South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk. Trevor Pitt History of the Telescope

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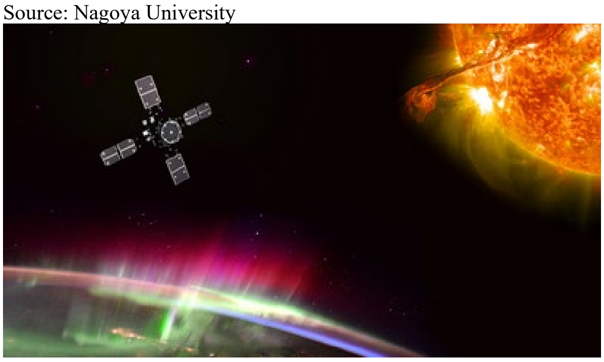
- Solar Superstorm Gannon crushed Earth’s plasmasphere to a record low

A rare solar superstorm collapsed Earth’s plasma shield and exposed the hidden processes that slow its recovery.
Date: November 23, 2025
Source: Nagoya University



Scientists have captured the first detailed observations of how a superstorm compresses Earth’s plasmasphere and reveals why recovery took more than four days, affecting navigation and communication systems. Credit: Institute for Space-Earth Environmental Research (ISEE), Nagoya University

A geomagnetic superstorm is one of the most extreme forms of space weather, created when the Sun sends enormous bursts of energy and charged particles toward Earth. These powerful events rarely occur, typically appearing only once every 20-25 years. On May 10-11, 2024, Earth was hit by the strongest event of this kind in more than two decades, known as the Gannon storm or Mother's Day storm.

A research effort led by Dr. Atsuki Shinbori of Nagoya University's Institute for Space-Earth Environmental Research gathered direct observations during the storm and produced the first detailed view of how such an event squeezes Earth's plasmasphere (a protective region of charged particles surrounding the planet). The results, published in *Earth, Planets and Space*, show how both the plasmasphere and the ionosphere respond during intense solar disturbances and offer insight that can improve predictions of satellite disruptions, GPS problems, and communication issues caused by extreme space weather.

Arase Satellite Captures a Rare Plasmasphere Collapse

Launched by the Japan Aerospace Exploration Agency (JAXA) in 2016, the Arase satellite travels through Earth's plasmasphere and measures plasma waves and magnetic fields. During the May 2024 superstorm, it happened to be in an ideal position to record the severe compression of the plasmasphere and the long, slow recovery that followed. This marked the first time scientists had continuous, direct data showing the plasmasphere contracting to such a low altitude during a superstorm.

"We tracked changes in the plasmasphere using the Arase satellite and used ground-based GPS receivers to monitor the ionosphere -- the source of charged particles that refill the plasmasphere. Monitoring both layers showed us how dramatically the plasmasphere contracted and why recovery took so long," Dr. Shinbori explained.

Superstorm Pushes Plasmasphere to Record-Low Altitudes

The plasmasphere works with Earth's magnetic field to help block harmful charged particles from the Sun and deep space, offering natural protection for satellites and other technology. Under normal conditions, this region stretches far from Earth, but the May storm forced its outer edge inward from about 44,000 km above the surface to only 9,600 km.

The storm formed after several major eruptions on the Sun released billions of tons of charged particles toward Earth. Within just nine hours, the plasmasphere was compressed to roughly one-fifth of its usual size. Its recovery was unusually slow, requiring more than four days to refill, which is the longest recovery time recorded since Arase began monitoring the region in 2017.

"We found that the storm first caused intense heating near the poles, but later this led to a big drop in charged particles across the ionosphere, which slowed recovery. This prolonged disruption can affect GPS accuracy, interfere with satellite operations, and complicate space weather forecasting," Dr. Shinbori noted.

Superstorm Pushes Auroras Farther Toward the Equator

During the peak of the storm, the Sun's activity compressed Earth's magnetic field so strongly that charged particles were able to travel much farther along magnetic field lines toward the equator. As a result, vivid auroras appeared in places that rarely experience them.

Auroras normally occur near the poles because Earth's magnetic field channels solar particles into the atmosphere there. This storm was powerful enough to shift the auroral zone far beyond its usual location near the Arctic and Antarctic circles, producing displays in mid-latitude regions such as Japan, Mexico, and southern Europe -- areas where auroras are seldom seen. Stronger geomagnetic storms allow the lights to reach increasingly equatorial regions.

Negative Storms Slow the Plasmasphere's Return to Normal

About an hour after the superstorm arrived, charged particles surged through Earth's upper atmosphere at high latitudes and flowed toward the polar cap. As the storm weakened, the plasmasphere began to replenish with particles supplied by the ionosphere.

This refill process usually takes only a day or two, but in this case the recovery stretched out to four days because of a phenomenon known as a negative storm. In a negative storm, particle levels in the ionosphere drop sharply over large areas when intense heating alters atmospheric chemistry. This reduces oxygen ions that help create hydrogen particles needed to restore the plasmasphere. Negative storms are invisible and can only be detected using satellites.

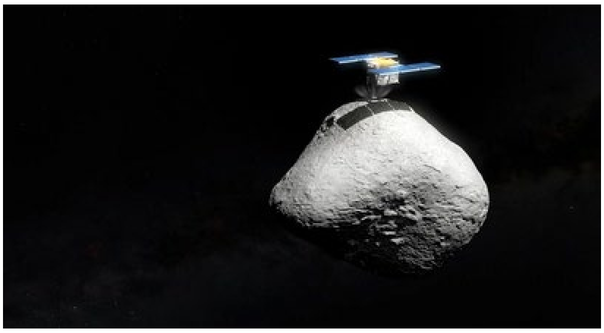
"The negative storm slowed recovery by altering atmospheric chemistry and cutting off the supply of particles to the plasmasphere. This link between negative storms and delayed recovery had never been clearly observed before," Dr. Shinbori said.

Why These Findings Matter for Space Weather and Technology

These results provide a clearer understanding of how the plasmasphere changes during a severe solar storm and how energy moves through this region of space. Several satellites experienced electrical problems or stopped transmitting data during the event, GPS signals became less accurate, and radio communications were disrupted. Knowing how long Earth's plasma layer takes to recover from such disturbances is essential for predicting future space weather and for protecting the technology that relies on stable conditions in near-Earth space.

- Japanese spacecraft faces a massive challenge from a house-size asteroid

Date: November 21, 2025
Source: ESO



An artist's impression of Japan's Hayabusa2 space mission touching down on the surface of the asteroid 1998 KY26. New observations with ESO's Very Large Telescope (VLT) have revealed that 1998 KY26 is just 11 m wide, almost three times smaller than previously thought, and is spinning once every 5 minutes, which is much faster than expected. The image above shows an updated size comparison between the asteroid and spacecraft. Credit: ESO/M. Kornmesser. Asteroid: T. Santana-Ros et al. Hayabusa2 model: SuperTKG (CC-BY-SA).

Astronomers have gathered new data on the asteroid 1998 KY26 using observatories across several continents, including the European Southern Observatory's Very Large Telescope (ESO's VLT). These coordinated observations show that the asteroid is almost three times smaller than earlier estimates and rotates far more rapidly. The object is the planned 2031 destination for Japan's Hayabusa2 extended mission, and the updated measurements provide essential details for planning spacecraft operations only six years before the encounter.

"We found that the reality of the object is completely different from what it was previously described as," says astronomer Toni Santana-Ros of the University of Alicante, Spain, who led the Nature Communications study. By combining the new results with earlier radar data, the team determined that the asteroid is only 11 meters across, small enough to fit inside the dome of the VLT unit telescope used during the observations. They also discovered that the asteroid completes a rotation in roughly five minutes. Previous work suggested a diameter of about 30 meters and a rotation period closer to ten minutes.

A Smaller and Faster Asteroid Raises Mission Challenges

"The smaller size and faster rotation now measured will make Hayabusa2's visit even more interesting, but also even more challenging," says co-author Olivier Hainaut, an astronomer at ESO in Germany. The rapid spin and tiny size mean that performing a touchdown manoeuvre, in which the spacecraft briefly makes contact with the surface, will be more difficult than mission teams originally expected.

1998 KY26 is planned as the final target of the Japanese Aerospace eXploration Agency (JAXA)'s Hayabusa2 spacecraft. During its primary mission, Hayabusa2 visited the 900-meter-diameter asteroid 162173 Ryugu in 2018 and returned samples to Earth in 2020. With sufficient fuel remaining, the spacecraft was assigned an extended mission ending in 2031, when it will reach 1998 KY26 to investigate very small asteroids. This encounter will mark the first time a spacecraft visits an asteroid of such tiny size, as all previous missions have explored bodies hundreds or thousands of meters wide.

Ground Telescopes Capture Rare Details of a Tiny Target

To support mission planning, Santana-Ros and colleagues observed 1998 KY26 from Earth. Because the asteroid is both extremely small and faint, the team needed to wait until the object made a relatively close pass by Earth and then rely on some of the largest available telescopes, including ESO's VLT in the Atacama Desert of northern Chile.

The observations indicate that the asteroid has a bright surface and is probably a solid piece of rock, possibly originating from a fractured planet or another asteroid. Even so, the researchers cannot completely rule out that it might instead be a cluster of loosely bound debris. "We have never seen a ten-meter-size asteroid in situ, so we don't really know what to expect and how it will look," says Santana-Ros, who is also affiliated with the University of Barcelona.

Insights for Future Exploration and Planetary Defence

"The amazing story here is that we found that the size of the asteroid is comparable to the size of the spacecraft that is going to visit it! And we were able to characterize such a small object using our telescopes, which means that we can do it for other objects in the future," says Santana-Ros. "Our methods could have an impact on the plans for future near-Earth asteroid exploration or even asteroid mining."

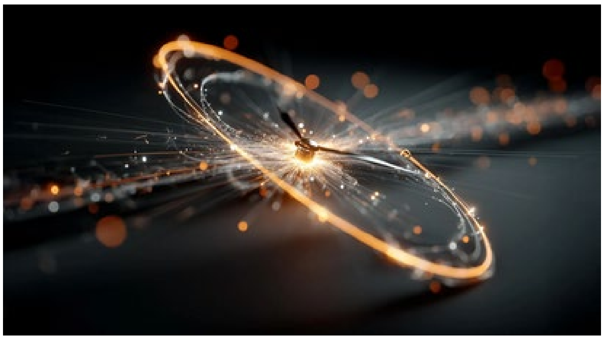
"Moreover, we now know we can characterize even the smallest hazardous asteroids that could impact Earth, such as the one that hit near Chelyabinsk, in Russia in 2013, which was barely larger than KY26," concludes Hainaut.

The findings appear in the paper titled "Hayabusa2♯ mission target 1998 KY26 preview: decametre size, high albedo and rotating twice as fast" published in *Nature Communications*.

The research team includes T. Santana-Ros (Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal, Universidad de Alicante, and Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (IEEC-UB), Spain), P. Bartczak (Instituto Universitario de Física Aplicada a las Ciencias y a las Tecnologías, Universidad de Alicante, Spain and Astronomical Observatory Institute, Faculty of Physics and Astronomy, A. Mickiewicz University, Poland [AOI AMU]), K. Muinonen (Department of Physics, University of Helsinki, Finland [Physics UH]), A. Rożek (Institute for Astronomy, University of Edinburgh, Royal Observatory Edinburgh, UK [IfA UoE]), T. Müller (Max-Planck-Institut für extraterrestrische Physik, Germany), M. Hirabayashi (Georgia Institute of Technology, United States), D. Farnocchia (Jet Propulsion Laboratory, California Institute of Technology, USA [JPL]), D. Oszkiewicz (AOI AMU), M. Micheli (ESA ESRIN / PDO / NEO Coordination Centre, Italy), R. E. Cannon (IfA UoE), M. Brozovic (JPL), O. Hainaut (European Southern Observatory, Germany), A. K. Virkki [Physics UH], L. A. M. Benner (JPL), A. Cabrera-Lavers (GRANTECAN and Instituto de Astrofísica de Canarias, Spain), C. E. Martínez-Vázquez (International Gemini Observatory/NSF NOIRLab, USA), K. Vivas (Cerro Tololo Inter-American Observatory/NSF NOIRLab, Chile).

- This tiny quantum clock packs a billion-fold energy mystery

Date: November 17, 2025
Source: University of Oxford



A new experiment shows that detecting the ticks of a quantum clock uses far more energy than producing them. This dramatic imbalance reveals that observation itself is what forces time to flow forward. Credit: AI/ScienceDaily.com

A team led by the University of Oxford has uncovered an unexpected contributor to entropy in quantum timekeeping: the act of measurement itself. In findings published on November 14 in *Physical Review Letters*, the researchers show that the energy required to read a quantum clock is far greater than the energy needed to run it. Their results point to new challenges and opportunities for developing next-generation quantum technologies.

Traditional clocks, from pendulums to atomic oscillators, depend on irreversible processes to track time. At the quantum level, these processes become extremely weak or may barely occur at all, which makes reliable timekeeping far more complicated. Devices such as quantum sensors and navigation systems, which rely on precise timing, will need internal clocks that use energy sparingly. Until now, the thermodynamic behaviour of these systems has remained largely unknown.

Investigating the Real Energy Cost of Time

The researchers set out to determine the true thermodynamic burden of keeping time in the quantum realm and to separate how much of that cost is caused by the act of measurement. To explore this, they built a tiny clock that uses single electrons hopping between two nanoscale regions (known as a double quantum dot). Each hop serves as a clock-like tick. The team then monitored these ticks using two different techniques; one measured extremely small electric currents, while the other used radio waves to detect subtle changes in the system. In both approaches, the detectors convert quantum events (electron jumps) into classical information that can be recorded: a quantum-to-classical transition.

A Billion-Fold Measurement Energy Surprise

The team calculated the entropy (amount of energy dissipated) generated both by the clock itself (i.e., the double quantum dot) and by the measurement devices. They found that the energy required to read the quantum clock (i.e., to convert its tiny signals into something measurable) can be up to a billion times larger than the energy used by the clockwork. This result challenges the long-held belief that measurement costs in quantum physics are negligible. It also reveals something striking: observation introduces irreversibility, which is what gives time its forward direction.

This finding overturns the usual expectation that improving quantum clocks requires better quantum components. Instead, the researchers argue that future progress depends on designing measurement methods that gather information more efficiently.

Rethinking Efficiency in Quantum Clock Design

Lead author Professor Natalia Ares (Department of Engineering Science, University of Oxford) said: "Quantum clocks running at the smallest scales were expected to lower the energy cost of timekeeping, but our new experiment reveals a surprising twist. Instead, in quantum clocks the quantum ticks far exceed that of the clockwork itself."

According to the researchers, this imbalance might actually offer an advantage. The additional energy used during measurement can provide richer information about the clock's behaviour, not only counting ticks but capturing every minor fluctuation. This could make it possible to build highly precise clocks that operate more efficiently.

Co-author Vivek Wadhia (PhD student, Department of Engineering Science) said: "Our results suggest that the entropy produced by the amplification and measurement of a clock's ticks, which has often been ignored in the literature, is the most important and fundamental thermodynamic cost of timekeeping at the quantum scale. The next step is to understand the principles governing efficiency in nanoscale devices so that we can design autonomous devices that compute and keep time far more efficiently, as nature does."

Co-author Florian Meier (PhD student, Technische Universität Wien) said: "Beyond quantum clocks, the research touches on deep questions in physics, including why time flows in one direction. By showing that it is the act of measuring -- not just the ticking itself -- that gives time its forward direction, these new findings draw a powerful

connection between the physics of energy and the science of information."
The study also involved researchers from TU Wien and Trinity College Dublin.

- AI creates the first 100-billion-star Milky Way simulation

Date: November 16, 2025
Source: RIKEN

A new AI-enhanced simulation models every star in the Milky Way with unprecedented speed and detail. The technique unlocks galaxy-scale realism while also promising major advances in climate and weather modelling. Credit: Shutterstock

Researchers led by Keiya Hirashima at the RIKEN Centre for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS) in Japan, working with partners from The University of Tokyo and Universitat de Barcelona in Spain, have created the first Milky Way simulation capable of tracking more than 100 billion individual stars across 10 thousand years of evolution. The team achieved this milestone by pairing artificial intelligence (AI) with advanced numerical simulation techniques. Their model includes 100 times more stars than the most sophisticated earlier simulations and was generated more than 100 times faster.
The work, presented at the international supercomputing conference SC '25, marks a major step forward for astrophysics, high-performance computing, and AI-assisted modelling. The same strategy could also be applied to large-scale Earth system studies, including climate and weather research.

Why Modelling Every Star Is So Difficult

For many years, astrophysicists have aimed to build Milky Way simulations detailed enough to follow each individual star. Such models would allow researchers to compare theories of galactic evolution, structure, and star formation directly to observational data. However, simulating a galaxy accurately requires calculating gravity, fluid behaviour, chemical element formation, and supernova activity across enormous ranges of time and space, which makes the task extremely demanding.
Scientists have not previously been able to model a galaxy as large as the Milky Way while maintaining fine detail at the level of single stars. Current cutting-edge simulations can represent systems with the equivalent mass of about one billion suns, far below the more than 100 billion stars that make up the Milky Way. As a result, the smallest "particle" in those models usually represents a group of roughly 100 stars, which averages away the behaviour of individual stars and limits the accuracy of small-scale processes. The challenge is tied to the interval between computational steps: to capture rapid events such as supernova evolution, the simulation must advance in very small-time increments. Shrinking the timestep means dramatically greater computational effort. Even with today's best physics-based models, simulating the Milky Way star by star would require about 315 hours for every 1 million years of galactic evolution. At that rate, generating 1 billion years of activity would take over 36 years of real time. Simply adding more supercomputer cores is not a practical solution, as energy use becomes excessive and efficiency drops as more cores are added.

A New Deep Learning Approach

To overcome these barriers, Hirashima and his team designed a method that blends a deep learning surrogate model with standard physical simulations. The surrogate was trained using high-resolution supernova simulations and learned to predict how gas spreads during the 100,000 years following a supernova explosion without requiring additional resources from the main simulation. This AI component allowed the researchers to capture the galaxy's overall behaviour while still modelling small-scale events, including the fine details of individual supernovae. The team validated the approach by comparing its results against large-scale runs on RIKEN's Fugaku supercomputer and The University of Tokyo's Miyabi Supercomputer System.
The method offers true individual-star resolution for galaxies with more than 100 billion stars, and it does so with remarkable speed. Simulating 1 million years took just 2.78 hours, meaning that 1 billion years could be completed in approximately 115 days instead of 36 years.

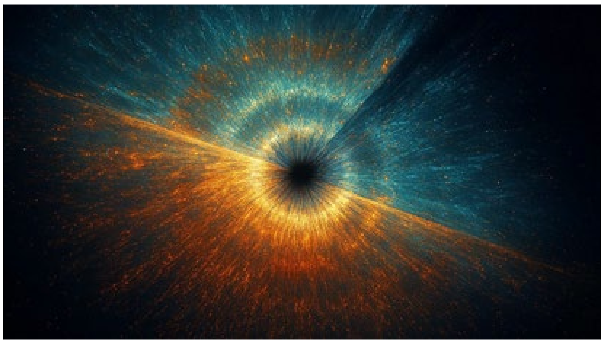
Broader Potential for Climate, Weather, and Ocean Modelling

This hybrid AI approach could reshape many areas of computational science that require

linking small-scale physics with large-scale behaviour. Fields such as meteorology, oceanography, and climate modelling face similar challenges and could benefit from tools that accelerate complex, multi-scale simulations.
"I believe that integrating AI with high-performance computing marks a fundamental shift in how we tackle multi-scale, multi-physics problems across the computational sciences," says Hirashima. "This achievement also shows that AI-accelerated simulations can move beyond pattern recognition to become a genuine tool for scientific discovery -- helping us trace how the elements that formed life itself emerged within our galaxy."

- Dark matter acts surprisingly normal in a new cosmic test

Dark matter may be the Universe's great unknown, but scientists just pulled off one of the sharpest tests yet of how it actually behaves.
Date: November 16, 2025
Source: Université de Genève



Dark matter seems to follow the same gravitational rules as ordinary matter, based on galactic motion across cosmic structures. Yet scientists can't rule out a subtle fifth force that may emerge with upcoming high-precision observations. Credit: AI/ScienceDaily.com

Does dark matter behave according to the same physical rules that apply to ordinary matter? This question remains one of the major puzzles in modern cosmology, since this invisible form of matter (which neither emits nor reflects any light) is still hypothetical and extremely difficult to study directly. Researchers from the University of Geneva (UNIGE) and collaborating institutions aimed to see whether dark matter follows familiar behaviour on the largest scales, or whether other forces might influence it. Their study, published in Nature Communications, indicates that dark matter appears to act much like ordinary matter, although they cannot yet rule out the possibility of an additional, previously unknown interaction. Because dark matter is thought to be five times more common than ordinary matter, even a small new insight helps clarify its role in shaping the Universe. Ordinary matter is affected by four known fundamental forces: gravity, electromagnetism, and the strong and weak forces within atoms. The question is whether dark matter responds to the same set of forces. While dark matter is invisible and difficult to detect, it may still follow these familiar laws or possibly be influenced by a fifth force that scientists have not yet identified.

Investigating How Dark Matter Moves Through Gravitational Wells

To explore this possibility, the UNIGE-led team examined whether dark matter sinks into gravitational wells the way ordinary matter does on cosmic scales. Massive objects distort the structure of space, forming these wells. Ordinary matter -- planets, stars and galaxies -- falls into them according to established physical principles that include Einstein's general relativity and Euler's equations. The team wanted to know whether dark matter behaves in the same predictable way.
"To answer this question, we compared the velocities of galaxies across the Universe with the depth of gravitational wells," explains Camille Bonvin, associate professor in the Department of Theoretical Physics at UNIGE's Faculty of Science and co-author of the study. "If dark matter is not subject to a fifth force, then galaxies -- which are mostly made of dark matter -- will fall into these wells like ordinary matter, governed solely by gravity. On the other hand, if a fifth force acts on dark matter, it will influence the motion of galaxies, which would then fall into the wells differently. By comparing the depth of the wells with the galaxies' velocities, we can therefore test for the presence of such a force."

Dark Matter Appears to Follow Euler's Equations

Using this method on modern cosmological data, the researchers found that dark matter moves into gravitational wells in the same manner as ordinary matter, meaning it is consistent with Euler's equations. "At this stage, however, these conclusions do not yet rule out the presence of an unknown force. But if such a fifth force exists, it cannot exceed 7% of the strength of gravity -- otherwise it would already have appeared in our analyses," says Nastassia Grimm first author of the study and former postdoctoral researcher at the Department of Theoretical

Physics at UNIGE's Faculty of Science who has recently joined the Institute of Cosmology and Gravitation at the University of Portsmouth.

What Comes Next in the Search for New Physics

These early findings represent an important step in refining our understanding of dark matter. The next key objective is to determine whether a subtle fifth force truly affects it.

"Upcoming data from the newest experiments, such as LSST and DESI, will be sensitive to forces as weak as 2% of gravity. They should therefore allow us to learn even more about the behaviour of dark matter," concludes Isaac Tutusaus, researcher at ICE-CSIC and IEEC and associate professor at IRAP, Midi-Pyrénées observatory, University of Toulouse, co-author of the study.

- Wild new "gyromorph" materials could make computers insanely fast

Gyromorphs merge order and disorder to deliver unprecedented light-blocking power for next-generation photonic computers.

Date: November 13, 2025
Source: New York University

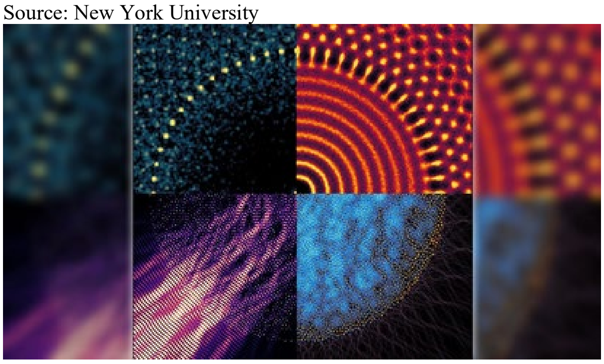


Illustration of a 60-fold gyromorph's properties. Top row: Structure of the gyromorph. Left: Structure factor. Right: Pair correlation function. Bottom row: Optical properties. Left: Polarized light beam fully reflected by a gyromorph. Right: Density of states depletion in the gyromorph. Credit: The Martiniani lab at NYU

Researchers are exploring a new generation of computers that operate using light, or photons, instead of electrical currents. Systems that rely on light to store and process information could one day run far more efficiently and complete calculations much faster than conventional machines.

Light-driven computing is still at an early stage, and one of the main technical obstacles involves controlling tiny streams of light traveling through a chip. Rerouting these microscopic signals without weakening them requires carefully engineered materials. To keep signals strong, the hardware must include a lightweight substance that prevents stray light from entering from any direction. This type of material is known as an "isotropic bandgap material."

Discovery of Gyromorphs at NYU

Scientists at New York University have identified a new material called "gyromorphs" that meets this challenge more effectively than any other known structure. Gyromorphs combine features normally associated with liquids and crystals, yet they exceed both in their ability to block incoming light from all angles. The discovery, reported in Physical Review Letters, introduces a fresh strategy for tuning optical behaviour and could help advance the development of photonic computers.

"Gyromorphs are unlike any known structure in that their unique makeup gives rise to better isotropic bandgap materials than is possible with current approaches," says Stefano Martiniani, an assistant professor of physics, chemistry, mathematics and neural science, and the senior author of the study.

Why Existing Materials Fall Short

For decades, researchers have looked to quasicrystals when designing isotropic bandgap materials. These structures, first proposed by physicists Paul Steinhardt and Dov Levine in the 1980s and later observed by Dan Schechtman, follow mathematical rules but do not repeat like traditional crystals.

Despite their promise, quasicrystals come with a trade-off noted by the NYU team. They may completely block light, but only from limited directions. Alternatively, they can weaken light from all directions but fail to fully stop it. This limitation has driven scientists to search for alternatives that can block signal-degrading light more comprehensively.

Engineering New Metamaterials

In their *Physical Review Letters* study, the NYU researchers created "metamaterials," which are engineered structures whose properties depend on their architecture rather than on their chemical composition. One major challenge in designing these materials lies in understanding how their arrangement leads to desired physical behaviours.

To overcome this, the team developed an algorithm capable of producing functional structures with built-in disorder. Their work revealed a new form of "correlated disorder" that sits between the fully ordered and fully random extremes.

"Think of trees in a forest -- they grow at random positions, but not completely random because they're usually a certain distance from one another," Martiniani explains. "This new pattern, gyromorphs, combines properties that we believed to be incompatible and displays a function that outperforms all ordered alternatives, including quasicrystals."

How Gyromorphs Achieve Their Unique Capabilities

During their analysis, the scientists observed that every isotropic bandgap material exhibited a shared structural signature.

"We wanted to make this structural signature as pronounced as possible," says Mathias Casiulis, a postdoctoral fellow in NYU's Department of Physics and the paper's lead author. "The result was a new class of materials -- gyromorphs -- that reconcile seemingly incompatible features.

"This is because gyromorphs don't have a fixed, repeating structure like a crystal, which gives them a liquid-like disorder, but, at the same time, if you look at them from a distance they form regular patterns. These properties work together to create bandgaps that light waves can't penetrate from any direction."

The research also included Aaron Shih, an NYU graduate student, and received support from the Simons Centre for Computational Physical Chemistry (839534) and the Air Force Office of Scientific Research (FA9550-25-1-0359).

- Space dust reveals how fast the Arctic is changing

Date: November 13, 2025
Source: University of Washington

Ice coverage in the Arctic sea is rapidly declining, which causes the remaining ice to melt faster and alters nutrient availability. In a University of Washington-led study, researchers show how particles from space can help recreate ice conditions over the past 30,000 years. Credit: Bonnie Light/University of Washington

Arctic sea ice has shrunk by more than 42% since 1979, when satellites first began providing consistent measurements. As the remaining ice thins and retreats, more open ocean is left exposed to sunlight. Ice helps cool the planet by reflecting sunlight, but darker seawater absorbs heat instead, which speeds up warming and contributes to even greater ice loss. Climate projections suggest the Arctic could experience ice-free summers within the next few decades, and scientists are still working to understand how this shift might affect ecosystems and human societies.

For many years, scientists have known that fine particles from space steadily fall to Earth and accumulate in ocean sediments. A study published on November 6 in *Science* shows that identifying where this cosmic dust appears, and where it is missing, offers clues about how sea ice coverage has changed over thousands of years.

"If we can project the timing and spatial patterns of ice coverage decline in the future, it will help us understand warming, predict changes to food webs and fishing, and prepare for geopolitical shifts," said Frankie Pavia, a UW assistant professor of oceanography who led the research.

How Cosmic Dust Helps Track Ancient Ice

Cosmic dust forms when stars explode or when comets break apart, and much of it carries a rare version of helium called helium-3 after passing near the sun. Researchers measure helium-3 to separate cosmic dust from material originating on Earth.

"It's like looking for a needle in a haystack," Pavia said. "You've got this small amount of cosmic dust raining down everywhere, but you've also got Earth sediments accumulating pretty fast."

In this project, however, Pavia focused more on places where the dust did not show up.

"During the last ice age, there was almost no cosmic dust in the Arctic sediments," he said.

Reconstructing 30,000 Years of Arctic Sea Ice

The team proposed that cosmic dust could serve as a stand-in for satellite measurements of ice. When the sea surface is covered with ice, the dust cannot settle on the seafloor, but open water allows it to reach the sediment. By measuring the amount of cosmic dust in sediment cores collected from three Arctic locations, the researchers recreated sea ice history over the past 30,000 years.

The three study sites "span a gradient of modern ice coverage," Pavia said. One site near the North Pole remains ice-covered throughout the year. A second sits near the seasonal edge of the ice in September, and the third was consistently ice-covered in 1980 but now experiences periodic ice-free conditions.

The team found that times of persistent ice cover matched periods with very little cosmic dust in the sediments. This was true during the last ice age about 20,000 years ago. As the planet warmed afterward, cosmic dust began to appear again in the sediment samples.

Linking Ice Changes to Nutrient Use

The researchers also compared their reconstructed ice record with data on nutrient availability. They discovered that nutrient consumption was highest when sea ice levels were low and declined as ice cover increased.

Nutrient cycling data comes from tiny shells once inhabited by foraminifera, organisms that digest nitrogen. Chemical signatures preserved in their shells reveal how much of the available nutrients these organisms used while they were alive.

"As ice decreases in the future, we expect to see increased consumption of nutrients by phytoplankton in the Arctic, which has consequences for the food web," Pavia said.

What Drives Shifts in Nutrients?

More work is needed to understand why nutrient use changes as ice declines. One possibility is that less ice leads to more photosynthesis at the surface, increasing nutrient uptake. Another idea suggests that melting ice dilutes nutrient concentrations in the water.

Both ideas could appear as higher nutrient consumption, but only the first would signal a rise in marine productivity.

Additional co-authors include Jesse R. Farmer at the University of Massachusetts Boston; Laura Gemery and Thomas M. Cronin at the United States Geological Survey; and Jonathan Treffkorn and Kenneth A. Farley at Caltech.

This research was supported by the National Science Foundation and a Foster and Coco Stanback Postdoctoral Fellowship.

- Physicists prove the Universe isn't a simulation after all

Researchers have mathematically proven that our universe cannot be a simulation.

Date: November 10, 2025
Source: University of British Columbia Okanagan campus

Physicists have proven that the universe's laws can't be fully described by computation. Reality itself depends on a deeper, non-algorithmic understanding that no simulation could reproduce. Credit: Shutterstock

The idea that our universe might be nothing more than an elaborate computer simulation has been a favourite theme in science fiction for decades. Yet new research from UBC Okanagan suggests that not only is this concept implausible -- it is mathematically impossible.

Dr. Mir Faizal, an Adjunct Professor at UBC Okanagan's Irving K. Barber Faculty of Science, and his collaborators, Drs. Lawrence M. Krauss, Arshid Shabir, and Francesco Marino, have shown that the underlying fabric of reality operates in a way no computer could ever replicate.

Their study, published in the *Journal of Holography Applications in Physics*, doesn't just dispute the idea of a simulated universe like *The Matrix*. It goes further, demonstrating that the cosmos itself is built upon a kind of understanding that lies outside the reach of any algorithm.

The Simulation Hypothesis Meets Mathematics

"It has been suggested that the universe could be simulated. If such a simulation were possible, the simulated universe could itself give rise to life, which in turn might create its own simulation. This recursive possibility makes it seem highly unlikely that our universe is the original one, rather than a simulation nested within another simulation," says Dr. Faizal. "This idea was once thought to lie beyond the reach of scientific inquiry. However, our recent research has demonstrated that it can, in fact, be scientifically addressed."

The team's findings rest on the evolving understanding of what reality truly is. Physics has moved far beyond Isaac Newton's view of solid objects moving through space. Einstein's theory of relativity replaced that classical model, and quantum mechanics transformed it yet again. Now, at the forefront of theoretical physics, quantum gravity proposes that even space and time are not fundamental elements. Instead, they arise from something deeper -- pure information.

The Hidden Realm Beneath Reality

Physicists describe this informational layer as a "Platonic realm," a mathematical foundation more real than the physical world we perceive. According to the new research, it is from this realm that space and time themselves emerge.

However, the scientists demonstrated that even this information-based structure cannot fully describe reality through computation alone. By applying advanced mathematical principles, including Gödel's incompleteness theorem, they proved that any consistent and complete model of existence requires what they call "non-algorithmic understanding."
To grasp this idea, imagine how a computer works -- it follows a set of defined instructions step by step. Yet, some truths exist that cannot be reached by following any sequence of logical operations. These are known as "Gödelian truths," and while they are real, they cannot be proven using computation.

Where Computation Fails

Consider the statement, "This true statement is not provable." If it were provable, it would be false, contradicting logic. If it cannot be proven, then it is true, which means any logical system attempting to prove it is incomplete. In either case, computation alone falls short.
"We have demonstrated that it is impossible to describe all aspects of physical reality using a computational theory of quantum gravity," says Dr. Faizal. "Therefore, no physically complete and consistent theory of everything can be derived from computation alone. Rather, it requires a non-algorithmic understanding, which is more fundamental than the computational laws of quantum gravity and therefore more fundamental than spacetime itself."

Why the Universe Cannot Be Simulated

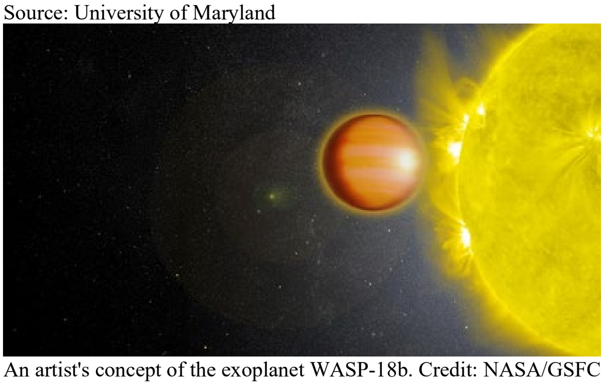
If the underlying rules of the Platonic realm seem similar to those governing a computer simulation, could that realm itself be simulated? The answer, according to the researchers, is no.
"Drawing on mathematical theorems related to incompleteness and indefinability, we demonstrate that a fully consistent and complete description of reality cannot be achieved through computation alone," explains Dr. Faizal. "It requires non-algorithmic understanding, which by definition is beyond algorithmic computation and therefore cannot be simulated. Hence, this universe cannot be a simulation."
Co-author Dr. Lawrence M. Krauss notes that the implications of this finding extend deep into the foundations of physics. "The fundamental laws of physics cannot be contained within space and time, because they generate them. It has long been hoped, however, that a truly fundamental theory of everything could eventually describe all physical phenomena through computations grounded in these laws. Yet we have demonstrated that this is not possible. A complete and consistent description of reality requires something deeper -- a form of understanding known as non-algorithmic understanding."

Reality Beyond Algorithms

As Dr. Faizal summarizes, "Any simulation is inherently algorithmic -- it must follow programmed rules. But since the fundamental level of reality is based on non-algorithmic understanding, the universe cannot be, and could never be, a simulation."
For years, the simulation hypothesis was regarded as untestable, confined to the realms of philosophy and speculative fiction. This new research, however, anchors it firmly in mathematical and physical theory -- delivering what may be the final, definitive answer to one of science's most intriguing questions.

- JWST captures stunning 3D view of a planet’s scorching atmosphere

Astronomers have unveiled the first-ever 3D map of an exoplanet’s atmosphere, revealing the blazing dynamics of WASP-18b.
Date: November 2, 2025
Source: University of Maryland



An artist's concept of the exoplanet WASP-18b. Credit: NASA/GSFC

Astronomers have produced the first three-dimensional map of a planet outside our solar system, revealing distinct temperature regions, including one so hot that water vapor breaks apart. The findings appear in *Nature Astronomy*, published October 28, 2025.
Led by researchers at the University of Maryland and Cornell University, the study charts temperatures across WASP-18b, a massive gas giant classified as an "ultra-hot Jupiter" located 400 light-years from Earth. The team applied a method known as 3D eclipse mapping, also called spectroscopic eclipse mapping, marking the first time this

technique has been used to build a full 3D temperature map. The work expands on a 2D eclipse map the group released in 2023 using highly sensitive observations from NASA's James Webb Space Telescope (JWST).

"This technique is really the only one that can probe all three dimensions at once: latitude, longitude and altitude," said the paper's co-lead author Megan Weiner Mansfield, an assistant professor of astronomy at UMD. "This gives us a higher level of detail than we've ever had to study these celestial bodies."

With this approach, scientists can begin charting atmospheric differences across many exoplanets' observable by JWST, much as ground-based telescopes once documented Jupiter's Great Red Spot and its banded clouds.

"Eclipse mapping allows us to image exoplanets that we can't see directly, because their host stars are too bright," said the paper's co-lead author Ryan Challener, a postdoctoral associate in Cornell University's Department of Astronomy. "With this telescope and this new technique, we can start to understand exoplanets along the same lines as our solar system neighbours."

Spotting exoplanets is difficult because they are typically far dimmer than their stars, often contributing less than 1% of the total light. Eclipse mapping measures tiny variations in that light as the planet moves behind its star, alternately hiding and revealing different regions. By tying these small brightness changes to specific locations on the planet and analysing them in multiple colours, scientists can reconstruct temperatures across latitude, longitude, and altitude.

WASP-18b is well suited for this test because it has about the mass of 10 Jupiter's, completes an orbit in only 23 hours, and reaches temperatures near 5,000 degrees Fahrenheit. Those properties provide a comparatively strong signal for the new mapping method.

The team's earlier 2D map used a single colour of light. For the 3D version, they reanalysed the same JWST data from the Near-Infrared Imager and Slitless Spectrograph (NIRISS) across many wavelengths. Each colour probes different layers of WASP-18b's atmosphere and corresponds to a specific temperature and altitude. Combining these layers yields a detailed three-dimensional temperature structure.

"If you build a map at a wavelength that water absorbs, you'll see the water deck in the atmosphere, whereas a wavelength that water does not absorb will probe deeper," Challener explained. "If you put those together, you can get a 3D map of the temperatures in this atmosphere."

The 3D analysis identifies spectroscopically distinct zones on the planet's permanent dayside, which always faces the star because the planet is tidally locked. A circular hot spot sits where the star's light strikes most directly, and winds appear too weak to spread that heat efficiently. A cooler ring encircles the hot centre near the limb of the planet.

Measurements also show reduced water vapor within the hot spot compared with the planet's average.

"We've seen this happen on a population level, where you can see a cooler planet that has water and then a hotter planet that doesn't have water," Weiner Mansfield explained. "But this is the first time we've seen this be broken across one planet instead. It's one atmosphere, but we see cooler regions that have water and hotter regions where the water's being broken apart. That had been predicted by theory, but it's really exciting to actually see this with real observations."

Additional JWST observations could sharpen the spatial detail in future 3D eclipse maps.

Weiner Mansfield noted that the method opens new opportunities to study many "hot Jupiter's," which number in the hundreds among the more than 6,000 confirmed exoplanets. She also aims to apply 3D eclipse mapping to smaller, rocky worlds beyond gas giants like WASP-18b.

"It's very exciting to finally have the tools to see and map out the temperatures of a different planet in this much detail. It's set us up to possibly use the technique on other types of exoplanets. For example, if a planet doesn't have an atmosphere, we can still use the technique to map the temperature of the surface itself to possibly understand its composition," Mansfield said. "Although WASP-18b was more predictable, I believe we will have the chance to see things that we could never have expected before."

This research was supported by the James Webb Space Telescope's Transiting Exoplanet Community Early Release Science Program.

- ❖ Scientists discover a way simulate the Universe on a laptop

A new tool lets scientists model the universe from their laptops—fast, smart, and stunningly simple.

Date: October 30, 2025
Source: University of Waterloo

Researchers have built a powerful tool that lets them simulate the universe on a laptop. It's transforming how scientists study the cosmos by making complex analyses faster, simpler, and more accessible. Credit: AI/ScienceDaily.com

As astronomers gather more data than ever before, studying the cosmos has become an increasingly complex task. A new innovation is changing that reality. Researchers have now developed a way to analyse enormous cosmic data sets using only a laptop and a few hours of processing time.

Leading this effort is Dr. Marco Bonici, a postdoctoral researcher at the Waterloo Centre for Astrophysics at the University of Waterloo. Bonici and an international team created Effort.jl, short for *EFfective Field theORy surrogate*. This tool uses advanced numerical techniques and smart data-preprocessing methods to deliver exceptional computational performance while maintaining the accuracy required in cosmology. The team designed it as a powerful emulator for the Effective Field Theory of Large-Scale Structure (EFTofLSS), allowing researchers to process vast datasets more efficiently than ever before.

Turning Frustration Into Innovation

The idea for Effort.jl emerged from Bonici's experience running time-consuming computer models. Each time he adjusted even a single parameter, it could take days of extra computation to see the results. That challenge inspired him to build a faster, more flexible solution that could handle such adjustments in hours rather than days.

"Using Effort.jl, we can run through complex data sets on models like EFTofLSS, which have previously needed a lot of time and computer power," Bonici explained. "With projects like DESI and Euclid expanding our knowledge of the universe and creating even larger astronomical datasets to explore, Effort.jl allows researchers to analyse data faster, inexpensively and multiple times while making small changes based on nuances in the data."

Smarter Simulations for a Faster Universe

Effort.jl belongs to a class of tools known as *emulators*. These are trained computational shortcuts that replicate the behaviour of large, resource-intensive simulations but run dramatically faster. By using emulators, scientists can explore many possible cosmic scenarios in a fraction of the time and apply advanced techniques such as gradient-based sampling to study intricate physical models with greater efficiency.

"We were able to validate the predictions coming out of Effort.jl by aligning them with those coming out of EFTofLSS," Bonici said. "The margin of error was small and showed us that the calculations coming out of Effort.jl are strong. Effort.jl can also handle observational quirks like distortions in data and can be customized very easily to the needs of the researcher."

Human Expertise Still Matters

Despite its impressive capabilities, Effort.jl is not a substitute for scientific understanding. Cosmologists still play a vital role in setting parameters, interpreting results, and applying physical insight to ensure meaningful conclusions. The combination of expert knowledge and computational power is what makes the system so effective.

Looking ahead, Effort.jl is expected to take on even larger cosmological datasets and work alongside other analytical tools. Researchers also see potential for its methods in areas beyond astrophysics, including weather and climate modelling.

The paper, "Effort.jl: a fast and differentiable emulator for the Effective Field Theory of the Large-Scale Structure of the Universe," was published in the *Journal of Cosmology and Astroparticle Physics*.

- ❖ New quantum network could finally reveal dark matter

Date: October 29, 2025
Source: Tohoku University

By linking superconducting qubits into optimized quantum networks, scientists dramatically improved sensitivity for detecting dark matter. The technique could also enhance technologies from GPS to medical imaging. Credit: Shutterstock

Detecting dark matter, the invisible substance thought to keep galaxies intact, remains one of the most enduring mysteries in physics. Although it cannot be directly observed or touched, researchers suspect that dark matter leaves behind faint traces. These subtle signals might be detectable using advanced quantum technologies that can sense extremely small disturbances.

A team at Tohoku University has proposed a new strategy to make quantum sensors more powerful by linking them together in carefully designed networks. These sensors rely on the principles of quantum physics to measure minute fluctuations that ordinary instruments would miss. By connecting them in optimized patterns, the researchers believe it may be possible to detect the elusive fingerprints of dark matter with unprecedented precision.

Superconducting Qubits Become Cosmic Detectors

The research centres on superconducting qubits, tiny electronic circuits kept at extremely low temperatures. These qubits are typically used in quantum computers, but in this case, they act as ultrasensitive detectors. The concept is similar to teamwork -- while a single sensor might struggle to pick up a weak signal, a coordinated network of qubits can amplify and identify it far more effectively.

To test this concept, the team experimented with several types of network structures, including ring, line, star, and fully connected configurations. They built systems using four and nine qubits and then applied variational quantum metrology (a technique that works much like training a machine-learning algorithm) to fine-tune how quantum states were prepared and measured. To further improve accuracy, they used Bayesian estimation to reduce noise, similar to sharpening a blurred photograph.

Strong Results Show Real-World Potential

The optimized networks consistently outperformed conventional approaches, even when realistic noise was added. This result suggests that the method could already be implemented on existing quantum devices.

"Our goal was to figure out how to organize and fine-tune quantum sensors so they can detect dark matter more reliably," explained Dr. Le Bin Ho, the study's lead author. "The network structure plays a key role in enhancing sensitivity, and we've shown it can be done using relatively simple circuits."

Beyond the hunt for dark matter, these quantum sensor networks could drive major advances in technology. Potential applications include quantum radar, gravitational wave detection, and highly accurate timekeeping. In the future, the same approach could help improve GPS precision, enhance MRI brain scans, and even reveal hidden underground structures.

"This research shows that carefully designed quantum networks can push the boundaries of what is possible in precision measurement," Dr. Ho added. "It opens the door to using quantum sensors not just in laboratories, but in real-world tools that require extreme sensitivity."

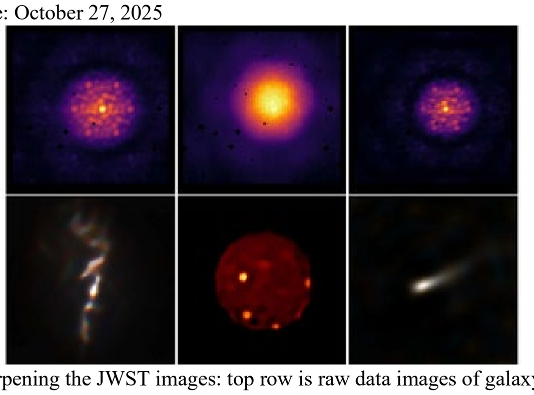
Next Steps for Quantum Research

Looking ahead, the Tohoku University team plans to expand this method to larger sensor networks and develop techniques to make them more resilient against noise.

Their findings were published in *Physical Review D* on October 1, 2025.

- AI restores James Webb telescope's crystal-clear vision

Date: October 27, 2025



Sharpening the JWST images: top row is raw data images of galaxy NGC 1068, Jupiter's moon Io and Wolf-Rayet star 137 (or WR 137). The bottom row shows sharpened or 'deblurred' images after being processed by the pipeline developed by Louis Desdoigts and Max Charles. Credit: Max Charles/University of Sydney

Two PhD students from Sydney have helped restore the sharp vision of the world's most powerful space observatory without ever leaving the ground. Louis Desdoigts, now a postdoctoral researcher at Leiden University in the Netherlands, and his colleague Max Charles celebrated their achievement with tattoos of the instrument they repaired inked on their arms -- an enduring reminder of their contribution to space science.

A Groundbreaking Software Fix

Researchers at the University of Sydney developed an innovative software solution that corrected blurriness in images captured by NASA's multi-billion-dollar James Webb Space Telescope (JWST). Their breakthrough restored the full precision of one of the telescope's key instruments, achieving what would once have required a costly astronaut repair mission.

This success builds on the JWST's only Australian-designed component, the Aperture Masking Interferometer (AMI). Created by Professor Peter Tuthill from the University of Sydney's School of Physics and the Sydney Institute for Astronomy, the AMI allows astronomers to capture ultra-high-resolution images of stars and exoplanets. It works by combining light from different sections of the telescope's main mirror, a process known as interferometry. When the JWST began its scientific operations, researchers noticed that AMI's performance was being affected by faint electronic distortions in its infrared camera detector. These distortions caused subtle image fuzziness, reminiscent of the Hubble Space Telescope's well-known early optical flaw that had to be corrected through astronaut spacewalks.

Solving a Space Problem from Earth

Instead of attempting a physical repair, PhD students Louis Desdoigts and Max Charles, working with Professor Tuthill and Associate Professor Ben Pope (at Macquarie University), devised a purely software-based calibration technique to fix the distortion from Earth.

Their system, called AMIGO (Aperture Masking Interferometry Generative Observations), uses advanced simulations and neural networks to replicate how the telescope's optics and electronics function in space. By pinpointing an issue where electric charge slightly spreads to neighbouring pixels -- a phenomenon called the brighter-fatter effect -- the team designed algorithms that digitally corrected the images, fully restoring AMI's performance.

"Instead of sending astronauts to bolt on new parts, they managed to fix things with code," Professor Tuthill said. "It's a brilliant example of how Australian innovation can make a global impact in space science."

Sharper Views of the Universe

The results have been striking. With AMIGO in use, the James Webb Space Telescope has delivered its clearest images yet, capturing faint celestial objects in unprecedented detail. This includes direct images of a dim exoplanet and a red-brown dwarf orbiting the nearby star HD 206893, about 133 light years from Earth.

A related study led by Max Charles further demonstrated AMI's renewed precision. Using the improved calibration, the telescope produced sharp images of a black hole jet, the fiery surface of Jupiter's moon Io, and the dust-filled stellar winds of WR 137 -- showing that JWST can now probe deeper and clearer than before.

"This work brings JWST's vision into even sharper focus," Dr. Desdoigts said. "It's incredibly rewarding to see a software solution extend the telescope's scientific reach -- and to know it was possible without ever leaving the lab."

Dr. Desdoigts has now landed a prestigious postdoctoral research position at Leiden University in the Netherlands.

Both studies have been published on the pre-press server arXiv. Dr. Desdoigts' paper has been peer-reviewed and will shortly be published in the *Publications of the Astronomical Society of Australia*. We have published this release to coincide with the latest round of James Webb Space Telescope General Observer, Survey and Archival Research programs.

Associate Professor Benjamin Pope, who presented on these findings at SXSW Sydney, said the research team was keen to get the new code into the hands of researchers working on JWST as soon as possible.

- Scientists may have found the planet that made the Moon

Researchers have traced chemical clues in rocks from Earth and the Moon to uncover the origins of Theia, the body that struck Earth billions of years ago.

Date: November 23, 2025

Source: Max Planck Institute for Solar System Research

Artist's impression of the collision between the early Earth and Theia. Since Theia originated in the inner Solar System, in this perspective the Sun can be seen in the background. Credit: MPS / Mark A. Garlick

Key Points

- **Reconstructing Theia's makeup:** A new study in Science identifies the most likely chemical composition of Theia, the ancient planetary body that collided with early Earth.
- **Clues to its birthplace:** Theia's reconstructed composition points to an origin in the inner Solar System and suggests it formed even closer to the Sun than Earth.
- **Moon rocks as evidence:** Scientists analysed lunar samples returned by the Apollo missions, using their precise iron isotope ratios for the first time to trace Theia's origins.

About 4.5 billion years ago, a dramatic event transformed the young Earth when a large protoplanet known as Theia struck our planet. Scientists still cannot fully reconstruct the sequence of the impact or what followed, but the consequences are clear. The collision altered Earth's size, structure, and orbit, and it ultimately led to the creation of the Moon, which has remained our constant companion in space ever since.

This raises several important questions. What kind of object collided with Earth so violently? How massive was Theia, what was it composed of, and from what region of the Solar System did it originate? These questions remain challenging because Theia did not survive the encounter. Even so, chemical clues linked to its existence persist within the modern Earth and Moon. A new study published on November 20, 2025, in *Science* and conducted by researchers from the Max Planck Institute for Solar System Research (MPS) and the University of Chicago uses these clues to reconstruct Theia's likely composition and identify where it may have formed.

"The composition of a body archives its entire history of formation, including its place of origin." *Thorsten Kleine, Director at MPS and co-author of the new study*

Isotopes as Records of a Body's Ancient Origins

The proportions of certain metal isotopes provide valuable insight into a body's past. Isotopes are different versions of the same element that vary only in the number of neutrons in the nucleus and therefore in their mass. In the early Solar System, these isotopes were not distributed evenly. Materials near the Sun contained slightly different isotope ratios than those formed farther out. As a result, a body's isotopic makeup preserves information about the original region where its building materials formed.

Tracking Theia's Signature in Earth and Lunar Rocks

In the new study, scientists measured iron isotope ratios in rocks from Earth and the Moon with a level of precision not achieved before. They analysed 15 samples from Earth and six lunar samples returned by the Apollo missions. The findings were consistent with previous work on chromium, calcium, titanium, and zirconium isotopes: Earth and Moon show no measurable differences in these ratios.

This close match, however, does not directly reveal what Theia was like. Multiple collision models could still produce the same final outcome. In some scenarios, the Moon forms mostly from Theia's material. In others, the early Earth contributes most of the material, or the two bodies mix so thoroughly that their individual signatures cannot be separated.

Reconstructing a Lost Planet from Chemical Evidence

To learn more about Theia, the team treated the Earth-Moon system like a puzzle that could be solved backward. By considering the identical isotopic signatures found in both bodies, they tested combinations of possible Theia compositions, sizes, and early Earth properties that could have produced the final state we observe today.

Their analysis included iron, chromium, molybdenum, and zirconium isotopes. Each element provides information about a different stage in planetary development. Long before the collision with Theia, the early Earth experienced an internal differentiation process. As Earth's metallic core formed, elements such as iron and molybdenum migrated inward and became concentrated there, leaving the mantle with much lower amounts. The iron now found in Earth's mantle must therefore have arrived after the core formed, possibly delivered by Theia. Elements like zirconium, which remained in the mantle, record the full history of the planet's formation.

Meteorites as Clues to Theia's Birthplace

When the researchers compared all mathematically possible combinations of Theia and early Earth compositions, they found that some outcomes were highly improbable.

"The most convincing scenario is that most of the building blocks of Earth and Theia originated in the inner Solar System. Earth and Theia are likely to have been neighbours."

Timo Hopp, MPS scientist and lead author of the new study

The early Earth's makeup can be explained mostly as a mix of known meteorite types. Theia is different. Meteorites originate from specific regions of the Solar System and act as reference points for the materials available during planet formation. In the case of Theia, the data suggest that its composition cannot be fully matched to known meteorite groups. Instead, the results indicate that some of Theia's building material came from even closer to the Sun than Earth's own source region. According to the team's calculations, Theia most likely formed interior to Earth's orbit before the two bodies eventually collided.

- A high-altitude telescope just changed what we know about black holes

Date: November 23, 2025
Source: Washington University in St. Louis

A record-setting balloon telescope mission brings scientists closer to unlocking how black holes unleash vast energy and light. Credit: Shutterstock

An international group of physicists, including scientists from Washington University in St. Louis, has gathered new measurements that shed light on how black holes draw in surrounding material and release tremendous amounts of radiation and energy.

The team directed a balloon-borne telescope known as XL-Calibur toward Cygnus X-1, a well-studied black hole located roughly 7,000 light-years away. "The observations we made will be used by scientists to test increasingly realistic, state-of-the-art computer simulations of physical processes close to the black hole," said Henric Krawczynski, the Wilfred R. and Ann Lee Konneker Distinguished Professor in Physics and a fellow at WashU's McDonnell Centre for the Space Sciences.

Measuring the Polarized Light Near a Black Hole

XL-Calibur is designed to measure the polarization of light, a property that describes the orientation of electromagnetic vibrations. By studying how this light is polarized, scientists can gain valuable clues about the shape and behaviour of the extremely hot gas and debris swirling around black holes at extreme speeds.

A recent paper in The Astrophysical Journal features the latest results from the Cygnus X-1 observations and reports the most accurate measurement so far of the black hole's hard X-ray polarization. The publication includes contributions from many WashU researchers, including graduate student Ephraim Gau and postdoctoral research associate Kun Hu, who served as corresponding authors.

"If we try to find Cyg X-1 in the sky, we'd be looking for a really tiny point of X-ray light," Gau said. "Polarization is thus useful for learning about all the stuff happening around the black hole when we can't take normal pictures from Earth."

A Balloon Flight Across the Northern Hemisphere

These findings came from XL-Calibur's July 2024 balloon flight from Sweden to Canada. During this mission, the instrument also collected data from the Crab pulsar and its surrounding wind nebula, one of the brightest and most stable sources of X-rays in the sky. Krawczynski noted that the 2024 flight set multiple technical milestones, including detailed measurements of both Cygnus X-1 and the Crab pulsar.

"Collaborating with colleagues at WashU, as well as other groups in the U.S. and Japan, on XL-Calibur has been extremely rewarding," said Mark Pearce, an XL-Calibur collaborator and a professor at KTH Royal Institute of Technology in Sweden. "Our observations of Crab and Cyg X-1 clearly show that the XL-Calibur design is sound. I very much hope that we can now build on these successes with new balloon flights."

Looking Ahead to Future Missions

The team aims to observe additional black holes and neutron stars during the telescope's next planned launch from Antarctica in 2027. By expanding the range of objects studied, researchers hope to create a more complete picture of how matter behaves in these extreme environments.

"Combined with the data from NASA satellites such as IXPE, we may soon have enough information to solve longstanding questions about black hole physics in the next few years," added Krawczynski, the project's primary investigator.

A Worldwide Scientific Effort

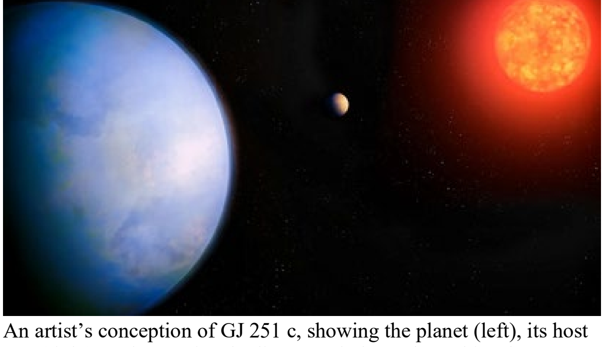
XL-Calibur is supported by a broad collaboration of institutions, including WashU, the University of New Hampshire, Osaka University, Hiroshima University, ISAS/JAXA, the KTH Royal Institute of Technology in Stockholm, and Goddard Space Flight Centre (and Wallops Flight Facility), as well as 13 additional research organizations.

The Washington University in St. Louis team also acknowledges funding from NASA through grants 80NSSC20K0329, 80NSSC21K1817, 80NSSC22K1291, 80NSSC22K1883, 80NSSC23K1041, and 80NSSC24K1178, along with support from the McDonnell Centre for the Space Sciences at Washington University in St. Louis.

- ❖ Nearby super-Earth emerges as a top target in the search for life

Researchers found that the planet may have liquid water on its surface – a necessary ingredient for life.

Date: November 23, 2025
Source: University of California – Irvine



An artist's conception of GJ 251 c, showing the planet (left), its host star (right), and a previously discovered planet that orbits closer to the star (middle). Credit: Michael Marcheschi / m2design, University of California, Irvine

University of California, Irvine astronomers have identified an exoplanet located within a star's habitable zone, a region where temperatures could allow liquid water to exist on the surface. Liquid water is considered essential for every form of life currently known. The planet lies in a relatively nearby part of the Milky Way Galaxy and appears to have a rocky structure similar to Earth. It is several times more massive, placing it in the category of a "super-Earth."

The UC Irvine team and its collaborators describe their analysis of this planet in a paper recently published in *The Astronomical Journal*.

"We have found so many exoplanets at this point that discovering a new one is not such a big deal," said co-author Paul Robertson, UC Irvine associate professor of physics & astronomy. "What makes this especially valuable is that its host star is close by, at just about 18 light-years away. Cosmically speaking, it's practically next door."

Studying a Planet Orbiting an Active M-Dwarf Star

The newly identified planet, named GJ 251 c, circles an M-dwarf star, which is the most common and one of the oldest types of stars in our galaxy. M-dwarfs often show significant stellar activity, including star spots (cool, dark regions on the star's surface) and flares (sudden bursts of outward energy away from the star). These variations can imitate the subtle radial velocity signals astronomers look for, sometimes making it difficult to determine whether a planet is truly present. Even so, the planet's close distance to Earth makes it a strong candidate for direct imaging using the University of California's Thirty Meter Telescope, which is currently under development.

The large mirrors planned for TMT could make it possible to directly observe faint worlds such as GJ 251 c and assess whether water may be present.

"TMT will be the only telescope with sufficient resolution to image exoplanets like this one. It's just not possible with smaller telescopes," said Corey Beard, Ph.D., data scientist at Design West Technologies, former graduate student from Robertson's group, and lead author of the study.

High-Precision Instruments Reveal Subtle Planet Signals

The research team detected GJ 251 c using data from the Habitable-zone Planet Finder and NEID -- two precision instruments designed for identifying exoplanets, both of which Robertson helped develop. These tools measure the tiny influences an orbiting planet has on its star.

As GJ 251 c pulls on its star through gravity, it produces small, periodic shifts in the star's light. HPF recorded these shifts, known as radial velocity signatures, and astronomers used them to confirm that the star is being influenced by an orbiting planet.

HPF also helps reduce the impact of M-dwarf stellar activity by observing in the infrared -- a region of the spectrum where disruptive signals from the star are weaker.

The team's computational models reached a strong enough level of statistical significance to classify GJ 251 c as an exoplanet candidate, reinforcing the need for direct imaging with TMT to verify its properties.

Preparing for Next-Generation Telescopes

"We are at the cutting edge of technology and analysis methods with this system," said Beard. "While its discovery is quite statistically significant, we are still determining the status of the planet due to the uncertainty of our instruments and methods. We need the next generation of telescopes to directly image this candidate, but what we also need is community investment."

Beard and Robertson hope their findings will encourage the exoplanet research community to conduct additional studies of GJ 251 c, especially as new ground-based observatories such as the Thirty Meter Telescope move closer to operational status.

Collaborators on the work include Jack Lubin of UCLA; Eric Ford and Suvrath Mahadevan of Pennsylvania State University; Gudmundur Stefansson of the University of the Netherlands; and Eric Wolf of the University of Colorado, Boulder.

The research received support from NSF grant AST-2108493 for the HPF exoplanet survey and NASA/NSF funding for the NN-EXPLORE program (grant number: 1716038); NASA ICAR program 80NSSC23K1399.

- Our Solar System is racing through space 3x faster than we thought

The solar system’s startlingly high cosmic speed may rewrite what we think we know about the universe.

Date: November 22, 2025
Source: Bielefeld University

A new analysis of radio galaxies suggests our solar system is moving 3.7 times faster than theory allows. The unexpected dipole signal raises deep questions about the universe’s uniformity and our place within it.

How fast and in which direction is our solar system moving through the universe? This seemingly simple question is one of the key tests of our cosmological understanding. A research team led by astrophysicist Lukas Böhme at Bielefeld University has now found new answers, ones that challenge the established standard model of cosmology. The study's findings have just been published in the journal *Physical Review Letters*.

"Our analysis shows that the solar system is moving more than three times faster than current models predict," says lead author Lukas Böhme. "This result clearly contradicts expectations based on standard cosmology and forces us to reconsider our previous assumptions."

A New Look at the Radio Galaxies of the Sky

To determine the motion of the solar system, the team analysed the distribution of so-called radio galaxies, distant galaxies that emit particularly strong radio waves, a form of electromagnetic radiation with very long wavelengths similar to those used for radio signals. Because radio waves can penetrate dust and gas that obscure visible light, radio telescopes can observe galaxies invisible to optical instruments.

As the solar system moves through the universe, this motion produces a subtle "headwind": slightly more radio galaxies appear in the direction of travel. The difference is tiny and can only be detected with extremely sensitive measurements.

Using data from the LOFAR (Low Frequency Array) telescope, a Europe-wide radio telescope network, combined with data from two additional radio observatories, the researchers were able to make an especially precise count of such radio galaxies for the first time. They applied a new statistical method that accounts for the fact that many radio galaxies consist of multiple components.

This improved analysis yielded larger but also more realistic measurement uncertainties. Despite this, the combination of data from all three radio telescopes revealed a deviation exceeding five sigma, a statistically very strong signal considered in science as evidence for a significant result.

Cosmological Consequences

The measurement shows an anisotropy ("dipole") in the distribution of radio galaxies that is 3.7 times stronger than what the standard model of the universe predicts. This model describes the origin and evolution of the cosmos since the Big Bang and assumes a largely uniform distribution of matter.

"If our solar system is indeed moving this fast, we need to question fundamental assumptions about the large-scale structure of the universe," explains Professor Dominik J. Schwarz, cosmologist at Bielefeld University and co-author of the study. "Alternatively, the distribution of radio galaxies itself may be less uniform than we have believed. In either case, our current models are being put to the test."

The new results confirm earlier observations in which researchers studied quasars, the extremely bright centres of distant galaxies where supermassive black holes consume matter and emit enormous amounts of energy. The same unusual effect appeared in these infrared data, suggesting that it is not a measurement error but a genuine feature of the universe.

The study highlights how new observational methods can fundamentally reshape our understanding of the cosmos and how much there still remains to discover in the universe.

- Massive hidden structures deep inside Earth may explain how life began

Giant structures deep inside Earth may preserve ancient core-mantle interactions that helped make the planet uniquely habitable.

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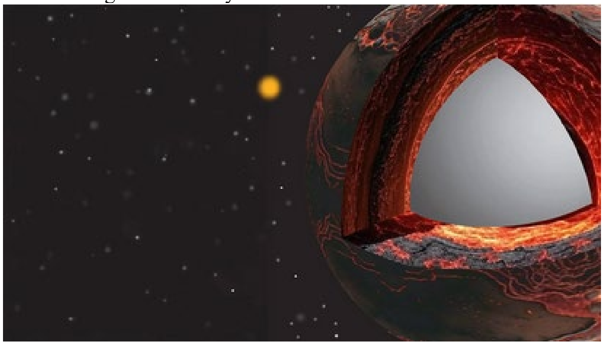
Source: Rutgers University



The illustration shows a cutaway revealing the interior of early Earth with a hot, melted layer above the boundary between the core and mantle. Scientists think some material from the core leaked into this molten layer and mixed in. Over time, that mixing helped create the uneven structure of Earth’s mantle that we see today. Credit: Yoshinori Miyazaki/Rutgers University

For many years, researchers have puzzled over two enormous and unusual features hidden deep inside Earth. Their size, shape and behaviour are so extreme that traditional ideas about how the planet formed and evolved have struggled to explain them.

A recent study in *Nature Geoscience*, led by Rutgers geodynamicist Yoshinori Miyazaki with a team of collaborators, presents a new interpretation that may finally clarify the origins of these structures and how they relate to Earth's long-term habitability.

These features, called large low-shear-velocity provinces and ultra-low-velocity zones, rest at the boundary between the mantle and the core nearly 1,800 miles below the surface. Large low-shear-velocity provinces are enormous masses of extremely hot, dense rock, with one positioned beneath Africa and the other under the Pacific Ocean. Ultra-low-velocity zones resemble thin, partly molten layers that cling to the core in puddle-like patches. Both strongly slow seismic waves, suggesting they contain materials or conditions unlike the surrounding mantle.

"These are not random oddities," said Miyazaki, an assistant professor in the Department of Earth and Planetary Sciences in the Rutgers School of Arts and Sciences. "They are fingerprints of Earth's earliest history. If we can understand why they exist, we can understand how our planet formed and why it became habitable."

Clues From Earth's Magma Ocean Past

According to Miyazaki, Earth was once encased in a global ocean of molten rock. As this ancient magma ocean cooled, many scientists expected the mantle to have developed distinct chemical layers, similar to how frozen juice separates into sugary concentrate and watery ice. However, seismic observations reveal no such clear layering. Instead, large low-shear-velocity provinces and ultra-low velocity zones appear to form complex, uneven piles at the bottom of the mantle.

"That contradiction was the starting point," Miyazaki said. "If we start from the magma ocean and do the calculations, we don't get what we see in Earth's mantle today. Something was missing."

Leaking Core Materials and a Long-Lost Magma Layer

The research team suggested that the missing factor is the core itself. Their model indicates that over billions of years, elements such as silicon and magnesium gradually escaped from the core into the mantle. This mixing would have disrupted the formation of strong chemical layers. It may also account for the unusual composition of the large low-shear-velocity provinces and ultra-low-velocity zones, which the scientists interpret as the cooled remains of a "basal magma ocean" altered by core-derived material.

"What we proposed was that it might be coming from material leaking out from the core," Miyazaki said. "If you add the core component, it could explain what we see right now."

How Deep-Earth Processes Shape Planetary Habitability

Miyazaki noted that the implications stretch beyond mineral chemistry. Interactions between the mantle and core may have influenced how Earth released heat, how volcanic activity developed and even how the atmosphere changed over time. This perspective may help clarify why Earth ended up with oceans and life, while Venus became extremely hot and Mars turned cold and barren.

"Earth has water, life and a relatively stable atmosphere," Miyazaki said. "Venus' atmosphere is 100 times thicker than Earth's and is mostly carbon dioxide, and Mars has a very thin atmosphere. We don't fully understand why that is. But what happens inside a planet, that is, how it cools, how its layers evolve, could be a big part of the answer."

A New Framework for Understanding Earth's Interior

By bringing together seismic observations, mineral physics and geodynamic simulations, the team reframed large low-shear-velocity provinces and ultra-low-velocity zones as essential records of how Earth formed. The study also suggests that these deep features may help fuel volcanic hotspots such as Hawaii and Iceland, creating a direct link between Earth's interior and the surface.

"This work is a great example of how combining planetary science, geodynamics and mineral physics can help us solve some of Earth's oldest mysteries," said Jie Deng of Princeton University, a co-author of the study. "The idea that the deep mantle could still carry the chemical memory of early core-mantle interactions opens up new ways to understand Earth's unique evolution."

The researchers noted that each new insight brings them closer to reconstructing the planet's earliest chapters. Bits of evidence that once seemed isolated now appear to fit together in a more coherent story.

"Even with very few clues, we're starting to build a story that makes sense," Miyazaki said. "This study gives us a little more certainty about how Earth evolved, and why it's so special."