ScienceNews
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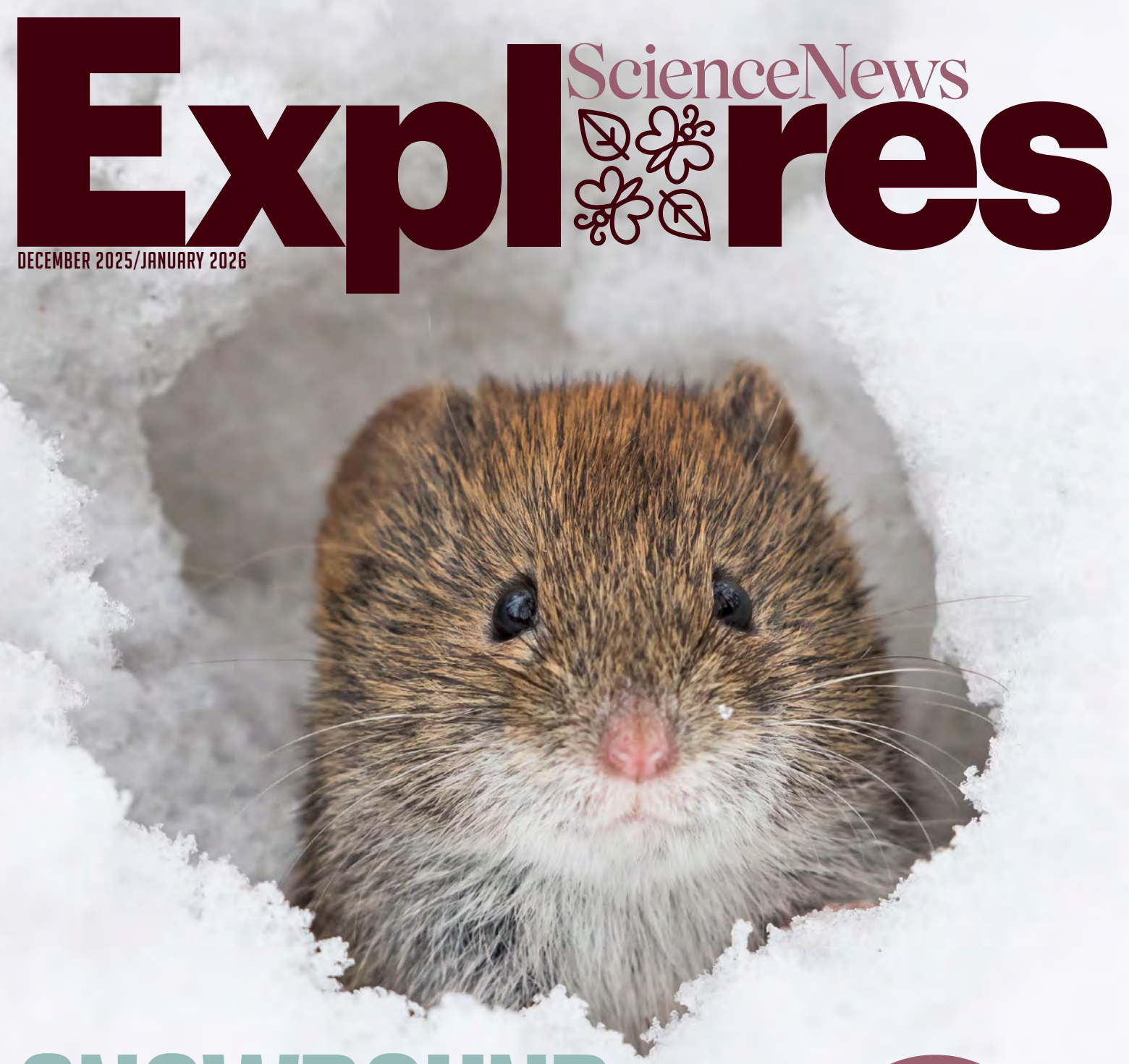

SNOWBOUND

There's life beneath the snow – but it's at risk of melting away

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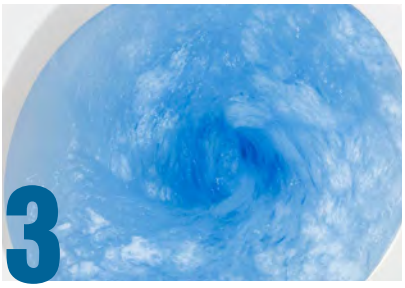
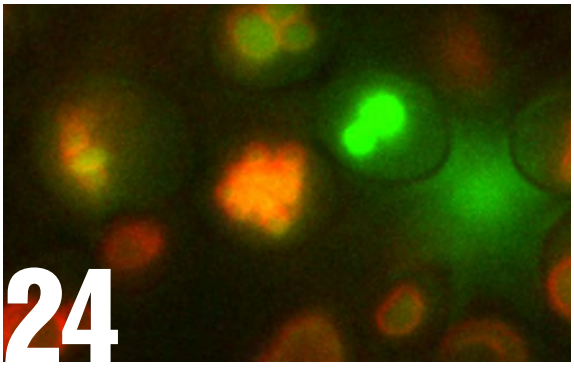
AEROSOLS FLY THROUGH THE SKY | FICTIONAL LANGUAGES, REAL COMMUNICATION | CLEANING UP 'FOREVER CHEMICALS'





RETOUCH MAN, NICHOLAS TAFFS/SHUTTERSTOCK

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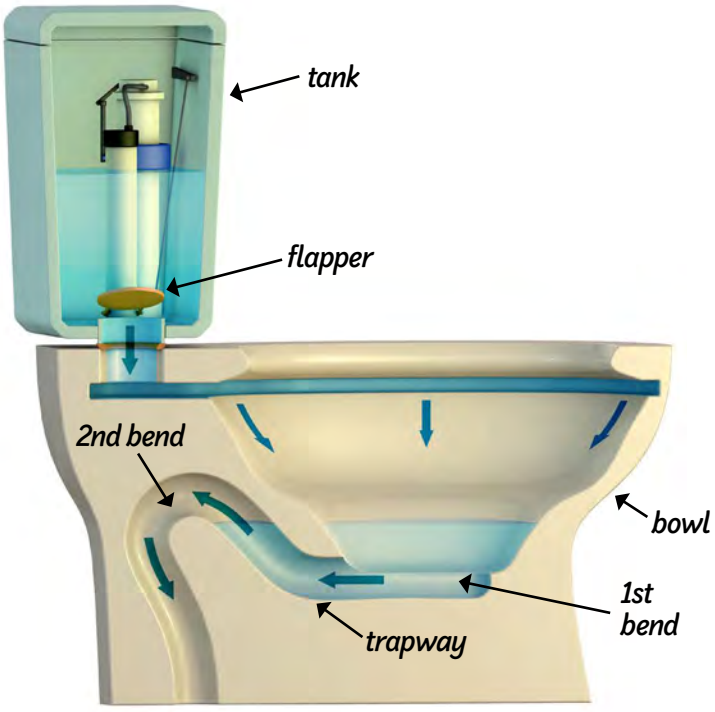
Q How does my toilet work?

— Faith Y.

A A flushable toilet uses gravity and suction to eliminate waste. The hole at the bottom of the bowl leads into an S-shaped pipe called a trapway. When the toilet is not in use, water covers just the first bend in the trapway. This stops smelly sewer gases from drifting up through the toilet and out into your bathroom. When you flush the toilet, the handle yanks up a rubber flapper in the tank. This allows fresh water to flow down into the bowl. As the bowl fills, gravity forces flushed water down the hole and over the trapway's second curve. Water rushing over that curve creates suction that pulls waste down and out of the toilet, toward the sewer or septic tank. As this water passes through, air enters the trapway and stops the suction. After flushing, the flapper closes, allowing the tank to refill with fresh water. A separate tube refills the bowl.



Q How many real and computer languages are there?

— Nicolette N.

A It can be difficult to draw the line between separate languages. "People in different regions speak the [same] language a little differently, and people in different social and ethnic groups often do as well," says Laura Wagner. She's a language scientist at the Ohio State University in Columbus. But scientists estimate that people around the world use more than 7,000 distinct languages today. The 20 most common are spoken by more than 3.7 billion people. Thousands of others are at risk of dying out. Computer programming languages now outnumber spoken languages. At least 8,000 — and maybe as many as 10,000 — have been developed. "It really depends on what one considers to be a computer language," says Martin Erwig. He's a computer scientist at Oregon State University in Corvallis. Some computer languages are used by programmers. Others describe the exchange of data, help teach computer science or are made up just for fun. Plus, new computer languages are created all the time. So it's difficult to keep track of the number.

Q Why can't we see UV light?

— Jason L.

A High-energy ultraviolet, or UV, light can damage cells. UV rays in sunlight, for example, cause sunburns. UV radiation can also damage the light-sensitive photoreceptor cells in our eyes that allow us to see, says Nathaniel Dominy. He's an evolutionary biologist at Dartmouth College in Hanover, N.H., who studies color vision in mammals. The outer parts of the eye that bend and focus incoming light — the lens and cornea — shield our photoreceptors from UV rays, Dominy says. "The cornea and lens are packed with invisible molecules to absorb this damaging light, acting a lot like natural sunscreen." But other animals have evolved to see UV light. Their UV vision lets them spot food, threats or potential mates. One example is reindeer. Scientists think their eyes have evolved to let in UV light because it helps them spot tasty plants or avoid predators during dark Arctic winters.

ANDREA DANTI/SHUTTERSTOCK

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Reach out to us on Instagram (@SN.explores), or email us at explores@sciencenews.org.

HEALTH

TikTok skincare routines may cause more harm than good

All most kids and teens need is sunscreen and a gentle cleanser

Skincare videos on TikTok can be a fun way for kids and teens to express themselves. But many of the routines shown might be more harmful than helpful, a study in the journal *Pediatrics* shows.

Most of these regimens are costly and lack sunscreen. Many have irritating ingredients and may damage young skin.

Pediatricians and dermatologists are worried about what these videos offer young people: possibly harmful skincare advice, wrapped up with unrealistic and unhealthy beauty standards.

Health care researcher Tara Lagu became interested in this topic when her 11-year-old niece asked for expensive skincare products for Christmas. Shocked, Lagu talked to Molly Hales. Hales is a dermatologist at Northwestern Medicine in Chicago, Ill. She jumped at the chance to explore this skincare trend.

Hales and a colleague made TikTok accounts saying they were 13 years old. They scrolled through the "For You" page until they had seen 100 skincare routine videos.

Based on appearance and context clues ("Get ready with me for the first day of sixth grade"), the creators were mostly tweens and teens. They used an average of six products with a total cost of $168.

More than half of the products had fragrance, which often causes allergic reactions. The 25 most-viewed videos had an average of 11 potentially irritating active ingredients. These can cause itching, burning or prickling sensations.

The most common of these ingredients were alpha-hydroxy acids. These chemicals exfoliate skin, removing surface layers. They're common in anti-aging products and in some products to prevent acne. But they can irritate and damage young skin.

Alpha-hydroxy acids also make skin more sun-sensitive. But on average, only 26 percent of the videos included any type of sun protection. That boosts the risk of sunburn and other sun damage.

Though not part of the study, Michigan pediatrician Molly O'Shea was distressed by the findings. "When you're young, using products that are designed for older skin can actually damage your skin," she says.

These videos could also pose a risk of negative mental health outcomes for kids and teens, Hales notes.

The videos place high importance on physical appearance. And the products seemed to be used as status symbols, says Hales. "That may make someone feel bad if they don't have the money or they're not in a position to be able to afford that kind of skincare routine."

For pre-adolescents who don't have any known skin condition, Hales recommends just one product: a daily sunscreen. If the skin

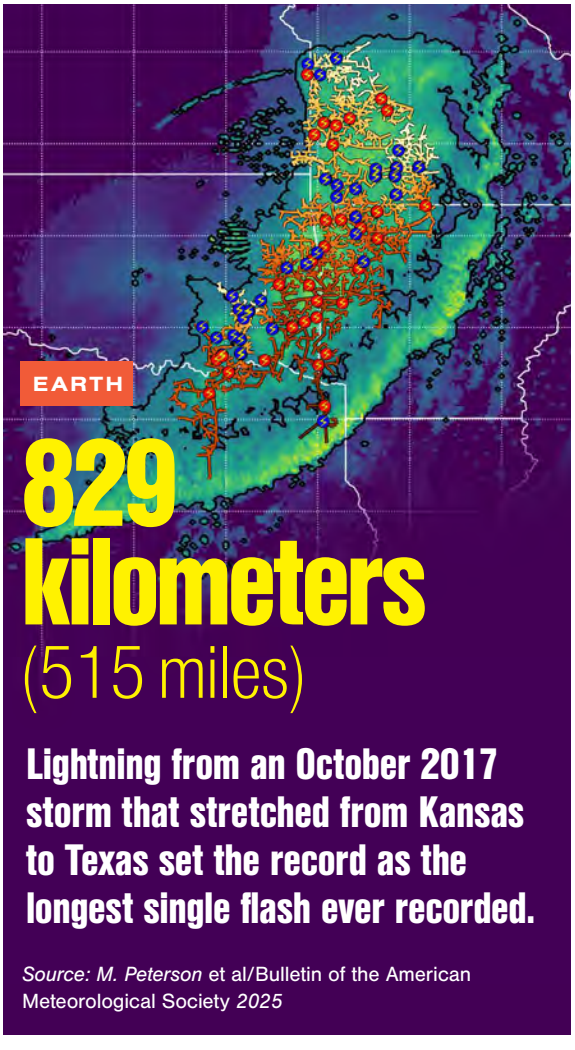
MIKIMAD/E+/GETTY IMAGES PLUS

becomes oilier during adolescence, add a gentle cleanser once or twice a day.

For teens struggling with acne, some over-the-counter products can be helpful, she notes. But it's important to choose products that target the right problem. At that point, she advises teens to talk to their doctor or a dermatologist.

There's no harm in using safe products from time to time because it feels luxurious or you enjoy it, she says. But know that you don't need elaborate skincare routines to take care of your skin. "In most cases," she says, "those products are probably making the skin less healthy, rather than more healthy."

— ANDREA TAMAYO



EARTH

829 kilometers (515 miles)

Lightning from an October 2017 storm that stretched from Kansas to Texas set the record as the longest single flash ever recorded.

Source: M. Peterson et al/Bulletin of the American Meteorological Society *2025*

MICHAEL PETERSON/GTRI; ESA, NASA & AKIRA FUJII

SPACE

A rogue black hole is on the loose in our galaxy

It's not a danger to Earth

Stargazers can identify the constellation Sagittarius by the eight bright stars that form a teapot configuration (as seen at the bottom of this image). Thousands of light-years beyond these stars lurks the first lone black hole ever confirmed.

For the first time, astronomers have confirmed the existence of a lone black hole. This rogue is wandering around our Milky Way galaxy with no companion star.

It's "the only [loner] so far," says Kailash Sahu. He's an astronomer at the Space Telescope Science Institute in Baltimore, Md.

In 2022, Sahu's team found the dark object moving through the constellation Sagittarius. At the time, this discovery made headlines. Until then, all known black holes had a companion star. Those companions had pointed to the presence of the black holes, which can't be seen because they emit no light.

New observations now confirm the rogue object is about seven times as massive as the sun. That's so massive that the dark object must be a black hole, Sahu's group reasoned.

Its original discovery relied on measurements of star positions from the Hubble Space Telescope from 2011 to 2017. The new study adds in Hubble data from 2021 and 2022 and data from the European Space Agency's Gaia spacecraft.

Solitary black holes should be common. But since they don't normally affect visible stars, they're hard to find. The rogue revealed itself only because it passed in front of a dim background star. During that passage in July 2011, the black hole's intense gravity magnified the star's light through what's known as gravitational lensing.

Located 5,000 light-years from Earth, the rogue is much closer than the supermassive black hole at our Milky Way's center. That black hole also lies in Sagittarius but is more than five times farther from us.

— KEN CROSWELL

ANIMALS

Young capuchins are kidnapping baby howler monkeys

It's very rare for primates to spend time with infants of another species

It's not clear why the capuchins took the baby howler monkeys. A few capuchins continued to carry the corpses around "like puppets or dolls," the researchers say.

A serious case of stranger danger has emerged on an island off the coast of Panama. A gang of five young capuchin monkeys on Jicarón Island has started abducting baby howler monkeys. This bizarre fad has no clear purpose. And it's often deadly for the kidnapped infants.

Capuchins "do such interesting, weird and quirky, and sometimes a little dark, things," says Brendan Barrett. These behaviors "can offer a dark window of reflection into stuff that we do."

Barrett studies how animal behavior evolves. He works at the Max Planck Institute of Animal Behavior in Konstanz, Germany. He is part of a team that described the disturbing findings in *Current Biology*.

The new baby-nabbing trend is an example of a nonhuman primate developing a tradition with no clear purpose.

Young male capuchins sometimes snag infants in their group. Baby capuchins are rarely harmed when members of their own species take them. Typically, the baby is returned when it gets hungry and starts calling for mom.

It's far less common for primates to spend time with infants of another species. So, it was surprising, Barrett says, when a member of his research group noticed a young white-faced capuchin (*Cebus capucinus imitator*) carrying a baby howler monkey (*Alouatta palliata coibensis*).

The team reviewed 18 months of footage of the Jicarón capuchins from cameras placed out in the wild. A young capuchin was seen in January 2022 carrying the first howler infant. Then, in September of that year, four more young male capuchins started carrying howler monkeys. In all, over 15 months, five male capuchins abducted 11 howler infants.

The kidnapped babies suffered. At least four died during the study period. Some were as young as a day or two old when they were nabbed. It was sometimes emotionally fraught to watch the tape, Barrett says. "You think you're going to be watching a horror movie."

It's not clear why male capuchins have been doing this. There's no evidence the males ate the babies, even after they died. Howlers and capuchins don't compete for the same food.

The Jicarón capuchins have no predators and might just be getting bored. Stealing infants might simply be "interesting and stimulating," Barrett says. "[I'm] wondering what else they're doing."

— *Freda Kreier*

NIKI HARRY/GETTY IMAGES; TYLER WENZEL/SHUTTERSTOCK

Think you know what you're seeing? Find out on page 32

Snowboa

ALBERT PEGO/SHUTTERSTOCK

Hard

There's life beneath the snow — but it's at risk of melting away

BY **BETHANY BROOKSHIRE**

A soft, thick coat of snow makes a lot of the world seem to slow down or even stop — at least temporarily. The fluffy piles absorb sound and make the world quiet and still.

But deep underneath, in pockets between the snow and the ground, life goes on. This is the subnivium — a tiny ecosystem all its own.

Here under the white stuff, small mammals, microbes, insects and even birds thrive. They use the subnivium to make the most of the winter months — hunting, breeding, breaking down leaves and more. All those cold-weather activities help determine which plants and animals thrive during the snow-free seasons.

But this seasonal ecosystem is in danger. Climate change is making winters warmer. Much of the precipitation that used to fall as snow now pours out of the sky as rain. Snow covers less ground and for less time. No snow means no subnivium. And as this snowy ecosystem shrinks, a host of organisms might pay the price.

Their loss could change the way forests function all year round. Scientists are working to understand what is going on below the snow and how it's responding to our warming world. To save the subnivium, not only should we fight climate change — we need to save the snow itself.

A NATURAL IGLOO

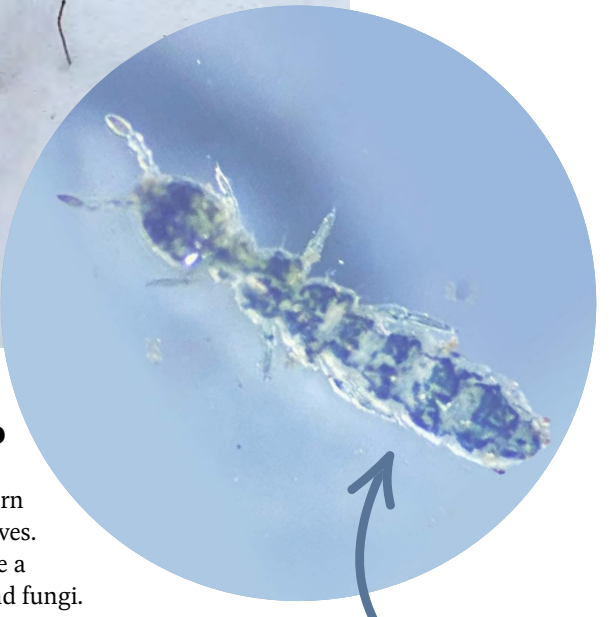
In places like the northern United States and Canada, snow doesn't always melt right away. It can stick around for days or weeks. As snow piles up, it forms a snowpack. Once that snowpack gets deep enough, a new ecosystem forms underneath.

"About 15 centimeters [or six inches of snow] is when you start to see the subnivium emerge," explains Jonathan Pauli. He studies community

A pine marten looks at a snow-measuring stick. American martens are one of many species that make use of the spaces underneath the snow — an ecosystem called the subnivium. Rove beetles (inset) are one of the species that is specially adapted for this ecosystem.

In winter, these fluffy, ferret-like predators slink in and out of the subnivium as they hunt their prey.

ALEXEJ SIREN



This tiny creature is a springtail, an arthropod that makes its winter home in the subnivium.

ecology — how members of an ecosystem interact — at the University of Wisconsin–Madison.

Snow doesn't fall in even layers. It drifts, heaping up around fallen trees or rocks. That leaves open spaces between the snow and the ground, just a few centimeters (about an inch). Those little pockets link up "like a maze," Pauli says, to form the subnivium.

Life beneath the snow is very different than at the surface. "Like a natural igloo," the thick snowpack insulates what lies beneath, Pauli says. Above the snow, the temperature might be −20° Celsius (−4° Fahrenheit). A few warm days might bring it up to 4 °C (40 °F). But beneath the snow, the ground is constantly just one degree above the freezing point of water — never lower, never higher.

That one degree makes all the difference, explains Alix Contosta. She's an ecosystem ecologist at the University of New Hampshire in Durham. "In general, you don't see a lot of activity below freezing, because most life needs liquid water," she says. But when the snow is deep enough, "it doesn't matter how cold the air is, the soil will remain above freezing."

That fact has changed the way scientists think about life in cold winter environments. When Contosta began her research, most believed "winter was a dormant season and there wasn't a whole lot happening," she says. But with soil warm enough for liquid water, life could go on.

THE SUBNIVEAL NEIGHBORHOOD

During autumn, many trees in northern regions lose their leaves. Those dead leaves are a buffet for bacteria and fungi. In the subnivium, they can munch away all winter, breaking down leaf litter or organic matter from the soil. By spring, when the snow disappears, those tiny organisms will have transformed a carpet of leaves into rich, fertile soil.

The tiny critters attract larger ones, including predators. Invertebrate predators include springtails, centipedes and beetles. They're exothermic. Their body temperature is the same as the environment around them. Above-freezing temps can allow them to stay active throughout winter.

"They're down there feeding, moving around, searching for mates, breeding," says Chris Ziadeh. He's an ecologist now at the U.S. Department of Agriculture in Dover, N.H.

Ziadeh and Contosta were part of a team that wanted to find out exactly which arthropods call the subnivium home. To do that, they set out pitfall traps. These cups are partially buried in the ground and capture whatever falls in. The researchers compared their subnivium catch to pitfall traps set in summer at the same sites.

Winter traps collected only one-sixth as many arthropods each day as summer ones. Some groups of arthropods went dormant in the winter. Others remained active. "It was predator-heavy in the subnivium relative to this summer," Ziadeh says. A few species, including a spider and several beetles, were mostly or only present in the winter. The scientists shared their findings in 2024 in *Environmental Entomology*.

Chris Ziadeh (above) lifts a pitfall trap out of the snow. The bright pink liquid contains a preservative to help scientists identify what arthropods landed in the trap. One common find is springtails (inset).

C. ZIADEH

Marmots, a type of ground squirrel, rely on the subnivium to keep their dens warm as the animals hibernate through the winter.

Those specialists could have an impact on the ecosystem all year, Ziadeh says. By munching on leaf litter, microbes and more, they put nutrients back into the soil. And dining on other, less active bugs, he says, "could keep down certain pest populations."

The hungry arthropods are themselves important prey for larger animals. Small mammals like voles and lemmings hide under the snow, making a meal of the arthropods there. And they, in turn, attract their own predators.

Pauli became interested in the subnivium while studying American martens. These fluffy, ferret-like predators are about the size of a housecat. "They're slinking in and out of that subnivium space," Pauli says. "They'll find an opening, and they'll kind of go down and disappear — and presumably hunt ... then pop up at another spot."

Even birds use the subnivium. Benjamin Zuckerberg spent a lot of time in New York's Adirondack Mountains while in graduate school. "Grouse would kind of explode out of the snow," he recalls. Now he studies how ecosystems adapt to climate change at the University of Wisconsin–Madison. Ruffed grouse and willow ptarmigans live above the snow, he says. But they dig — or even dive — into drifts to roost, using the subnivium to stay warm.

AN ECOSYSTEM GONE COLD

The subnivium melts away in spring. But it has a year-round impact on other ecosystems. Animals that find food and warmth here can live to see the spring.

To save the subnivium, the first thing that's needed is to stop climate change. "It's about keeping our winters cool," explains Elizabeth Burakowski.

Plants benefit, too. Tiny, delicate roots might burst if the ground froze. The warmth of the subnivium helps them make it through winter. By preventing root damage, plants "can be more successful during [the] growing season," Zuckerberg explains.

Decomposers have even broader effects. As microbes and fungi break down plant matter, they build nutrient-rich soil. "While they do that, they breathe," Contosta says. They take in oxygen and pump out carbon dioxide — a process called soil respiration. Some of the carbon from leaf litter gets stashed in their cells. "As long as those microbes stay alive, the carbon that's in their biomass is part of [the] soil," Contosta explains.

A 2020 study examined how much snowpack affected microbe activity. Scientists dug snow away from some areas and piled it up in others. A deeper snowpack led to a larger and more diverse population of microbes. Those microbes were more active with deeper snow, too. More microbes mean more respiration.

JASON RANSOM/NATIONAL PARK SERVICE

As the snow melts and spring arrives, those microbes die and release nutrients from their bodies into the soil — right when plants start to resume growing. "All of these nutrients, all of these carbon molecules, it's ready for them when they wake up," explains Kaizad Patel. He's a soil scientist at Pacific Northwest National Lab in Richland, Wash.

HOTTER AND COLDER

Climate change is coming for the subnivium. A warmer Earth creates less snow.

Oddly, warming that leads to less snow can actually make the ground colder. Snowpack acts like a blanket. The heat it traps keeps the subnivium just above freezing. If carbon emissions keep rising at the current rate, the presence of the subnivium might drop around the world from 126 days per year on average now to just 110 days by 2100. But there would be 10 more days every winter where the ground was frozen and bare. That's according to a 2019 study in *Nature Climate Change*.

That frozen ground is bad news for subnivium dwellers. If soil microbes freeze, they'll explode. That spills their nutrients into the soil during the winter, instead of spring. "That means the carbon and nitrogen that has been released in May is now being released in March," Patel notes, "two months before the plants need it."

Tiny roots also can burst in frozen ground. Dying roots and fewer nutrients add up to a "double whammy" for trees, Patel says. Now weakened, trees may grow poorly or be more likely to fall prey to new diseases or insects.

Arthropods will suffer too, especially those most adapted to the subnivium. "They're probably going to become locally extinct or just disappear altogether," Ziadeh says. After all, that environment on which they depended — "it's just gone."

Even species that normally lie dormant through the winter might be harmed. In 2024, Pauli and Zuckerberg studied the cold tolerance of various insects. Then they used a model to see how those insects would be affected as global temps change.

Warming of 5 degrees C (9 degrees F) would leave insects exposed to dangerous cold, the researchers reported in July 2025 in the journal *Diversity and Distributions*.

Larger animals also rely on the subnivium. Hoary marmots and pikas are both cold-loving rodents. Pikas scurry between boulders, nibbling grasses they stored in the fall. But, Aaron Johnston notes, "They do spend a fair amount of time moving around within the subnivium during the winter." Johnston is a wildlife ecologist in Bozeman, Mont. He works for the U.S. Geological Survey Northern Rocky Mountain Science Center. Johnston and his colleagues have found that pika numbers drop when there's not enough snow.

Unlike pikas, marmots hibernate underground in winter. But a lack of snow is stressful for them too. The subnivium normally keeps their burrows at around 5 °C (41 °F). At this temp, marmots have adapted to stay warm using very little energy. But without snow, their burrow temperatures may may drop to a frigid 0 °C (32 °F). Now, marmots must use four times more energy to stay warm. If they run out of energy during the winter, they die.

Pikas scurry within the subnivium during winter. Scientists have found that the animals' numbers drop when there isn't enough snow.

FINDING REFUGE FOR THE COLD

To save the subnivium, the first thing that's needed is to stop climate change. "It's about keeping our winters cool," explains Elizabeth Burakowski. She's a climate scientist at the University of New Hampshire in Durham.

That's something the whole world will have to tackle together. In the meantime, Burakowski is hunting for climate refuges. These are "small pockets of really unique, protected climate zones that preserve snowpack, that preserve cold," she explains.

These colder areas could be on the north slopes of mountains. They might even lie behind large boulders. By warming slower than other areas, Burakowski says, they might allow patches of subnivium to persist.

She's also interested in how we might make more subnivium. The right number of trees in a forest seems to be key for snow buildup, for instance. "We think that there's this Goldilocks zone," she says. There needs to be "a thin enough forest canopy that more of the snow is reaching the forest floor, but thick enough that it's also shading the forest floor."

Burakowski and her colleagues are still looking for such refuges. If found, they could keep pockets of snow around for a bit longer, giving the subnivium — and its residents — a better chance at survival.

A pika (above) perches among the rocks. This little rodent stays active in winter under the subnivium, living off piles of grasses it stored away in the summer and fall.

WILL THOMPSON

How to Invent a Language

Fictional languages offer insight into real-world communication

BY **MARIA TEMMING**

The distant moon Pandora from the *Avatar* movies is a richly immersive alien world. Dragon-like creatures prowl the skies. Supersmart whalelike beasts write poetry under the sea. Jungle plants glow multicolor in the dark. And Pandora's native Na'vi people boast their own elaborate customs and language.

Na'vi, the fictional people of the *Avatar* movies, speak a constructed language, or conlang. It's one of many fictional languages that have been made for TV, movies, books and more.

MAXIMUM FILM/ALAMY

Most of this vivid world-building exists only on screen. But the Na'vi language is very real. In fact, some *Avatar* fans have learned to speak it.

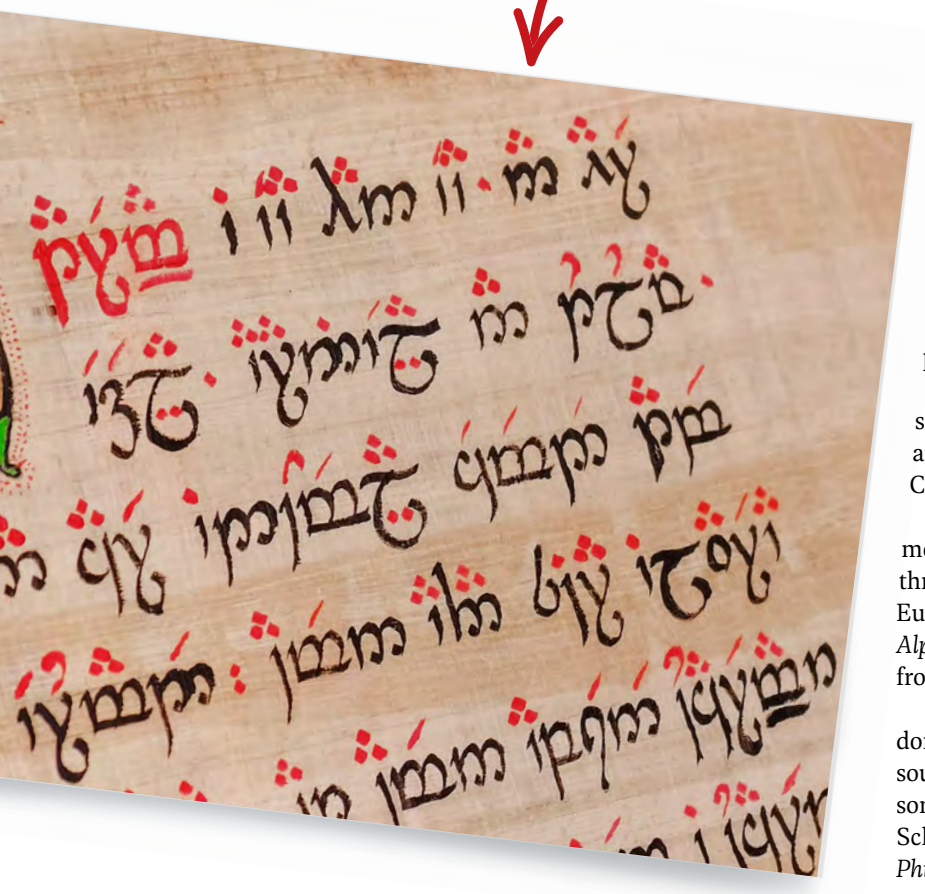
Paul Frommer is the mastermind behind Na'vi. As a linguist at the University of Southern California in Los Angeles, he's fascinated by the structure of languages. So when Frommer heard that director James Cameron was looking for someone to build a language for the first *Avatar* film, he jumped at the chance.

"What would it be like to create a language that people could actually speak, that would be entirely new?" Frommer wondered. "That was all tremendously exciting."

Na'vi is far from the only constructed language, or conlang, in fiction. Language scholar J.R.R. Tolkien famously created the Elvish tongues for *The Lord of the Rings* long before writing the books. Now, linguists like Frommer have come up with conlangs for characters in all kinds of media.

James Cameron included influences from Polynesian cultures, including the Māori of New Zealand, when creating the Na'vi.

For J.R.R. Tolkien, making up the iconic Elvish languages seen in The Lord of the Rings was a guilty pleasure, which he called his "secret vice."



MOVTCD/PROD.DB/ALAMY; LAIOTZ/SHUTTERSTOCK; LUCA ANTONIO LORENZELLI/ALAMY

The Na'vi language has influences from Polynesia (inset, a Māori woman). Languages in this region often have voiceless consonants, such as "t" and "k," but not the voiced versions of those sounds: "d" and "g."

Creating a conlang involves more than stringing together some made-up words. Languages are like machines, with many complex interlocking parts. Linguists must wield their expertise in these systems to invent ones that suit their fictional speakers. But language creation doesn't just add depth to imagined worlds. It can also offer insight into the nature of language itself.

MAKING SOUND DECISIONS

The most basic building blocks of any spoken language are sounds. So the first thing many language creators — or conlangers — do is nail down their sound system.

There's an "incredible variety of speech sounds in the world's languages," Frommer says, and picking ones to include in a conlang is like choosing spices to flavor a dish.

For *Avatar*, Cameron had already brainstormed the names for some characters and Pandoran wildlife. "It kind of had a bit of a Polynesian feel," Frommer says. Polynesia is a region of more than 1,000 islands in the Pacific. Languages in this region often have *voiceless* consonants, such as "t" and "k," but not the *voiced* versions of those sounds: "d" and "g." Frommer followed the same rules in Na'vi.

Christine Schreyer faced a different challenge in crafting a conlang for the 2018 film *Alpha*. Since the movie is set in Europe around 20,000 years ago, Schreyer needed to create an authentic-sounding human language. But no one knows how people spoke back then.

"I looked at what are called proto-languages," says Schreyer. She's a linguistic anthropologist at the University of British Columbia Okanagan Campus in Canada.

Proto-languages are the estimated ancestors of modern languages. Researchers had sketched out three such languages representing what people in Europe and Asia might have spoken around the time *Alpha* was set. Schreyer used a blend of the sounds from each in her conlang, Beama.

Some of Beama's sounds exist in English. Others don't. "It had ejectives, which are, like, more popping sounds," Schreyer says. Such sounds are heard in some African and Indigenous American languages. Schreyer and a colleague described the work in *Philosophical Transactions of the Royal Society B* in 2021.

WORD-BUILDING

Armed with an inventory of sounds, a conlanger needs to come up with rules for the words in their language. "Every language has rules about what can start its words, what can end its words," Schreyer says. For instance, English doesn't start words with the "ng" sound, but some African and Asian languages — and Na'vi — do.

Languages also have distinct ways of linking sounds into syllables. English has many dense clusters of consonants. Hawaiian has more vowel-heavy syllables. Picking a conlang's syllable structure helps define its character. Beama mimics the vowel-heavy syllables of one of the proto-languages Schreyer studied.

Once they know how their sounds can fit together, a conlanger is ready to start building words. There's not necessarily a rhyme or reason to this part. In real-world languages, Frommer says, "typically there is no relation between sound and meaning."

Yet languages do have rules for how their words may shapeshift in different situations. In English, adding "s" can turn a singular noun plural. Adding "ed" can change a verb from present to past tense.

World languages offer conlangers a broad palette of inspiration for these kinds of changes.

Take nouns. In English, they can only be singular or plural. "Nouns in Arabic distinguish singular from dual — exactly two of something — and plural," notes David Peterson. He's a conlanger based in Garden Grove, Calif. In creating the High Valyrian language for TV's *Game of Thrones*, he gave nouns four different forms that depend on quantity.

Likewise, verbs can change depending on aspect, which marks whether an action is ongoing or complete. David Peterson and his wife, linguist and conlanger Jessie Peterson, found a creative way to do this in their language for the fire people in the 2023 animated film *Elemental*.

The basic form of a Firish verb is ongoing action. But adding the suffix "ksh" can mark it as complete. That suffix is based on a Firish verb that means to douse a flame — which is how the Petersons imagined that fire beings would describe something as being over.

PIECING TOGETHER SENTENCES

When arranging words into sentences, "there are certain top-level grammatical decisions you make," David Peterson says. "Then you get progressively more complex."

One top-level decision is noun and verb order. English usually has subject-verb-object order. A person (subject) creates (verb) a language (object). But it doesn't have to be that way. World languages arrange words differently.

One of the least common is object-verb-subject order. That's why linguist Marc Okrand chose it for his Klingon conlang in the 1980s. In *Star Trek* films and TV shows, Klingons hail from a planet some 100 light-years from Earth. So Okrand wanted the Klingon language he invented to sound unfamiliar to most Earthlings.

Deciding on word order is just the beginning of building out a language's grammar. At first, a conlanger may come up with only enough grammar rules to translate the needed lines for a book, show or film. But no conlang is ever truly finished — the same way no natural language is ever done evolving.

Frommer, for example, still debuts new aspects of Na'vi on his blog. That includes some words suggested by fans who speak the language.

FICTIONAL LANGUAGE, REAL SPEAKERS

Days before the first *Avatar* movie premiered in 2009, Frommer received a shocking email. The long message was written by a stranger — entirely in Na'vi.

The fire people of *Elemental* speak Firish, a conlang that has influences from fire itself.

"My reaction was ... 'What? What is this all about?'" Frommer recalls.

A glossary of Na'vi words had leaked to the public. The emailer had studied that, along with interviews in which Frommer had described Na'vi grammar. A hub of Na'vi learners quickly gathered online.

In 2011, Schreyer got curious why so many people were studying a made-up language. When she surveyed Na'vi learners online, nearly 300 people from 38 countries, ages 10 to 81, responded. Some were big fans of *Avatar* and wanted to feel more connected to the film. Others were just fascinated by languages. Schreyer shared the findings in *Transformative Works and Cultures*.

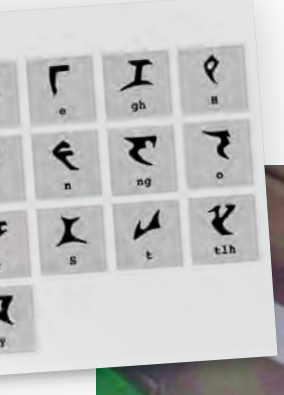
"People were learning Na'vi so quickly," Schreyer says. "I wondered how endangered language communities could replicate that." Endangered languages are ones at risk of disappearing as their speakers die out or switch to speaking something else. This includes many Indigenous languages.

Schreyer has worked with members of the Taku River Tlingit First Nation in Canada to revitalize their ancestral language. After seeing how audio files, social media and other tools helped people learn Na'vi, Schreyer and her colleagues brought some of those ideas to a site that helps people learn Tlingit words.

Na'vi is not the only conlang to draw real-world speakers. The nonprofit Klingon Language Institute has helped *Star Trek* fans study Klingon for decades.

ALBUM/ALAMY; DIMITRIOS KARAMITROS/SHUTTERSTOCK

Klingons (below) in *Star Trek* speak a language that sounds especially foreign to English-speakers. The accompanying plqaD alphabet also looks foreign.



PICTORIAL PRESS LTD/ALAMY

In Firish, adding the suffix "ksh" marks a verb as being complete. It's based on the Firish word meaning to douse a flame.

Joseph Windsor, an expert in theoretical linguistics, estimates there are some 100 advanced Klingon speakers in the world today. He doesn't count himself among them — though he knows enough to identify as a Klingon speaker on the Canadian census. (A census is an official count of a population.)

About a decade ago, Windsor decided to use Klingon to run a language experiment. He looked at stress — the syllable emphasis that can help distinguish a word's meaning. (It's what sets the noun *re*cord apart from the verb re*cord*.)

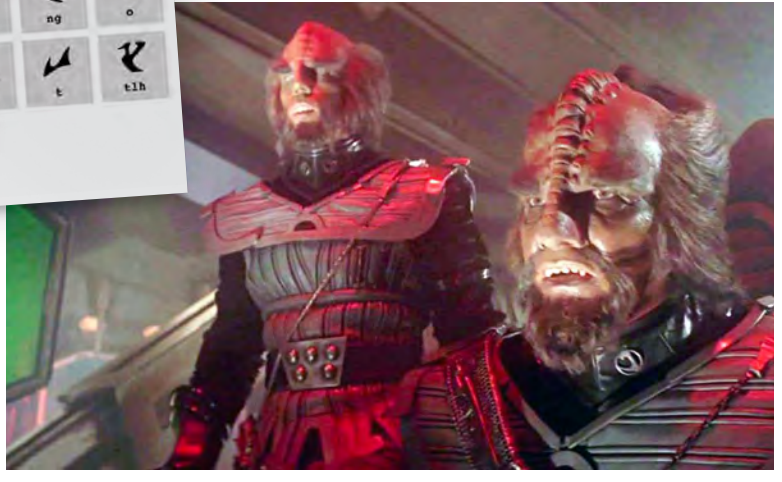
"Stress in Klingon, from a human language perspective, [is] completely unnatural," says Windsor, who works at the University of Calgary in Canada. The rules for which syllables to emphasize don't follow the patterns seen in real-world languages. But when Windsor analyzed an 18-minute clip of seven advanced Klingon speakers talking, he found something surprising.

The speakers stressed Klingon syllables with 84 percent accuracy. This hints that it doesn't matter how bizarre a stress system is. If there are regular rules to memorize, the human brain can pick it up pretty well.

WHAT MAKES A LANGUAGE

Conlangs are also helping explore what our brains recognize as a language.

The brain processes real-world languages using areas in the frontal and temporal regions of the left hemisphere. This neural circuitry cares only about language, says Saima Malik-Moraleda. It doesn't process other language-like means of expressing ideas, such as math or computer code.



Malik-Moraleda is a cognitive neuroscientist at the Massachusetts Institute of Technology in Cambridge. She and her colleagues wondered: Does the brain handle conlangs in the same way as real-world languages, which have evolved among groups of people over many generations? Or does it treat conlangs like other invented types of communication, such as code?

Malik-Moraleda's team recruited 10 speakers of Klingon, eight Na'vi speakers, three people who knew High Valyrian and three who spoke Dothraki. (David Peterson also invented Dothraki for *Game of Thrones*.) In brain scans, people's language centers lit up when they listened to recordings of the conlang they knew. Those brain regions were not as active when participants did non-language mental exercises. The team shared these findings in *Proceedings of the National Academy of Sciences* in March 2025.

The results offer clues to solving the mystery: "What makes a language a language?" Malik-Moraleda says. Maybe it is the ability to convey almost any meaning — including complex internal experiences, Malik-Moraleda says. Both conlangs and natural languages can do that. Math and computer code may not.

CONLANGING 101

Conlangs designed to be spoken in books, TV shows and movies make up just a small fraction of the world's invented languages. People have been conlanging for centuries. They've done it for journaling, art, international communication and more.

"There are thousands of language creators all over the world," David Peterson says. "Most of them are doing it just because they love it." Some hobbyists have designed languages expressed through gestures, musical notes or even knots.

You don't need to be a linguist to get started, either. Jessie Peterson took her first crack at making a conlang when she was 10 years old. Growing up in rural Missouri, she says, "I was fascinated by other languages but never had access to them." She made up a secret language to speak with her friends on the playground.

The key to becoming a good conlanger, the Petersons add, is studying many different languages. Especially unrelated languages. "Even if it's not learned to any sort of fluency," Jessie Peterson says. Just sampling how different languages convey meaning "can really open your mind" to the possibilities for your conlang.

"Then there's just practice," David Peterson says. "Create a language. Create it bad, and then create the second one better."

COOL JOB

This linguist has invented over 20 languages

Margaret Ransdell-Green even writes songs in these conlangs

The phrase "*níje lí*?" might sound like gibberish to anyone on Earth. But if you ever ran into a gray Ríli humanoid in the fantastical world of Aeniith, those words would come in handy. It means "How are you?" in Rílin, one of the 22 languages invented by Margaret Ransdell-Green.

Ransdell-Green has been inventing languages since she was 8 years old. She's designed seven for her own fictional world of Aeniith. But Ransdell-Green also uses her expertise as a linguist to build languages for authors, comic book creators and other artists. One of her constructed languages, or conlangs, was inspired by the calls of goats. Another was inspired by the chemical signals between the root systems of plants and mycelia, the rootlike structures of fungi.

Based in Fairbanks, Alaska, Ransdell-Green is doing exactly what she dreamed of as a kid. "Thirteen-year-old me would be completely jazzed," she says. "I'm doing the stuff that she was just discovering and loving, and my love has only grown more." In this interview, she shares her experiences and advice with *Science News Explores*. (This interview has been edited for content and readability.) — *Celina Zhao*

Q What do you think about when making a new language?

A Language is a part of a people's culture. I imagine who these people are and what they've been through. A lot of that shows up in the language, especially when I write their poetry, mythology and literature. For example, there's a diaspora in the history of the Rílin people. They were pushed out of their home while all kinds of tragic things were happening. So in their poetry, there are themes about traveling across the wilderness. There are emotions like regret about what has happened.

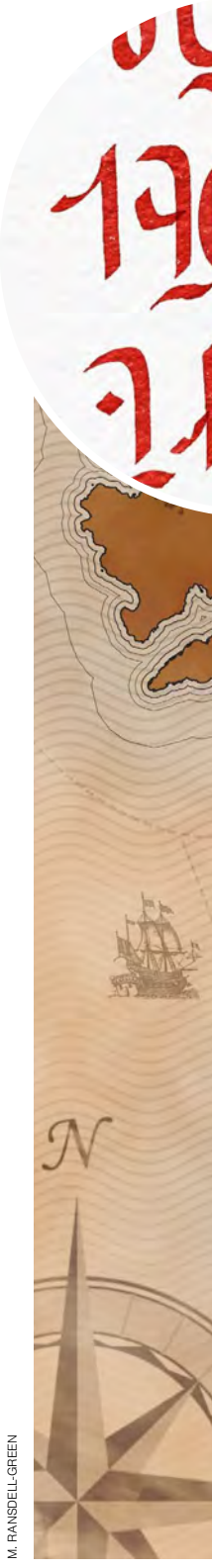
Q What project are you most proud of and why?

A I've been singing for pretty as much as long as I've been doing languages. Many years back, I wrote my first song in a constructed language. Now, my husband and I compose music together and play in a band together. We love doing songs in constructed languages. One of the Rílin songs we've even made an audience participation thing, where they sing part of the chorus. At first, I thought it would never go well because people don't even know what the language is. But people are pretty good sports about it.

A lot of constructed language work, or even linguistics, can be super isolating. But music has allowed me to communicate to more people about what I'm doing. Even if you know nothing about language, you can enjoy a song.

Q What advice do you have for anyone who's interested in conlangs?

A The first step is just learning about languages. If you can get into at least one other language besides your native language, that's a great start. In terms of world-building for constructed languages, there are a lot of amazing resources on the internet now. One is The Language Construction Kit. I'm also the president of the Language Creation Society. We're a nonprofit organization that supports people doing constructed languages. We have members from all over the world, including some as young as 13.



M. RANSDELL-GREEN

Symbol	Gotevian Scale Degree	Name	Note if in the key of "Ka Oirhai" (C Mixolydian)
ϛ	1	"Ka"	C
ϰ	2	"Mo"	Bb
ϡ	3	"Se"	A
ϑ	4	"Vi"	G
ϕ	5	"Nu"	F
ϟ	6	"Li"	E
ϝ	7	"Cha"	D
ϛ̣	1	"Ka"	C *(low octave)*

ϛ̂	Octave Up
ϛ̣	Octave Down
–	Rest
,	Measure
ϟ̲	Flat 3rd "Feo" *(Floor)*

Margaret Ransdell-Green (inset, upper right) has created several languages for her fictional world of Aeniith. This includes poetry in Rílin (inset, middle) and these notations for music in Gotevian.

PLANTS

Unlocking pine cone secrets

See how pine cone ‘scales’ change with temperature

By Science Buddies

Pine cones have a vital job: keeping pine tree seeds safe through the cold, damp months of winter. Pine cones do this by closing their “scales” tightly over the seeds, shielding them from cold, wind, ice and hungry animals. When the weather is warm and dry enough, those scales open up to release the seeds. In this activity, let’s see how pine cones change with temperature — from the comfort of our own kitchens.

OBJECTIVE *Observe how temperature affects pine cone size*

EXPERIMENTAL PROCEDURE

1. Label three pine cones A, B and C. Measure the initial length and circumference (at the widest point) of each.

2. Hold pine cone A under ice water for two minutes, then measure its new length and circumference.

3. Place pine cones A and B on a foil-covered baking tray.

4. Put the tray in the oven at 120° Celsius (250° Fahrenheit) for 45 minutes.

5. Remove the pine cones from the oven and let them cool.

6. Measure the length and circumference of all three pine cones.

7. Calculate how much the length and circumference of pine cone A changed after it was put in cold water and then after it was put in the oven.

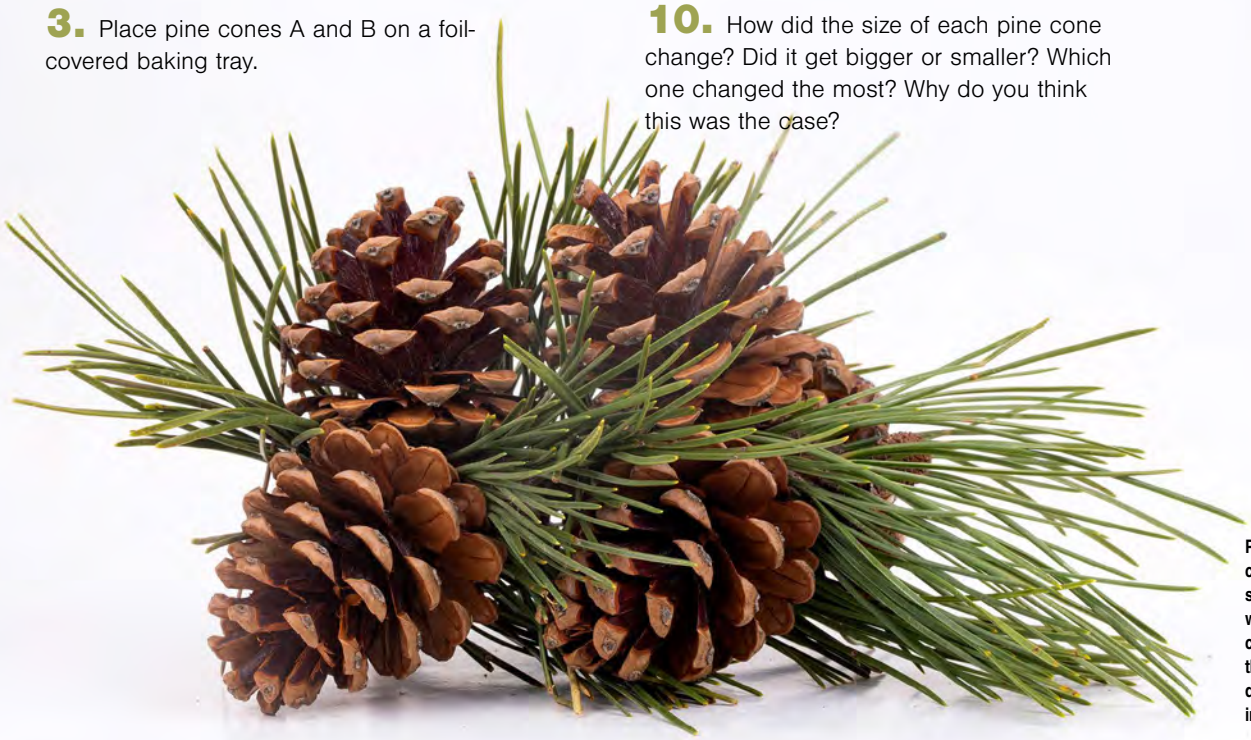
8. Calculate how much the length and circumference of pine cone B changed after it was put in the oven.

9. Calculate how much the length and circumference of pine cone C changed after being left at room temperature.

10. How did the size of each pine cone change? Did it get bigger or smaller? Which one changed the most? Why do you think this was the case?

Find the full activity, including how to analyze your data, at snexplores.org/pinecone. This activity is brought to you in partnership with Science Buddies.

SCIENCE BUDDIES

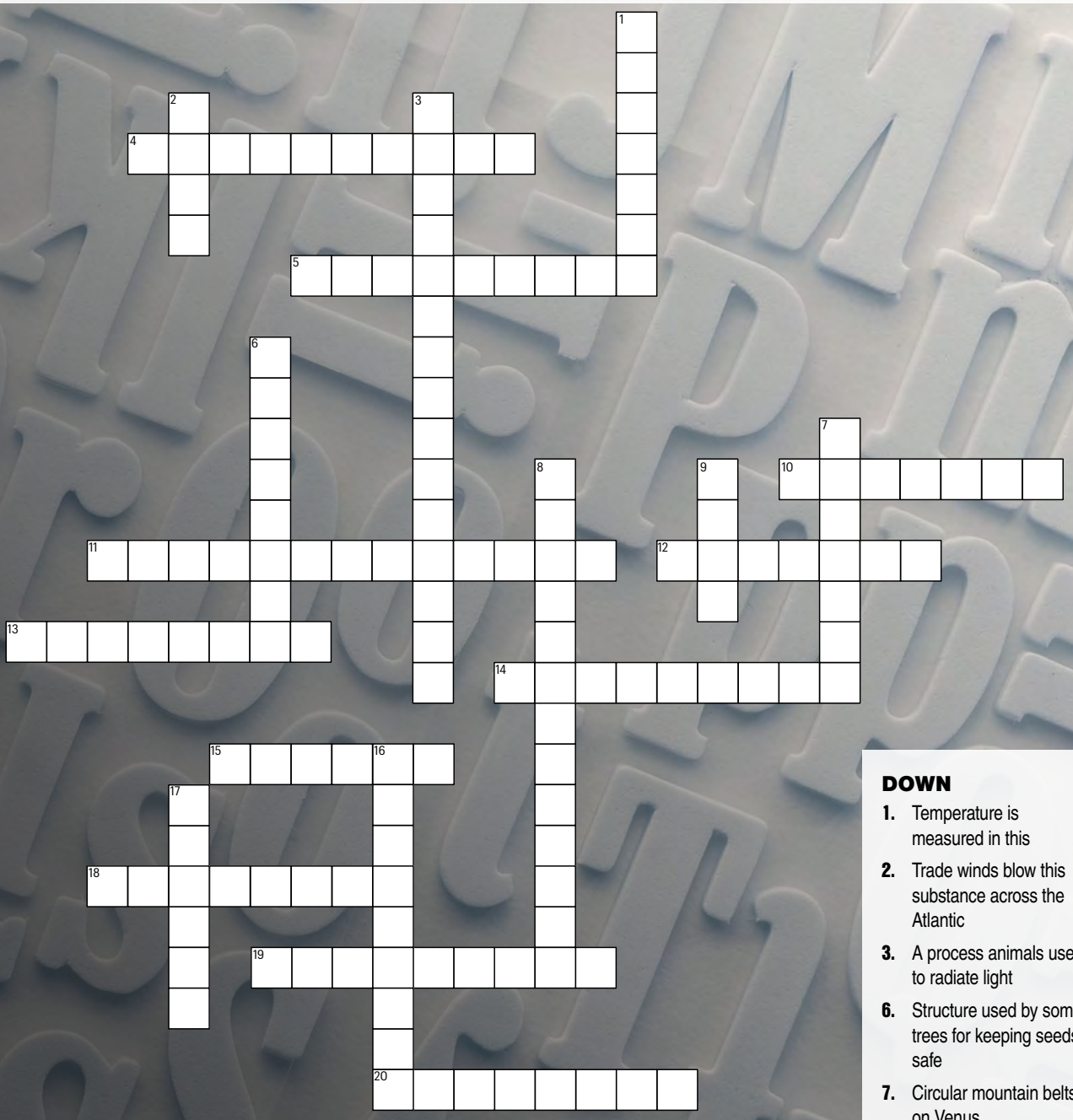


Pine cones stay tightly closed to protect the seeds within. When it’s warm and dry, the pine cone opens up to let the seeds escape, drift away and grow into new trees.

ESIN DENIZ/SHUTTERSTOCK

Crossword

If you're having trouble figuring out the answers to the clues below, make sure you read all the stories in this issue. Check your work by following the QR code at the bottom of the page.



ACROSS

4. When one tectonic plate is pushed under another

5. Animals that kidnapped baby monkeys

10. Short for constructed language

11. Light-sensitive cell in the eye

12. A "storage tank" within a cell

13. Element from urine that can be used to make fertilizer

14. Scientists just found a rogue one

15. Surprisingly complex device found in the bathroom

18. Tiny bits of solid or liquid found in the atmosphere

19. Wear this to protect your skin

20. The galaxy we live in

DOWN

1. Temperature is measured in this

2. Trade winds blow this substance across the Atlantic

3. A process animals use to radiate light

6. Structure used by some trees for keeping seeds safe

7. Circular mountain belts on Venus

8. The estimated ancestor of a modern language

9. The abbreviation for per- and polyfluoroalkyl substances

16. The subnivium is an example of this

17. A fluffy, housecat-sized, ferret-like predator

BART SADOWSKI PL/SHUTTERSTOCK

MATERIALS SCIENCE

Pee may be an untapped goldmine of materials

Upcycled urine may change how we view this waste

Most of us don't think too much about what's in our pee. We go, we flush, we forget. But that wastes a golden opportunity, some scientists say. They're finding new — and quite valuable — uses for the chemicals in urine.

A recent study shows that some yeast can turn ingredients from urine into hydroxyapatite. This calcium-based mineral makes bone hard. Surgeons and dentists sometimes use it to repair bones and teeth. It also could help make sturdy building materials. And it's worth more than past pee-based products.

"We're taking a waste product and turning it into something high-value," says Jeremy Guest. He hopes his team's findings may inspire cities to "manage waste in a new way." Guest is an environmental engineer at the University of Illinois Urbana–Champaign. His team shared its new work in *Nature Communications*.

TURNING TINKLE INTO TREASURE

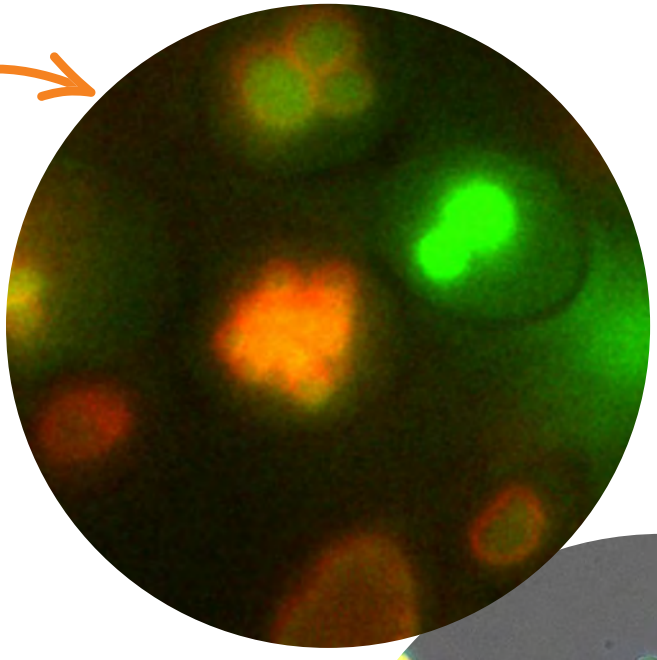
Cities today view pee as simply a problem to be solved. Sewage treatment plants filter germs from water to stop the spread of disease. This cleaning also strips out elements in pee that could harm the environment. Nitrogen is one such contaminant. So is phosphorus.

But those elements aren't necessarily bad, says Treavor Boyer. Most "contaminants are just chemicals in the wrong place at the wrong time." Boyer is an environmental engineer at Arizona State University in Tempe. He did not take part in the new research. But he does study how we might recover resources from wastewater.

The nitrogen and phosphorus from urine can be used to make fertilizer, for instance. But fertilizer is not very costly. So it's hard to make mining nutrients from wastewater worth it, explains Guest.

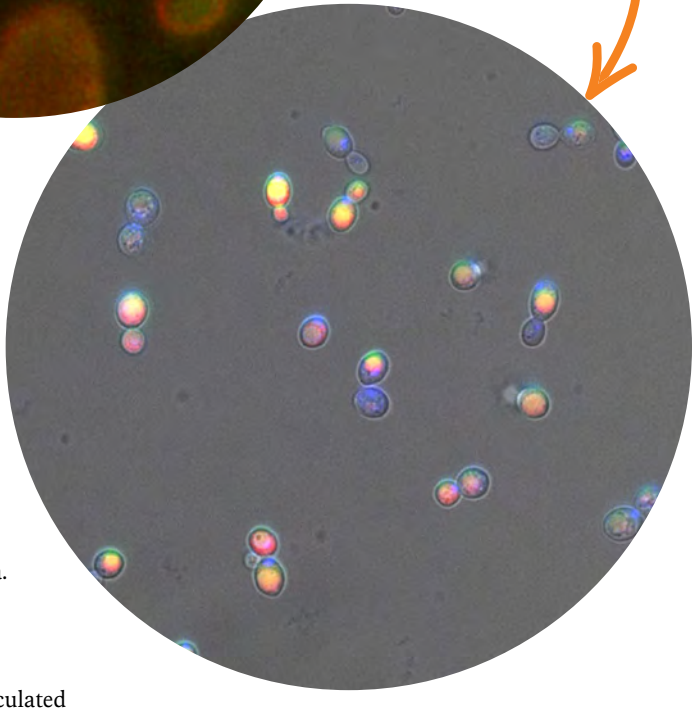
That's why his team turned to hydroxyapatite. It's made from the same stuff as fertilizer but sells for more. That might motivate cities to revamp their water processing to harvest it.

3D_MAN/SHUTTERSTOCK



In these dyed yeast cells, red shows the outline of vacuoles. Calcium packed inside the vacuoles glows green.

Here, yeast cells' vacuoles glow red. Calcium appears green and phosphate molecules show up as blue. (Where they overlap can appear yellow.)



BERKELEY LAB

The scientists used microscopes and colored dyes to track how materials moved in and out of yeast cells.

TINY HYDROXYAPATITE FACTORIES

Inspiration struck when a scientist in Peter Ercius' lab noticed something strange. Ercius studies how materials change in liquids (such as inside living cells) at the Lawrence Berkeley National Laboratory in California.

His team had been looking at a yeast called *Saccharomyces boulardii*. "Yeast has been used for thousands of years," notes Ercius. People use it to make bread, for instance. "We know how to grow yeast, how to keep them alive, how to keep them happy." But his team wanted to know more about how this yeast works.

One day, a scientist spotted odd mineral buildups inside the yeast cells. Curious, the team imaged the yeast from different angles and used dyes to track materials moving in and out of the cells.

The yeast were taking up minerals from the liquid around them and cramming those materials into vacuoles — storage tanks inside their cells. Inside the vacuoles, the yeast crafted different chemicals. When released from the cell, these chemicals crystallized into hydroxyapatite.

This process mimics how human osteoblasts, a type of bone cell, create this material. In honor of that, the scientists named their yeast cells "osteoyeast."

The yeast produced about 1 gram of the mineral from each liter (quart) of urine. Urine doesn't naturally contain enough calcium to support this process, so the researchers added a bit extra.

FROM THE LAB TO THE BATHROOM

Guest and his coworkers calculated how much their hydroxyapatite could sell for. Their estimate: between $19 and $138 per cubic meter (roughly 264 gallons) of urine. That's about the volume of a refrigerator. The same pool of pee makes only about $12 to $33 worth of fertilizer.

Making this product would require separating urine from other waste. (Urinals already do this, as do the toilets astronauts use in space.) The collected pee would go through a few treatment stages. Urine and yeast might enter a stainless-steel tank. There, the yeast would use minerals from the pee to build hydroxyapatite.

That mineral could then be drawn from the tank. Everything else would go on to be treated like normal sewage. A processing center would remove any germs from the hydroxyapatite, Guest says. The purified mineral could then be turned into something useful.

— *Katie Grace Carpenter*

ANIMALS

Rudolph's red nose could glow through bioluminescence

But thanks to physics, his snout might appear different colors to observers on the ground

PADDY MCGUINNESS/ALAMY

This time of year, "Rudolph the Red-Nosed Reindeer" is nearly inescapable. As the song goes, Rudolph is bullied for having a nose so bright it glows (*like a lightbulb!*). But one fateful Christmas Eve, his much-mocked nose makes Rudolph a hero. Using it as a beacon, Rudolph guides Santa's flying sleigh through a foggy night to deliver gifts around the world.

Rudolph's super-bright snout might seem as fantastical as his ability to fly. But a light-up body part needs no holiday magic. Many animals radiate a whole rainbow of colors through bioluminescence.

Given what we know about real animals that glow, a reindeer sporting a luminous nose would be unusual. Still, having a built-in red headlight would make a great adaptive trait for sleigh-pulling reindeer. Rudolph's red nose just might look a little different to someone on the ground.

NOSE LIGHT, NOSE BRIGHT

Most bioluminescent animals use the same simple chemical reaction to light up cells in their bodies. It takes only two main ingredients. The first is a compound called a luciferin. The other is an enzyme called a luciferase. "When oxygen is present in the cell, they react together and they give off light," says Danielle DeLeo. This marine biologist studies bioluminescence at Florida International University in Miami.

Mixing and matching different luciferins and luciferases creates different colors. Bioluminescent reactions light up the eerie bluish-green lanterns that dangle from anglerfish. They give certain marine worms a purple shimmer. And they illuminate fireflies' flashy backsides with a variety of colors.

A lot of bioluminescence is near the blue end of the color spectrum. But some animals can glow red. Much like Rudolph, red-lit critters often do it to navigate dark and murky places.

Some deep-sea fish glow red, DeLeo notes. Red light can't travel far through seawater. But in the pitch black of the deep sea, "you can use that light to kind of see short distances," she says. "Animals that might be a little bit further away from you aren't going to pick up on that red light and then attack you."

In foggy air, on the other hand, red light cuts through the gloom. Red has the longest wavelengths of any color we can see. With those longer wavelengths, it's less likely to be scattered by water droplets in foggy air, says Nathaniel Dominy. "Blue light, green light, yellow light will scatter. Red light will travel far." Dominy is an evolutionary biologist who studies mammal color vision. He works at Dartmouth College in Hanover, N.H.

If a sleigh-pulling reindeer were going to have a glowing nose, red would be the best color for it, says Dominy. "For Rudolph, that red light is going to allow them to navigate under foggy conditions more effectively than any other light."

The odds of this trait evolving in reindeer, though, is "very, very low," DeLeo says. Most bioluminescent animals are found in the ocean. And among the land animals that do glow, none are mammals. Still, it's not impossible for bioluminescence to emerge in a new species. "It's evolved at least 100 times across the tree of life," DeLeo notes.

RUDOLPH THE RED-SHIFTED REINDEER

To someone on the ground who spied Rudolph flying, his nose might not look red at all. The reason is that when a light source is moving toward you, its light waves get squished and look bluer. When it's moving away, its light waves get stretched out and appear redder.

"We don't see that typically around us, because things have to travel really fast for the redshift or the blueshift," says Laura Driessen. She's a radio astronomer at the University of Sydney in Australia. Santa's sleigh could be an exception.

Santa would have to move at superspeed to have enough time to visit houses around the world in a single night, Driessen says. Say Santa travels at 10 percent the speed of light. As Rudolph approaches a house, his nose would be blueshifted to look orange. As he flies away, his nose would redshift to nearly the deepest crimson human eyes can see — so dark it would look almost black.

Rudolph's nose wouldn't be the only thing blueshifted and redshifted, either. Blueshifted brown hues, for instance, would take on a greenish tinge. "We'd see a green sleigh and reindeer coming towards us. Then, for the brief moment that [Santa] has stopped and chucked the presents down our chimney, everything would look the normal color," Driessen says. As they moved away, Santa and his reindeer would almost disappear as they went into infrared.

Such fast movement and a brightly glowing nose would cost Rudolph a lot of energy, Dominy notes. "I would want to make sure that he could get as much energy as possible. Sugary foods." So anyone leaving out treats for Santa this Christmas Eve should be sure to leave out plenty of cookies for his reindeer, too.

— *Maria Temming*

Sugary foods would probably help Rudolph (opposite page) fuel his speedy flights and glowing nose.

Most bioluminescent animals rely on the same chemical reaction to glow. Fireflies (top) use this reaction to produce flickering patterns of light in their abdomen to attract mates. Deep-sea anglerfish (bottom) lure prey with their bluish-green lanterns.

NEW AFRICA, KHUNGCENTER, SAM ROBERTSHAW/SHUTTERSTOCK

EARTH

See how aerosols fly through Earth's sky

A NASA visual tracks how sea salt, dust and other tiny particles drifted over six weeks

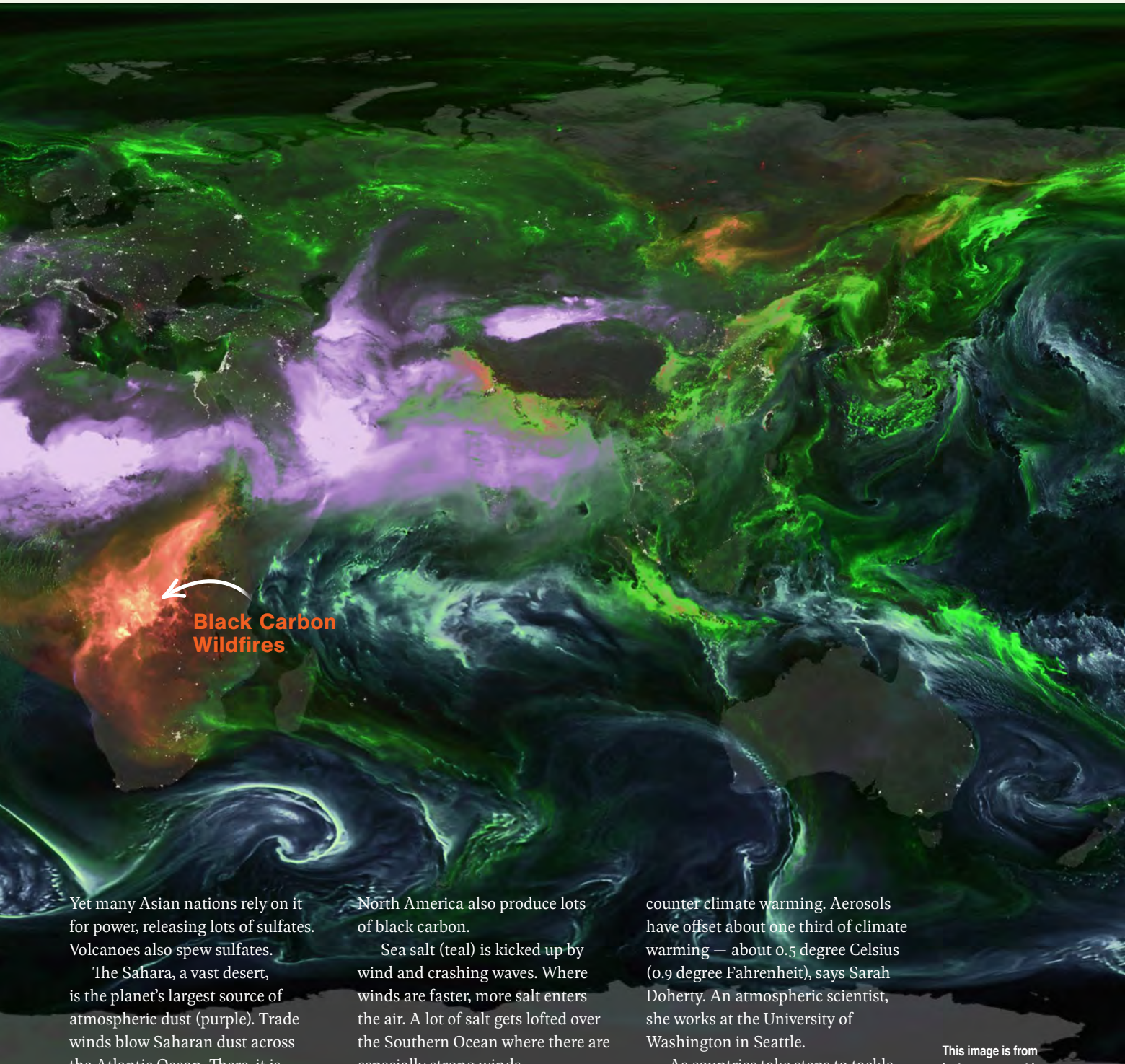
Black carbon *Dust* *Sea salt* *Sulfate*

The sky abounds with tiny bits of solid or liquid called aerosols. They play roles in managing Earth's temperature. A new NASA visualization reveals how these airborne bits swirl through the atmosphere.

NASA's Goddard Earth Observing System created the visual. It combined observations from space and the ground with computer models to track Earth's aerosols over six weeks in 2024.

Sulfates (green) are often linked to fossil fuel burning, especially coal. Some countries, such as the United States, have reduced their coal use.

NASA'S GLOBAL MODELING AND ASSIMILATION OFFICE AND NASA'S SCIENTIFIC VISUALIZATION STUDIO



Yet many Asian nations rely on it for power, releasing lots of sulfates. Volcanoes also spew sulfates.

The Sahara, a vast desert, is the planet's largest source of atmospheric dust (purple). Trade winds blow Saharan dust across the Atlantic Ocean. There, it is thought to fertilize Earth's largest rainforest, the Amazon.

Black carbon (red) comes from burning vegetation and fossil fuels. Major sources include fires purposely set to clear and prepare farmland for future crops. Land managers do this in sub-Saharan Africa and the Amazon. Major wildfires in North America also produce lots of black carbon.

Sea salt (teal) is kicked up by wind and crashing waves. Where winds are faster, more salt enters the air. A lot of salt gets lofted over the Southern Ocean where there are especially strong winds.

When natural sources or human activities emit greenhouse gases, they can stay in the atmosphere for years and spread around the world. Aerosols, on the other hand, stay aloft for only days. And they form regional plumes.

Black carbon absorbs solar radiation and warms the climate. But overall, most high-flying aerosols counter climate warming. Aerosols have offset about one third of climate warming — about 0.5 degree Celsius (0.9 degree Fahrenheit), says Sarah Doherty. An atmospheric scientist, she works at the University of Washington in Seattle.

As countries take steps to tackle air pollution, the cooling effect of aerosols is expected to fade. In fact, this may already be occurring. "We've seen a recent acceleration in the rate of [global] warming," Doherty says. There are some hints that this is at least partly due to fewer aerosols in the atmosphere.

— Nikk Ogasa

This image is from just one moment in 2024. The pattern of aerosols can look very different at other times in other years. For instance, after the powerful 1991 eruption of Mount Pinatubo in the Philippines, the global atmosphere would have been blanketed in green.

MATERIALS SCIENCE

New materials yank 'forever chemicals' from water

The filters work fast and can be reused

New materials could snatch harmful "forever chemicals" out of water in a faster, more sustainable way.

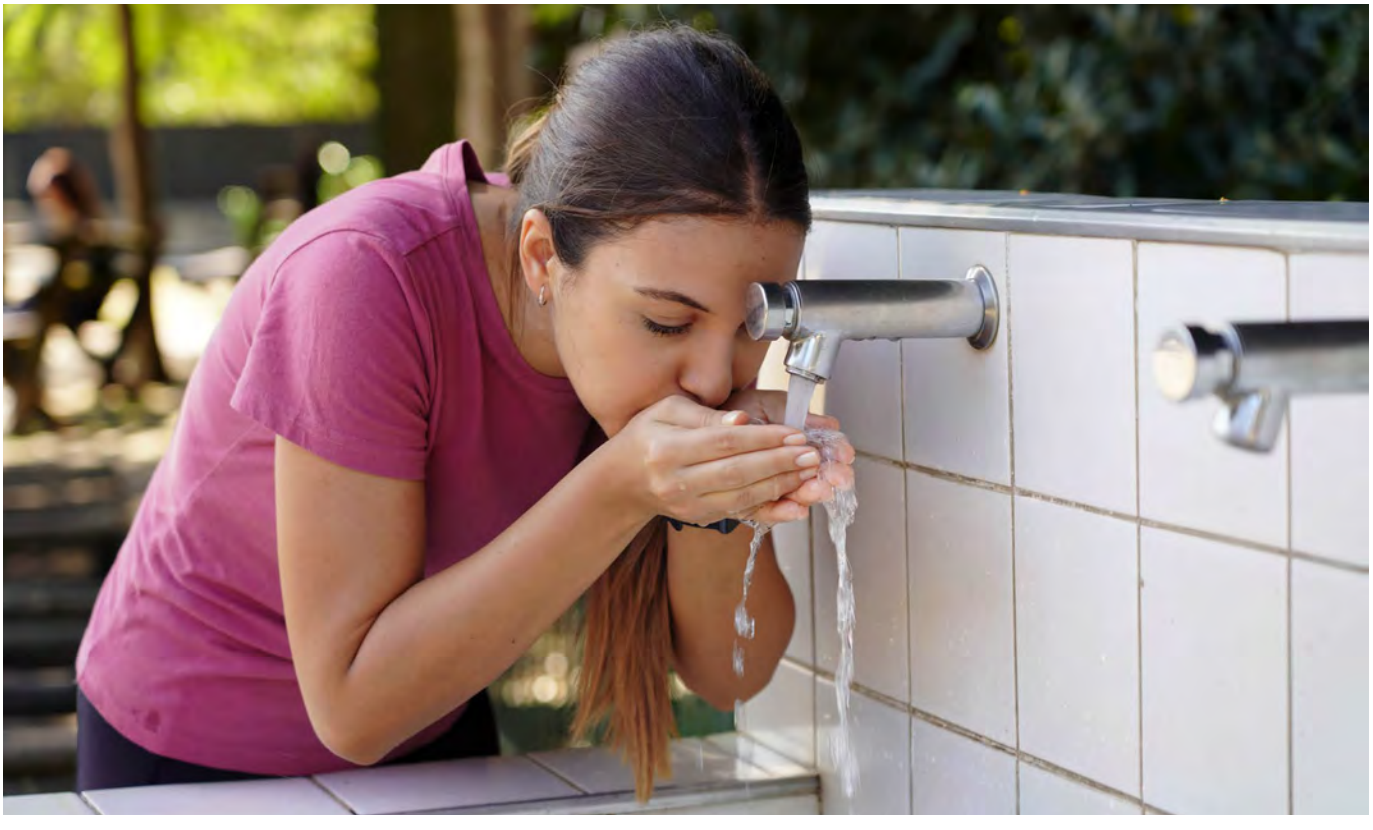
So-called forever chemicals are a group of more than 10,000 compounds. Their official name is per- and polyfluoroalkyl substances, or PFAS for short. They're used to make food packaging, makeup and many other products.

PFAS are like "the Avengers" of chemicals, in that they're super hard to destroy, says Soumya Mukherjee. He's a materials chemist at the University of Limerick in Ireland. But in many ways, PFAS are more like villains than heroes. Because they're so tough, PFAS that get into waterways stick around for a long time. Exposure to those chemicals has been linked to health problems.

Some existing materials, such as activated carbon, can filter PFAS out of water. But it takes hours for activated carbon to suck up all the PFAS it can fit, and activated carbon isn't easy to recycle.

So Mukherjee's team turned to metal–organic frameworks, or MOFs. A MOF's metals and organic molecules form a huge network with a lot of open spaces. PFAS can line the surfaces of all these nooks and crannies.

The researchers created four types of MOFs. All contained the metal zirconium but had differences in their organic molecules. These differences changed how PFAS interacted with the MOFs. The researchers also took each of the four MOFs and added a



New materials could someday help remove PFAS from drinking water. Researchers are tweaking the chemistry of these PFAS traps to improve their performance and make them reusable.

ZIGRES/SHUTTERSTOCK

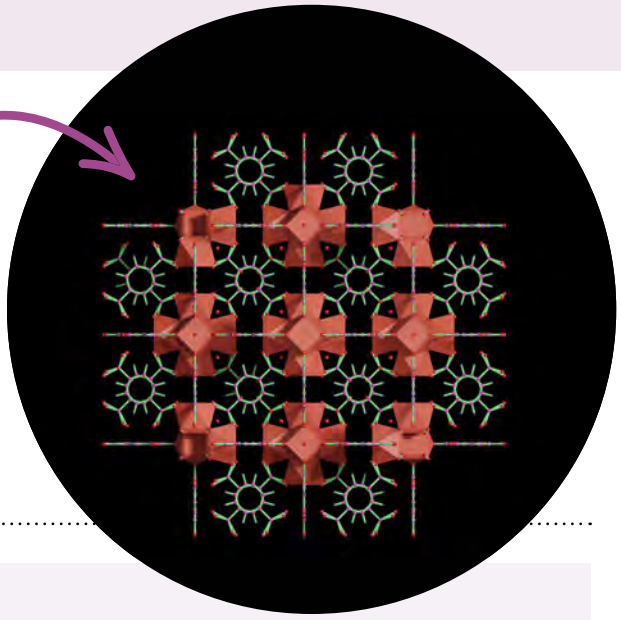
layer of organosilicone (OS). This can change how PFAS sticks to a surface. That gave the team a total of eight materials to test — the original and OS-coated versions of each MOF.

Some of the MOFs grabbed more PFAS than activated carbon did. (Activated carbon took up only 40 percent of one forever chemical called PFOA. It took up 71 percent of another called PFOS.) The new materials also trapped forever chemicals in less than 30 minutes — much faster than activated carbon worked. Washing the used MOFs in acetone or other common lab chemicals removed the PFAS so they could be used again.

The researchers shared their results in *Advanced Materials*.

None of the materials did a great job snagging one type of forever chemical. "There is hardly anything that really works well yet for GenX," Mukherjee says. GenX was the smallest of the PFAS tested. Smaller molecules can more easily run away from the MOFs, he says. Scientists are still looking for materials with the right chemistry to capture those evasive pollutants.

— *Carolyn Wilke*



This 3-D rendering of a metal-organic framework shows the nooks and crannies that can stash PFAS molecules.

DATA DIVE

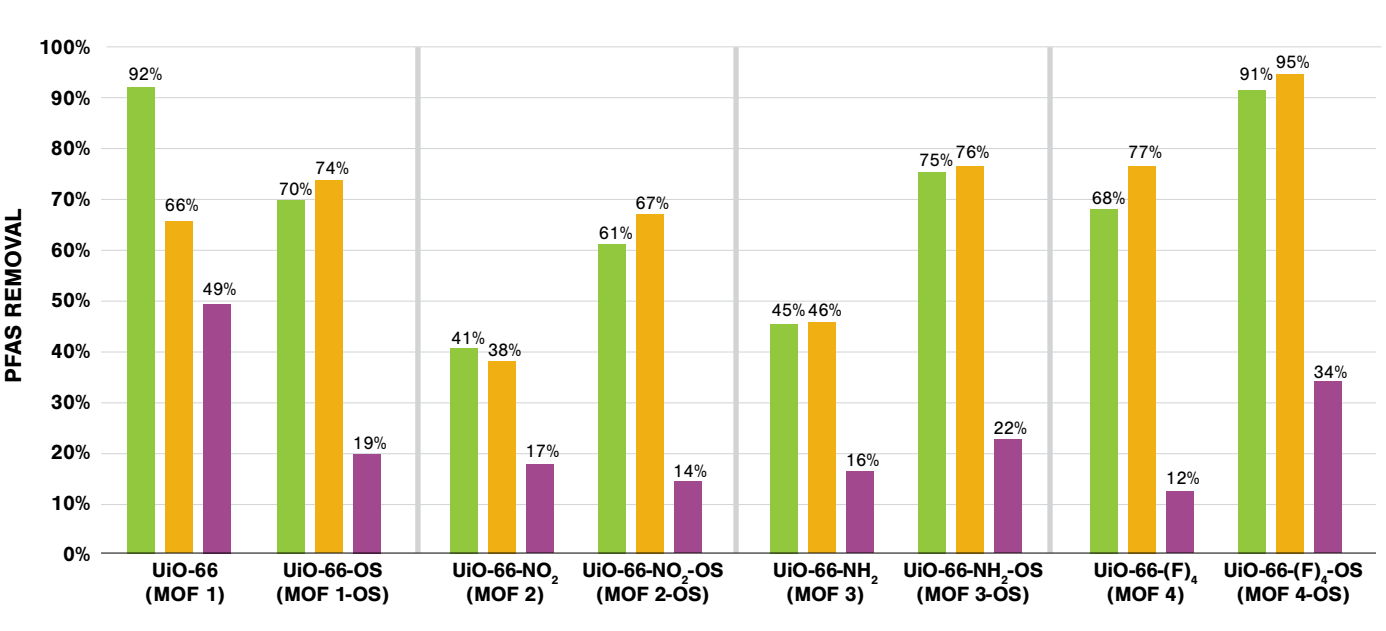
1. Look at the first of each pair of MOFs (MOF 1, MOF 2, MOF 3 and MOF 4). Which of these performs best at removing PFAS?

2. Now compare the MOF in each pair with its corresponding MOF-OS. Which performs better at removing PFAS — the one with or without OS?

3. Overall, which MOF or MOF-OS removes the most PFOA and PFOS? How much more PFOS does it remove than GenX?

4. In water, PFAS is usually a mixture of different molecules. What strategy could researchers use to capture different kinds of PFAS in the same solution?

FOREVER CHEMICAL FILTERS



SANJAYA VIRAJ BANDARA/SHUTTERSTOCK; N. ILIĆ *ET AL/ADVANCED MATERIALS* 2025

Mukherjee's team made eight types of MOFs. All types contain the same metal and have the same structure. But they have differences in their organic molecules that change their properties. Each pair of materials shown in this graph has the same MOF. The second in each pair is coated with organosilicone (OS). The data show how well different materials picked up three different types of PFAS chemicals (PFOA, PFOS and GenX). In each test, researchers exposed one type of MOF to a known amount of one type of PFAS. They measured how much of that PFAS was left after 24 hours, then calculated the percentage the MOF had removed.

ANSWER

The surface of Venus is morphing

It's sort of like plate tectonics on Earth

Things on the surface of Venus may be moving. Strange, circular mountain belts known as coronae dot the surface. Hot plumes of rock welling up from the planet's mantle seem to be shaping these coronae. A mantle is a thick layer that can separate a planet's crust from its core.

One way these plumes sculpt the coronae is subduction. That's a process that occurs on Earth. When two solid pieces of Earth's surface — tectonic plates — collide, one plate is pushed under the edge of the other.

Venus' surface isn't broken up into plates as Earth's is. But subduction may still occur along the edges of the coronae.

As a plume rises beneath a disk of crust, it also may bulge out to the sides. That would push on the crust around the disk. If Venus' crust is strong, it may bend and dive down — or subduct — under the disk.

But if the crust is weak, an upward push might crack the surrounding crust. That detached crust could drip, like honey, into the planet's mantle.

Some coronae may even form as rising plumes get lodged in the ground below the surface. The crust above may swell into a round landform, like a tectonic blister.

If Venus is geologically active today, perhaps it could have been more Earthlike in the past. Scientists shared these findings in *Science Advances*.

— *Nikk Ogasa*

NASA's Magellan spacecraft captured this image of rounded mountain belts called coronae. The Bahet Corona (left) covers an area about the size of the state of Massachusetts. Such coronae may have volcanoes at the center (inset, illustration).

NASA/JPL; PETER RUBIN/JPL-CALTECH/NASA

INSIDE THE MIND OF A YOUNG SCIENTIST

A Regeneron International Science and Engineering Fair finalist answers three questions about her science

Science competitions can be fun and rewarding. But what goes on in the mind of one of these young scientists? Lya Kim, a finalist at the 2025 Regeneron International Science and Engineering Fair, shares her experience.

Q What problem did you set out to solve?
A When astronauts try to grow food in space, "there are problems," Lya says. On Earth, gravity tells plant roots to grow down and shoots to grow up. But in a weightless environment, plants coil and twist. "We tried to [solve] that problem by introducing a new method of 'magneto-priming,'" Lya says. That's "just a fancy word for magnetizing." Once plants were magnetized, magnets could be used to mimic the guiding force of gravity to help them grow straight.

Q What surprised you the most?
A Lya's group tested how well magnets helped magnetized and non-magnetized seeds grow. "I didn't think we'd have that significant a difference between the magneto-primed seeds and the non-magneto-primed seeds," Lya says. But photos confirmed that the magnetized seeds sprouted straighter. "We could literally see that," Lya marvels.

Q Do you plan to continue this work?
A Now that the team has seen how magnetism affects plant growth on a large scale, Lya wonders how it might affect plants on a molecular scale. For instance, could it affect plant cells' ability to make proteins? Could it affect how water spreads through plant tissues? These are the types of questions she would like to investigate next.

Regeneron International Science and Engineering Fair finalist

Lya Kim

Lya Kim, 16, teamed up with classmates Dong Hyun Lee and Dong Gyu Lee to design a new system for growing plants in space. The team first placed seeds inside a stack of donut-shaped magnets for 24 hours to magnetize them. Then, they planted the seeds in petri dishes inside a machine that mimics changing gravity. Magnets helped the magnetized seeds grow faster and straighter than non-magnetized seeds. Lya is a sophomore at Saipan International School. Saipan is the largest of the 14 Northern Mariana Islands, an archipelago north of Australia.

Learn more about the Regeneron International Science and Engineering Fair

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