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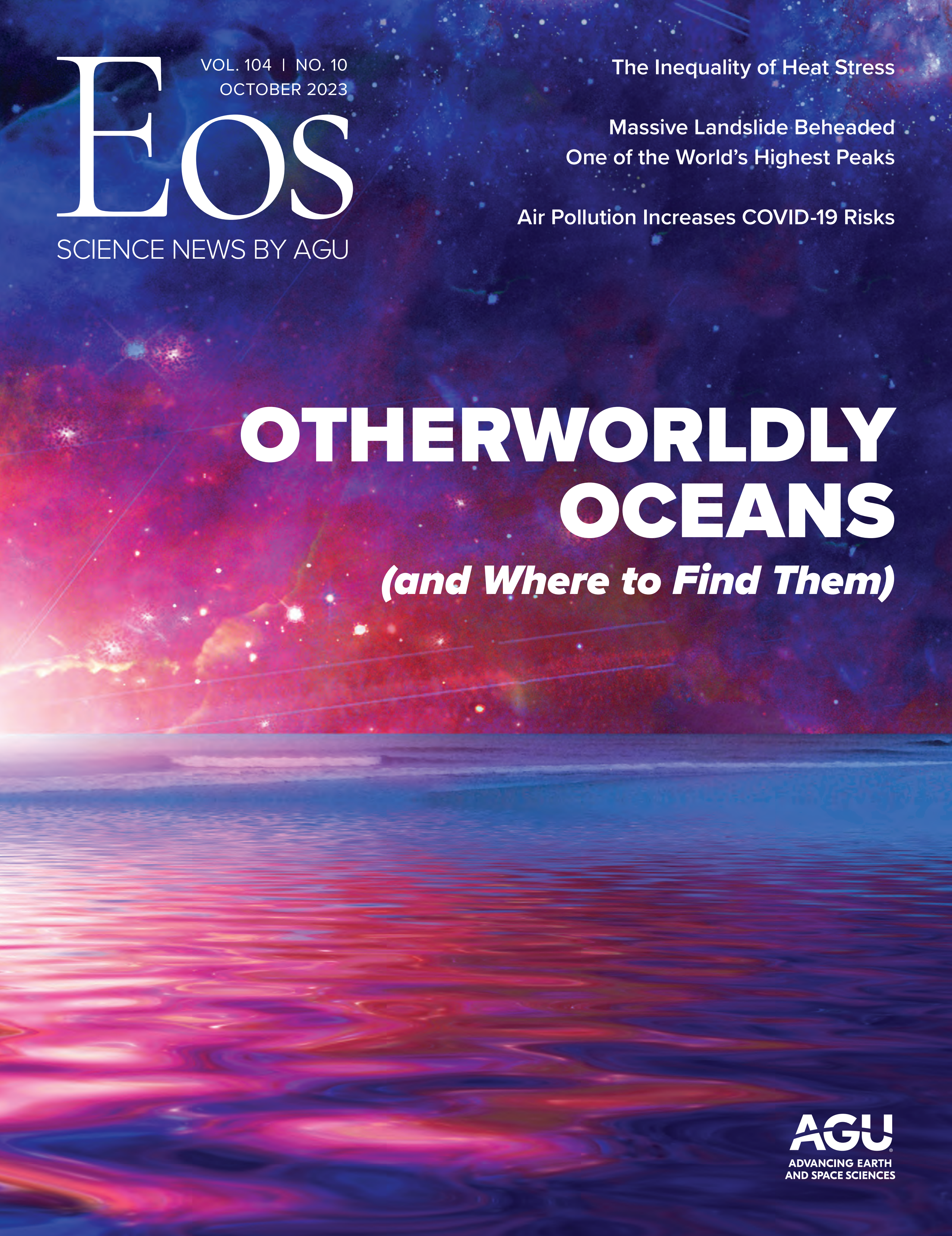

OTHERWORLDLY OCEANS

(and Where to Find Them)

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Essential Ingredient for Life Found on Enceladus

Sunlight shines through plumes of ice crystals and dust grains jetting from Saturn's moon Enceladus, as seen by the Cassini mission. Credit: NASA/JPL/Space Science Institute

Saturn's moon Enceladus couldn't look less Earth-like. Instead of an atmosphere and oceans warmed by the Sun, it has a thick shell of ice that covers a global sea, likely kept liquid by tidal squeezing from its host planet.

And yet Enceladus is one of the likeliest candidates for life beyond Earth in the solar system, an intriguing status that has become even more possible, thanks to a new discovery.

Using archival data from the Cassini mission, researchers uncovered evidence of phosphorus in the form of sodium phosphates in Enceladus's subsurface ocean, the first time the chemical has been measured in a liquid environment beyond Earth. Sodium phosphates are a family of molecules that combine sodium (Na^+) and phosphate ions (PO_4^{3-}) with various other elements.

Phosphorus is the rarest of elements necessary to life as we know it. It's often found locked up in rocks, unavailable for organisms to use. The presence of phosphorus in water on Enceladus at more than 100 times greater abundance than on Earth is suggestive of how available it might be throughout the outer solar system.

"The previous concern that phosphorus might be a bottleneck for the emergence of life on Enceladus is gone," said Frank Postberg, a planetary scientist at the Free University of Berlin who coled the new study published in *Nature* (bit.ly/Enceladus-phosphates).

Phosphorus is one of six elements present in the proteins and genetic molecules—DNA and RNA—of all known life. Of the six, carbon, hydrogen, nitrogen, and oxygen are common in the solar system and beyond, with sulfur being rarer and phosphorus rarer still. Much of the challenge for determining the origins of life is tracing how these elements (often written as CHNOPS and pronounced "schnapps") came together and the conditions necessary to build the first recognizable biochemicals.

"We already knew that Enceladus has a number of things we tend to think of as requirements for life," said Sarah Hörst, a planetary scientist at Johns Hopkins University who was not involved in the study. Her work uses Cassini data as well as laboratory experiments. "Now we see that there are phosphorus-containing compounds, which gets us closer to the possibility of the chemistry of life as we know it."

The Probe That Keeps On Giving

The Cassini mission was launched in 1997 and ended in 2017 when the spacecraft's controllers deliberately crashed it into Saturn. That was done, in part, to prevent the probe from

"The previous concern that phosphorus might be a bottleneck for the emergence of life on Enceladus is gone."

possibly contaminating Saturnian moons with elements from Earth.

When Cassini first flew past Enceladus in 2005, researchers spotted plumes of ice jetting from surface cracks near the moon's south pole. Over the next decade, controllers directed the spacecraft through the plumes several times to grab material for analysis.

Data collected by the craft's Cosmic Dust Analyzer revealed salty, alkaline water and organic molecules in the plumes, opening the possibility of finding life.

Of course, organic molecules by themselves don't mean life: Astrochemists have found them in comets and interstellar clouds, neither of which are hospitable. However, Cassini revealed that Enceladus has hydrothermal activity and an ocean underneath its ice, which provides shelter from radiation and an energy source—things the atmosphere and the Sun provide on Earth to allow life to flourish.

"Enceladus has been very helpfully throwing its material into space where it is much easier to measure with spacecraft," Hörst said. "The Cosmic Dust Analyzer obviously wasn't designed to measure Enceladus because we didn't know about the plumes, but it's become a really powerful tool for measuring the composition of Enceladus's ocean. Enceladus is awesome."

Biochemical Riddles in the Dark

The data set obtained from Cassini was so huge it couldn't be fully processed while the probe was operational.

"Enceladus is awesome."

It took 3.5 years to find sodium phosphates, Postberg said. "We didn't look for phosphates or anything specific; we just wanted to look for something new."

Even then, he and his colleagues had to answer two important questions: Was this analysis reliable, and how could Enceladus have so much more phosphorus in its oceans than Earth does?

Over the next year and a half, part of the team performed geochemical experiments and modeling to answer those questions. They showed that assuming the rocky seabed of Enceladus has a chemical makeup similar to that of most meteorites and many comets, an alkaline ocean like Enceladus's would dissolve the amounts of phosphates measured in the plumes.

Postberg cautioned that none of the data so far have contained clear signatures for the sixth essential element for all known life: sulfur.

As both Postberg and Hörst pointed out, Enceladus bears similarities to many other icy moons in the outer solar system, including Saturn's moon Titan and Jupiter's moon Europa. If the geological and chemical conditions for life are widely present on these worlds, that raises the distinct possibility that life-bearing worlds very different from Earth are common in the cosmos.

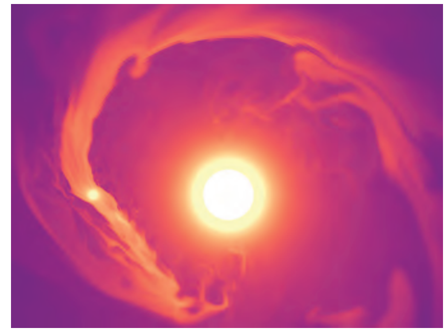
By **Matthew R. Francis** (@DrMRFrancis), Science Writer

A Planet Is Dramatically Losing Its Atmosphere

Earth's atmosphere is just a thin veneer of gas. Despite its seemingly ephemeral nature, however, our atmosphere, for the most part, isn't going anywhere. That's not the case for all planets.

Scientists observing a distant exoplanet recently found vast quantities of helium rapidly streaming away from the planet's upper atmosphere. Filaments of gas several million kilometers long stretch away from the distant world, a finding that highlights the dynamic nature of planetary systems.

About 900 light-years away, a Jupiter-sized gas planet orbits HAT-P-32, a run-of-the-mill star slightly hotter than the Sun. But this star's planetary system looks nothing like our own: There's just one planet, HAT-P-32b, and it orbits far closer to its host star than even Mercury orbits the Sun. (HAT-P-32b completes an orbit—that is, a planetary year—in just over 50 hours, or more than 40 times faster than Mercury.)



This simulated image shows gigantic streams of helium escaping the atmosphere of planet HAT-P-32b as it orbits its host star. Credit: M. MacLeod (Harvard-Smithsonian Center for Astrophysics) and A. Oklopčić (Anton Pannekoek Institute for Astronomy, University of Amsterdam)

Scientists observing a distant exoplanet recently found vast quantities of helium rapidly streaming away from the planet's upper atmosphere.

Follow the Gas

Because HAT-P-32b orbits so close to its host star, it's constantly bombarded with high levels of radiation. All that energy dumping onto the planet has a striking outcome: Hydrogen and helium gases are streaming away from HAT-P-32b's upper atmosphere. To better understand where all that gas is going, Zhoujian Zhang, an astronomer at the University of California, Santa Cruz, and his colleagues trained the University of Texas at Austin's Hobby-Eberly Telescope on the HAT-P-32 system.

The researchers opted to observe the planet over its full orbit, timing their observations precisely so that their data captured views of HAT-P-32b when it was not only directly in front of its host star but also off to both sides and behind it.

Previous observations of the HAT-P-32 system have typically focused only on recording transits, when the planet is directly in front of the star, as seen from Earth. "It's rare for people to cover the full orbital period," Zhang said.

Transit observations reveal information about only a small portion of HAT-P-32b's orbit. To look for evidence of material at different points in the planet's orbit, it's obviously necessary to look over the entire 360°, Zhang said. "If we only focus on the planet's transit, then we would miss the chance to determine whether the planet's escaping atmosphere is extended."

A Two-Tailed Planet

The researchers' persistence paid off: The spectrographic data they amassed confirmed that not only was helium streaming away from HAT-P-32b but also the gas extended even farther in space than previously believed. (The instrument the researchers used was sensitive to only helium, not hydrogen.) The new observations were most consistent with simulations that modeled two tails of helium gas extending from HAT-P-32b, one ahead of the planet in its orbit and one behind.

Other planets with trailing tails of gas have been spotted, but HAT-P-32b is the first extrasolar planet known to have both leading and trailing tails. "It's pretty special," said

Zhang, who, along with his colleagues, reported the new results in *Science Advances* (bit.ly/exoplanet-tails).

Together, the projected length of those two tails is more than 6 million kilometers, or more than 50 times the radius of the planet, the team calculated. That's astonishingly large, said Stefan Czesla, an astronomer at the Karl Schwarzschild Observatory in Tautenburg, Germany, who was not involved in the research but has extensively studied the HAT-P-32 system. "It's a huge structure," he said.

One Trillion Kilograms per Second

Zhang and his team also used their computer simulations to estimate the rate at which helium is escaping from HAT-P-32b's upper atmosphere. They calculated that more than 1 trillion kilograms of helium are streaming away from the planet every second. That's orders of magnitude more than the paltry 50 or so grams of helium lost each second by Earth's atmosphere.

Despite the prodigious rate of escape, it would still take well over a billion years for HAT-P-32b to lose its atmosphere entirely, the researchers calculated. And even that's not likely to happen, Czesla pointed out, because the star in the system will probably die before then. The gas's rate of escape means that the atmosphere will remain "longer than the star will live," he said.

"It's rare for people to cover the full orbital period."

HAT-P-32b is a dramatic example of a planet losing its atmosphere. By studying more worlds like this one, astronomers might be able to solve a long-standing mystery, Zhang said. Scientists have long been baffled by a relative dearth of Neptune-mass planets with close orbits around their stars. One idea is that these planets are literally disappearing, molecule by molecule, as their atmospheres are stripped away by high-energy radiation. "Mass loss is one of the scenarios that can explain the observations," Zhang said.

By **Katherine Kornei** (@KatherineKornei), Contributing Writer

Rocky Exoplanet May Have a Magnetic Field

Astronomers have detected radio bursts from a small red star that might be caused by magnetic interactions between the star and one of its planets. If future observations reveal more of this activity, the Earth-sized planet would be the first rocky exoplanet discovered to have a magnetic field.

"It's potentially important for planets to have a magnetic field because it can play a role in whether those planets are habitable," said J. Sebastian Pineda, an astrophysicist at the University of Colorado Boulder. Pineda is the lead author of the *Nature Astronomy* paper that reported the discovery (bit.ly/star-radio-bursts).

So far, astronomers have detected magnetic fields around a few giant-sized gaseous exoplanets. The discovery of such a field surrounding a rocky exoplanet would offer insight into the interior structure, atmospheric evolution, and potential for life of Earth-sized planets.

Stellar Space Weather

A magnetic field can be both a burden and a boon to a planet, said coauthor Jackie Villadsen, a radio astronomer at Bucknell University in Lewisburg, Pa. It's like bringing a shield to a water balloon fight: The shield makes you a bigger target, and even though you are protected from a direct hit, you might still get splashed around the shield's edges.

Similarly, a magnetosphere can increase the chance that particles from a stellar flare interact with the planet. But it also fends off some of those particles traveling along a star's magnetic field lines by bending those lines around the planet.

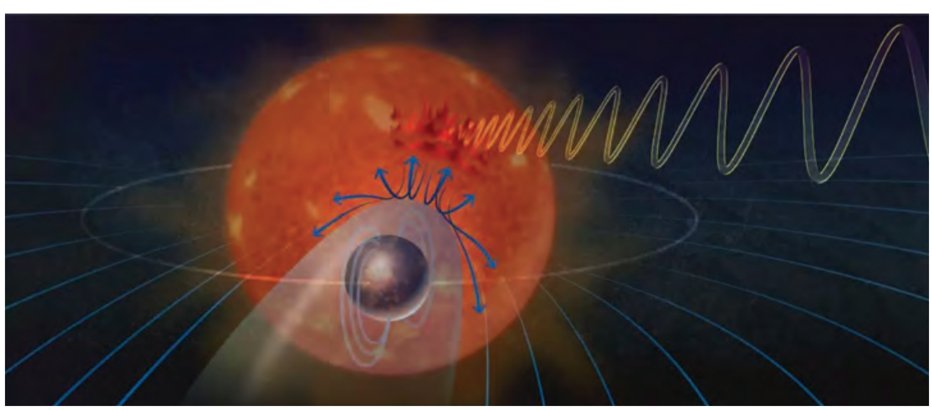
When the latter happens, the particles release energy that can travel back to the star and cause ripples in the stellar magnetic field lines, like plucking a guitar string, Villadsen explained. Those ripples can create a detectable burst of radio energy.

Using the Very Large Array radio telescope in New Mexico, Pineda and Villadsen searched for radio bursts from the nearby red dwarf star YZ Ceti. The star is just 12 light-years away and has three known exoplanets.

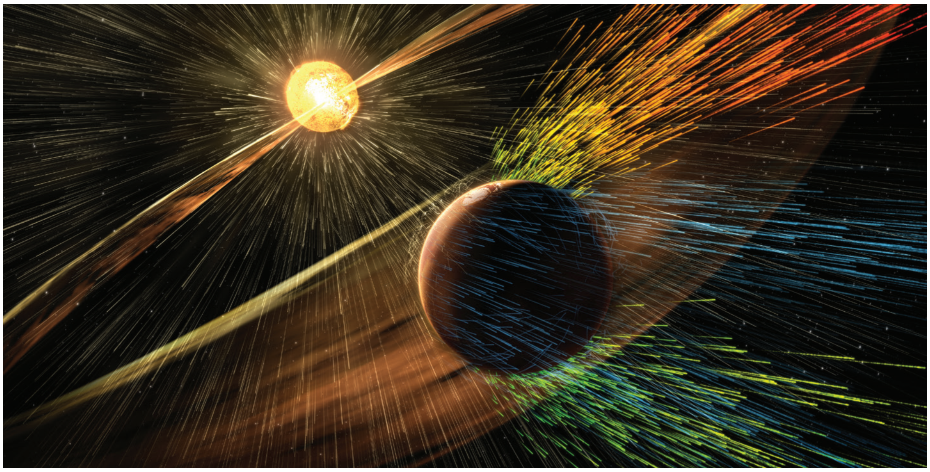
The first several radio bursts they saw were not so strange, the researchers said. Small red stars can be quite active. And though the star is older than the most active stars of similar size, it's plausible that it still produces strong flares.

But a subsequent burst caught the team's attention because it occurred just 2 days after a prior one. That interval matches the orbital period of the star's innermost planet, YZ Ceti b, which is 70% of Earth's mass and probably rocky.

"The radio waves themselves are coming from near the star's surface," like an aurora in the star's atmosphere, Pineda said. The timing suggests that an interaction between stellar wind and YZ Ceti b's magnetic field might have caused the bursts. This stellar space weather could be the first evidence of a magnetic field generated by a rocky exoplanet.



During star-planet magnetic interactions, stellar plasma (blue lines) is deflected by the exoplanet's magnetic field (blue arrows). That interaction bends the star's magnetic field and generates energy that can turn back toward the star. If that energy reaches the star, it can create auroras and release radio waves (yellow waves). Credit: National Science Foundation/Alice Kitterman



Magnetic fields can protect a planet's atmosphere from being stripped away by a star's wind. Mars, illustrated above, lacks such a protective field and has lost much of its atmosphere to solar wind. Credit: NASA/GSFC, Public Domain

The study "is a nice piece of work," said Philippe Zarka, an astrophysicist at Observatoire de Paris who was not involved with the new research. The two clear bursts are consistent with astronomers' understanding of how stars and planets interact magnetically, he noted.

But to confirm, the team would need to monitor the star over a long period of time, Villadsen said. If it releases a radio burst every time YZ Ceti b returns to the same spot, the bursts are probably caused by the planet's magnetic field. That would be the "absolute smoking gun," Zarka said.

Know the Star, Know the Planet

The researchers could not definitively say that YZ Ceti b has a magnetic field, in part because so little is known about flares coming from older red dwarf stars such as YZ Ceti. Their flares may produce these kinds of radio bursts all on their own.

Past studies have discovered magnetic star-planet interactions for Sun-like stars whose magnetic properties are better understood. "This experiment has yet to be done for small rocky planets around low-mass stars like YZ Ceti," explained Evgenya Shkolnik, "but this study is an important, early step." Shkolnik is an astrophysicist at Arizona State University and was not involved with this research.

"The good news is that planetary magnetic fields are ubiquitous in our own solar system," Shkolnik added, "so they should also be so in exoplanetary systems."

Studying flares and radio bursts from many stars like YZ Ceti will clarify how these kinds of stars typically behave and help researchers home in on planet-generated radio bursts.

"Ultimately, radio telescopes that monitor a wider portion of the sky will be really valuable," Villadsen said. As would a space-based radio telescope, which could measure the magnetic field–generated radio signal from the planet rather than from the star, said Cornell University scientist Jake Turner, who studies exoplanet magnetic fields and atmospheres and was not involved in the new study. (Earth's atmosphere blocks those lower-energy radio signals from reaching ground-based radio instruments.)

An adage guides exoplanet researchers: To understand the planet, you have to first understand the star.

"'Know the star, know the planet' is really, really true here," Pineda said. "But it's going to require expanding 'know the star' to all sorts of things that so far haven't been the focus for studying exoplanets."

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer