South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk Tony Roberts "Airborne Observatories" **Live talk.**

Tony Roberts has observed the heavens since a child in the sixties and is the current chair at both SAGAS and Croydon Astronomical Society.

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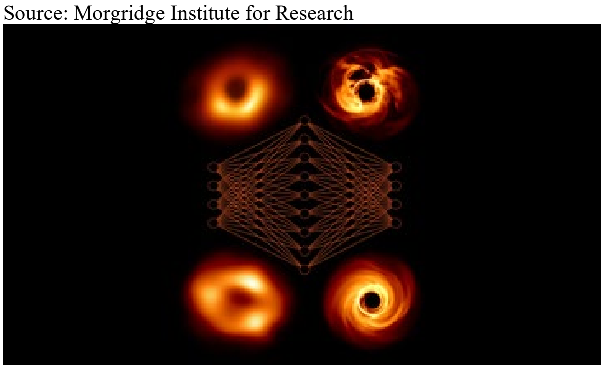
- AI Reveals Milky Way's Black Hole Spins Near Top Speed

Date: June 15, 2025
Source: Morgridge Institute for Research



Artist impression of a neural network that connects the observations (left) to the models (right). Credit: EHT Collaboration/Janssen et al.

An international team of astronomers has trained a neural network with millions of synthetic simulations and artificial intelligence (AI) to tease out new cosmic curiosities about black holes, revealing the one at the centre of our Milky Way is spinning at nearly top speed.

These large ensembles of simulations were generated by throughput computing capabilities provided by the Centre for High Throughput Computing (CHTC), a joint entity of the Morgridge Institute for Research and the University of Wisconsin-Madison. The astronomers published their results and methodology today in three papers in the journal *Astronomy & Astrophysics*.

High-throughput computing, celebrating its 40th anniversary this year, was pioneered by Wisconsin computer scientist Miron Livny. It's a novel form of distributed computing that automates computing tasks across a network of thousands of computers, essentially turning a single massive computing challenge into a supercharged fleet of smaller ones. This computing innovation is helping fuel big-data discovery across hundreds of scientific projects worldwide, including the search for cosmic neutrinos, subatomic particles and gravitational waves as well as to unravel antibiotic resistance.

In 2019, the Event Horizon Telescope (EHT) Collaboration released the first image of a supermassive black hole at the centre of the galaxy M87. In 2022, they presented the image of the black hole at the centre of our Milky Way, Sagittarius A*. However, the data behind the images still contained a wealth of hard-to-crack information. An international team of researchers trained a neural network to extract as much information as possible from the data.

From a handful to millions

Previous studies by the EHT Collaboration used only a handful of realistic synthetic data files. Funded by the National Science Foundation (NSF) as part of the Partnership to Advance Throughput Computing (PATh) project, the Madison-based CHTC enabled the astronomers to feed millions of such data files into a so-called Bayesian neural network, which can quantify uncertainties. This allowed the researchers to make a much better comparison between the EHT data and the models.

Thanks to the neural network, the researchers now suspect that the black hole at the centre of the Milky Way is spinning at almost top speed. Its rotation axis points to the Earth. In addition, the emission near the black hole is mainly caused by extremely hot electrons in the surrounding accretion disk and not by a so-called jet. Also, the magnetic fields in the accretion disk appear to behave differently from the usual theories of such disks.

"That we are defying the prevailing theory is of course exciting," says lead researcher Michael Janssen, of Radboud University Nijmegen, the Netherlands. "However, I see our AI and machine learning approach

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primarily as a first step. Next, we will improve and extend the associated models and simulations."

Impressive scaling

"The ability to scale up to the millions of synthetic data files required to train the model is an impressive achievement," adds Chi-kwan Chan, an Associate Astronomer of Steward Observatory at the University of Arizonaand a longtime PATh collaborator. "It requires dependable workflow automation, and effective workload distribution across storage resources and processing capacity."

"We are pleased to see EHT leveraging our throughput computing capabilities to bring the power of AI to their science," says Professor Anthony Gitter, a Morgridge Investigator and a PATh Co-PI. "Like in the case of other science domains, CHTC's capabilities allowed EHT researchers to assemble the quantity and quality of AI-ready data needed to train effective models that facilitate scientific discovery."

The NSF-funded Open Science Pool, operated by PATh, offers computing capacity contributed by more than 80 institutions across the United States. The Event Horizon black hole project performed more than 12 million computing jobs in the past three years.

"A workload that consists of millions of simulations is a perfect match for our throughput-oriented capabilities that were developed and refined over four decades" says Livny, director of the CHTC and lead investigator of PATh. "We love to collaborate with researchers who have workloads that challenge the scalability of our services."

Scientific papers referenced

Deep learning inference with the Event Horizon Telescope I. Calibration improvements and a comprehensive synthetic data library. By: M. Janssen et al. In: *Astronomy & Astrophysics*, 6 June 2025.

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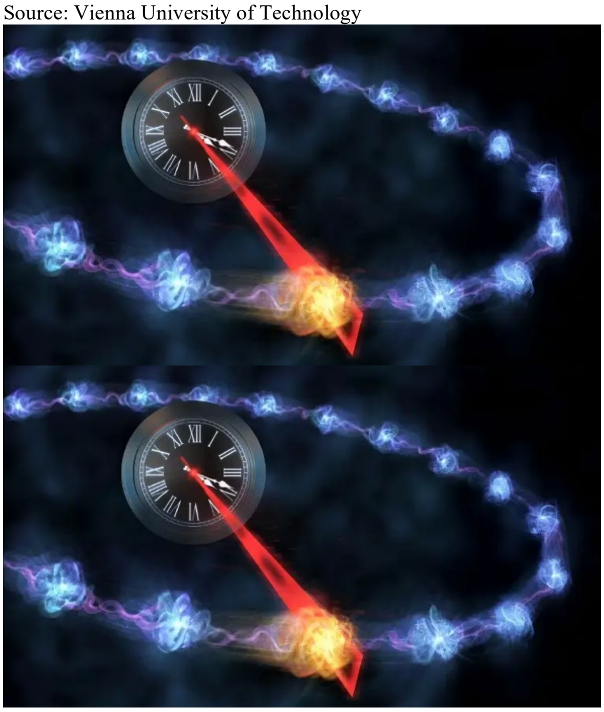
- This mind-bending physics breakthrough could redefine timekeeping

Quantum effects are often used today for extremely precise measurements. But where is the absolute limit of accuracy? Results from TU Wien and collaborators show that it is better than expected.

Date: June 11, 2025
Source: Vienna University of Technology



Artist's impression of a quantum clock. Credit: Alexander Rommel & TU Wien

How can the strange properties of quantum particles be exploited to perform extremely accurate measurements? This question is at the heart of the research field of quantum metrology. One example is the atomic clock, which uses the quantum properties of atoms to measure time much more accurately than would be possible with conventional clocks.

However, the fundamental laws of quantum physics always involve a certain degree of uncertainty. Some randomness or a certain amount of statistical noise has to be accepted. This results in fundamental limits to the accuracy that can be achieved. Until now, it seemed to be an immutable law that a clock twice as accurate requires at least twice as much energy. But now a team of researchers from TU Wien, Chalmers University of Technology, Sweden, and University of Malta have demonstrated that special tricks can be used to increase accuracy exponentially. The crucial point is using two different time scales - similar to how a clock has a second hand and a minute hand.

What exactly is a clock?

"We have analysed in principle, which clocks could be theoretically possible," says Prof. Marcus Huber from the Atomic Institute at the TU Wien. "Every clock needs two components: first, a time base generator - such as a pendulum in a pendulum clock, or even a quantum oscillation. And second, a counter - any element that counts how many time units defined by the time base generator have already passed."

The time base generator can always return to exactly the same state. After one complete oscillation, the pendulum of a pendulum clock is exactly where it was before. After a certain number of oscillations, the caesium atom in an atomic clock returns to exactly the same state it was in before. The counter, on the other hand, must change - otherwise the clock is useless.

"This means that every clock must be connected to an irreversible process," says Florian Meier from TU Wien. "In the language of thermodynamics, this means that every clock increases the entropy in the universe; otherwise, it is not a clock." The pendulum of a pendulum clock generates a little heat and disorder among the air molecules around it, and every laser beam that reads the state of an atomic clock generates heat, radiation and thus entropy.

"We can now consider how much entropy a hypothetical clock with extremely high precision would have to generate - and, accordingly, how much energy such a clock would need," says Marcus Huber. "Until now, there seemed to be a linear relationship: if you want a thousand times the precision, you have to generate at least a thousand times as much entropy and expend a thousand times as much energy."

Quantum time and classical time

However, the research team at TU Wien, together with the Austrian Academy of Sciences (ÖAW) in Vienna and the teams from Chalmers University of Technology, Sweden, and University of Malta, has now shown that this apparent rule can be circumvented by using two different time scales.

"For example, you can use particles that move from one area to another to measure time, similar to how grains of sand indicate the time by falling from the top of the glass to the bottom," says Florian Meier. You can connect a whole series of such time-measuring devices in series and count how many of them have already passed through - similar to how one clock hand counts how many laps the other clock hand has already completed.

"This way, you can increase accuracy, but not without investing more energy," says Marcus Huber. "Because every time one clock hand completes a full rotation and the other clock hand is measured at a new location - you could also say every time the environment around it notices that this hand has moved to a new location - the entropy increases. This counting process is irreversible."

However, quantum physics also allows for another kind of particle transport: the particles can also travel through the entire structure, i.e. across the entire clock dial, without being measured anywhere. In a sense, the particle is then everywhere at once during this process; it has no clearly defined location until it finally arrives - and only then is it actually measured, in an irreversible process that increases entropy.

Like second and minute clock hands

"So, we have a fast process that does not cause entropy - quantum transport - and a slow one, namely the arrival of the particle at the very end," explains Yuri Minoguchi, TU Wien. "The crucial thing about our method is that one hand behaves purely in terms of quantum physics, and only the other, slower hand actually has an entropy-generating effect."

The team has now been able to show that this strategy enables an exponential increase in accuracy per increase in entropy. This means that much higher precision can be achieved than would have been thought possible according to previous theories. "What's more, the theory could be tested in the real world using superconducting circuits, one of the most advanced quantum technologies currently available.," says Simone Gasparinetti, co-author of the study and leader of the experimental team at Chalmers. "This is an important result for research into high-precision quantum measurements and suppression of unwanted fluctuations," says Marcus Huber, "and at the same time it helps us to better understand one of the great unsolved mysteries of physics: the connection between quantum physics and thermodynamics."

- Black holes could act as natural supercolliders -- and help uncover dark matter

Date: June 3, 2025
Source: Johns Hopkins University

As federal funding cuts impact decades of research, scientists could turn to black holes for cheaper, natural alternatives to expensive facilities searching for dark matter and similarly elusive particles that hold clues to the universe's deepest secrets, a new Johns Hopkins study of supermassive black holes suggests.

The findings could help complement multi-billion-dollar expenses and decades of construction needed for research complexes like Europe's Large Hadron Collider, the largest and highest-energy particle accelerator in the world.

"One of the great hopes for particle colliders like the Large Hadron Collider is that it will generate dark matter particles, but we haven't seen any evidence yet," said study co-author Joseph Silk, an astrophysics professor at Johns Hopkins University and the University of Oxford, UK. "That's why there are discussions underway to build a much more powerful version, a next-generation supercollider. But as we invest $30 billion and wait 40 years to build this supercollider — nature may provide a glimpse of the future in super massive black holes."

The research was published on June 3 in *Physical Review Letters*.

Particle colliders smash protons and other subatomic particles into each other at nearly the speed of light, exposing the most fundamental aspects of matter. Subtle energy flashes and debris from the clash could reveal previously undiscovered particles, including potential candidates for dark matter, a critical but ghostly component of the universe that scientists have yet to detect. Facilities such as the Large Hadron Collider, a 17-mile circular tunnel, have also helped transform the internet, cancer therapy, and high-performance computing.

A black hole can spin around its axis like a planet, but with much greater strength because of its intense gravitational field. Scientists are increasingly discovering that some rapidly spinning massive black holes at the centres of galaxies release enormous outbursts of plasma, likely because of jets powered by energy from their spin and surrounding accretion disks. It's these events that could potentially generate the same results as human-made supercolliders, the new study shows.

"If supermassive black holes can generate these particles by high-energy proton collisions, then we might get a signal on Earth, some really high-energy particle passing rapidly through our detectors," said Silk, who is also a researcher at the Institute of Astrophysics in Paris and at the University of Oxford. "That would be the evidence for a novel particle collider within the most mysterious objects in the universe, attaining energies that would be unattainable in any terrestrial accelerator. We'd see something with a strange signature that conceivably provides evidence for dark matter, which is a bit more of a leap but it's possible."

The new study shows that plunging "gas flows" near a black hole can draw energy from its spin, becoming much more violent than scientists thought possible. Near a rapidly spinning black hole, these particles can chaotically collide. Although not identical, the process is similar to the collisions scientists create using intense magnetic fields to accelerate particles in the circular tunnel of a high-energy particle collider.

"Some particles from these collisions go down the throat of the black hole and disappear forever. But because of their energy and momentum, some also come out, and it's those that come out which are accelerated to unprecedentedly high energies," Silk said.

"We figured out how energetic these beams of particles could be: as powerful as you get from a supercollider, or more. It's very hard to say what the limit is, but they certainly are up to the energy of the newest supercollider that we plan to build, so they could definitely give us complementary results."

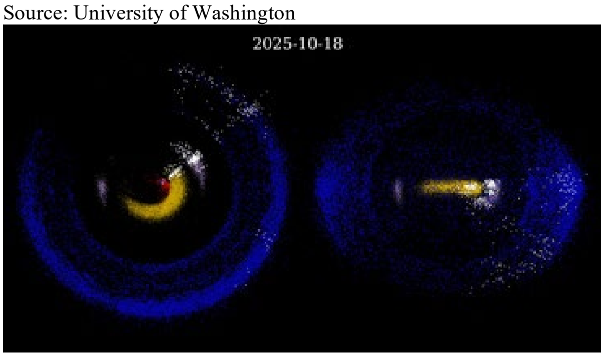
To detect such high-energy particles, scientists could use observatories already tracking supernovae, massive black hole eruptions, and other cosmic events, Silk said. These include detectors like the IceCube Neutrino Observatory in the South Pole or the Kilometre Cube Neutrino Telescope, which recently detected the most energetic neutrino ever recorded under the Mediterranean Sea.

"The difference between a supercollider and a black hole is that black holes are far away," Silk said. "But nevertheless, these particles will get to us."

Dr. Andrew Mummery, a theoretical physicist at University of Oxford, is also an author of the study.

- Millions of new solar system objects to be found and 'filmed in Technicolor' -- studies predict

Date: June 3, 2025
Source: University of Washington



Researchers from the UW and Queen's University Belfast believe that knowledge of the objects in the solar system will expand exponentially when a new telescope comes online later this year. Shown here is a visualization of what astronomers predict the NSF–DOE Vera C. Rubin Observatory's LSST Camera will see, including asteroids and other objects in the sky. Credit: Sorcha.space/University of Washington

A group of astronomers from across the globe, including a team from the University of Washington and led by Queen's University Belfast, have revealed new research showing that millions of new solar system objects will be detected by a brand-new facility, which is expected to come online later this year.
The NSF-DOE Vera C. Rubin Observatory is set to revolutionize our knowledge of the solar system's "small bodies" -- asteroids, comets and other minor planets.
The Rubin Observatory, under construction on the Cerro Pachón ridge in northern Chile, features the 8.4-meter Simonyi Survey Telescope with a unique three-mirror design capable of surveying the entire visible sky every few nights. At its heart is the world's largest digital camera -- the 3.2 gigapixel Legacy Survey of Space and Time (LSST) Camera -- covering a 9.6 square-degree field of view with six filters, roughly 45 times the area of the full moon. Together, this "wide-fast-deep" system will generate 20 terabytes of data every night -- creating an unprecedented time-lapse "movie" of the cosmos over the next 10 years, and an incredibly powerful dataset with which to map the solar system.
The team of astronomers, led by Queen's University's Meg Schwamb, created Sorcha, an innovative new open-source software used to predict what discoveries are likely to be made. Sorcha is the first end-to-end simulator that ingests Rubin's planned observing schedule. It applies assumptions on how Rubin Observatory sees and detects astronomical sources in its images with the best model of what the solar system and its small body reservoirs look like today.
"Accurate simulation software like Sorcha is critical," said Schwamb, a reader in the School of Mathematics and Physics at Queen's University. "It tells us what Rubin will discover and lets us know how to interpret it. Our knowledge of what objects fill Earth's solar system is about to expand exponentially and rapidly."
In addition to the eight major planets, the solar system is home to a vast population of small bodies that formed alongside the planets more than 4.5 billion years ago. Many of these smaller bodies remain essentially unchanged since the solar system's birth, acting as a fossil record of its earliest days. By studying their orbits, sizes and compositions, astronomers can reconstruct how planets formed, migrated and evolved.
These objects -- numbering in the tens of millions -- -- provide a powerful window into processes such as the delivery of water and organic material to Earth, the reshaping of planetary orbits by giant planets and the ongoing risk posed by those whose paths bring them near our planet.
In addition to Queen's University and the UW, the international team includes researchers from the Centre for Astrophysics | Harvard & Smithsonian and the University of Illinois Urbana-Champaign.
A series of papers describing the software and the predictions have been accepted for publication by *The Astronomical Journal.*
Beyond just finding these new small bodies, Rubin Observatory will observe them multiple times using different optical filters, revealing their surface colours. Past solar system surveys typically observed with a single filter.
"With the LSST catalogue of solar system objects, our work shows that it will be like going from black-and-white television to brilliant colour," said Joe Murtagh, a doctoral student at Queen's University. "It's very exciting -- we expect that millions of new solar system objects will be detected and most of these will be picked up in the first few years of sky survey."
The team's simulations show that Rubin will map:

- 127,000 near-Earth objects -- asteroids and comets whose orbits cross or approach Earth. That's more than tripling today's known objects, about 38,000, and detecting more than 70% of potentially hazardous bodies larger than 140 meters. This will cut the risk of undetected asteroid impact of catastrophic proportions by at least two times, making a tremendous contribution to planetary defence.

- Over 5 million main-belt asteroids, up from about 1.4 million, with precise colour and rotation data on roughly one in three asteroids within the survey's first years. This will give scientists unprecedented insight into the characteristics and history of the solar system's building blocks.
- 109,000 Jupiter Trojans, bodies sharing Jupiter's orbit at stable "Lagrange" points -- more than seven times the number catalogued today. These bodies represent some of the most pristine material dating all the way back to the formation of the planets.
- 37,000 trans-Neptunian objects, residents of the distant Kuiper Belt -- nearly 10 times the current census -- shedding light on Neptune's past migration and the outer solar system's history.
- Approximately 1,500-2,000 Centaurs, bodies on short-lived giant planet-crossing orbits in the middle solar system. Most Centaurs will eventually be ejected from the solar system, but a few lucky ones will survive to become short-period comets. The LSST will provide the first detailed view of the Centaurs and the important transition stage from Centaur to comet.

Rubin Observatory's LSST is a once-in-a-generation opportunity to fill in the missing pieces of our solar system, said Mario Juric, a member of the Sorcha team and a UW professor of Astronomy. Juric also is a team lead of Rubin's Solar System Processing Pipelines and a director of UW's DiRAC Institute.

"Our simulations predict that Rubin will expand known small-body populations by factors of 4-9x, delivering an unprecedented trove of orbits, colours and light curves," Juric said. "With this data, we'll be able to update the textbooks of solar system formation and vastly improve our ability to spot -- and potentially deflect -- the asteroids that could threaten Earth."

It took 225 years of astronomical observations to detect the first 1.5 million asteroids, and researchers found that Rubin will double that number in less than a year, said Jake Kurlander, a doctoral student at the UW.

"Rubin's unparalleled combination of breadth and depth make it a uniquely effective discovery machine," Kurlander said.

Siegfried Eggl, an assistant professor of Aerospace Engineering at the University of Illinois Urbana-Champaign added: "Only by debiasing LSST's complex observing pattern can we turn raw detections into a true reflection of the solar system's history -- where the planets formed, and how they migrated over billions of years. Sorcha is a game changer in that respect."

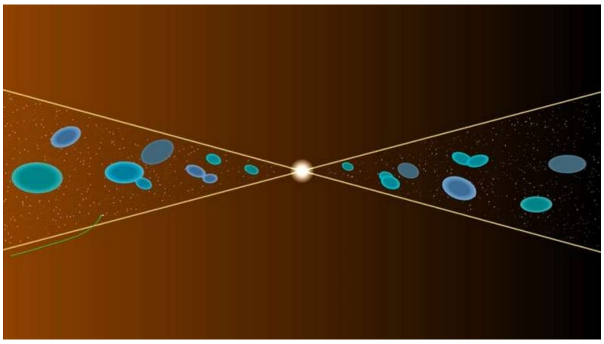
The Sorcha code is open-source and freely available with the simulated catalogues, animations at https://sorcha.space. By making these resources available, the Sorcha team has enabled researchers worldwide to refine their tools and be ready for the flood of LSST data that Rubin will generate, advancing the understanding of the small bodies that illuminate the solar system like never before.

Rubin Observatory is scheduled to unveil its first spectacular imagery at its "First Look" event on June 23, offering the world an early glimpse of the survey's power. Full science operations are slated to begin later this year.

❖ Particles energized by magnetic reconnection in the nascent solar wind

Research offers insights into processes that heat the solar atmosphere and accelerate the solar wind

Date: June 3, 2025
Source: Southwest Research Institute



An SwRI-led study identified particles accelerated to extremely high energies by magnetic reconnection near the Sun. As NASA's Parker Solar Probe (trajectory shown in green) crossed the heliospheric current sheet, it encountered merging magnetic islands (blues) and protons accelerated toward the Sun, establishing reconnection as their source, distinct from unrelated solar processes. Credit: JHUAPL

New research led by a Southwest Research Institute scientist identified a new source of energetic particles near the Sun. These definitive observations were made by instruments aboard NASA's Parker Solar Probe, which detected the powerful phenomena as the spacecraft dipped in and out of the solar corona.

These new results offer fresh perspectives on how magnetic reconnection could heat the solar atmosphere, which then transitions into the solar wind, and also how solar flares accelerate a small fraction of charged particles to near-relativistic speeds.

"Through the SwRI-led Magnetospheric Multiscale mission, scientists made the first direct detection of the source of magnetic reconnection near Earth, observing how this explosive physical process converts stored magnetic energy into kinetic energy and heat," said SwRI's Dr. Mihir Desai, lead author of a new paper about this research. "Now Parker has made direct observations of how magnetic reconnection at the heliospheric current sheet (HCS), where the interplanetary field reverses its polarity, energizes charged particles to extremely high energies."

As Parker crossed the HCS, scientists discovered a sunward-directed reconnection jet and sunward-propagating highly energetic protons, establishing their origin from HCS reconnection sites and not from unrelated processes at the Sun. Within the core of the reconnection exhaust, Parker detected trapped energetic protons a thousand times greater than the available magnetic energy per particle.

"These findings indicate that magnetic reconnection in the HCS is an important source of energetic particles in the near-Sun solar wind," Desai said. "Everywhere there are magnetic fields there will be magnetic reconnection. But the Sun's magnetic fields are much stronger near the star, so there's a lot more stored energy to be released."

Magnetic reconnection -- when magnetic field lines converge, break apart and reconnect in an explosive physical process -- energizes particles and generates high-speed flows. At the heart of space weather, reconnection is responsible for powerful solar events, such as solar flares and coronal mass ejections (CMEs), and drives disturbances in Earth's space environment. Such disturbances produce spectacular auroras but can also shut down electrical power grids and disrupt satellite-based communication and navigation systems.

"Reports from the American Meteorological Society indicated that the powerful solar events in May 2024 wreaked havoc with farmers when extreme geomagnetic storms disrupted the precise GPS-guided navigation systems used to plant, fertilize and harvest rows of seeds, causing an estimated loss of up to $500 million in earning potential," Desai said. "Parker's access to this new data is critical, particularly as we remain in the midst of a very active solar cycle."

Parker was able to make these measurements due to its record-breaking proximity to the Sun, flying through its corona up to three times a year. Of particular interest is understanding how the Sun's atmosphere heats up and accelerates the solar wind.

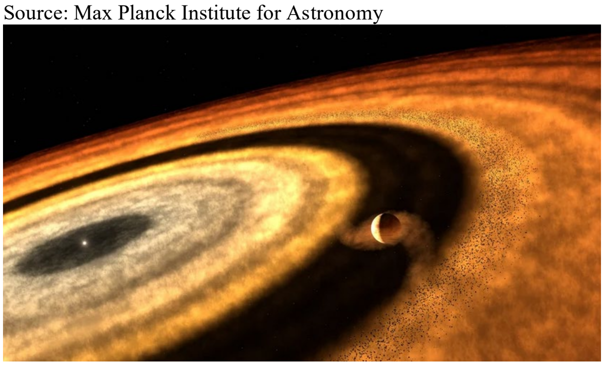
Understanding these processes can also help scientists develop ways to predict and mitigate the effects of solar flares and CMEs, as well as provide new insights for laboratory fusion research.

The Parker Solar Probe was developed as part of NASA's Living With a Star program to explore aspects of the Sun-Earth system that directly affect life and society. The Living With a Star program is managed by the agency's Goddard Space Flight Centre in Greenbelt, Maryland, for NASA's Science Mission Directorate in Washington. The Johns Hopkins University Applied Physics Laboratory designed, built and operates the spacecraft and manages the mission for NASA.

- Webb reveals the origin of the ultra-hot exoplanet WASP-121b

The detection of atmospheric methane and silicon monoxide suggests that it originated in a region analogous to the Solar System's domain of gas and ice giants.

Date: June 2, 2025
Source: Max Planck Institute for Astronomy



This artistic impression depicts the stage at which WASP-121b accumulated most of its gas, as inferred from the latest… [more]

Observations with the James Webb Space Telescope (JWST) have provided new clues about how the exoplanet WASP-121b has formed and where it might have originated in the disc of gas and dust around its star. These insights stem from the detection of multiple key molecules: water vapour, carbon monoxide, silicon monoxide, and methane. With these detections, a team led by astronomers Thomas Evans-Soma and Cyril Gapp was able to compile an inventory of the carbon, oxygen, and silicon in the atmosphere of WASP-121b. The detection of methane in particular also suggests strong vertical winds on the cooler nightside, a process often ignored in current models.

WASP-121b is an ultra-hot giant planet that orbits its host star at a distance only about twice the star's diameter, completing one orbit in approximately 30.5 hours. The planet exhibits two distinct hemispheres: one that always faces the host star, with temperatures locally exceeding 3000 degrees Celsius, and an eternal nightside where temperatures drop to 1500 degrees.

"Dayside temperatures are high enough for refractory materials -- typically solid compounds resistant to strong heat -- to exist as gaseous components of the planet's atmosphere," Thomas Evans-Soma explained. He is an astronomer affiliated with the Max Planck Institute for Astronomy (MPIA) in Heidelberg, Germany, and the University of Newcastle, Australia. He led the study published today in *Nature Astronomy*.

Unveiling the birthplace of WASP-121b

The team investigated the abundance of compounds that evaporate at very different temperatures, providing clues about the planet's formation and evolution. "Gaseous materials are easier to identify than liquids and solids," noted MPIA student Cyril Gapp, the lead author of a second study published today in *The Astronomical Journal*. "Since many chemical compounds are present in gaseous form, astronomers use WASP-121b as a natural laboratory to probe the properties of planetary atmospheres."

The team concluded that WASP-121b likely accumulated most of its gas in a region cold enough for water to remain frozen yet sufficiently warm for methane (CH_4) to evaporate and exist in its gaseous form. Since planets form within a disc of gas and dust surrounding a young star, such conditions occur at distances where stellar radiation creates the appropriate temperatures.

In our own Solar System, this region lies somewhere between the orbits of Jupiter and Uranus. This is remarkable, given that WASP-121b now orbits perilously close to its host star's surface. It suggests that, after its formation, it undertook a long journey from the icy outer regions to the centre of the planetary system.

Reconstructing WASP-121b's eventful youth

Silicon was detected as silicon monoxide (SiO) gas, but originally entered the planet via rocky material such as quartz stored in planetesimals -- essentially asteroids -- after acquiring most of its gaseous envelope. The formation of planetesimals takes time, indicating that this process occurred during the later stages of planetary development.

"The relative abundances of carbon, oxygen, and silicon offer insights into how this planet formed and acquired its material." -- Thomas Evans-Soma

Planet formation begins with icy dust particles that stick together and gradually grow into centimetre- to metre-sized pebbles. They attract surrounding gas and small particles, accelerating their growth. These are the seeds of future planets like WASP-121b. Drag from the surrounding gas causes the moving pebbles to spiral inward towards the star. As they migrate, their embedded ices begin to evaporate in the disc's warmer inner regions.

While the infant planets orbit their host stars, they may grow large enough to open substantial gaps within the protoplanetary disc. This halts the inward drift of pebbles and the supply with embedded ices but leaves enough gas available to build an extended atmosphere.

In the case of WASP-121b, this appears to have occurred at a location where methane pebbles evaporated, enriching the gas that the planet supplied with carbon. In contrast, water pebbles remained frozen, locking away oxygen. This scenario best explains why Evans-Soma and Gapp observed a higher carbon-to-oxygen ratio in the planet's atmosphere than in its host star. WASP-121b continued attracting carbon-rich gas after the flow of oxygen-rich pebbles had stopped, setting the final composition of its atmospheric envelope.

The detection of methane requires strong vertical currents

As the temperature of an atmosphere changes, the quantities of different molecules, such as methane and carbon monoxide, are expected to vary. At the ultra-high temperatures of WASP-121b's dayside, methane is highly unstable and won't be present in detectable quantities. Astronomers have determined for planets like WASP-121b that gas from the dayside hemisphere should be mixed around to the relatively cool nightside hemisphere faster than the gas composition can adjust to the lower temperatures. Under this scenario, one would expect the abundance of methane to be negligible on the nightside, just as it is on the dayside. When instead the astronomers detected plentiful methane on the nightside of WASP-121b, it was a total surprise.
To explain this result, the team proposes that methane gas must be rapidly replenished on the nightside to maintain its high abundance. A plausible mechanism for doing this involves strong vertical currents lifting methane gas from lower atmospheric layers, which are rich in methane thanks to the relatively low nightside temperatures combined with the high carbon-to-oxygen ratio of the atmosphere. "This challenges exoplanet dynamical models, which will likely need to be adapted to reproduce the strong vertical mixing we've uncovered on the nightside of WASP-121b," said Evans-Soma.

JWST's role in the discovery

The team used JWST's Near-Infrared Spectrograph (NIRSpec) to observe WASP-121b throughout its complete orbit around its host star. As the planet rotates on its axis, the heat radiation received from its surface varies, exposing different portions of its irradiated atmosphere to the telescope. This allowed the team to characterize the conditions and chemical composition of the planet's dayside and nightside.
The astronomers also captured observations as the planet transited in front of its star. During this phase, some starlight filters through the planet's atmospheric limb, leaving spectral fingerprints that reveal its chemical makeup. This type of measurement is especially sensitive to the transition region where gases from the dayside and nightside mix. "The emerging transmission spectrum confirmed the detections of silicon monoxide, carbon monoxide, and water that were made with the emission data," Gapp noted. "However, we could not find methane in the transition zone between the day and night side."

Additional information

The MPIA scientists involved in this study included Thomas M. Evans-Soma (also at the University of Newcastle, Australia), Cyril Gapp (also at Heidelberg University), Eva-Maria Ahrer, Duncan A. Christie, Djemma Ruseva (also at the University of St Andrews, UK), and Laura Kreidberg.
Other researchers included David K. Sing (Johns Hopkins University, Baltimore, USA), Joanna K. Barstow (The Open University, Milton Keynes, UK), Anjali A. A. Piette (University of Birmingham, UK and Carnegie Institution for Science, Washington, USA), Jake Taylor (University of Oxford, UK), Joshua D. Lothringer (Space Telescope Science Institute, Baltimore, USA and Utah Valley University, Orem, USA), and Jayesh M. Goyal (National Institute of Science Education and Research (NISER), Odisha, India).
NIRSpec is part of the European Space Agency's (ESA) contribution to the Webb mission, built by a consortium of European companies led by Airbus Defence and Space (ADS). NASA's Goddard Space Flight Centre provided two sub-systems (detectors and micro-shutters). MPIA was responsible for procuring electrical components of the NIRSpec grating wheels.

- Scientists discover new evidence of intermediate-mass black holes

Date: May 30, 2025
Source: Vanderbilt University

Omega Centauri is about 10 times as massive as other big globular clusters – almost as massive as a small galaxy – and consists of roughly 10 million stars that are gravitationally bound.
ESA/Hubble, NASA, Maximilian Häberle (MPIA)

In the world of black holes, there are generally three size categories: stellar-mass black holes (about five to 50 times the mass of the sun), supermassive black holes (millions to billions of times the mass of the sun), and intermediate-mass black holes with masses somewhere in between.

While we know that intermediate-mass black holes should exist, little is known about their origins or characteristics -- they are considered the rare "missing links" in black hole evolution.

However, four new studies have shed new light on the mystery. The research was led by a team in the lab of Assistant Professor of Physics and Astronomy Karan Jani, who also serves as the founding director of the Vanderbilt Lunar Labs Initiative. The work was funded by the National Science Foundation and the Vanderbilt Office of the Vice Provost for Research and Innovation.

The primary paper, "Properties of 'Lite' Intermediate-Mass Black Hole Candidates in LIGO-Virgo's Third Observing Run," was published in *Astrophysical Journal Letters* and led by Lunar Labs postdoctoral fellow Anjali Yelikar and astrophysics Ph.D. candidate Krystal Ruiz-Rocha. The team reanalysed data from the Nobel-Prize winning Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors in the U.S. and the Virgo detector in Italy.

The researchers found that these waves corresponded to mergers of black holes greater than 100 to 300 times the mass of the sun, making them the heaviest gravitational-wave events recorded in astronomy.

"Black holes are the ultimate cosmic fossils," Jani said. "The masses of black holes reported in this new analysis have remained highly speculative in astronomy. This new population of black holes opens an unprecedented window into the very first stars that lit up our universe."

Earth-based detectors like LIGO capture only a split second of the final collision of these "lightweight" intermediate-mass black holes, making it challenging to determine how the universe creates them. To tackle this, Jani's lab turned to the upcoming European Space Agency and NASA's Laser Interferometer Space Antenna (LISA) mission, launching in the late 2030s.

In two additional studies published in *Astrophysical Journal*, "A Sea of Black Holes: Characterizing the LISA Signature for Stellar-origin Black Hole Binaries," led by Ruiz-Rocha, and "A Tale of Two Black Holes: Multiband Gravitational-wave Measurement of Recoil Kicks," led by former summer research intern Shobhit Ranjan, the team showed LISA can track these black holes years before they merge, shedding light on their origin, evolution, and fate.

Detecting gravitational waves from black hole collisions requires extreme precision -- like trying to hear a pin drop during a hurricane. In a fourth study also published in *Astrophysical Journal*, "No Glitch in the Matrix: Robust Reconstruction of Gravitational Wave Signals under Noise Artifacts," the team showcased how artificial intelligence models guarantee that signals from these black holes remain uncorrupted from environmental and detector noise in the data. The paper was led by postdoctoral fellow Chayan Chatterjee and expands upon Jani's AI for New Messengers Program, a collaboration with the Data Science Institute.

"We hope this research strengthens the case for intermediate-mass black holes as the most exciting source across the network of gravitational-wave detectors from Earth to space," Ruiz-Rocha said. "Each new detection brings us closer to understanding the origin of these black holes and why they fall into this mysterious mass range."

Moving forward, Yelikar said the team will explore how intermediate-mass black holes could be observed using detectors on the moon.

"Access to lower gravitational-wave frequencies from the lunar surface could allow us to identify the environments these black holes live in -- something Earth-based detectors simply can't resolve," she said.

In addition to continuing this research, Jani will also be working with the National Academies of Sciences, Engineering, and Medicine on a NASA-sponsored study to identify high-value lunar destinations for human exploration to address decadal-level science objectives.

As part of his participation in this study, Jani will be contributing to the *Panel on Heliophysics, Physics, and Physical Science*, to identify and articulate the science objectives related to solar physics, space weather, astronomy, and fundamental physics that would be most enabled by human explorers on the moon.

"This is an exciting moment in history -- not just to study black holes, but to bring scientific frontiers together with the new era of space and lunar exploration," Jani said. "We have a rare opportunity to train the next generation of students whose discoveries will be shaped by, and made from, the moon."

- When lightning strikes: Gamma-ray burst unleashed by lightning collision

Date: May 21, 2025
Source: The University of Osaka

An upward positive leader that produced a downward terrestrial gamma-ray flash, extending from a television broadcast tower.
Credit: Yuuki Wada

Lightning is a phenomenon that has fascinated humanity since time immemorial, providing a stark example of the power and unpredictability of the natural world. Although the study of lightning can be challenging, scientists have, in recent years, made great strides in developing our understanding of this extreme spectacle.

A study that will be published in *Science Advances*, led by researchers from The University of Osaka, describes a world-first observation of an intense burst of radiation, known as a terrestrial gamma-ray flash (TGF), synchronized with a lightning discharge.

"The ability to study extreme processes such as TGFs originating in lightning allows us to better understand the high-energy processes occurring in Earth's atmosphere," explains Yuuki Wada, lead author of the study.

It had been hypothesized that TGFs arise from lightning discharges as a result of the acceleration of electrons to very high speeds. However, the transient nature of this phenomenon, which lasts for only tens of microseconds, made it difficult to confirm this hypothesis.

In this study, a state-of-the-art multi-sensor setup was used to observe TGFs emerging from lightning storms in Kanazawa City, Ishikawa Prefecture, including optical, radio-frequency, and high-energy radiation.

Two discharge paths were observed, one descending from the thundercloud to the ground-based transmission tower and one ascending in the opposite direction. The researchers found that a TGF occurred just before the two discharge paths met, creating a highly concentrated electric field that accelerated electrons in the air to near light speed.

The first TGF photon was observed 31 microseconds before the collision of the discharge paths, and the full burst lasted for 20 microseconds after they met to form the lightning strike. A discharge of −56 kA occurred as a result of the collision of lightning leaders.

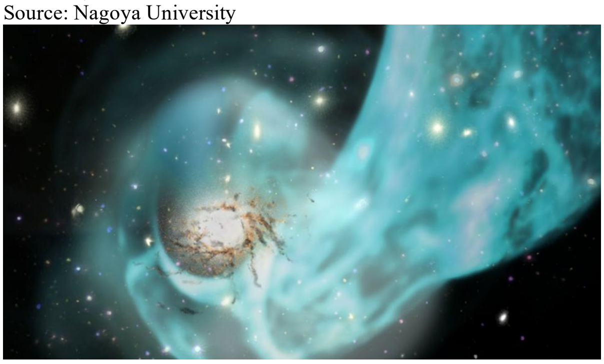
This observation contributes critical data to the longstanding mystery of how lightning generates enough energy to produce gamma rays -- phenomena typically associated with outer space events like supernovae or black hole jets. The study also supports emerging theories about lightning leader dynamics and the potential role of thermal runaway or relativistic feedback in these extreme bursts.

"The multi-sensor observations performed here are a world-first; although some mysteries remain, this technique has brought us closer to understanding the mechanism of these fascinating radiation bursts," says Harufumi Tsuchiya, senior author.

The research offers not only a rare glimpse into the inner workings of lightning, but also valuable data that could be used to improve the safety and resilience of structures vulnerable to high-energy atmospheric phenomena.

- Understanding why galaxy clusters are warm may explain the origin of giant interstellar structures

Date: May 2, 2025
Source: Nagoya University



The XRISM science team, including members of Nagoya University, has explained how galaxy clusters maintain their heat despite emitting X-rays, which typically have a cooling effect on the hot gas. By observation of the Centaurus cluster of galaxies, the XRISM team discovered the existence of a fast-moving, high-temperature gas flow in the centre of the cluster. Their findings, published by *Nature*, may solve the 'cooling flow problem', explaining why clusters of galaxies look like they do.

Galaxy clusters are made of hundreds of galaxies and are the largest objects in the universe. The clusters are important for studying the large-scale structure of the universe and understanding how galaxies (including our own) live, grow, and evolve.

Clusters are governed by a massive dark matter halo, the strong gravity of which attracts high-temperature gas from the intergalactic space outside the cluster. In the process, the hot gases emit X-rays, which have a cooling effect. As matter cools, it tends to condense and fall towards the centre of the cluster and create stars. Although such star formation is seen, the amount is much smaller than expected and the centre of galaxy clusters is unexpectedly warm, suggesting that the temperature is maintained by some mechanism that compensates for the 'cooling' effect.

The research team conducted observations of the Centaurus cluster of galaxies, which is located approximately 150 million light-years from Earth. The team used a soft X-ray spectrometer 'Resolve' onboard the XRISM satellite to accurately measure the detailed velocity of the flow of high-temperature gas in the centre of the galaxy cluster. This flow supplies energy to its centre and maintains the high temperature.

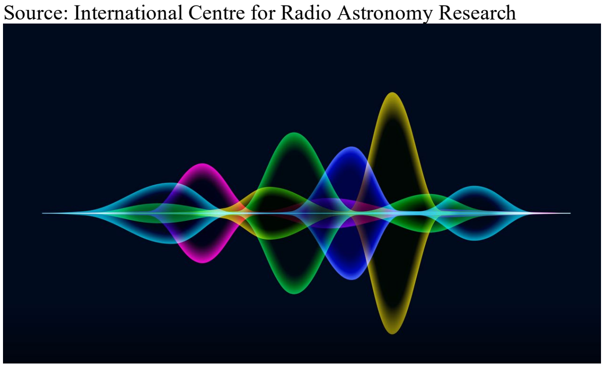
"We found little turbulence of the high-temperature gas in the galaxy cluster," Professor Nakazawa said. "The mechanism, which stops the cooling of the hot gas of this cluster, is a general 'stirring' of the hot gas that supplies energy to the centre from outside regions, thus maintaining the high temperature."

Computer simulations of the movement of hot gas after the merging of clusters of galaxies that happened during their growth process were used to explain these motions, which is called 'gas sloshing.'

"High-precision spectroscopy will also help us to better understand how the massive structure of galaxy clusters evolves," Nakazawa said. "It deepens our understanding not only of galaxy clusters, but also of the formation and evolution of large-scale structures in the universe as a whole."

- ❖ Cosmic mystery deepens as astronomers find object flashing in both radio waves and X-rays

Date: May 28, 2025
Source: International Centre for Radio Astronomy Research



Astronomers from the International Centre for Radio Astronomy Research (ICRAR), in collaboration with international teams, have made a startling discovery about a new type of cosmic phenomenon.

The object, known as ASKAP J1832-0911, emits pulses of radio waves and X-rays for two minutes every 44 minutes.

This is the first time objects like these, called long-period transients (LPTs), have been detected in X-rays. Astronomers hope it may provide insights into the sources of similar mysterious signals observed across the sky.

The team discovered ASKAP J1832-0911 by using the ASKAP radio telescope on Wajarri Country in Australia, owned and operated by Australia's national science agency, CSIRO.

They correlated the radio signals with X-ray pulses detected by NASA's Chandra X-ray Observatory, which was coincidentally observing the same part of the sky.

"Discovering that ASKAP J1832-0911 was emitting X-rays felt like finding a needle in a haystack," said lead author Dr Ziteng (Andy) Wang from the Curtin University node of ICRAR.

"The ASKAP radio telescope has a wide field view of the night sky, while Chandra observes only a fraction of it. So, it was fortunate that Chandra observed the same area of the night sky at the same time."

LPTs, which emit radio pulses that occur minutes or hours apart, are a relatively recent discovery. Since their first detection by ICRAR researchers in 2022, ten LPTs have been discovered by astronomers across the world.

Currently, there is no clear explanation for what causes these signals, or why they 'switch on' and 'switch off' at such long, regular and unusual intervals.

"This object is unlike anything we have seen before," Dr Wang said.
"ASKAP J1831-0911 could be a magnetar (the core of a dead star with powerful magnetic fields), or it could be a pair of stars in a binary system where one of the two is a highly magnetised white dwarf (a low-mass star at the end of its evolution)."
However, even those theories do not fully explain what we are observing. This discovery could indicate a new type of physics or new models of stellar evolution."
Detecting these objects using both X-rays and radio waves may help astronomers find more examples and learn more about them.
According to second author Professor Nanda Rea from the Institute of Space Science (ICE-CSIC) and Catalan Institute for Space studies (IEEC) in Spain, "Finding one such object hints at the existence of many more. The discovery of its transient X-ray emission opens fresh insights into their mysterious nature,"
"What was also truly remarkable is that this study showcases an incredible teamwork effort, with contributions from researchers across the globe with different and complementary expertise," she said.
The discovery also helps narrow down what the objects might be. Since X-rays are much higher energy than radio waves, any theory must account for both types of emission -- a valuable clue, given their nature remains a cosmic mystery.
The paper "*Detection of X-ray Emission from a Bright Long-Period Radio Transient*" was published overnight in *Nature*.
ASKAP J1832-0911 is located in our Milky Way galaxy about 15,000 light-years from Earth.

- What the Universe tried to hide: The 21-centimeter signal explained

Date: June 22, 2025
Source: University of Cambridge

Radio waves from the early universe carry secrets of its first stars, and scientists are decoding them using bold new models and telescopes like REACH and SKA. Credit: Shutterstock

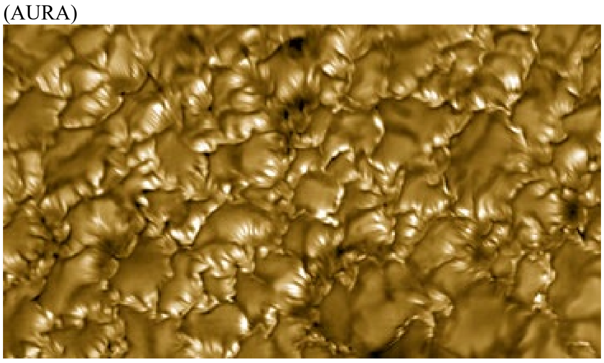
Understanding how the universe transitioned from darkness to light with the formation of the first stars and galaxies is a key turning point in the universe's development, known as the Cosmic Dawn. However, even with the most powerful telescopes, we can't directly observe these earliest stars, so determining their properties is one of the biggest challenges in astronomy.
Now, an international group of astronomers led by the University of Cambridge have shown that we will be able to learn about the masses of the earliest stars by studying a specific radio signal - created by hydrogen atoms filling the gaps between star-forming regions - originating just a hundred million years after the Big Bang.
By studying how the first stars and their remnants affected this signal, called the 21-centimeter signal, the researchers have shown that future radio telescopes will help us understand the very early universe, and how it transformed from a nearly homogeneous mass of mostly hydrogen to the incredible complexity we see today. Their results are reported in the journal *Nature Astronomy*.
"This is a unique opportunity to learn how the universe's first light emerged from the darkness," said co-author Professor Anastasia Fialkov from Cambridge's Institute of Astronomy. "The transition from a cold, dark universe to one filled with stars is a story we're only beginning to understand."
The study of the universe's most ancient stars hinges on the faint glow of the 21-centimetre signal, a subtle energy signal from over 13 billion years ago. This signal, influenced by the radiation from early stars and black holes, provides a rare window into the universe's infancy.
Fialkov leads the theory group of REACH (the Radio Experiment for the Analysis of Cosmic Hydrogen). REACH is a radio antenna and is one of two major projects that could help us learn about the Cosmic Dawn and the Epoch of Reionisation, when the first stars recognised neutral hydrogen atoms in the universe.
Although REACH, which captures radio signals, is still in its calibration stage, it promises to reveal data about the early universe. Meanwhile, the Square Kilometre Array (SKA) -- a massive array of antennas under construction -- will map fluctuations in cosmic signals across vast regions of the sky.

Both projects are vital in probing the masses, luminosities, and distribution of the universe's earliest stars. In the current study, Fialkov - who is also a member of the SKA - and her collaborators developed a model that makes predictions for the 21-centimeter signal for both REACH and SKA, and found that the signal is sensitive to the masses of first stars.
"We are the first group to consistently model the dependence of the 21-centimeter signal of the masses of the first stars, including the impact of ultraviolet starlight and X-ray emissions from X-ray binaries produced when the first stars die," said Fialkov, who is also a member of Cambridge's Kavli Institute for Cosmology. "These insights are derived from simulations that integrate the primordial conditions of the universe, such as the hydrogen-helium composition produced by the Big Bang."
In developing their theoretical model, the researchers studied how the 21-centimeter signal reacts to the mass distribution of the first stars, known as Population III stars. They found that previous studies have underestimated this connection as they did not account for the number and brightness of X-ray binaries - binary systems made of a normal star and a collapsed star - among Population III stars, and how they affect the 21-centimeter signal.
Unlike optical telescopes like the James Webb Space Telescope, which capture vivid images, radio astronomy relies on statistical analysis of faint signals. REACH and SKA will not be able to image individual stars, but will instead provide information about entire populations of stars, X-ray binary systems and galaxies.
"It takes a bit of imagination to connect radio data to the story of the first stars, but the implications are profound," said Fialkov.
"The predictions we are reporting have huge implications for our understanding of the nature of the very first stars in the Universe," said co-author Dr Eloy de Lera Acedo, Principal Investigator of the REACH telescope and PI at Cambridge of the SKA development activities. "We show evidence that our radio telescopes can tell us details about the mass of those first stars and how these early lights may have been very different from today's stars.
"Radio telescopes like REACH are promising to unlock the mysteries of the infant Universe, and these predictions are essential to guide the radio observations we are doing from the Karoo, in South Africa."
The research was supported in part by the Science and Technology Facilities Council (STFC), part of UK Research and Innovation (UKRI). Anastasia Fialkov is a Fellow of Magdalene College, Cambridge. Eloy de Lera Acedo is an STFC Ernest Rutherford Fe

- Sharpest-ever solar view shows tiny stripes driving big space storms

NSF Daniel K. Inouye Solar Telescope captures sharpest-ever view of the solar surface to reveal our finest look at narrow magnetic stripe-like features known as striations.

Date: June 22, 2025
Source: Association of Universities for Research in Astronomy (AURA)



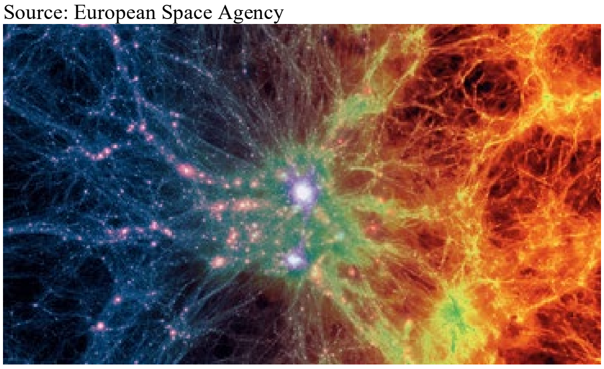
Sharpest-ever view of the Sun’s surface, using the NSF Inouye Solar Telescope, reveals ultra-fine magnetic “stripes,” known as striations, just 20 kilometres wide. Credit: NSF/NSO/AURA

A team of solar physicists has released a new study shedding light on the fine-scale structure of the Sun's surface. Using the unparalleled power of the U.S. National Science Foundation (NSF) Daniel K. Inouye Solar Telescope, built and operated by the NSF National Solar Observatory (NSO) on Maui, scientists have observed, for the first time ever in such high detail, ultra-narrow bright and dark stripes on the solar photosphere, offering unprecedented insight into how magnetic fields shape solar surface dynamics at scales as small as 20 kilometres (or 12.4 miles). The level of detail achieved allows us to clearly link these stripes to the ones we see in state-of-the-art simulations -- so we can better understand their nature.
These stripes, called striations and seen against the walls of solar convection cells known as granules, are the result of curtain-like sheets of magnetic fields that ripple and shift like fabric blowing in the wind. As light from the hot granule walls passes through these magnetic "curtains," the interaction produces a pattern of alternating brightness and darkness that traces variations in the underlying magnetic field. If the field is

weaker in the curtain than in its surroundings it appears dark, if it is relatively stronger it appears bright.
"In this work, we investigate the fine-scale structure of the solar surface for the first time with an unprecedented spatial resolution of just about 20 kilometres, or the length of Manhattan Island," says NSO scientist Dr. David Kuridze, the study's lead author. "These striations are the fingerprints of fine-scale magnetic field variations."
The findings were not anticipated, and only possible because of the Inouye Solar Telescope's unprecedented abilities. The team used the Inouye's Visible Broadband Imager (VBI) instrument operating in the G-band, a specific range of visible light especially useful for studying the Sun because it highlights areas with strong magnetic activity, making features like sunspots and fine-scale structures like the ones in the study easier to see. The setup allows researchers to observe the solar photosphere at an impressive spatial resolution better than 0.03 arcseconds (i.e., about 20 kilometres on the Sun). This is the sharpest ever achieved in solar astronomy. To interpret their observations, the team compared the images with cutting-edge simulations that recreate the physics of the Sun's surface.
The study confirms that these striations are signatures of subtle but powerful magnetic fluctuations -- variations of only a hundred gauss, comparable to a typical refrigerator magnet's strength -- that alter the density and opacity of the plasma, shifting the visible surface by mere kilometres. These shifts, known as Wilson depressions, are detectable thanks only to the unique resolving power of the 4-meter primary mirror of the NSF Inouye Solar Telescope, the largest in the world.
"Magnetism is a fundamental phenomenon in the universe, and similar magnetically induced stripes have also been observed in more distant astrophysical objects, such as molecular clouds," shares NSO scientist and co-author of the study Dr. Han Uitenbroek. "Inouye's high resolution, in combination with simulations, allows us to better characterize the behaviour of magnetic fields in a broad astrophysical context."
Studying the magnetic architecture of the solar surface is essential for understanding the most energetic events in the Sun's outer atmosphere -- such as flares, eruptions, and coronal mass ejections -- and, consequently, improving space weather predictions. This discovery not only enhances our understanding of this architecture but also opens the door to studying magnetic structures in other astrophysical contexts -- and at small scales once thought unachievable from Earth.
"This is just one of many firsts for the Inouye, demonstrating how it continues to push the frontier of solar research," says NSO Associate Director for the NSF Inouye Solar Telescope, Dr. David Boboltz. "It also underscores Inouye's vital role in understanding the small-scale physics that drive space weather events that impact our increasingly technological society here on Earth."
The paper describing this study, titled "The striated solar photosphere observed at 0.03" resolution," is now available in *The Astrophysical Journal Letters*.

- Massive thread of hot gas found linking galaxies — and it’s 10 times the mass of the Milky Way

Date: June 19, 2025
Source: European Space Agency



A simulation of the cosmic web , the vast network of threads and filaments that extends throughout the Universe. Stars, galaxies, and galaxy clusters spring to life in the densest knots of this web, and remain connected by vast threads that stretch out for many millions of light-years. These threads are invisible to the eye, but can be uncovered by telescopes such as ESA s XMM-Newton. Credit: Illustris Collaboration / Illustris Simulation

Astronomers have discovered a huge filament of hot gas bridging four galaxy clusters. At 10 times as massive as our galaxy, the thread could contain some of the Universe's 'missing' matter, addressing a decades-long mystery.

The astronomers used the European Space Agency's XMM-Newton and JAXA's Suzaku X-ray space telescopes to make the discovery.

Over one-third of the 'normal' matter in the local Universe - the visible stuff making up stars, planets, galaxies, life - is missing. It hasn't yet been seen, but it's needed to make our models of the cosmos work properly.

Said models suggest that this elusive matter might exist in long strings of gas, or filaments, bridging the densest pockets of space. While we've spotted filaments before, it's tricky to make out their properties; they're typically faint, making it difficult to isolate their light from that of any galaxies, black holes, and other objects lying nearby.

New research is now one of the first to do just this, finding and accurately characterizing a single filament of hot gas stretching between four clusters of galaxies in the nearby Universe.

"For the first time, our results closely match what we see in our leading model of the cosmos - something that's not happened before," says lead researcher Konstantinos Migkas of Leiden Observatory in the Netherlands. "It seems that the simulations were right all along."

XMM-Newton on the case

Clocking in at over 10 million degrees, the filament contains around 10 times the mass of the Milky Way and connects four galaxy clusters: two on one end, two on the other. All are part of the Shapley Supercluster, a collection of more than 8000 galaxies that forms one of the most massive structures in the nearby Universe.

The filament stretches diagonally away from us through the supercluster for 23 million light-years, the equivalent of traversing the Milky Way end to end around 230 times.

Konstantinos and colleagues characterized the filament by combining X-ray observations from XMM-Newton and Suzaku, and digging into optical data from several others.

The two X-ray telescopes were ideal partners. Suzaku mapped the filament's faint X-ray light over a wide region of space, while XMM-Newton pinpointed very precisely contaminating sources of X-rays - namely, supermassive black holes - lying within the filament.

"Thanks to XMM-Newton we could identify and remove these cosmic contaminants, so we knew we were looking at the gas in the filament and nothing else," adds co-author Florian Pacaud of the University of Bonn, Germany. "Our approach was really successful, and reveals that the filament is exactly as we'd expect from our best large-scale simulations of the Universe."

Not truly missing

As well as revealing a huge and previously unseen thread of matter running through the nearby cosmos, the finding shows how some of the densest and most extreme structures in the Universe - galaxy clusters - are connected over colossal distances.

It also sheds light on the very nature of the 'cosmic web', the vast, invisible cobweb of filaments that underpins the structure of everything we see around us.

"This research is a great example of collaboration between telescopes, and creates a new benchmark for how to spot the light coming from the faint filaments of the cosmic web," adds Norbert Schartel, ESA XMM-Newton Project Scientist.

"More fundamentally, it reinforces our standard model of the cosmos and validates decades of simulations: it seems that the 'missing' matter may truly be lurking in hard-to-see threads woven across the Universe."

Piecing together an accurate picture of the cosmic web is the domain of ESA's Euclid mission. Launched in 2023, Euclid is exploring this web's structure and history. The mission is also digging deep into the nature of dark matter and energy - neither of which have ever been observed, despite accounting for a whopping 95% of the Universe - and working with other dark Universe detectives to solve some of the biggest and longest-standing cosmic mysteries.

- A thousand colours, one galaxy: Astronomers reveal a cosmic masterpiece

Date: June 18, 2025
Source: ESO

This image shows a detailed, thousand-colour image of the Sculptor Galaxy captured with the MUSE instrument at ESO s Very Large Telescope (VLT). Regions of pink light are spread throughout this whole galactic snapshot, which come from ionised hydrogen in star-forming regions. These areas have been overlaid on a map of already formed stars in Sculptor to create the mix of pinks and blues seen here. Credit: ESO/E. Congiu et al.

Astronomers have created a galactic masterpiece: an ultra-detailed image that reveals previously unseen features in the Sculptor Galaxy. Using the European Southern Observatory's Very Large Telescope (ESO's VLT), they observed this nearby galaxy in thousands of colours simultaneously. By capturing vast amounts of data at every single location, they created a galaxy-wide snapshot of the lives of stars within Sculptor.

"Galaxies are incredibly complex systems that we are still struggling to understand," says ESO researcher Enrico Congiu, who led a new Astronomy & Astrophysics study on Sculptor. Reaching hundreds of thousands of light-years across, galaxies are extremely large, but their evolution depends on what's happening at much smaller scales. "The Sculptor Galaxy is in a sweet spot," says Congiu. "It is close enough that we can resolve its internal structure and study its building blocks with incredible detail, but at the same time, big enough that we can still see it as a whole system."

A galaxy's building blocks -- stars, gas and dust -- emit light at different colours. Therefore, the more shades of colour there are in an image of a galaxy, the more we can learn about its inner workings. While conventional images contain only a handful of colours, this new Sculptor map comprises thousands. This tells astronomers everything they need to know about the stars, gas and dust within, such as their age, composition, and motion.

To create this map of the Sculptor Galaxy, which is 11 million light-years away and is also known as NGC 253, the researchers observed it for over 50 hours with the Multi Unit Spectroscopic Explorer (MUSE) instrument on ESO's VLT. The team had to stitch together over 100 exposures to cover an area of the galaxy about 65,000 light-years wide.

According to co-author Kathryn Kreckel from Heidelberg University, Germany, this makes the map a potent tool: "We can zoom in to study individual regions where stars form at nearly the scale of individual stars, but we can also zoom out to study the galaxy as a whole."

In their first analysis of the data, the team uncovered around 500 planetary nebulae, regions of gas and dust cast off from dying Sun-like stars, in the Sculptor Galaxy. Co-author Fabian Scheuermann, a doctoral student at Heidelberg University, puts this number into context: "Beyond our galactic neighbourhood, we usually deal with fewer than 100 detections per galaxy."

Because of the properties of planetary nebulae, they can be used as distance markers to their host galaxies. "Finding the planetary nebulae allows us to verify the distance to the galaxy -- a critical piece of information on which the rest of the studies of the galaxy depend," says Adam Leroy, a professor at The Ohio State University, USA, and study co-author.

Future projects using the map will explore how gas flows, changes its composition, and forms stars all across this galaxy. "How such small processes can have such a big impact on a galaxy whose entire size is thousands of times bigger is still a mystery," says Congiu.

More information

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