# South Downs Mercury

**The monthly circular of South Downs Astronomical Society**
**Issue: 600 – October 3rd 2025 Editor: Roger Burgess**

**Main Talk. Owen Brazell "Galaxy clusters"**

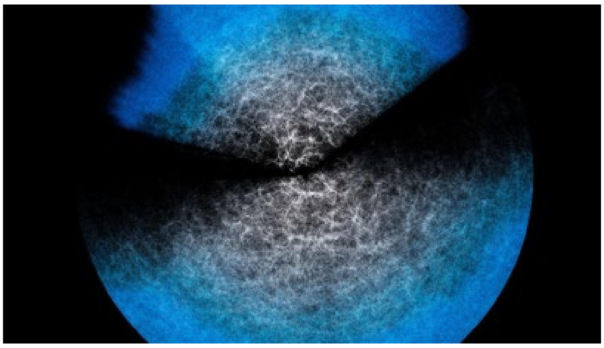
Bio:

Owen has been interested in astronomy from an early age and got his first telescope when he was ten years old so has been involved in astronomy for over 50 years. He did an astronomy O level, probably the only time he used a Patrick Moore book, and this led to him doing an Honours degree in Astronomy at St Andrews University and then a part time MSc from Queen Mary college but has spent his working life in the oil exploration industry. Nevertheless, he has found time to be on the council of the British Astronomical Association a number of times and was deputy director of its deep sky section for 20 years. He now holds the post of President of the Webb Society and is also chairman of Abingdon AS. He has also been on the council of the FAS. His main interests are in visual deep sky observing which he does with a variety of telescopes up to 22" in aperture. He also has an interest in observing comets and in solar observing. He has given talks on various aspects deep sky observing to many societies and has written a monthly deep sky column in the Astronomy Now magazine for many years. He also writes a monthly Galaxy of the Month column for the Webb Society website. He has also contributed material to a number of books

**Please support a raffle we are organizing this month.**

- Cosmic simulations that once needed supercomputers now run on a laptop

Effort.jl, a powerful new emulator, can match complex models with astonishing speed and accuracy, running on something as ordinary as a laptop.
Date: September 18, 2025
Source: Sissa Medialab



Two 'fans' corresponding to the two main areas DESI has observed, above and below the plane of our Milky Way (see this map). DESI is mounted on the U.S. National Science Foundation Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory (KPNO), a Program of NSF NOIRLab. DESI has made the largest 3D map of our Universe to date and uses it to study dark energy. Earth is at the centre of the two fans, where bluer points indicate more distant objects. This is a still from an animated rotation of the DESI Year-3 data map. Credit: DESI Collaboration/DOE/KPNO/NOIRLab/NSF/AURA/R. Proctor

If you think a galaxy is big, compare it to the size of the Universe: it's just a tiny dot which, together with a huge number of other tiny dots, forms clusters that aggregate into superclusters, which in turn weave into filaments threaded with voids -- an immense 3D skeleton of our Universe.
If that gives you vertigo and you're wondering how one can understand or even "see" something so vast, the answer is: it isn't easy. Scientists combine the physics of the Universe with data from astronomical instruments and build theoretical models, such as EFTofLSS (Effective Field Theory of Large-Scale Structure). Fed with observations, these models describe the "cosmic web" statistically and allow its key parameters to be estimated.
Models like EFTofLSS, however, demand a lot of time and computing resources. Since the astronomical datasets at our disposal are growing exponentially, we need ways to lighten the analysis without losing precision. This is why emulators exist: they "imitate" how the models respond, but operate much faster.
Since this is a kind of "shortcut," what's the risk of losing accuracy? An international team including, among others, INAF (Italy), The University of Parma (Italy) and the University of Waterloo (Canada) has published in the Journal of Cosmology and Astroparticle Physics (JCAP) a study testing the emulator Effort.jl, which they designed. It shows that Effort.jl delivers essentially the same

correctness as the model it imitates -- sometimes even finer detail -- while running in minutes on a standard laptop instead of a supercomputer.
"Imagine wanting to study the contents of a glass of water at the level of its microscopic components, the individual atoms, or even smaller: in theory you can. But if we wanted to describe in detail what happens when the water moves, the explosive growth of the required calculations makes it practically impossible," explains Marco Bonici, a researcher at the University of Waterloo and first author of the study. "However, you can encode certain properties at the microscopic level and see their effect at the macroscopic level, namely the movement of the fluid in the glass. This is what an effective field theory does, that is, a model like EFTofLSS, where the water in my example is the Universe on very large scales and the microscopic components are small-scale physical processes."
The theoretical model statistically explains the structure that gives rise to the data collected: the astronomical observations are fed to the code, which computes a "prediction." But this requires time and substantial compute. Given today's data volume -- and what is expected from surveys just begun or coming soon (such as DESI, which has already released its first batch of data, and Euclid) -- it's not practical to do this exhaustively every time.
"This is why we now turn to emulators like ours, which can drastically cut time and resources," Bonici continues. An emulator essentially mimics what the model does: its core is a neural network that learns to associate the input parameters with the model's already-computed predictions. The network is trained on the model's outputs and, after training, can generalize to combinations of parameters it hasn't seen. The emulator doesn't "understand" the physics itself: it knows the theoretical model's responses very well and can anticipate what it would output for a new input. Effort.jl's originality is that it further reduces the training phase by building into the algorithm knowledge we already have about how predictions change when parameters change: instead of making the network "re-learn" these, it uses them from the start. Effort.jl also uses gradients -- i.e., "how much and in which direction" predictions change if you tweak a parameter by a tiny amount -- another element that helps the emulator learn from far fewer examples, cutting compute needs and allowing it to run on smaller machines.
A tool like this needs extensive validation: if the emulator doesn't know the physics, how sure are we that its shortcut yields correct answers (i.e., the same ones the model would give)? The newly published study answers exactly this, showing that Effort.jl's accuracy -- on both simulated and real data -- is in close agreement with the model. "And in some cases, where with the model you have to trim part of the analysis to speed things up, with Effort.jl we were able to include those missing pieces as well," Bonici concludes. Effort.jl thus emerges as a valuable ally for analysing upcoming data releases from experiments like DESI and Euclid, which promise to greatly deepen our knowledge of the Universe on large scales.
The study "Effort.jl: a fast and differentiable emulator for the Effective Field Theory of the Large-Scale Structure of the Universe" by Marco Bonici, Guido D'Amico, Julien Bel and Carmelita Carbone is available in the *Journal of Cosmology and Astroparticle Physics (JCAP)*.

- The Moon could finally reveal dark matter

Date: September 18, 2025
Source: Kavli Institute for the Physics and Mathematics of the Universe

A NASA artist's illustration of Artemis astronauts working on the Moon. Credit: NASA

An international research collaboration has used advanced computer simulations to investigate how faint radio signals from the early Universe, soon to be observed from missions on the far side of the Moon, could shed light on the fundamental properties of dark matter, reports a new study published in *Nature Astronomy* on September 16, 2025.
Ordinary matter, which makes up the stars, planets, and everything we can see, makes up only about 20 per cent of all matter in the Universe. The remaining 80 per cent is believed to be dark matter: a mysterious substance that does not emit, absorb, or reflect

light, and whose true nature remains one of the greatest unsolved problems in modern physics. Despite its invisibility, dark matter is known to play a vital role in the formation of galaxies, such as the Milky Way, and in shaping the large-scale structure of the Universe.

One of the key properties of dark matter is the mass of its constituent particles. If these particles are relatively light, such as less than about 5 per cent of electron mass, then dark matter is considered warm and would inhibit the formation of structures smaller than galaxies. However, if the particles are heavier, dark matter is classified as cold, which would promote the growth of smaller-scale structures.

Astronomers have long sought to determine the dark matter particle mass by studying small-scale structures composed of gas and stars because this information is crucial for particle physicists to develop theoretical models of dark matter.

A new study led by The University of Tsukuba Postdoctoral Fellow Hyunbae Park, who carried out this study during his time as a University of Tokyo Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI) Project Researcher, and including Kavli IPMU Professor and Max Planck Insitute for Astrophysics Visiting Scientist Naoki Yoshida, focused on small gas clouds that existed during the cosmic Dark Ages, the first 100 million years after the Big Bang before the formation of stars and galaxies. Because the formation and evolution of stars and galaxies involve complex and poorly understood processes, simulating their behaviour accurately remains a major challenge in modern computational astrophysics. By targeting an era before these complexities arose, the researchers were able to simulate early cosmic structures with unprecedented precision.

The simulation results revealed how gas gradually cooled as the Universe expanded while developing small gas clumps via gravitational interaction with dark matter during the Dark Ages. The gas in these clumps became much denser than in the average Universe and heated up due to compression. This variation in density and temperature was imprinted in the 21-centimeter radio emission from hydrogen atoms. The team modelled this ancient signal from the primordial gas clouds and found that its sky-averaged strength depends sensitively on whether dark matter is warm or cold. According to the researchers, this difference could allow future lunar experiments to distinguish between competing dark matter scenarios.

The Dark Ages signal is expected to appear at frequencies around 50 MHz or lower with a characteristic frequency modulation, and the difference between the two dark matter scenarios is less than a milli-kelvin in brightness temperature. These frequencies are heavily contaminated by human-made signals on Earth, and further obscured by the ionosphere making it virtually impossible to detect the signal from ground-based observatories. In contrast, the far side of the Moon offers a radio-quiet environment, shielded from terrestrial interference, and is considered an ideal location for detecting the elusive Dark Ages signal.

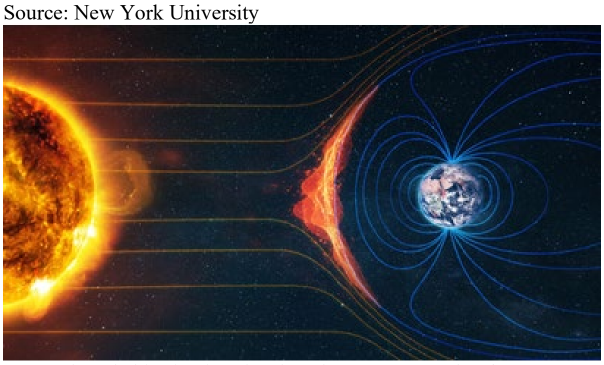
Although building radio observatories on the Moon poses major technological and financial challenges, an increasing number of nations are pursuing such missions as part of the new space race, combining scientific ambition with technological advancement. With this growing international momentum, it is now considered feasible to determine the mass of dark matter particles through lunar-based observations in the coming decades. Among these nations, Japan is actively developing the Tsukuyomi project, which plans to deploy radio antennas on the Moon.

The team's research provides essential theoretical guidance for these near-future missions to maximize their scientific return.

- This new AI can spot solar storms days before they strike

Breakthrough improves early warnings to protect satellites and power grids

Date: September 17, 2025
Source: New York University



NYU Abu Dhabi scientists developed an AI system that forecasts solar wind with 45% better accuracy than current models. This breakthrough strengthens defences against space weather that threatens satellites and critical infrastructure. Credit: Shutterstock

Scientists at NYU Abu Dhabi (NYUAD) have developed an artificial intelligence (AI) model that can forecast solar wind speeds up to four days in advance, significantly more accurately than current methods. The study is published in *The Astrophysical Journal Supplement Series.*

Solar wind is a continuous stream of charged particles released by the Sun. When these particles speed up, they can cause "space weather" events that disrupt Earth's atmosphere and drag satellites out of orbit, damage their electrons, and interfere with power grids. In 2022, a strong solar wind event caused SpaceX to lose 40 Starlink satellites, showing the urgent need for better forecasting.

The NYUAD team, led by Postdoctoral Associate Dattaraj Dhuri and Co-Principal Investigator at the Centre for Space Science (CASS) Shravan Hanasoge, trained their AI model using high-resolution ultraviolet (UV) images from NASA's Solar Dynamics Observatory, combined with historical records of solar wind. Instead of analysing text, like today's popular AI language models, the system analyses images of the Sun to identify patterns linked to solar wind changes. The result is a 45 percent improvement in forecast accuracy compared to current operational models, and a 20 percent improvement over previous AI-based approaches.

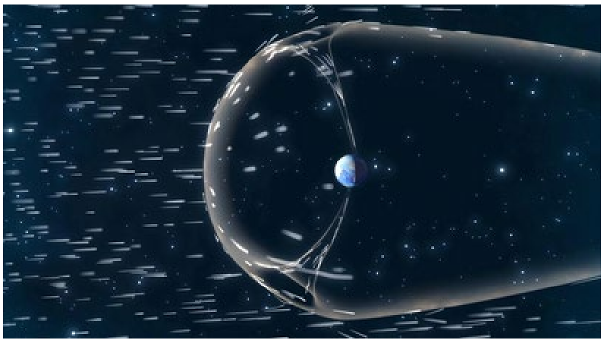
"This is a major step forward in protecting the satellites, navigation systems, and power infrastructure that modern life depends on," said Dhuri, lead author of the study. "By combining advanced AI with solar observations, we can give early warnings that help safeguard critical technology on Earth and in space."

The breakthrough demonstrates how AI can solve one of space science's toughest challenges: predicting the solar wind. With more reliable forecasts, scientists and engineers can better prepare for space weather events, strengthening resilience against disruptions to critical infrastructure.

NYU Abu Dhabi has established more than 90 faculty labs and projects, producing over 9,200 internationally recognized research publications. Times Higher Education ranks NYU among the world's top 35 universities, making NYUAD the highest globally ranked university in the UAE

- To better understand the long-term impact of increasing rocket emissions, we collaborated with an international research team led by Laura Revell from the University of Canterbury. Using a chemistry climate model developed at ETH Zurich and the Physical Meteorological ObservNASA spacecraft detect a mysterious force shaping the solar wind

Date: September 11, 2025
Source: Southwest Research Institute



This illustration shows Earth’s magnetosphere interacting with the solar wind. The magnetosphere shields the Earth from harmful solar and cosmic radiation. Credit: NASA Goddard/CIL/Josh Masters

A new study led by Southwest Research Institute’s Dr. Michael Starkey has provided observational evidence from the SwRI-led Magnetospheric Multiscale (MMS) Mission of pickup ions (PUIs) and associated wave activity in the near-Earth solar wind environment. The MMS mission, launched by NASA in 2015, placed four spacecraft in orbit to observe Earth’s magnetosphere, a magnetic field around the planet that shields it from harmful solar and cosmic radiation.

PUIs are formed when neutral particles flowing through the heliosphere are ionized in the solar wind. These PUIs are dragged along with the solar wind and gyrate around the local magnetic field, forming a distinct plasma population with different characteristics from the typical solar wind population.

The PUIs were observed to have a typical velocity distribution absent of any other significant energetic ion or electron populations. The wave activity was identified using magnetic field data from MMS combined with theoretical analysis of the expected wave growth modes based on models of the observed PUIs.

“The results of this study indicate that PUIs can in fact generate waves in the solar wind near Earth and motivate the need for further statistical studies of these processes,” Starkey said. “It may be that PUIs play a larger role in the heating and thermalization of the solar wind near Earth than previously thought, which would have large implications for models of the solar wind throughout the heliosphere."

By modelling the individual ion components (solar wind and PUIs), the authors identified which populations could be responsible for the observed wave activity. They concluded that the observed waves were likely generated by helium and/or hydrogen PUIs but, due to instrument limitations, they were unable to pinpoint the precise ion species responsible.

At farther distances from the Sun, the relative density of PUIs in the solar wind increases, which increases their contribution toward the heating and thermalization of the solar wind through wave-particle interactions. At the outer edges of the solar system, PUIs contribute significantly to the total dynamic pressure in the solar wind, which has large implications for physical processes taking place at the termination shock and in the heliosheath.

"Near Earth, the intensity of PUIs is relatively low, and so it is typically assumed that their contribution to wave-particle interactions in the solar wind is negligible," Starkey added. "If this assumption is false, current theory and modelling of the solar wind and its evolution throughout the heliosphere would need to be updated."

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- Rapid rocket growth raises alarm over Earth's fragile ozone layer

Date: September 15, 2025
Source: ETH Zurich

Falcon Heavy, a reusable heavy-lift launch vehicle from SpaceX, in flight for the first time on 6th February 2018. Credit: SpaceX / Keystone

The rapid rise in global rocket launches could slow the recovery of the vital ozone layer, says Sandro Vattioni. The problem is being underestimated - yet it could be mitigated by forward-looking, coordinated action.

In recent years, the night sky has filled with satellites from rapidly expanding constellations in low Earth orbit, driven by a booming space industry. While this development brings exciting opportunities, it also raises new environmental concerns.

Rocket launches and re-entering space debris release pollutants into the middle atmosphere, where they can damage the ozone layer which protects life on Earth from harmful UV radiation -- a growing concern that scientists are only beginning to understand.

Research on the effects of rocket emissions on the ozone layer began over 30 years ago, but for a long time, these effects were considered small.[1] This perception is starting to change as launch activity accelerates. In 2019, there were just 97 orbital space rocket launches globally. By 2024, that number had surged to 258, and is expected to keep rising rapidly.[2]

**A long-underestimated concern**

In the middle and upper atmosphere, emissions from rockets and re-entering space debris can remain up to 100 times longer than emissions from ground-based sources due to the absence of removal processes such as cloud-driven washout. While most launches occur in the Northern Hemisphere, atmospheric circulation spreads these pollutants globally.

atory in Davos (PMOD/WRC) we simulated how projected rocket emissions will affect the ozone layer by 2030.[3]

Assuming a growth scenario with 2,040 annual launches in 2030 -- about eight times the figure for 2024 -- global average ozone thickness would decline by almost 0.3%, with seasonal reductions of up to 4% over Antarctica, where the ozone hole still forms each spring.

While these numbers may seem modest at first sight, it's important to remember that the ozone layer is still recovering from past damage caused by long-lived chlorofluorocarbons (CFCs), which were successfully banned by the Montreal Protocol in 1989. Yet today, the thickness of the global ozone layer is still roughly 2% below pre-industrial levels and is not expected to fully recover until around 2066.[4] Our findings indicate that emissions from rockets -- currently unregulated -- could delay this recovery by years or decades, depending on the rocket industry growth.

**With rockets, too, the choice of fuel matters**

The main contributors to ozone depletion from rocket emissions are gaseous chlorine and soot particles. Chlorine catalytically destroys ozone molecules, while soot particles warm the middle atmosphere, accelerating ozone-depleting chemical reactions.

While most rocket propellants emit soot, chlorine emissions primarily come from solid rocket motors. Currently, the only propulsion systems that have a negligible effect on the ozone layer are those which use cryogenic fuels such as liquid oxygen and hydrogen. However, due to the technological complexity of handling cryogenic fuels, only about 6% of rocket launches currently use this technology.[5]

**Re-entry effects are still uncertain**

We would like to mention that our study only considered emissions released from rockets during ascent into space. But this is only part of the picture. Most satellites in low Earth orbit re-enter the atmosphere at the end of their operational life, burning up in the process.

This process generates additional pollutants, including various metal particles and nitrogen oxides, due to the intense heat generated upon re-entry. While nitrogen oxides are known to deplete ozone catalytically, metal particles may contribute to forming polar stratospheric clouds or serve as reaction surfaces themselves, both of which can intensify ozone loss.

These re-entry effects are still poorly understood and not yet incorporated into most atmospheric models. From our point of view, it is clear that with increasing satellite constellations, re-entry emissions will become more frequent, and the total impact on the ozone layer is likely to be even higher than current estimates. Science is called upon to fill these gaps in our understanding.[6]

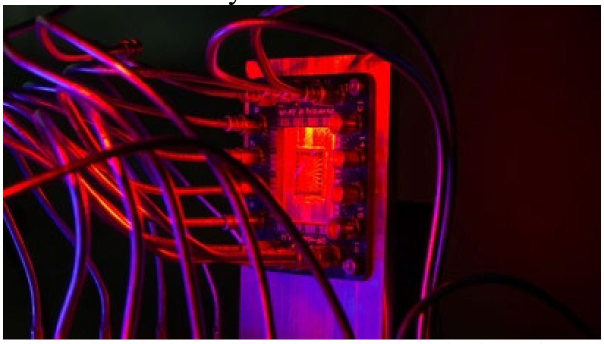
**Needed: Foresight and coordinated action**

But that alone will not be enough. The good news: We believe a launch industry that avoids ozone damaging effects is entirely possible: Monitoring rocket emissions, minimizing the usage of chlorine and soot-producing fuels, promoting alternative propulsion systems, and implementing the necessary and appropriate regulations are all key to ensuring that the ozone layer continues its recovery.[4] This will take coordinated efforts between scientists, policymakers, and industry.

The Montreal Protocol successfully demonstrated that even planetary-scale environmental threats can be addressed through global cooperation. As we enter a new era of space activity, the same kind of foresight and international coordination will be needed to avoid harmful effects on the ozone layer - one of the Earth's most vital natural shields.

- Scientists just built a detector that could finally catch dark matter

Date: September 10, 2025
Source: University of Zurich



Using the improved superconducting nanowire single-photon detector (SNSPD), researchers are searching for very light dark matter. Credit: UZH

About 80 percent of the universe's mass is thought to consist of dark matter. And yet, little is known about the composition and structure of the particles that make up dark matter, presenting physicists with some fundamental questions. To explore this elusive matter, researchers are attempting to capture photons, or light particles, which are produced when dark matter particles collide with the visible matter we are familiar with. Most experiments to date have focused on dark matter particles with masses that more or less overlap with those of known elementary particles. If the particles are lighter than an electron, however, it is unlikely they would be detectable with the current standard, namely detectors based on liquid xenon. So far, no experiment has succeeded in directly detecting dark matter. Yet this in itself is an important finding, as it shows that dark matter particles do not exist within the mass range and interaction strength tested.

**New device sensitive to lower-energy events**

An international team led by Laura Baudis, Titus Neupert, Björn Penning and Andreas Schilling from UZH's Department of Physics has now been able to probe the existence of dark matter particles across a wide mass range below one mega electron volt (MeV). Using an improved superconducting nanowire single-photon detector (SNSPD), the researchers reached a sensitivity threshold of about one-tenth the mass of an electron, above which dark matter particles are highly unlikely to exist. "This is the first time we've been able to search for dark matter particles in such a low mass range, made possible by a

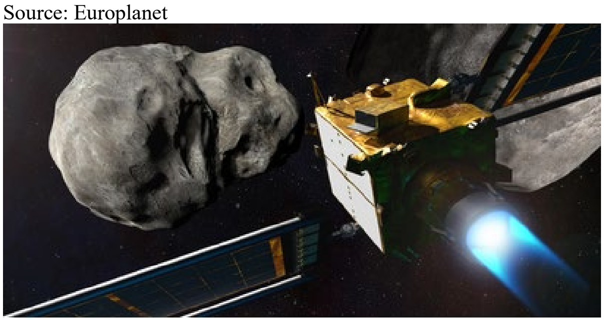
new detector technology," says first author Laura Baudis.
In a 2022 proof of concept, the researchers had tested the first SNSPD device that's highly sensitive to lower-energy photons. When a photon strikes the nanowire, it heats it up slightly and causes it to instantly lose its superconductivity. The wire briefly becomes a regular conductor, and the resulting increase in electrical resistance can be measured.

**Detecting smallest dark matter particles**

For their latest experiment, the UZH scientists optimized their SNSPD for dark matter detection. In particular, they equipped it with superconducting microwires instead of nanowires to maximize its cross section. They also gave it a thin, planar geometry that makes it highly sensitive to changes in direction. Scientists assume that the Earth passes through a "wind" of dark matter particles, and the particle's direction therefore shifts over the course of the year depending on relative velocity. A device capable of picking up directional changes can help to filter out non-dark-matter events.
"Further technological improvements to the SNSPD could enable us to detect signals from dark matter particles with even smaller masses. We also want to deploy the system underground, where it will be better shielded from other sources of radiation," Titus Neupert says. Below the mass range of electrons, current models to describe dark matter face considerable astrophysical and cosmological constraints.

- Hit the wrong spot and an asteroid returns on a collision course

Asteroid deflection could save Earth, or accidentally doom it, depending on where we aim the impact.
Date: September 9, 2025
Source: Europlanet



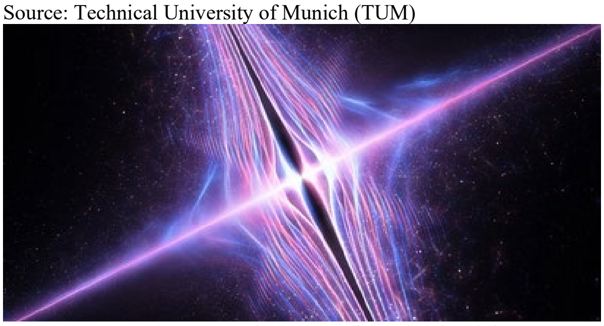
An artwork of NASA’s DART mission, which was a kinetic impactor designed to test whether it is possible to deflect an asteroid. Credit: NASA/Johns Hopkins APL

Selecting the right spot to smash a spacecraft into the surface of a hazardous asteroid to deflect it must be done with great care, according to new research presented at the EPSC-DPS2025 Joint Meeting this week in Helsinki. Slamming into its surface indiscriminately runs the risk of knocking the asteroid through a 'gravitational keyhole' that sends it back around to hit Earth at a later date.
"Even if we intentionally push an asteroid away from Earth with a space mission, we must make sure it doesn't drift into one of these keyholes afterwards. Otherwise, we'd be facing the same impact threat again down the line," said Rahil Makadia, a NASA Space Technology Graduate Research Opportunity Fellow at the University of Illinois at Urbana-Champaign, who is presenting the findings at the EPSC-DPS2025 meeting.
NASA's DART, the Double Asteroid Redirection Test mission, struck the small asteroid Dimorphos, which is in orbit around the larger asteroid Didymos, in September 2022. DART was a 'kinetic impactor' - effectively a projectile that slammed into the asteroid with enough energy to nudge it into a new orbit, thereby proving that it is possible to deflect an asteroid that could be on a collision course with Earth.
A European Space Agency mission called Hera will follow-up on the DART impact when it reaches Didymos and Dimorphos in December 2026.
Where DART struck on Dimorphos was of relatively little concern, since the Didymos system is too massive to be deflected onto a collision course with Earth. However, for another hazardous asteroid orbiting the Sun, even a small variation in its orbit could send it through a gravitational keyhole.
The keyhole effect revolves around a small region of space where a planet's gravity can modify a passing asteroid's orbit such that it returns on a collision course with that planet at a later date. In this way, a gravitational keyhole unlocks more dangerous orbits. Should a kinetic impactor mission similar to DART nudge a hazardous asteroid so that it passes through a gravitational keyhole, then it only postpones the danger.
"If an asteroid passed through one of these keyholes, its motion through the Solar System would steer it onto a path that causes it to hit Earth in the future," said Makadia.
The trick, therefore, is to find the best spot on the surface of an asteroid to impact with a spacecraft so that the chances of pushing it through the keyhole are minimized.

Each point on the surface of an asteroid has a different probability of sending the asteroid through a gravitational keyhole after deflection by a kinetic impactor. Makadia's team has therefore developed a technique for computing probability maps of an asteroid's surface. Their method uses the results from DART as a guide, although each asteroid, with its own characteristics, will be subtly different.
The asteroid's shape, surface topology (hills, craters etc), rotation and mass all must be determined first. Ideally this would be done with a space mission to rendezvous with the asteroid, producing high-resolution images and data. However, this might not be possible for all threatening asteroids, particularly if the time between discovery and impact on Earth is short.
"Fortunately, this entire analysis, at least at a preliminary level, is possible using ground-based observations alone, although a rendezvous mission is preferred," said Makadia.
By computing the subsequent trajectory of the asteroid following a kinetic impact, and seeing which trajectories would be the most dangerous, scientists can calculate where the safest location to strike on the asteroid's surface will be.
"With these probability maps, we can push asteroids away while preventing them from returning on an impact trajectory, protecting the Earth in the long run," said Makadia.

- Google’s quantum computer just simulated the hidden strings of the Universe

Date: August 25, 2025
Source: Technical University of Munich (TUM)


Google’s quantum processor has successfully simulated the behaviour of particles and their hidden strings, marking a leap forward in exploring the universe’s fundamental laws. Credit: Shutterstock

The research, published in the academic journal *Nature*, represents an essential step in quantum computing and demonstrates its potential by directly simulating fundamental interactions with Google's quantum processor. In the future, researchers could use this approach to gain deeper insights into particle physics, quantum materials, and even the nature of space and time itself. The aim is to understand how nature works at its most fundamental level, described by so-called gauge theories.
"Our work shows how quantum computers can help us explore the fundamental rules that govern our universe," says co-author Michael Knap, Professor of Collective Quantum Dynamics at the TUM School of Natural Sciences. "By simulating these interactions in the laboratory, we can test theories in new ways."
Pedram Roushan, co-author of this work from Google Quantum AI emphasizes: "Harnessing the power of the quantum processor, we studied the dynamics of a specific type of gauge theory and observed how particles and the invisible 'strings' that connect them evolve over time."
Tyler Cochran, first author and graduate student at Princeton, says: "By adjusting effective parameters in the model, we could tune properties of the strings. They can fluctuate strongly, become tightly confined, or even break." He explains that the data from the quantum processor reveals the hallmark behaviours of such strings, which have direct analogues to phenomena in high-energy particle physics. The results underscore the potential for quantum computers to facilitate scientific discovery in fundamental physics and beyond.
The research was supported, in part, by the UK Research and Innovation (UKRI) under the UK government’s Horizon Europe funding guarantee [grant number EP/Y036069/1], the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany’s Excellence Strategy–EXC–2111–390814868, TRR 360 – 492547816, DFG grants No. KN1254/1-2, KN1254/2-1, DFG FOR 5522 Research Unit (project id 499180199), the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement No. 851161 and No. 771537), the European Union (grant agreement No 101169765), as well as the Munich Quantum Valley, which is supported by the Bavarian state government with funds from the Hightech Agenda Bayern Plus.

- A star torn apart by a black hole lit up the Universe twice

Machine learning enables real-time detection of fleeting anomalies before they fade away.
Date: August 22, 2025
Source: University of California, Santa Cruz

Artistic depiction of the explosive interaction between the black hole and the massive nearby star (blue). As the separation between the star and the black hole decreased, the black hole's intense gravity pulled gas and dust off of the star into a disk. Before the star was able to swallow the black hole, gravitational stress from the black hole triggered the star's explosion. Collisions between the stellar explosion and shells of material from earlier interactions located above and below the disk, powered a dramatic re-brightening event. Credit: Melissa Weiss/CfA

Key Takeaways

- Astronomers used a UC Santa Cruz-led AI system to detect a rare supernova, SN 2023zkd, within hours of its explosion, allowing rapid follow-up observations before the fleeting event faded.
- Evidence suggests the blast was triggered by a massive star's catastrophic encounter with a black hole companion, either partially swallowing the star or tearing it apart before it could explode on its own.
- Researchers say the same real-time anomaly-detection AI used here could one day be applied to fields like medical diagnostics, national security, and financial-fraud prevention.

The explosion of a massive star locked in a deadly orbit with a black hole has been discovered with the help of artificial intelligence used by an astronomy collaboration led by the University of California, Santa Cruz, that hunts for stars shortly after they explode as supernovae.

The blast, named SN 2023zkd, was first discovered in July 2023 with the help of a new AI algorithm designed to scan for unusual explosions in real time. The early alert allowed astronomers to begin follow-up observations immediately -- an essential step in capturing the full story of the explosion.

By the time the explosion was over, it had been observed by a large set of telescopes, both on the ground and from space. That included two telescopes at the Haleakalāa Observatory in Hawaiʻi used by the Young Supernova Experiment (YSE) based at UC Santa Cruz.

"Something exactly like this supernova has not been seen before, so it might be very rare," said Ryan Foley, associate professor of astronomy and astrophysics at UC Santa Cruz. "Humans are reasonably good at finding things that 'aren't like the others,' but the algorithm can flag things earlier than a human may notice. This is critical for these time-sensitive observations."

Time-bound astrophysics

Foley's team runs YSE, which surveys an area of the sky equivalent to 6,000 times the full moon (4% of the night sky) every three days and has discovered thousands of new cosmic explosions and other astrophysical transients -- dozens of them just days or hours after explosion.

The scientists behind the discovery of SN 2023zkd said the most likely interpretation is that a collision between the massive star and the black hole was inevitable. As energy was lost from the orbit, their separation decreased until the supernova was triggered by the star's gravitational stress as it was partially swallowed the black hole.

The discovery was published on August 13 in the *Astrophysical Journal*. "Our analysis shows that the blast was sparked by a catastrophic encounter with a black hole companion, and is the strongest evidence to date that such close interactions can actually detonate a star," said lead author Alexander Gagliano, a fellow at the NSF Institute for Artificial Intelligence and Fundamental Interactions.

An alternative interpretation considered by the team is that the black hole completely tore the star apart before it could explode on its own. In that case, the black hole quickly pulled in the star's debris and bright light was generated when the debris crashed into the gas surrounding it. In both cases, a single, heavier black hole is left behind.

An unusual, gradual glow up

Located about 730 million light-years from Earth, SN 2023zkd initially looked like a typical supernova, with a single burst of light. But as the scientists tracked its decline over several months, it did something unexpected: It brightened again. To understand this unusual behaviour, the scientists analysed archival data, which showed something even

more unusual: The system had been slowly brightening for more than four years before the explosion. That kind of long-term activity before the explosion is rarely seen in supernovae.
Detailed analysis done in part at UC Santa Cruz revealed that the explosion's light was shaped by material the star had shed in the years before it died. The early brightening came from the supernova's blast wave hitting low-density gas. The second, delayed peak was caused by a slower but sustained collision with a thick, disk-like cloud. This structure -- and the star's erratic pre-explosion behaviour -- suggest that the dying star was under extreme gravitational stress, likely from a nearby, compact companion such as a black hole.
Foley said he and Gagliano had several conversations about the spectra, leading to the eventual interpretation of the binary system with a black hole. Gagliano led the charge in that area, while Foley played the role of "spectroscopy expert" and served as a sounding board -- and often, sceptic.
At first, the idea that the black hole triggered the supernova almost sounded like science fiction, Foley recalled. So, it was important to make sure all of the observations lined up with this explanation, and Foley said Gagliano methodically demonstrated that they did.
"Our team also built the software platform that we use to consolidate data and manage observations. The AI tools used for this study are integrated into this software ecosystem," Foley said. "Similarly, our research collaboration brings together the variety of expertise necessary to make these discoveries."
Co-author Enrico Ramirez-Ruiz, also a professor of astronomy and astrophysics, leads the theory team at UC Santa Cruz. Fellow co-author V. Ashley Villar, an assistant professor of astronomy in the Harvard Faculty of Arts and Sciences, provided AI expertise. The team behind this discovery was led by the Centre for Astrophysics | Harvard & Smithsonian and the Massachusetts Institute of Technology as part of YSE.
This work was funded by the National Science Foundation, NASA, the Moore Foundation, and the Packard Foundation. Several students, including Gagliano, are or were NSF graduate research fellows, Foley said.

Societal costs of uncertainty
But currently, Foley said the funding situation and outlook for continued support is very uncertain, forcing the collaboration to take fewer risks, resulting in decreased science output overall. "The uncertainty means we are shrinking," he said, "reducing the number of students who are admitted to our graduate program -- many of them being forced out of the field or to take jobs outside the U.S."
Although predicting the path this AI approach will take is difficult, Foley said this research is cutting edge. "You can easily imagine similar techniques being used to screen for diseases, focus attention for terrorist attacks, treat mental health issues early, and detect financial fraud," he explained. "Anywhere real-time detection of anomalies could be useful, these techniques will likely eventually play a role."

- A record-breaking antenna just deployed in space. Here’s what it will see

Date: August 18, 2025
Source: NASA's Jet Propulsion Laboratory

The NISAR satellite uses a radar antenna reflector that’s 39 feet (12 meters) in diameter to gather information about Earth’s changing surface. The mission scans nearly all the planet’s land and ice surfaces twice every 12 days. Credit: NASA/JPL-Caltech

Seventeen days after NISAR's launch from southeastern India, an essential piece of science hardware has unfurled in orbit. Spanning 39 feet (12 meters), the drum-shaped antenna reflector on the NISAR (NASA-ISRO Synthetic Aperture Radar) satellite mission from NASA and the Indian Space Research Organisation (ISRO) successfully unfurled in low Earth orbit. The reflector had been stowed, umbrella-like, until the 30-foot (9-meter) boom that supports it could be deployed and locked in place.
Launched by ISRO on July 30 from the Satish Dhawan Space Centre on India's southeastern coast, NISAR will track the motion of ice sheets and glaciers, the deformation of land due to earthquakes, volcanoes, and landslides, and changes in forest and wetland ecosystems down to fractions of an inch. It also will aid

decision-makers in fields as diverse as disaster response, infrastructure monitoring, and agriculture.

"The successful deployment of NISAR's reflector marks a significant milestone in the capabilities of the satellite," said Karen St. Germain, director, Earth Science Division at NASA Headquarters in Washington. "From innovative technology to research and modelling to delivering science to help inform decisions, the data NISAR is poised to gather will have a major impact on how global communities and stakeholders improve infrastructure, prepare for and recover from natural disasters, and maintain food security."

The mission carries the most sophisticated radar systems ever launched as part of a NASA mission. In a first, the satellite combines two synthetic aperture radar (SAR) systems: an L-band system that can see through clouds and forest canopy, and an S-band system that can see through clouds as well but is more sensitive to light vegetation and moisture in snow. The reflector plays a key role for both systems, which is why the successful deployment of the hardware is such a significant milestone.

"This is the largest antenna reflector ever deployed for a NASA mission, and we were of course eager to see the deployment go well. It's a critical part of the NISAR Earth science mission and has taken years to design, develop, and test to be ready for this big day," said Phil Barela, NISAR project manager at NASA's Jet Propulsion Laboratory in Southern California, which managed the U.S. portion of the mission and provided one of the two radar systems aboard NISAR. "Now that we've launched, we are focusing on fine-tuning it to begin delivering transformative science by late fall of this year."

<See link to video at bottom of page.>

**How Bloom Works**

Weighing about 142 pounds (64 kilograms), the reflector features a cylindrical frame made of 123 composite struts and a gold-plated wire mesh. On Aug. 9, the satellite's boom, which had been tucked close to its main body, started unfolding one joint at a time until it was fully extended about four days later. The reflector assembly is mounted at the end of the boom.

Then, on Aug. 15, small explosive bolts that held the reflector assembly in place were fired, enabling the antenna to begin a process called the "bloom" -- its unfurling by the release of tension stored in its flexible frame while stowed like an umbrella. Subsequent activation of motors and cables then pulled the antenna into its final, locked position.

To image Earth's surface down to pixels about 30 feet (10 meters) across, the reflector was designed with a diameter about as wide as a school bus is long. Using SAR processing, NISAR's reflector simulates a traditional radar antenna that for the mission's L-band instrument would have to be 12 miles (19 kilometres) long to achieve the same resolution.

"Synthetic aperture radar, in principle, works like the lens of a camera, which focuses light to make a sharp image. The size of the lens, called the aperture, determines the sharpness of the image," said Paul Rosen, NISAR's project scientist at JPL. "Without SAR, spaceborne radars could generate data, but the resolution would be too rough to be useful. With SAR, NISAR will be able to generate high-resolution imagery. Using special interferometric techniques that compare images over time, NISAR enables researchers and data users to create 3D movies of changes happening on Earth's surface."

The NISAR satellite is the culmination of decades of space-based radar development at JPL. Starting in the in the 1970s, JPL managed the first Earth-observing SAR satellite, Seasat, which launched in 1978, as well as Magellan, which used SAR to map the cloud-shrouded surface of Venus in the 1990s.

**More About NISAR**

The NISAR mission is a partnership between NASA and ISRO spanning years of technical and programmatic collaboration. The successful launch and deployment of NISAR builds upon a strong heritage of cooperation between the United States and India in space. The data produced by NISAR's two radar systems, one provided by NASA and one by ISRO, will be a testament to what can be achieved when countries unite around a shared vision of innovation and discovery.

The ISRO Space Applications Centre provided the mission's S-band SAR. The U R Rao Satellite Centre provided the spacecraft bus. Launch services were through Satish Dhawan Space Centre. After launch, key operations, including boom and radar antenna reflector deployment, are being executed and monitored by the ISRO Telemetry, Tracking and Command Network's global system of ground stations.

Managed by Caltech in Pasadena, JPL leads the U.S. component of the project. In addition to the L-band SAR, reflector, and boom, JPL also provided the high-rate communication subsystem for science data, a solid-state data recorder, and payload data subsystem. NASA's Goddard Space Flight Centre in Greenbelt, Maryland, manages the Near Space Network, which receives NISAR's L-band data.

- NASA’s PREFIRE satellites reveal a secret glow escaping from our planet

Date: August 18, 2025
Source: NASA's Jet Propulsion Laboratory

Extended through 2026, NASA’s PREFIRE mission is using twin CubeSats to track hidden heat escaping Earth, uncovering how ice and clouds shape storms and climate. Credit: NASA/JPL-Caltech

The twin cube satellites will operate through at least September 2026, expanding focus from the poles to the whole planet to improve modelling and weather forecasts.
NASA's PREFIRE (Polar Radiant Energy in the Far-InfraRed Experiment) mission has been extended through September 2026 and is broadening its focus from Earth's poles to the entire globe. The mission's two shoebox-size CubeSats gauge the capacity of water vapor, clouds, and other elements of Earth's system to trap heat and keep it from radiating into space. This information can help improve forecasts, including weather severity and storm frequency.
Launched in spring 2024, PREFIRE has been measuring how much heat the planet emits into space from the Arctic and Antarctic. Earth absorbs a significant amount of the Sun's energy in the tropics. Winds, weather, and ocean currents transport that heat toward the poles, which receive much less sunlight. Ice, snow, and clouds, among other parts of the polar environment, emit some of that heat into space, much of it as far-infrared radiation. The difference between the amount of heat Earth absorbs at the tropics and radiates out from the Arctic and Antarctic is a key influence on the planet's temperature, helping to drive dynamic systems of climate and weather.
At the core of the mission is a pair of advanced spectrometers designed by NASA's Jet Propulsion Laboratory in Southern California. They measure wavelengths of light in the far-infrared range of the electromagnetic spectrum and are sensitive to 10 times more far-infrared wavelengths than any similar instrument. This information gives researchers insight into processes associated with surface ice melt and formation, snowmelt and accumulation, and changes in cloud cover.
"The PREFIRE satellites show that at these longer wavelengths, the amount of radiation going into space can differ from one type of ice to another by as much as 5%," said Brian Drouin, PREFIRE's project scientist at JPL. "Measurements that look at the same areas but with shorter wavelengths do not show this difference."
Although the PREFIRE CubeSats have been gathering data on the entire globe, the science team has concentrated their analysis on Earth's polar regions for its prime mission. Going forward, they will expand their work to include data from the rest of the world.
"We have the capacity to collect data for the whole world, not just the poles. What we'll be able to do is look at the size of ice particles in clouds that affect energy exchange between Earth and space," said PREFIRE's principal investigator, Tristan L'Ecuyer of the University of Wisconsin-Madison. "We'll be able to incorporate the data into weather prediction models to improve forecasts and improve our understanding of how moisture circulates, which affects where storms form and how precipitation moves around the world."
The satellites are in what's called an asynchronous near-polar orbit, traveling near the poles with each pass but hours apart from one another. This provides two snapshots of the same area over time, enabling the mission to capture phenomena that occur on short timescales, such as cloud cover's temporary effects on the temperature of the area beneath it.

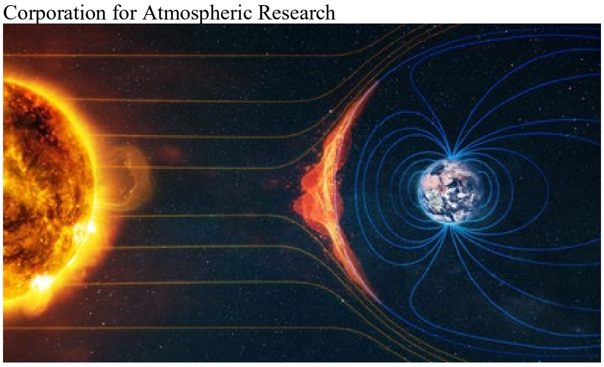
**More About PREFIRE**

NASA's Jet Propulsion Laboratory manages PREFIRE for the agency's Science Mission Directorate and provided the spectrometers. Blue Canyon Technologies built the CubeSats and the University of Wisconsin-Madison processes the data the instruments collect. The launch services provider, Rocket Lab USA

Inc. of Long Beach, California, launched both PREFIRE CubeSats from Rocket Lab Launch Complex 1 in New Zealand in May and June 2024.

- The surprising way rising CO2 could supercharge space storms

Date: August 17, 2025
Source: National Centre for Atmospheric Research/University Corporation for Atmospheric Research



Future storms will pack a proportionally bigger punch in a thinner atmosphere, reshaping satellite risks. Credit: Shutterstock

Rising concentrations of carbon dioxide in the upper atmosphere will change the way geomagnetic storms impact Earth, with potential implications for thousands of orbiting satellites, according to new research led by scientists at the US. National Science Foundation National Centre for Atmospheric Research (NSF NCAR).

Geomagnetic storms, caused by massive eruptions of charged particles from the surface of the Sun that buffet Earth's atmosphere, are a growing challenge for our technologically dependent society. The storms temporarily increase the density of the upper atmosphere and therefore the drag on satellites, which impacts their speed, altitude, and how long they remain operational.

The new study used an advanced computer model to determine that the upper atmosphere's density will be lower during a future geomagnetic storm compared with a present-day storm of the same intensity. That's because the baseline density will be lower, and future storms won't increase it to levels as high as what occurs with storms currently. However, the relative magnitude of the density increase -- the rise from baseline to peak during a multiday storm -- will be greater with future storms.

"The way that energy from the Sun affects the atmosphere will change in the future because the background density of the atmosphere is different and that creates a different response," said NSF NCAR scientist Nicolas Pedatella, the lead author. "For the satellite industry, this is an especially important question because of the need to design satellites for specific atmospheric conditions."

The study, a collaboration with Japan's Kyushu University, was published in *Geophysical Research Letters*.

**Colder and thinner air**

Earth's upper atmosphere has become increasingly important in recent decades because of society's dependence on advanced navigation systems, online data transmission, national security applications, and other technologies that rely on satellite operations. Unlike the lower atmosphere, which warms with emissions of carbon dioxide, the upper atmosphere becomes colder. This has to do with the varying impacts of carbon dioxide: instead of absorbing and reemitting heat to nearby molecules in the relatively dense air near Earth's surface, carbon dioxide reemits the heat out into space at high altitudes where the air is much thinner.

Previous studies have estimated the extent to which increasing levels of carbon dioxide and other greenhouse gases will lead to a decrease in the upper atmosphere's neutral density, or its concentration of non-ionized particles such as oxygen and nitrogen. But Pedatella and his colleagues posed a somewhat different question: how will future atmospheric density change during powerful geomagnetic storms?

The researchers homed in on the geomagnetic superstorm of May 10-11, 2024, when a series of powerful solar disturbances known as coronal mass ejections buffeted Earth's atmosphere. They analysed how the atmosphere would have responded to the same storm in 2016 and in three future years that will each occur around the minimum of the 11-year solar cycle (2040, 2061, and 2084).

To perform the analysis, they turned to an NSF NCAR-based modelling system, the Community Earth System Model Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension, that simulates the entire atmosphere from Earth's surface to the upper thermosphere, 500-700 kilometres (about 310-435 miles) above the surface. This enables scientists to determine how changes in the lower atmosphere, such as higher concentrations of greenhouse gases, can affect remote regions of the atmosphere far aloft.

They ran the simulations on the Derecho supercomputer at the NSF NCAR-Wyoming Supercomputing Centre.

The researchers found that, later this century, various regions of the upper atmosphere will be 20-50% less dense at the peak of a storm comparable to the one that occurred last year, assuming significantly higher carbon dioxide levels. However, compared with the atmosphere's density just before and after the storm, the relative change in density will be greater. Whereas such a storm now more than doubles the density at its peak, it may nearly triple it in the future. This is because the same storm will have a proportionately larger impact on a less dense atmosphere.

Pedatella said more research is needed to better understand how space weather will change, including studying different types of geomagnetic storms and whether their impacts will vary at various times in the 11-year solar cycle, when the atmosphere's density changes.

"We now have the capability with our models to explore the very complex interconnections between the lower and upper atmosphere," he said. "It's critical to know how these changes will occur because they have profound ramifications for our atmosphere."

*This material is based upon work supported by the NSF National Centre for Atmospheric Research, a major facility sponsored by the U.S. National Science Foundation and managed by the University Corporation for Atmospheric Research. Any opinions, findings and conclusions or recommendations expressed in this material do not necessarily reflect the views of NSF.*

- Could these strange rocks be the first true evidence of life on Mars?

Date: September 21, 2025
Source: Texas A&M University

Perseverance rover reached the Bright Angel site on Mars by navigating through a dune field, bypassing large boulders. The rover is now investigating this area’s unique geological features to understand Mars’ past environmental conditions and support future human exploration. Credit: NASA/JPL-Caltech

A new study co-authored by Texas A&M University geologist Dr. Michael Tice has revealed potential chemical signatures of ancient Martian microbial life in rocks examined by NASA's Perseverance rover.

The findings, published by a large international team of scientists, focus on a region of Jezero Crater known as the Bright Angel formation -- a name chosen from locations in Grand Canyon National Park because of the light-coloured Martian rocks. This area in Mars' Neretva Vallis channel contains fine-grained mudstones rich in oxidized iron (rust), phosphorus, sulphur and -- most notably -- organic carbon. Although organic carbon, potentially from non-living sources like meteorites, has been found on Mars before, this combination of materials could have been a rich source of energy for early microorganisms.

"When the rover entered Bright Angel and started measuring the compositions of the local rocks, the team was immediately struck by how different they were from what we had seen before," said Tice, a geobiologist and astrobiologist in the Department of Geology and Geophysics. "They showed evidence of chemical cycling that organisms on Earth can take advantage of to produce energy. And when we looked even closer, we saw things that are easy to explain with early Martian life but very difficult to explain with only geological processes."

Tice went on to explain that "living things do chemistry that generally occurs in nature anyway given enough time and the right circumstances. To the best of our current knowledge, some of the chemistry that shaped these rocks required either high temperatures or life, and we do not see evidence of high temperatures here. However, these findings require experiments and ultimately laboratory study of the sample here on Earth in order to completely rule out explanations without life."

The team published its findings in *Nature.*

**A window into Mars' watery past**

The Bright Angel formation is composed of sedimentary rocks deposited by water, including mudstones (fine-grained sedimentary rocks made of silt and clay)and layered beds that suggest a dynamic environment of flowing rivers and standing water. Using Perseverance's suite of instruments, including the SHERLOC and PIXL spectrometers, scientists detected organic molecules and small arrangements of minerals that appear to have formed through "redox reactions," chemical processes involving the transfer of electrons. On Earth, those processes are often driven by biological activity.

Among the most striking features are tiny nodules and "reaction fronts" -- nicknamed "poppy seeds" and "leopard spots" by the rover team -- enriched in ferrous iron phosphate (likely vivianite) and iron sulphide (likely greigite). These minerals commonly form in low-temperature, water-rich environments and are often associated with microbial metabolisms.

"It's not just the minerals, it's how they are arranged in these structures that suggests that they formed through the redox cycling of iron and sulphur," Tice said. "On Earth, things like these sometimes form in sediments where microbes are eating organic matter and 'breathing' rust and sulphate. Their presence on Mars raises the question: could similar processes have occurred there?"

**Organic matter and redox chemistry**

The SHERLOC instrument detected a Raman spectral feature known as the G-band, a signature of organic carbon, in several Bright Angel rocks. The strongest signals came from a site called "Apollo Temple," where both vivianite and greigite were most abundant.

"This co-location of organic matter and redox-sensitive minerals is very compelling," said Tice. "It suggests that organic molecules may have played a role in driving the chemical reactions that formed these minerals."

Tice notes it's important to understand that "organic" does not necessarily mean formed by living things.

"It just means having a lot of carbon-carbon bonds," he explained. "There are other processes that can make those besides life. The kind of organic matter detected here could have been produced by abiotic processes or it could have been produced by living things. If produced by living things, it would have to have been degraded by chemical reactions, radiation or heat to produce the G-band that we observe now."

The study outlines two possible scenarios: one in which these reactions occurred abiotically (driven by geochemical processes) and another in which microbial life may have affected the reactions, as it does on Earth. Strikingly, although some features of the nodules and reaction fronts could be produced by abiotic reactions between organic matter and iron, the known geochemical processes that could have produced the features associated with sulphur usually only work at relatively high temperatures.

"All the ways we have of examining these rocks on the rover suggest that they were never heated in a way that could produce the leopard spots and poppy seeds," said Tice. "If that's the case, we have to seriously consider the possibility that they were made by creatures like bacteria living in the mud in a Martian lake more than three billion years ago."

While the team emphasizes that the evidence is not definitive proof of past life, the findings meet NASA's criteria for "potential biosignatures" -- features that warrant further investigation to determine whether they are biological or abiotic in origin.

**A sample worth returning**

Perseverance collected a core sample from the Bright Angel formation, named "Sapphire Canyon," which is now stored in a sealed tube carried by the rover. This sample is among those prioritized for return to Earth in a potential future mission.

"Bringing this sample back to Earth would allow us to analyse it with instruments far more sensitive than anything we can send to Mars," said Tice. "We'll be able to look at the isotopic composition of the organic matter, the fine-scale mineralogy, and even search for microfossils if they exist. We'd also be able to perform more tests to determine the highest temperatures experienced by these rocks, and whether high temperature geochemical processes might still be the best way to explain the potential biosignatures."

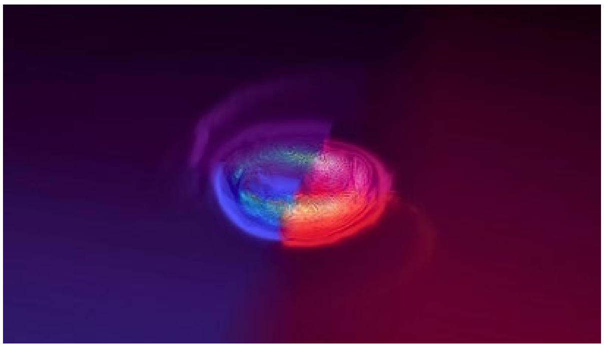
Tice, who has long studied ancient microbial ecosystems on Earth, said the parallels between Martian and terrestrial processes are striking -- with one important difference.

"What's fascinating is how life may have been making use of some of the same processes on Earth and Mars at around the same time," he said. "We see evidence of microorganisms reacting iron and sulphur with organic matter in the same way in rocks of the same age on Earth, but we'd never be able to see exactly the same features that we see on Mars in the old rocks here. Processing by plate tectonics has heated all our rocks too much to preserve them this way. It's a special and spectacular thing to be able to see them like this on another planet."

- Neutrinos may be the hidden force behind gold and platinum

Neutrinos may secretly be the cosmic switch behind gold, platinum, and the signals of colliding stars.

Date: September 21, 2025
Source: Penn State



New simulations of neutron star mergers reveal that the mixing and changing of tiny particles called neutrinos impacts how the merger unfolds, including the composition and structure of the merger remnant as well as the resulting emissions. This image depicts the density of neutrinos within the remnant as varying textures, and the colours represent energy densities of different neutrino Flavors. Credit: David Radice research group / Penn State

The collision and merger of two neutron stars -- the incredibly dense remnants of collapsed stars -- are some of the most energetic events in the universe, producing a variety of signals that can be observed on Earth. New simulations of neutron star mergers by a team from Penn State and the University of Tennessee Knoxville reveal that the mixing and changing of tiny particles called neutrinos that can travel astronomical distances undisturbed impacts how the merger unfolds, as well as the resulting emissions. The findings have implications for longstanding questions about the origins of metals and rare earth elements as well as understanding physics in extreme environments, the researchers said.

The paper, published in the journal *Physical Review Letters*, is the first to simulate the transformation of neutrino "Flavors" in neutron star mergers. Neutrinos are fundamental particles that interact weakly with other matter, and come in three Flavors, named for the other particles they associate with: electron, muon and tau. Under specific conditions, including the inside of a neutron star, neutrinos can theoretically change Flavors, which can change the types of particles with which they interact.

"Previous simulations of binary neutron star mergers have not included the transformation of neutrino flavour," said Yi Qiu, graduate student in physics in the Penn State Eberly College of Science and first author of the paper. "This is partly because this process happens on a nanosecond timescale and is very difficult to capture and partly because, until recently, we didn't know enough about the theoretical physics underlying these transformations, which falls outside of the standard model of physics. In our new simulations, we found that the extent and location of neutrinos mixing and transforming impacts the matter that is ejected from the merger, the structure and composition of what remains after the merger -- the remnant -- as well as the material around it."

The researchers built a computer simulation of a neutron star merger from the ground up, incorporating a variety of physical processes, including gravity, general relativity, hydrodynamics and the neutrino mixing. They also accounted for the transformation of electron flavour neutrinos to muon flavour, which the researchers said is the most relevant neutrino transformation in this environment. They modelled several scenarios, varying the timing and location of the mixing as well as the density of the surrounding material.

The researchers found that all of these factors influenced the composition and structure of the merger remnant, including the type and quantities of elements created during the merger. During a collision, the neutrons in a neutron star can be launched at other atoms in the debris, which can capture the neutrons and ultimately decay into heavier elements, such as heavy metals like gold and platinum as well as rare earth elements that are used on Earth in smart phones, electric vehicle batteries and other devices.

"A neutrino's flavour changes how it interacts with other matter," said David Radice, Knerr Early Career Professor of Physics and associate professor astronomy and astrophysics in the Penn State Eberly College of Science and an author of the paper. "Electron type neutrinos can take a neutron, one of the three basic parts of an atom, and transform it into the other two, a proton and electron. But muon type neutrinos cannot do this. So, the conversion of neutrino Flavors can alter how many neutrons are available in the system, which directly impacts the creation of heavy metals and rare earth elements. There are still many lingering questions about the cosmic origin of these important elements, and we found that accounting for neutrino mixing could increase element production by as much as a factor of 10."

Neutrino mixing during the merger also influenced the amount and composition of matter ejected from the merger, which the researchers said could alter the emissions detectable from Earth. These emissions typically include gravitational waves -- ripples in space time -- as well as electromagnetic radiation like X-rays or gamma rays.
"In our simulations, neutrino mixing impacted the electromagnetic emissions from neutron star mergers and possibly the gravitational waves as well," Radice said. "With cutting-edge detectors like LIGO, Virgo and KAGRA and their next generation counterparts, such as the proposed Cosmic Explorer observatory that could start operations in the 2030s, astronomers are poised to detect gravitational waves more often than we have before. Better understanding how these emissions are created from neutron star mergers will help us interpret future observations."
The researchers said modelling the mixing processes was similar to a pendulum being turned upside down. Initially, many changes occurred on an incredibly rapid timescale, but eventually the pendulum settles to a stable equilibrium. But much of this, they said, is an assumption.
"There's still a lot we don't know about the theoretical physics of these neutrino transformations," Qiu said. "As theoretical particle physics continues to advance, we can greatly improve our simulations. What remains uncertain is where and how these transformations occur in neutron star mergers. Our current understanding suggests they are very likely, and our simulations show that, if they take place, they can have major effects, making it important to include them in future models and analyses."
Now that the infrastructure for these complex simulations has been created, the researchers said they expect other groups will use the technology to continue to explore the impacts of neutrino mixing.
"Neutron star mergers function like cosmic laboratories, providing important insights into extreme physics that we can't replicate safely on Earth," Radice said.
In addition to Qiu and Radice, the research team includes Maitraya Bhattacharyya, postdoctoral scholar in the Penn State Institute for Gravitation and the Cosmos, and Sherwood Richers at the University of Tennessee, Knoxville. Funding from the U.S. Department of Energy, the Sloan Foundation and the U.S. National Science Foundation supported this work.

- Hubble reveals baby stars in a galaxy torn by gravity

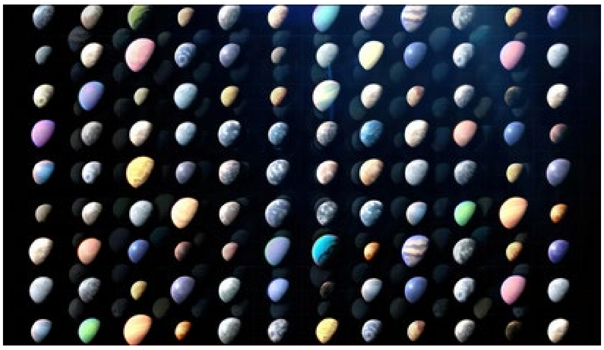
Date: September 21, 2025
Source: ESA/Hubble

The lopsided spiral Messier 96 shines in this vivid new Hubble image, revealing glowing pink rings of newborn stars and the dramatic effects of cosmic tug-of-war shaping its uneven form. Credit: ESA/Hubble & NASA, F. Belfiore, D. Calzetti

This new Hubble Space Telescope Picture of the Week features a galaxy whose asymmetric appearance may be the result of a galactic tug of war. Located 35 million light-years away in the constellation Leo, the spiral galaxy Messier 96 is the brightest of the galaxies in its group. The gravitational pull of its galactic neighbours may be responsible for Messier 96's uneven distribution of gas and dust, asymmetric spiral arms, and off-centre galactic core.
This asymmetric appearance is on full display in a new Hubble image, which incorporates observations made in ultraviolet and optical light. Hubble images of Messier 96 have been released previously in 2015 and 2018. Each successive image has added new data, building up a beautiful and scientifically valuable view of the galaxy.
This third version gives an entirely new perspective on Messier 96’s-star formation. The bubbles of pink gas in this image surround hot, young, massive stars, illuminating a ring of star formation in the outskirts of the galaxy. These young stars are still embedded within the clouds of gas from which they were born. The new data included for the first time in this image will be used to study how stars are born within giant dusty gas clouds, how dust filters starlight, and how stars affect their environments.

- NASA just confirmed its 6,000th alien world. Some are truly bizarre

NASA’s catalogue of confirmed exoplanets has hit 6,000, revealing everything from lava worlds to Styrofoam-light planets.
Date: September 21, 2025
Source: NASA's Jet Propulsion Laboratory


Scientists have found thousands of exoplanets (planets outside our solar system) throughout the galaxy. Most can be studied only indirectly, but scientists know they vary widely, as depicted in this artist’s concept, from small, rocky worlds and gas giants to water-rich planets and those as hot as stars. Credit: NASA’s Goddard Space Flight Centre

The official number of exoplanets -- planets outside our solar system -- tracked by NASA has reached 6,000. Confirmed planets are added to the count on a rolling basis by scientists from around the world, so no single planet is considered the 6,000th entry. The number is monitored by NASA's Exoplanet Science Institute (NExScI), based at Caltech's IPAC in Pasadena, California. There are more than 8,000 additional candidate planets awaiting confirmation, with NASA leading the world in searching for life in the universe.

"This milestone represents decades of cosmic exploration driven by NASA space telescopes -- exploration that has completely changed the way humanity views the night sky," said Shawn Domagal-Goldman, acting director, Astrophysics Division, NASA Headquarters in Washington. "Step by step, from discovery to characterization, NASA missions have built the foundation to answering a fundamental question: Are we alone? Now, with our upcoming Nancy Grace Roman Space Telescope and Habitable Worlds Observatory, America will lead the next giant leap -- studying worlds like our own around stars like our Sun. This is American ingenuity, and a promise of discovery that unites us all."

The milestone comes 30 years after the first exoplanet was discovered around a star similar to our Sun, in 1995. (Prior to that, a few planets had been identified around stars that had burned all their fuel and collapsed.) Although researchers think there are billions of planets in the Milky Way galaxy, finding them remains a challenge. In addition to discovering many individual planets with fascinating characteristics as the total number of known exoplanets climbs, scientists are able to see how the general planet population compares to the planets of our own solar system.

For example, while our solar system hosts an equal number of rocky and giant planets, rocky planets appear to be more common in the universe. Researchers have also found a range of planets entirely different from those in our solar system. There are Jupiter-size planets that orbit closer to their parent star than Mercury orbits the Sun; planets that orbit two stars, no stars, and dead stars; planets covered in lava; some with the density of Styrofoam; and others with clouds made of gemstones.

"Each of the different types of planets we discover gives us information about the conditions under which planets can form and, ultimately, how common planets like Earth might be, and where we should be looking for them," said Dawn Gelino, head of NASA's Exoplanet Exploration Program (ExEP), located at the agency's Jet Propulsion Laboratory in Southern California. "If we want to find out if we're alone in the universe, all of this knowledge is essential."

**Searching for other worlds**

Fewer than 100 exoplanets have been directly imaged, because most planets are so faint they get lost in the light from their parent star. The other four methods of planet detection are indirect. With the transit method, for instance, astronomers look for a star to dim for a short period as an orbiting planet passes in front of it.

To account for the possibility that something other than an exoplanet is responsible for a particular signal, most exoplanet candidates must be confirmed by follow-up observations, often using an additional telescope, and that takes time. That's why there is a long list of candidates in the NASA Exoplanet Archive (hosted by NExScI) waiting to be confirmed.

"We really need the whole community working together if we want to maximize our investments in these missions that are churning out exoplanets candidates," said Aurora Kesseli, the deputy science lead for the NASA Exoplanet Archive at IPAC. "A big part of what we do at NExScI is build tools that help the community go out and turn candidate planets into confirmed planets."

The rate of exoplanet discoveries has accelerated in recent years (the database reached 5,000 confirmed exoplanets just three years ago), and this trend seems likely to continue. Kesseli and her colleagues anticipate receiving thousands of additional exoplanet candidates from the ESA (European

Space Agency) Gaia mission, which finds planets through a technique called astrometry, and NASA's upcoming Nancy Grace Roman Space Telescope, which will discover thousands of new exoplanets primarily through a technique called gravitational microlensing.

**Future exoplanets**

At NASA, the future of exoplanet science will emphasize finding rocky planets similar to Earth and studying their atmospheres for biosignatures -- any characteristic, element, molecule, substance, or feature that can be used as evidence of past or present life.

NASA's James Webb Space Telescope has already analysed the chemistry of over 100 exoplanet atmospheres.

But studying the atmospheres of planets the size and temperature of Earth will require new technology. Specifically, scientists need better tools to block the glare of the star a planet orbits. And in the case of an Earth-like planet, the glare would be significant: The Sun is about 10 billion times brighter than Earth -- which would be more than enough to drown out our home planet's light if viewed by a distant observer.

NASA has two main initiatives to try overcoming this hurdle. The Roman telescope will carry a technology demonstration instrument called the Roman Coronagraph that will test new technologies for blocking starlight and making faint planets visible. At its peak performance, the coronagraph should be able to directly image a planet the size and temperature of Jupiter orbiting a star like our Sun, and at a similar distance from that star.

With its microlensing survey and coronagraphic observations, Roman will reveal new details about the diversity of planetary systems, showing how common solar systems like our own may be across the galaxy.

Additional advances in coronagraph technology will be needed to build a coronagraph that can detect a planet like Earth. NASA is working on a concept for such a mission, currently named the Habitable Worlds Observatory.

**More about ExEP, NExScI**

NASA's Exoplanet Exploration Program is responsible for implementing the agency's plans for the discovery and understanding of planetary systems around nearby stars. It acts as a focal point for exoplanet science and technology and integrates cohesive strategies for future discoveries. The science operations and analysis centre for ExEP is NExScI, based at IPAC, a science and data centre for astrophysics and planetary science at Caltech. JPL is managed by Caltech for NASA.