

Within 3,500 light-years of Earth, there are 82 known stars that might host curious extraterrestrials who could detect Earth's shadow, the researchers report in the April *Astrobiology*. The stars, roughly similar to or a bit cooler than the sun, encircle the solar system in nearly the same plane as Earth's orbit — a narrow band that's home to the 12 zodiac constellations. And these are just the stars that astronomers know about. Heller and Pudritz calculate that there could be 300,000 stars hosting 30,000 rocky habitable worlds in this sliver of the galaxy.

Since there's a chance that the inhabitants of those worlds know about us, they might already be trying to get in touch, the researchers suggest. Even if we have no interest in an interstellar palaver, they say, we can't hide from aliens that might see Earth silhouetted against the sun.

— *Christopher Crockett*

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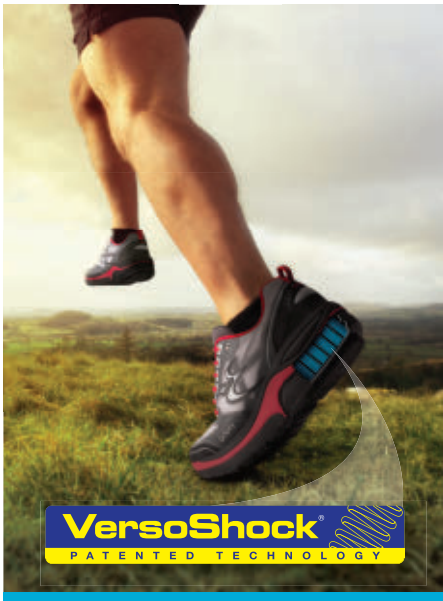

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