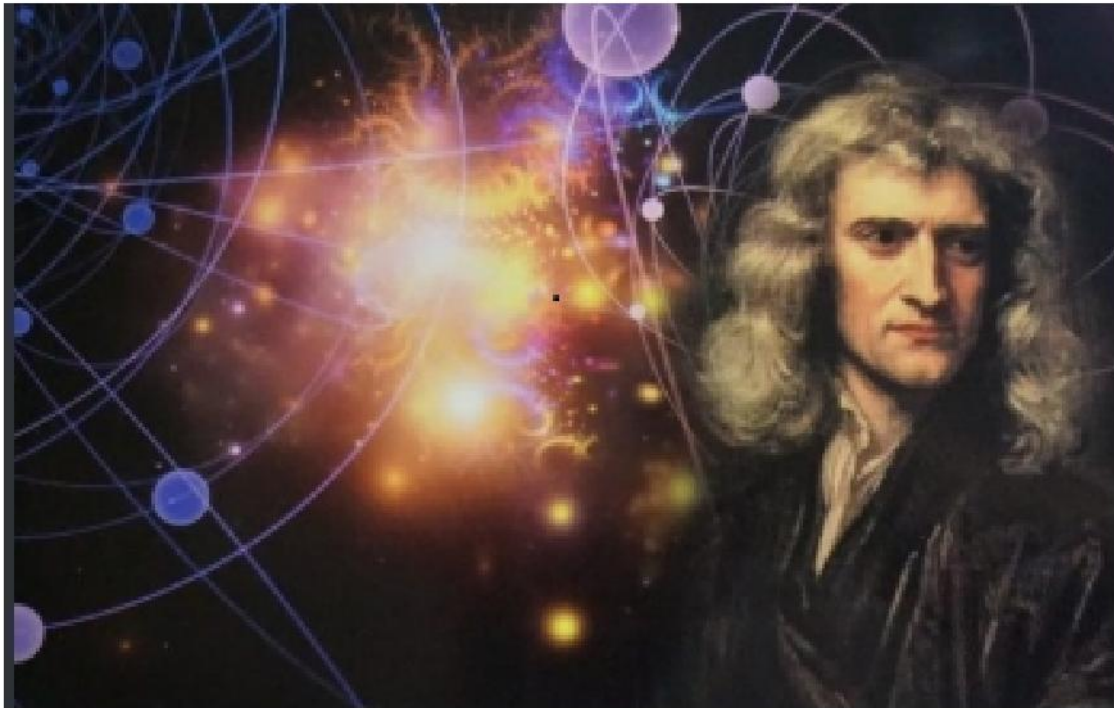
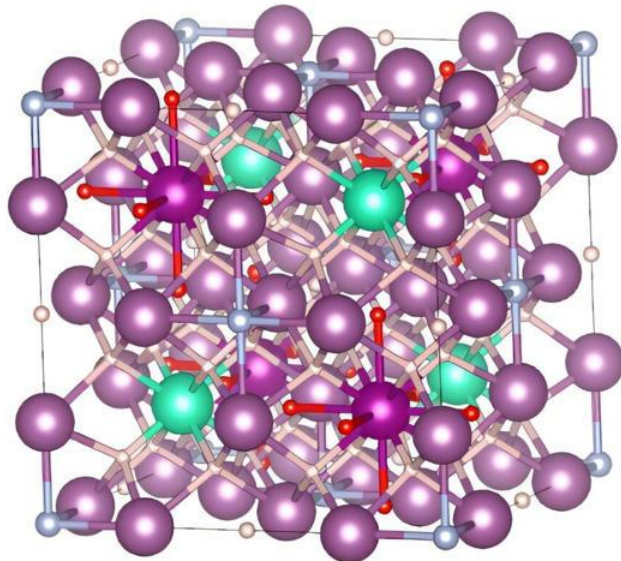


GENERAL PHYSICS TO ASTROPHYSICS VOL 4



Multicomponent hydride designs could advance science of superconducting materials



A rare earth hydride structure that may achieve high-temperature superconductivity. Credit: Adam Denchfield

New materials designed by a University of Illinois Chicago graduate student may help scientists meet one of today's biggest challenges: building superconductors that operate at normal temperatures and pressures.

Superconductors are used widely in everyday applications from MRI machines to power transmission. But to work, they must be cooled to extremely low temperatures, which limits their potential. Scientists worldwide are pursuing materials that could show superconductivity at "very high" temperatures—in this context, closer to room temperature—without requiring super-cooling.

In [a paper](#) for the *Proceedings of the National Academy of Sciences*, Adam Denchfield and a team of UIC scientists proposed three promising new designs for superconducting materials. In computer simulations, the designs demonstrate some of the properties needed for very high-temperature superconductivity.

Hyowon Park, associate professor of physics, and Russell Hemley, professor of physics and chemistry, co-authored the paper with Denchfield, a Ph.D. candidate in physics at UIC.

For decades, scientists have looked for materials that could make superconductivity—the lossless transmission of electricity—possible at higher temperatures, such as room temperature. That would allow the use of superconductors for advanced power grids, more efficient electric motors and more advanced magnetically levitated trains.

In 2023, a group of scientists published a controversial paper on a superconducting material containing a rare earth element called lutetium that works at close to ambient temperature and air pressure. The controversy inspired Denchfield to explore past literature on the type of material they described, called rare earth trihydrides.

"I looked at the results, and I was just as skeptical as many others in the field," Denchfield said. "So I set out to look into the literature to seek alternate explanations and found studies from the late 1960s studying rare earth trihydrides."

These older studies showed very strange changes in the electrical conductivity of the materials when cooled that are still not fully understood. Denchfield found that special arrangements of the lutetium atoms in combination with hydrogen and nitrogen can cause the material to exhibit intriguing properties including high-temperature superconductivity.

His research eventually led to [a paper on a promising lutetium-hydrogen-nitrogen compound](#) and experimental results that were consistent with superconductivity. The work by Hemley's group was covered in the [New York Times](#).

But Denchfield didn't stop there. He started to explore whether other rare earth hydride combinations and structures, such as replacing lutetium with its periodic-table cousins yttrium and scandium, could work even better. With the goal of increasing the superconducting temperature as much as possible, he landed on three types of cubic structures that could produce the desired properties in simulations.

"We basically put forward three template structures of increasing complexity that we want other people to be able to take and mess with, plug and play different elements," Denchfield said. "I would describe this as an exploratory paper, a motivational and inspirational work that should inspire the search for a whole new class of structures that could be very high-temperature superconductors."

Material designs described in the paper achieve critical temperature—the point where superconductive properties appear—above 200 degrees Kelvin, roughly equivalent to -100 degrees Fahrenheit. Denchfield said some designs could achieve the "holy grail" of superconductivity at ambient pressure and room temperatures. To verify the predictions, materials with the new designs will have to be synthesized in the laboratory and tested.

"The new study led by Adam builds on the previous milestones of our group: the discovery of the first near-room-temperature superconductor in another rare earth hydride under pressure, then the tantalizing evidence for similar high-temperature superconductivity in the lutetium-based material," Hemley said.

"The prospects for new classes of related materials with different compositions is the latest chapter in our exciting efforts to discover and create new materials that could one day revolutionize energy technologies."

More information: Adam Denchfield et al, Designing multicomponent hydrides with potential high T_c superconductivity, *Proceedings of the National Academy of Sciences* (2024). [DOI: 10.1073/pnas.2413096121](https://doi.org/10.1073/pnas.2413096121)

Provided by University of Illinois at Chicago

Quantum breakthrough: Scientists created antimatter from light

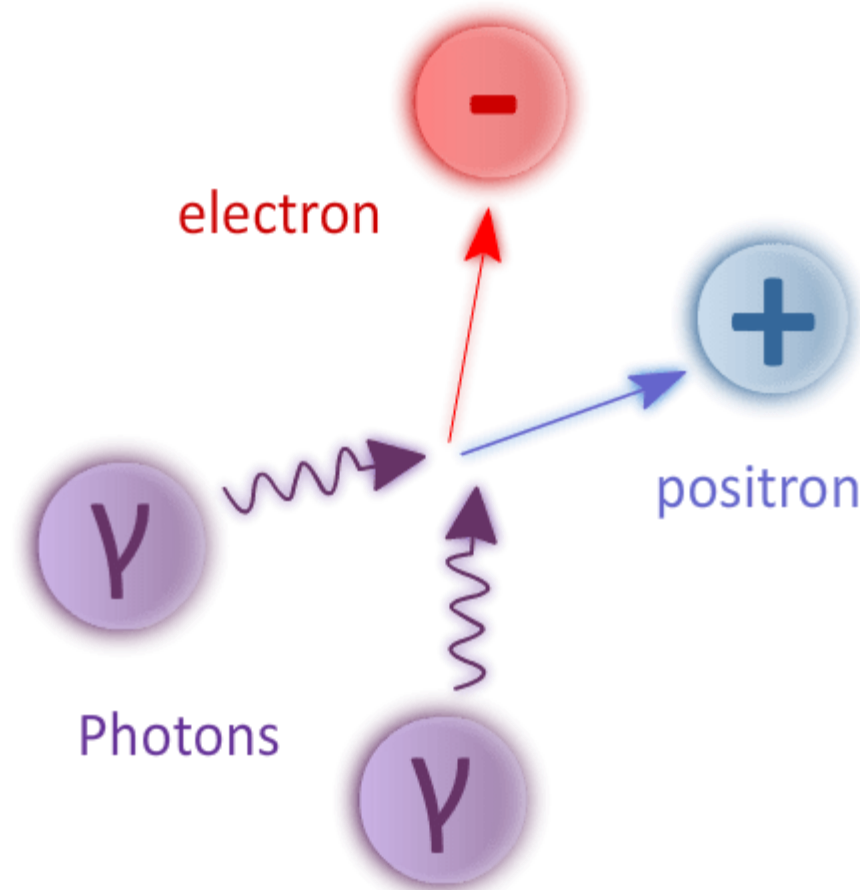
High-intensity lasers now enable scientists to create antimatter jets in the lab. (CREDIT: Nicole Rager Fuller/NSF)© The Brighter Side of News

[High-powered lasers](#) have transformed the way researchers explore extreme physical phenomena, pushing the boundaries of quantum physics and astrophysics. These lasers, when focused to nearly their diffraction limit, generate electromagnetic fields of immense strength.

Such fields not only allow the acceleration of energetic particles but also enable the study of processes that typically occur only in the most extreme environments, such as the creation of electron-positron pairs—a phenomenon previously confined to astrophysical settings like pulsar magnetospheres.

At laser intensities exceeding 10^{23} W/cm², quantum-electrodynamical (QED) effects become non-linear. One of the most fascinating processes is the Breit-Wheeler process, in which gamma photons collide to produce [matter-antimatter pairs](#), specifically electrons and positrons.

While non-linear pair creation using intense lasers has been observed, the linear Breit-Wheeler process, which requires two real photons to interact, remains elusive in laboratory settings. This process is rare due to its small cross-section, demanding high photon fluxes for successful observation.



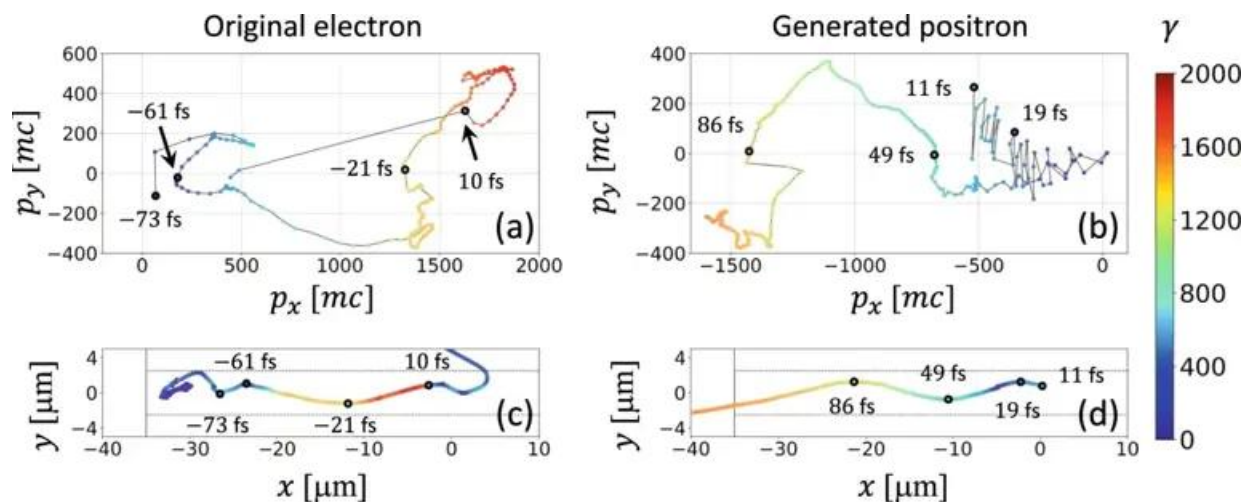
The Breit-Wheeler process is the creation of an electron-positron pair following the collision of two high-energy photons (gamma photons). (CREDIT: CC BY-SA 4.0)© The Brighter Side of News

Creating these conditions involves innovative experimental setups. High-intensity laser facilities such as the [Extreme Light Infrastructure Beamlines](#) and Apollon offer unprecedented opportunities to explore these regimes. These facilities enable dense flashes of gamma rays through colliding laser pulses, simulating astrophysical conditions. "When the laser pulses penetrate the sample, each of them accelerates a cloud of extremely fast electrons," explained Toma Toncian of [Helmholtz-Zentrum Dresden-Rossendorf](#) in Germany. "These two electron clouds then race toward each other with full force, interacting with the laser propagating in the opposite direction."

The generated gamma photons collide, initiating the [Breit-Wheeler process](#). Even more remarkably, the collision creates magnetic fields that confine and accelerate the positrons into narrow, jet-shaped beams. Within a distance of just 50 micrometers, the positrons can achieve energy levels of up to one gigaelectronvolt.

Astrophysical Implications in the Lab

This experimental setup mimics processes thought to occur near neutron stars, specifically pulsars. These rapidly spinning, magnetized stars emit collimated jets of particles, believed to result from gamma-ray collisions in their magnetospheres.



Trajectories of an accelerated plasma electron and a generated positron. (CREDIT: Communications Physics)© The Brighter Side of News

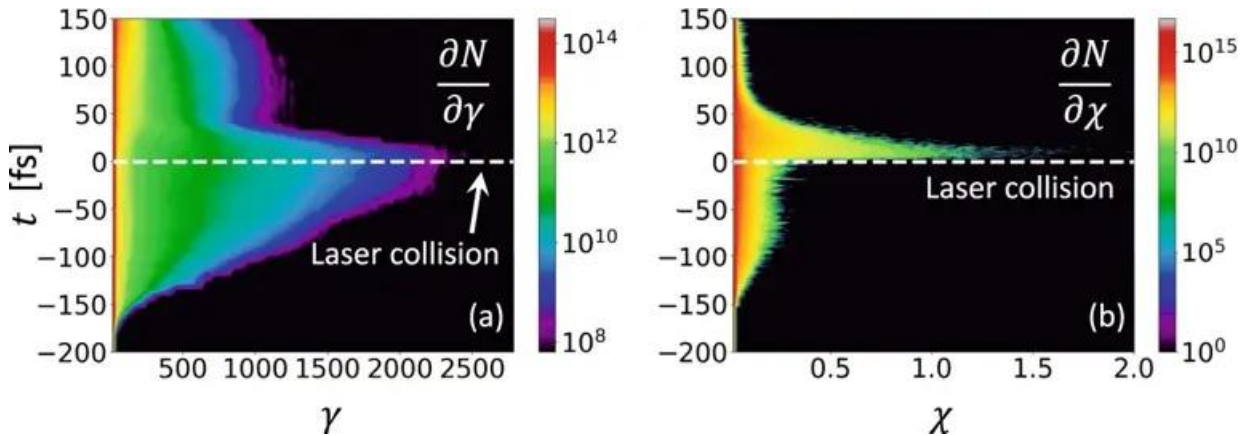
According to Alexey Arefiev of UC San Diego, "With our new concept, such phenomena could be simulated in the laboratory, at least to some extent, which would then allow us to understand them better."

These findings bridge the gap between laboratory physics and astrophysical phenomena. By studying these processes in controlled settings, scientists can gain insights into the extreme environments surrounding [neutron stars](#) and the mechanisms that populate their magnetospheres with plasma.

The balance between linear and non-linear pair creation in these environments is crucial, as it dictates the density and dynamics of plasma near pulsars.

Future Prospects

The promise of this experimental design extends beyond mere observation of the Breit-Wheeler process. The ability to confine and accelerate positrons has implications for generating [antimatter jets](#), which could serve as a model for understanding astrophysical jet dynamics.



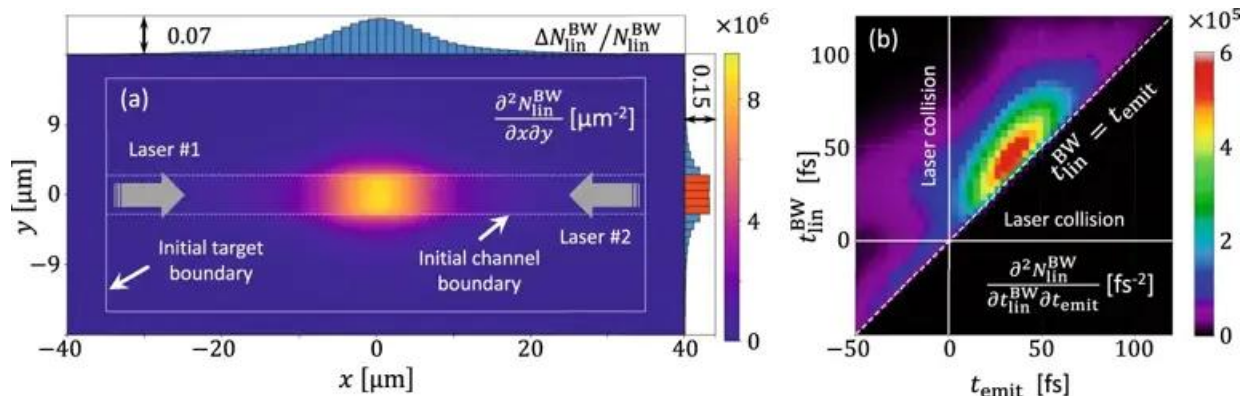
Growth and collapse of the electron γ and χ as the laser collision occurs. (CREDIT: Communications Physics)© The Brighter Side of News

Preliminary tests at the European XFEL X-ray laser facility aim to validate predictions about the magnetic fields generated during these experiments.

Furthermore, these experiments align well with the capabilities of the [Extreme Light Infrastructure Nuclear Physics](#) facility in Romania, which features advanced short-pulse lasers and gamma-ray beams. This facility's unique infrastructure is perfectly suited for exploring high-intensity laser-matter interactions and validating theoretical predictions.

The significance of this work is underscored by the sheer scale of the positron yield. Simulations suggest that at laser intensities below $5 \times 10^{22} \text{ W/cm}^2$, the [positron production rate](#) could reach $\sim 10^9$, a staggering four orders of magnitude greater than previous proposals.

Such advancements offer a unique opportunity to study not just the Breit-Wheeler process but also the transition between linear and non-linear pair cascades.



Probability density that an electron–positron pair is created by the linear Breit–Wheeler process at longitudinal and transverse coordinate x and y . (CREDIT: Communications Physics)© The Brighter Side of News

The researchers' findings, published in [Communications Physics](#), demonstrate that current laser technology is sufficient to achieve these groundbreaking results. This realization propels high-intensity laser experiments into a new era, where laboratory-based studies of astrophysical phenomena become increasingly feasible.

As these methods evolve, they hold the potential to unlock deeper understanding of the universe's most extreme environments and the fundamental laws that govern them.

Breakthrough research questions

Einstein's Theory of General Relativity

Einstein's equations by introducing two functions, μ and η , which describe changes in gravity and metric distortions. (CREDIT: Nicolle Fuller/National Science Foundation)© The Brighter Side of News

The accelerating expansion of the [Universe](#), first observed in 1998, remains one of the most profound mysteries in modern physics. It challenges long-standing assumptions about the cosmos and has spurred decades of scientific investigation.

Scientists propose several theories to explain this phenomenon. Some attribute it to a cosmological constant, a fixed energy density filling space. Others suggest a more dynamic form of dark energy or even fundamental modifications to [Einstein's theory of general relativity](#). To test these ideas, researchers rely on extensive surveys of large-scale cosmic structures, mapping the distribution of matter and galaxies.

New Methods to Decipher the Universe's Expansion

While the Λ CDM model has been a cornerstone of cosmology, it is showing its limitations as researchers seek to explain observations beyond its scope. Two major approaches are emerging to explore theories that extend beyond Λ CDM.

One approach focuses on broad theoretical frameworks, such as Horndeski theories, which integrate scalar-tensor models with second-order equations of motion. These theories aim to link observational data directly to underlying physics. However, they often involve significant degeneracies—overlapping effects among different parameters—making it difficult to draw precise conclusions from current datasets.

A second approach is more empirical, modifying [Einstein's equations](#) with two key parameters, μ and η . These parameters describe deviations in gravity and metric distortions.

- μ accounts for changes in Poisson's equation, influencing the behavior of gravitational fields.
- η measures discrepancies between time and spatial distortions, providing insights into how gravity behaves on cosmic scales.

These parameters are essential for interpreting gravitational lensing data from projects like the [Dark Energy Survey](#) (DES) and analyzing galaxy clustering from surveys like BOSS and eBOSS. By refining these methods, scientists hope to uBoth approaches aim to move beyond current models, leveraging advanced observations to unlock the secrets of the accelerating Universe. This ongoing exploration promises to reshape our understanding of cosmology and fundamental physics.

However, this approach has its challenges. The constraints on μ and η are interdependent across different redshifts, requiring either a fixed evolution model or sophisticated reconstruction techniques. Moreover, the framework assumes the validity of Euler's equation for dark matter, which introduces potential degeneracies that complicate data interpretation.

Pushing the Boundaries of General Relativity

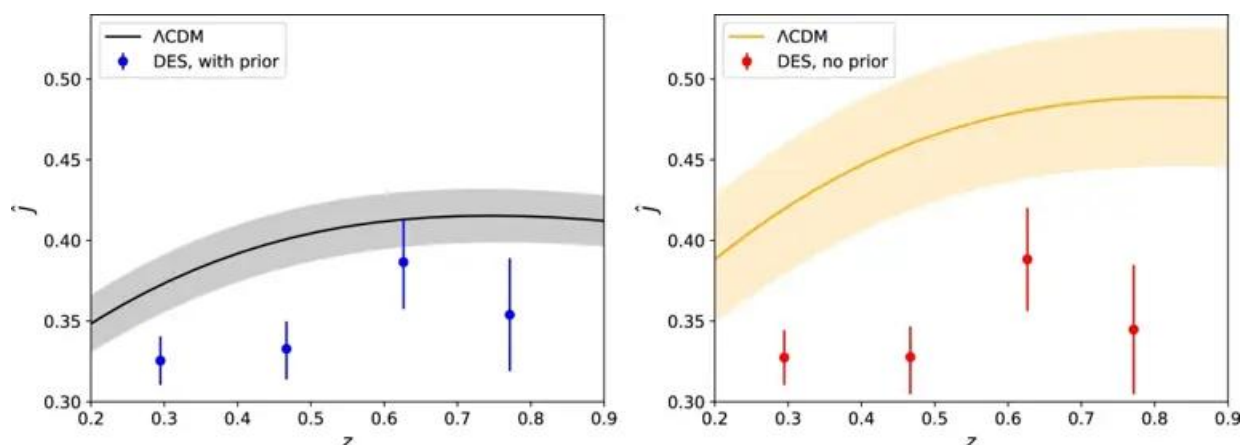
Einstein's general relativity revolutionized our understanding of gravity, depicting the Universe as a flexible fabric deformed by massive objects. This theory, confirmed by the 1919 solar eclipse, predicted the [deflection of light](#) by gravity, a phenomenon known as gravitational lensing. By studying how light bends around celestial bodies, scientists gain critical insights into the Universe's structure and uncover new insights into the forces driving the Universe's expansion.

But are Einstein's equations valid on the largest cosmic scales? Researchers from the [University of Geneva](#) (UNIGE) and Toulouse III – Paul Sabatier have sought to answer this question. Using DES data, they analyzed the distortion of time and space, comparing their findings to Einstein's predictions.

Camille Bonvin, an associate professor at UNIGE, highlights the novelty of this approach: "Until now, Dark Energy Survey data have been used to measure the distribution of matter in the Universe. In our study, we used this data to directly measure the [distortion of time and space](#), enabling us to compare our findings with Einstein's predictions."

A Universe Slightly Out of Sync

The DES provided data on 100 million galaxies across four time periods: 3.5, 5, 6, and 7 billion years ago. These measurements revealed how gravitational wells—regions where gravity deforms space-time—evolved.



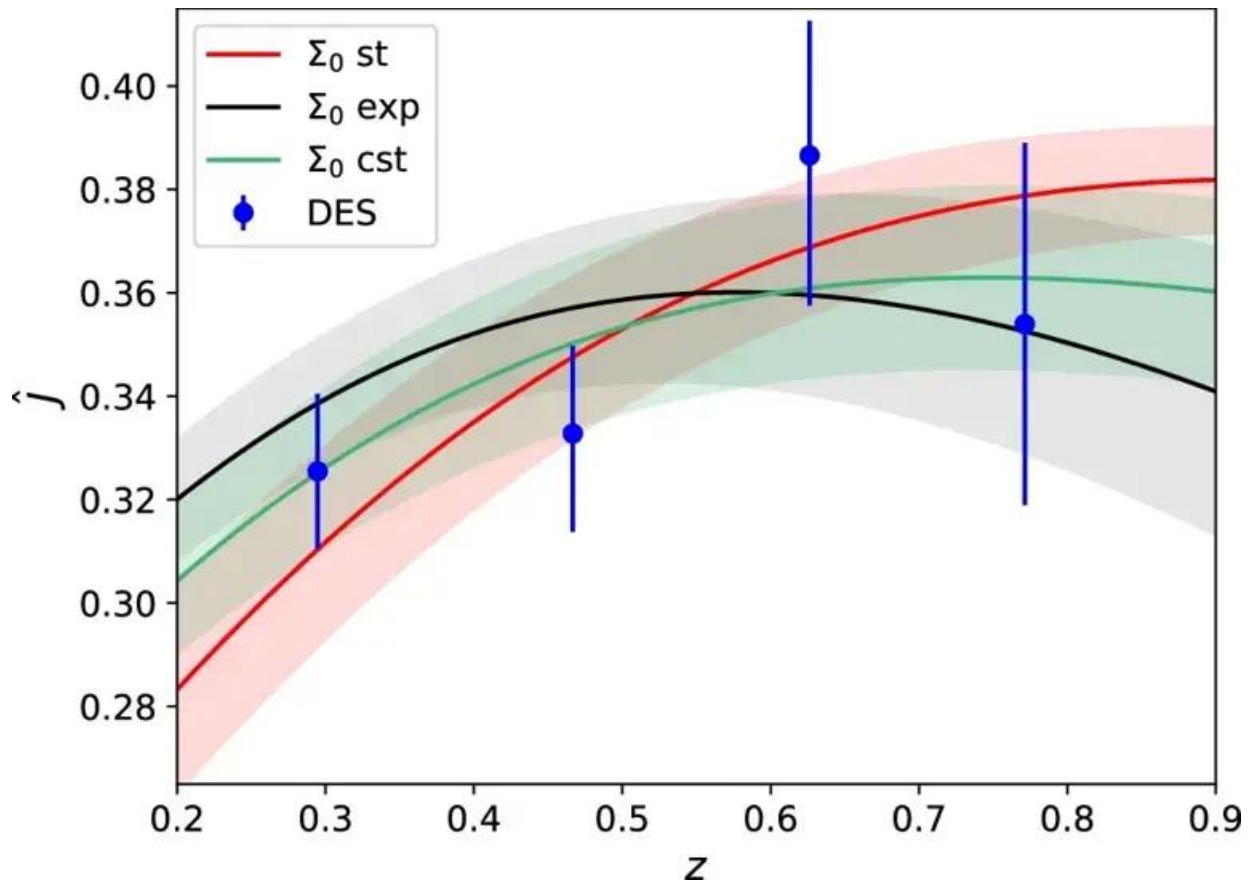
Measured values of $\langle \hat{J} \rangle$ with 1 standard deviation error bars at the mean redshifts of the MAGLIM sample.
(CREDIT: Nature Communications)© The Brighter Side of News

According to Isaac Tutusaus, lead author of the study, "We discovered that in the distant past — 6 and 7 billion years ago — the depth of the wells aligns well with [Einstein's predictions](#). However, closer to today, 3.5 and 5 billion years ago, they are slightly shallower than predicted by Einstein."

This discrepancy coincides with the period when the Universe's expansion began accelerating. The data hint at a possible link between the two phenomena, suggesting that gravity might operate differently on cosmic scales. Tutusaus notes, "The slower growth of gravitational wells and the accelerating expansion might share the same underlying cause."

The 3-Sigma Challenge

The study found a 3-sigma level of incompatibility between Einstein's predictions and the observed data. While this is significant, it falls short of the 5-sigma threshold needed to definitively challenge the theory. Nastassia Grimm, a co-author and postdoctoral researcher at UNIGE, explains, "Such an incompatibility threshold arouses our interest and calls for further investigations. But this incompatibility is not large enough, at this stage, to invalidate [Einstein's theory](#)."



Predictions for $\langle \hat{J} \rangle$ for modified gravity models with $\Sigma \neq 1$ and $\mu = 1$. (CREDIT: Nature Communications)© The Brighter Side of News

Further research is necessary to confirm these findings. The team is turning to the Euclid space telescope, launched last year, which promises more precise gravitational lensing data. Over its six-year mission, Euclid will observe 1.5 billion galaxies, offering unprecedented insights into the Universe's history and allowing scientists to test Einstein's equations more rigorously.

As cosmologists delve deeper into the mysteries of the Universe, the boundaries of established theories are being pushed. The work of the UNIGE and Toulouse teams represents a critical step in this journey.

With upcoming data from [Euclid](#), the scientific community is poised to refine its understanding of gravity and cosmic expansion. These efforts may ultimately reshape our perception of the Universe, bringing us closer to solving one of science's greatest enigmas.

Could we travel to parallel universes?



What would it take to access another universe?© Devrimb/Getty Images

While [parallel universes are a staple of science fiction](#), there are some real scientific theories to support them. But if parallel universes do exist, could we ever travel to them? It certainly wouldn't be easy, but let's explore this possibility.

Parallel universes crop up in two places in physical theories. One is in our conception of [inflation](#), the theory of the extremely early universe. In those tumultuous times, many universes may have inflated all at once (and kept going) and branched out into a tremendous number of individual universes, each with their own kinds of physics and arrangements of matter. But traveling to the other universes wouldn't be easy, because they're far beyond our observable horizon and moving away faster than the [speed of light](#). That would take a lot of frequent flyer miles.

The other potential [multiverse](#) is in the many-worlds interpretation of quantum mechanics. This interpretation says that when some random quantum process occurs, one "universe" gets one of the possible results, while other universes get the others. Thus, the multiverse is constantly being filled with every possible quantum possibility.

But how would we get to one of those parallel universes?

The trick is to build a time machine. It doesn't matter how you do it; you just need to go back in time. Normally, going back in time introduces all sorts of nasty paradoxes, like the infamous [grandfather paradox](#), or, less violently, inconsistent histories. Try going back in time and destroying your time machine. Now it doesn't exist, which means you can't go back in time to destroy it, which means it should exist.

Perhaps [time travel](#) into the past is forbidden for exactly these reasons, according to Stephen Hawking's chronology protection conjecture. Or perhaps time travel into the past is allowed, but with one strict rule: You can't change the past. This is known as Igor Novikov's self-consistency conjecture. But how could you go into the past without changing it?

One possible answer is that when you travel into the past, you don't go into your own past. Instead, you slip into another history. If you go back in time and kill Hitler, you're not killing the Hitler of your past; you're killing somebody else's. And in that alternate universe, Hitler was always killed by a time-traveling assassin from another universe. When you return to the future, you come back home, with an unchanged past.

The many-worlds interpretation offers a natural platform for creating these alternate histories. If the universe is constantly splitting and branching anyway, then time travel simply moves you from one of those branches to another. Or, in another possibility, when you go back in time, you create a new branch that didn't exist before.

While this all sounds neat and tidy, it runs into the slight complication that nobody has ever gotten it to work. We don't know how this process actually unfolds or through what mechanism the alternate history emerges.

Attempts to navigate the issue by studying quantum mechanics have had mixed results. Left to their own devices, quantum fields tend to go haywire when time machines are involved. You can stabilize them — if you give up some of the core tenets of the theory, like the correspondence principle or unitarity, which say that quantum processes eventually lead to macroscopic behavior and that fundamental reactions are reversible. Nobody is really willing to give those up, since they seem central to the theory — so we're stuck on that front.

Besides, even classical, non-quantum systems run into issues. Let's say you have a switch that can turn your time machine on and off — say, by opening or closing a [wormhole](#). We don't know how the alternate histories can accommodate changes in their space-time structures like that, regardless of whatever quantum processes are happening on a subatomic level.

However, if we could build a time machine, we could easily test whether alternate histories are created. All we'd have to do is change something in the past that you remember. If you're not allowed to do it (say, no matter how hard you try, you just can't kill Hitler), then you know there's only one timeline with a past that is locked in stone. But if you accomplish the mission, then you know that alternate histories are real and that the many-worlds interpretation of quantum mechanics might be valid.

We don't know if any of this is possible. On the other hand, we can't exactly rule it out. Time travel into the past seems forbidden but for reasons we can't readily discern. Our past seems to be gone forever — but it's also possible that it's just one branch of many and that visiting alternate universes is as easy as ... Well, it's not easy at all.

How cold is space? Understanding the physics behind the universe's temperature

When we gaze up at the vastness of the night sky, we often ponder the extremes of the cosmos. One of the most intriguing aspects is the temperature of space, a question that captures our imagination and curiosity. But, **how cold is space**? This article delves into the science behind the universe's temperature and the factors that determine these extreme conditions.

From the **frigid void** between stars to the intense heat emitted by our sun, space presents a dramatic range of temperatures that challenge our understanding of physics. To understand this celestial climate, we must explore the principles that govern heat in the cosmos.

What determines the temperature of space?

The temperature in space is a complex matter, primarily because space is mostly void, lacking the matter—like air—that we use to measure temperature here on Earth. Instead, temperature in space is influenced by radiation, the movement of particles, and the presence of matter, although sparse.

Space is not empty but filled with **cosmic radiation**, which plays a critical role in defining its temperature. The primary form of heat transfer in space is through radiation, as conduction and convection are almost nonexistent due to the low particle density.

The sun's radiation is also a significant influence on temperature in space. Near the Earth and other celestial bodies, the temperature can swing dramatically depending on exposure to sunlight or the position within a shadow.

Astronomical entities such as **nebulae** and interstellar clouds can also affect the local temperature of regions in space through absorption and emission of radiation, though their impact is less direct.

The concept of temperature in space is further complicated by the fact that an object exposed to space will experience different temperatures on its sunlit side compared to its shaded side, illustrating the impact of direct solar radiation.

Why is space so cold despite the sun's heat?

The reason space remains cold, even with the sun's immense heat, lies in its vast emptiness. Space is a near-perfect vacuum, providing **very little matter** to absorb or retain heat. This means that the primary method of heat transfer, radiation, does not have a medium through which to effectively distribute heat.

In the shadowed areas of space, such as behind planets or within the depths of nebulae, temperatures can plummet as there are no particles to be heated by the sun's radiation. Consequently, these regions can be some of the **coldest places** in the universe.

Whereas on Earth, the atmosphere acts as a blanket, trapping heat and ensuring a livable climate, space lacks this protective layer. Thus, despite the intense heat of the sun, the vast regions of space remain immensely cold.

How do temperatures vary in different parts of space?

Variations in space temperature can be extreme. Near stars, temperatures can soar to millions of degrees, while in the depths of interstellar space, temperatures can plummet to just above **absolute zero**. This stark contrast illustrates just how much the presence of energy sources such as stars affects the thermal state of space.

For instance, the temperature of space near Earth can vary significantly. In the sunlight, an object might experience temperatures as high as 250°F, while in the shadow of Earth or another body, temperatures can drop to around -455°F.

Moreover, different regions in space, like the **Boomerang Nebula**, have their unique thermal characteristics. The Boomerang Nebula, in particular, holds the title for the lowest temperature observed in the universe at a brisk -272°C.

What is absolute zero and how does it relate to space?

Absolute zero is the theoretical lowest possible temperature where particles have minimal vibrational motion, approximating zero kinetic energy. It is quantified as **0 Kelvin**, equivalent to -459.67°F. In the universe, temperatures close to absolute zero are possible due to the lack of substantial matter in most of space.

While no place in space has been observed at absolute zero, the temperature of the **Cosmic Microwave Background** (CMB) provides a baseline for the "warmth" of the

cosmos. The CMB, a remnant of the Big Bang, fills space with a nearly uniform temperature of about 2.7 Kelvin.

Understanding absolute zero is crucial when discussing the temperature of space because it represents the coldest limit and helps scientists to contextualize the thermal dynamics of the universe.

How do spacesuits protect astronauts from extreme temperatures?

Astronauts venturing into space are met with the challenge of surviving the extreme temperatures. Spacesuits, or Extravehicular Mobility Units (EMUs), are marvels of engineering designed to **protect astronauts** from harsh conditions.

These suits have multiple layers with specialized functions, such as:

- Thermal insulation to retain body heat.
- Reflective surfaces to deflect solar radiation.
- Cooling systems to prevent overheating.
- Heating elements to combat the cold in shadowed areas.

Spacesuits are a testament to human ingenuity, enabling astronauts to conduct spacewalks and work on the **International Space Station** despite the temperature extremes they face.

Now that we've explored the scientific principles behind the temperature of space, let's delve into some **frequently asked questions** that further illuminate this fascinating subject.

How Cold Is Space Actually?

Space Temperature Extremes

Space can reach staggeringly low temperatures, approximately **-455°F** in its coldest regions. This temperature can vary depending on location and proximity to heat sources like stars. In the shade of space structures like the International Space Station, temperatures can drop significantly, while direct sunlight can raise temperatures to about 250°F.

The sparse distribution of gas and dust particles in space limits heat transfer, making these regions incredibly cold. The overall temperature of space is influenced by the Cosmic Microwave Background, a remnant of the Big Bang, which sits at approximately 2.7 Kelvin, contributing to the frigid environment of space.

How Is Space Cold If There Is No Matter?

The Vacuum's Impact on Heat Transfer

Space is cold because it is nearly a perfect vacuum with very few particles to retain heat. With negligible matter, there is nothing to conduct or convect heat, leaving radiation as the primary means of heat transfer.

Heat from stars like the sun travels through radiation, but the vacuum of space does not absorb much heat, resulting in extremely cold temperatures. The lack of matter means that any object in space can lose heat rapidly, contributing to the overall coldness of the environment.

What Would Be the Temperature of the Space in the Universe?

Temperature Diversity in the Cosmos

The temperature of space varies widely, from the intense heat near stars to the cold vacuum of empty space. The average temperature is influenced by the Cosmic Microwave Background radiation.

Regions far from stellar objects are incredibly cold due to the lack of heat transfer. These areas, close to absolute zero, showcase the vast temperature range throughout the universe, impacted by radiation and sparse particles.

What Is the Background Temperature of the Universe?

Understanding the Cosmic Microwave Background

The background temperature of the universe, derived from the Cosmic Microwave Background radiation, is approximately **2.73 Kelvin**. The CMB provides a nearly uniform temperature across the universe, offering insight into the thermal history of the cosmos.

This temperature, close to absolute zero, is crucial in understanding the cooling process that has occurred since the Big Bang.

Incorporating a visual element to our discussion, let's examine a video that elucidates **the temperature of space**:

In conclusion, the temperature of space is a topic that fascinates us because it defies our everyday experiences with temperature. Through understanding the physics behind the universe's temperature, we gain a deeper appreciation for the complexities of space and the scientific advancements that allow us to explore it safely.

Electric Cars vs. Hydrogen Vehicles

Efficiency of Electric Cars



Efficiency of Electric Cars (image credits: Pixabay)

Electric cars shine brightly in terms of efficiency. They boast the ability to convert about 60-80% of the electricity from the grid directly into power at the wheels. In comparison, hydrogen vehicles, lagging at a lower efficiency rate of around 30-40%, seem like a distant echo from sustainable practices.

It's analogous to the difference between sipping and spilling; where EVs utilize each drop of energy, hydrogen vehicles let much go to waste. This high efficiency makes EVs a preferred choice for those conscious of energy conservation and cost-effectiveness.

Wide Availability of EV Charging Infrastructure



Wide Availability of EV Charging Infrastructure (image credits: Wikimedia)

Driving across countries in an EV is becoming increasingly feasible, thanks to a well-established charging infrastructure. In urban areas, EV charging stations have become almost as common as coffee shops. Hydrogen refueling stations, on the other hand, remain few and far between, making it much tougher for hydrogen vehicles to roam freely.

The convenience of accessing a nearby charger gives EVs a definitive edge in this arena.

Concerns Around EV Battery Production

While EVs champion energy efficiency, their batteries tell a different story. The extraction of critical minerals such as lithium, cobalt, and nickel raises substantial environmental and ethical questions. The mining processes can be harmful to local ecosystems and communities, presenting a significant hurdle in the journey towards sustainability.

This aspect looms large over the EV industry, and finding a solution is necessary for a truly sustainable future.

Zero Emission Potential of EVs



Zero Emission Potential of EVs (image credits: Pixabay)

EVs, when powered by renewable energy sources, transform into silent, emission-free vehicles that glide through streets without contributing to air pollution. It's like a breath of fresh air in the transport sector. This capability positions EVs as a major player in the fight to decarbonize our world, offering a glimpse into a cleaner future.

For environmentally-conscious consumers, this aspect is often a tipping point towards investing in an electric car.

Charging Time Challenges for EVs



Charging Time Challenges for EVs (image credits: Pexels)

Despite the benefits, EVs do have their share of limitations, with charging time being a significant one. Unlike the quick refueling process of traditional vehicles, EVs usually take longer to recharge. However, advancing technology is constantly closing this gap with the advent of fast-charging solutions, and innovation is on the horizon.

It's similar to watching a pot of water boil; patience is key, but technology is providing bigger burners every day.

Quick Refueling of Hydrogen Vehicles



Quick Refueling of Hydrogen Vehicles (image credits: Wikimedia)

This is where hydrogen vehicles have an unmistakable leg up. They can be refueled within the short span of 3-5 minutes, mirroring the efficiency of gasoline vehicles and offering an appealing prospect for long-distance drivers. For those who value speed and efficiency without a wait, hydrogen vehicles present an undeniable benefit that's hard to ignore, akin to filling up your tank at a gas station and getting back on the road almost in a blink.

Hydrogen Production Dilemmas



Hydrogen Production Dilemmas (image credits: Pexels)

Hydrogen's current production paints a complex picture. Most hydrogen is derived from natural gas, releasing CO₂ into the atmosphere, reducing its green credentials. The dream of green hydrogen, produced from renewable resources, remains limited and aspirational.

Until this dream materializes on a larger scale, it remains an area fraught with environmental concerns.

Range Advantage of Hydrogen Vehicles



Range Advantage of Hydrogen Vehicles (image credits: Flickr)

With an energy density that allows more miles per fill-up, hydrogen vehicles often boast a superior range compared to their electric counterparts. Particularly for larger vehicles like trucks and buses, this translates into fewer stops and a more efficient journey. It's like carrying a larger canteen on a long hike; more energy means less worry about finding the next refill.

Infrastructure Challenges for Hydrogen Vehicles



Infrastructure Challenges for Hydrogen Vehicles (image credits: Wikimedia)

While hydrogen holds promise, its infrastructure is akin to a puzzle with missing pieces. Building refueling stations is not just pricey; it's a Herculean task. Their scarcity creates significant barriers hindering hydrogen vehicle adoption, a significant hurdle to overcome before considering widespread adoption.

Superior Cold Weather Performance of Hydrogen Vehicles



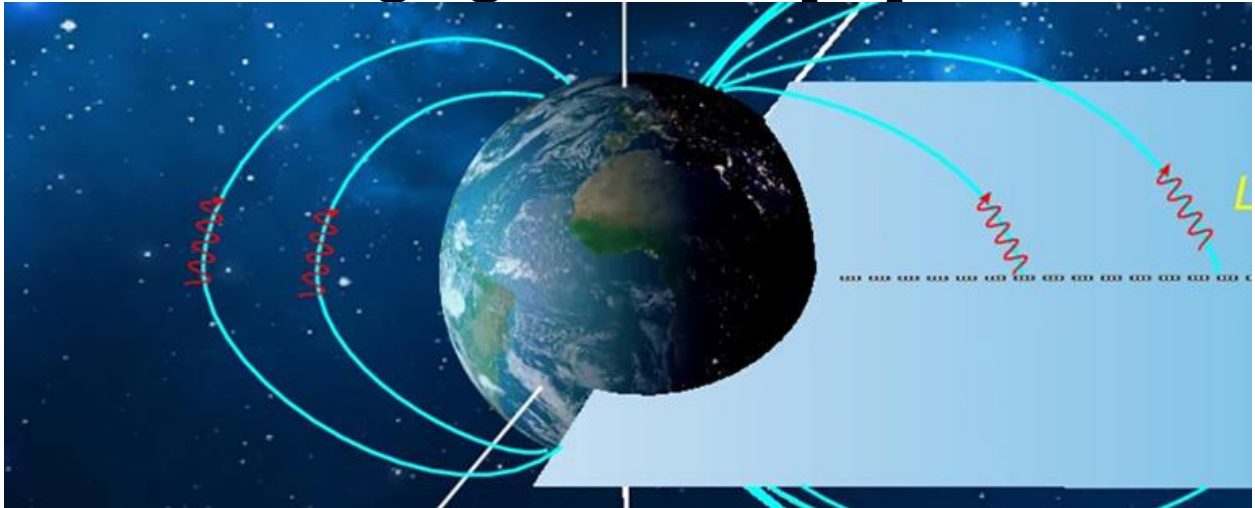
Superior Cold Weather Performance of Hydrogen Vehicles (image credits: Unsplash)

When it comes to extreme cold, hydrogen vehicles often outperform EVs. Batteries tend to lose their efficiency in frosty conditions, much like a smartphone draining faster in the chill. Hydrogen vehicles, on the other hand, maintain their performance, offering reliability in regions with biting winters.

This characteristic is an attractive feature for drivers facing harsh climatic challenges.

What do you think about this topic? Share your thoughts in the comments below — we'd love to hear from you! Want more stories like this? Follow us and never miss out!

Astronomers Capture Mysterious 'Chorus Waves' Emerging From Deep Space



An international team of astronomers has detected mysterious chirping signals in an unexpected region of space, raising major questions about how they're created.

Known as chorus waves, these signals are split-second bursts of electromagnetic radiation emitted from high above Earth's surface. When converted into an audio format and drawn out, they sound eerily like birds chirping.

We've [known about them](#) for decades, and the consensus is that they're caused by [plasma instability](#): ionized gas falling out of equilibrium and spilling waves of electromagnetism in distinct patterns.

Until now, the furthest from Earth they've been detected is 51,000 kilometers (31,690 miles). That's around the spot where Earth's magnetic field appears most like a magnet with distinct, opposing poles; a feature physicists thought was critical in creating the necessary instabilities in plasma flowing through the Solar System.

However, new research has found bursts of radiation with very similar properties some 165,000 kilometers (102,526 miles) away from our planet, where [Earth's magnetic field](#) is much more distorted. It seems chorus waves are not as closely tied to a neatly dipolar magnetic field as we thought.

"Such similarities indicate that their generation is not uniquely determined by the local environment and that they can develop anywhere in space," [write](#) the researchers in their published paper.

The research relied on a close analysis of high-resolution imagery from the [NASA Magnetospheric Multiscale](#) (MMS) satellite mission, launched in 2015, to identify the waves so far from home.

And although the findings challenge some of the current assumptions about chorus waves, one previously hypothesized process was observed for the first time: the transfer of energy from plasma particles to chorus waves occurs in regions where electrons are relatively scarce, known as electron holes.

It's evidence that a phenomenon known as [electron cyclotron resonance](#) is at play and powering the distinct chirping patterns seen here, where electron frequency and wave frequency are both matched, driving greater energy transfer.

"These electron holes associated with chorus waves have been well studied by simulations and have now been observed in situ," [write](#) the researchers.

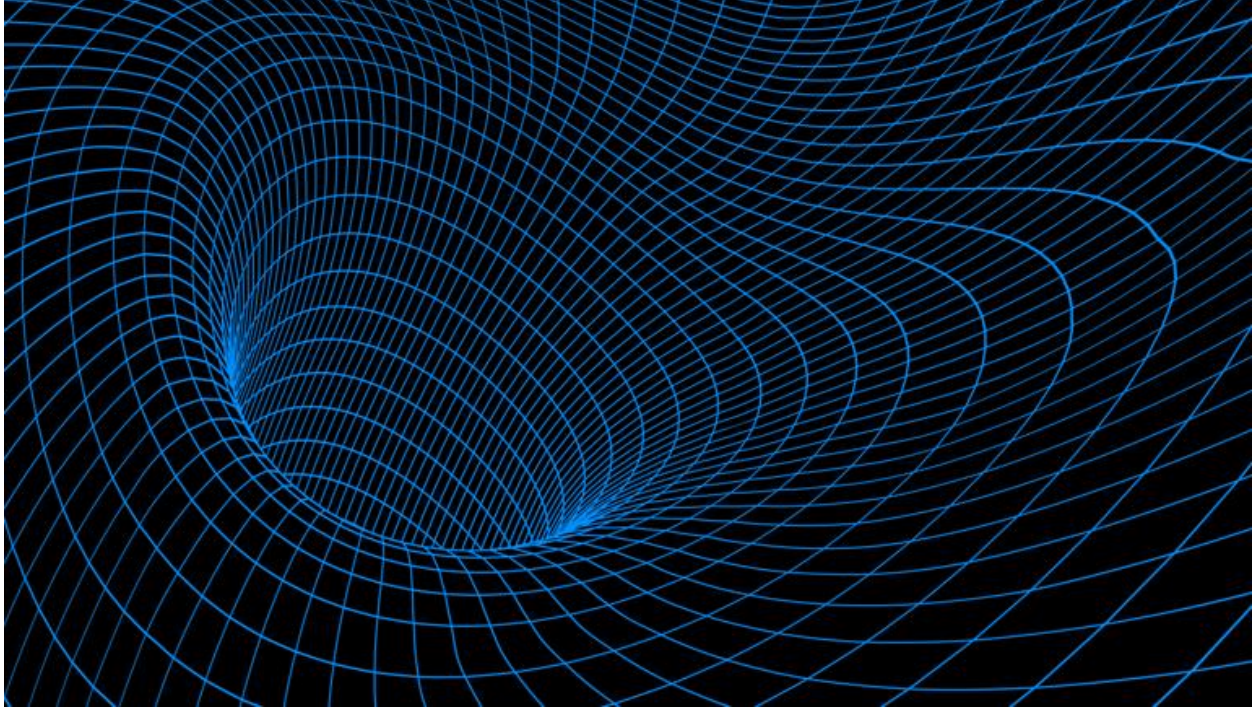
As chorus waves represent some of the strongest electromagnetic radiation pulses in space – key to [Earth's radiation belt](#) and a potential threat to satellite operations – we need to know as much about them as we can to understand when to expect them.

Other planets have chorus waves too, including [Mars](#), [Jupiter](#), and [Saturn](#), so these discoveries tell us more about the wider cosmos and how magnetic fields are [shaped around planets](#).

"Our observations may help to resolve long-standing controversies regarding chorus emissions and in gaining an understanding of the energy transport observed in space and astrophysical environments," [write](#) the researchers.

The research has been published in [Nature](#).

If you could see spacetime, it would look like this



Spacetime is the fabric of the universe, where space and time are woven together and warped by gravity. One way to conceptualize this is to imagine a grid representing the three dimensions of space and the one dimension of time. Massive objects like planets, stars, and black holes cause the grid to warp, revealing how gravity influences the movement of objects and the flow of time within the universe. (Even small things like coffee cups and ants cause ripples in spacetime, but only a very tiny bit.)

ScienceClic created this magnificent video below to give you a sense of what it might be like if we could see spacetime. Far out.

BOING BOING

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Physicists identify new quantum state called "magic"

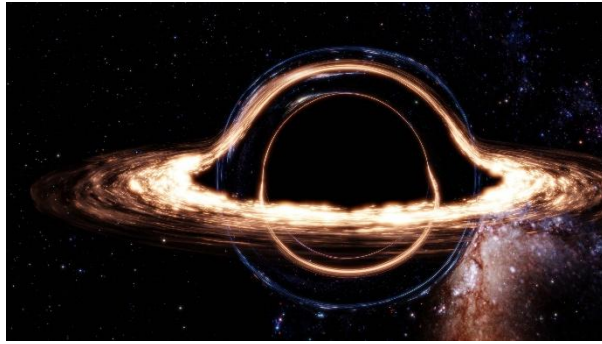


Image: Public Domain via [Pixabay](#)

It was Arthur C. Clarke who [famously said](#) that "Any sufficiently advanced technology is indistinguishable from magic" (although I'd argue that [Jack Kirby](#) and [Jim Starlin](#) rather perfected the idea). Now, a group of real-life scientists at the [RIKEN Interdisciplinary Theoretical and Mathematical Sciences](#) in Japan have taken it a step further: by identifying a new quantum property to measure the weirdness of spacetime, and officially calling it "magic." From the scientific paper "[Probing chaos by magic monotones](#)," recently published in the journal *Physical Review D*:

There is a property of a quantum state called "magic." As shown by the Gottesman-Knill theorem, so-called stabilizer states, which are composed of only Clifford gates, can be efficiently computed on a classical computer, and thus quantum computation gives no advantage. Nonstabilizer states are called magic states, which are necessary to achieve the universal quantum computation. Magic (monotone) is the measure of the amount of nonstabilizer resource, and it measures how difficult it is for a classical computer to simulate the state. We study magic of states in the integrable and chaotic regimes of the higher-spin generalization of the Ising model through two quantities: "mana" and "robustness of magic" (RoM). We find that in the chaotic regime, mana increases monotonically in time in the early-time region, and at late times these quantities oscillate around some nonzero value that increases linearly with respect to the system size. Our result also suggests that under chaotic dynamics, any state evolves to a state whose mana almost saturates the optimal upper bound; i.e., the state becomes "maximally magical."

And the kicker: Our results suggest that magic of quantum states is strongly involved in the emergence of spacetime geometry.

The scientists expanded upon their work in an interview with [Phys.org](#):

[Lead author Kanato] Goto and iTHEMS colleagues Tomoki Nosaka and Masahiro Nozaki searched for another quantum quantity that could apply

to the boundary system and could also be mapped to the bulk to describe black holes more fully. In particular, they noted that black holes have a chaotic characteristic that needs to be described.

"When you throw something into a black hole, information about it gets scrambled and cannot be recovered," says Goto. "This scrambling is a manifestation of chaos."

The team came across "magic," which is a mathematical measure of how difficult a [quantum state](#) is to simulate using an ordinary classical (non-quantum) computer. Their calculations showed that in a chaotic system almost any state will evolve into one that is "maximally magical"—the most difficult to simulate.

In other words: the science that explains why black holes are so damn confounding? It's literally just magic.

Einstein was right about ripples in spacetime

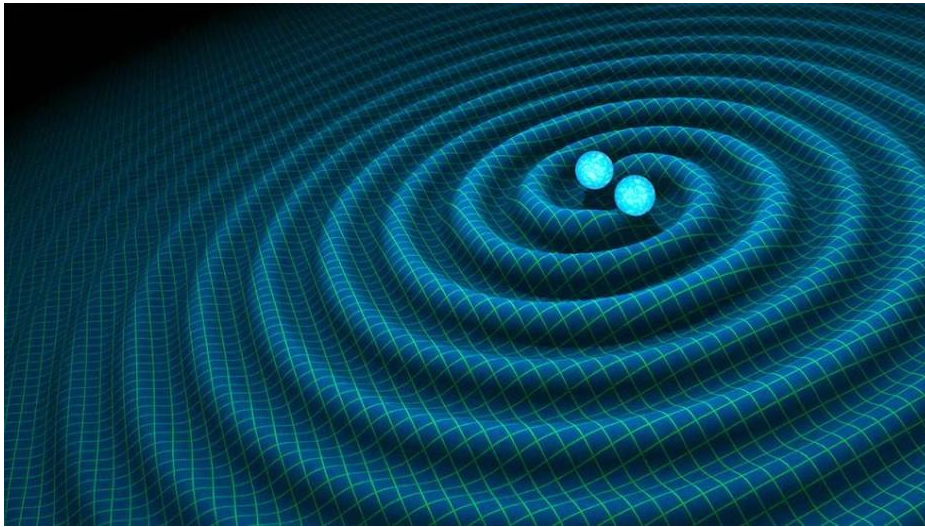
Gravitational waves are real, and scientists have detected them. In the video above, PBS Space Time explains the discovery by researchers at the Laser Interferometer Gravitational-Wave Observatory (LIGO). From the New York Times:

A team of physicists who can now count themselves as astronomers announced on Thursday that they had heard and recorded the sound of two black holes colliding a billion light-years away, a fleeting chirp that fulfilled the last prophecy of Einstein's general theory of relativity.

That faint rising tone, physicists say, is the first direct evidence of gravitational waves, the ripples in the fabric of space-time that Einstein predicted a century ago (Listen to it [here](#)). And it is a ringing (pun intended) confirmation of the nature of black holes, the bottomless gravitational pits from which not even light can escape, which were the most foreboding (and unwelcome) part of his theory.

More generally, it means that scientists have finally tapped into the deepest register of physical reality, where the weirdest and wildest implications of Einstein's universe become manifest.

Below, NASA's animated simulation of the black holes merging and releasing the gravitational radiation ([background here](#)):



above image credits: R. Hurt/Caltech-JPL

Dark Energy Camera Reveals Hidden Wonders of the Antlia Cluster



Dark Energy Camera Reveals Hidden Wonders of the Antlia Cluster | The Daily Galaxy --Great Discoveries Channel© Daily Galaxy

Astronomers have captured a dazzling image of the **Antlia Cluster**, showcasing hundreds of galaxies in extraordinary detail. This cosmic structure, located approximately 130 million light-years away, represents one of the universe's most magnificent displays of gravitational organization. The image was taken using the **Dark Energy Camera (DECam)**, a 570-megapixel marvel mounted on the Víctor M. Blanco 4-meter Telescope in Chile. This cluster is a significant focus for astronomers, not only because of its visual beauty but also due to its scientific importance in understanding galaxy evolution and the influence of dark matter.

The Antlia Cluster is a composite of more than 230 known galaxies, ranging from massive ellipticals to faint dwarfs, and offers an intricate view of the interactions and dynamics that define galaxy clusters. These clusters are among the largest structures in the universe, formed when dark matter's gravitational pull gathers galaxies into densely packed groups, which eventually merge into massive clusters. The Antlia Cluster is a prime example of this process, showcasing a

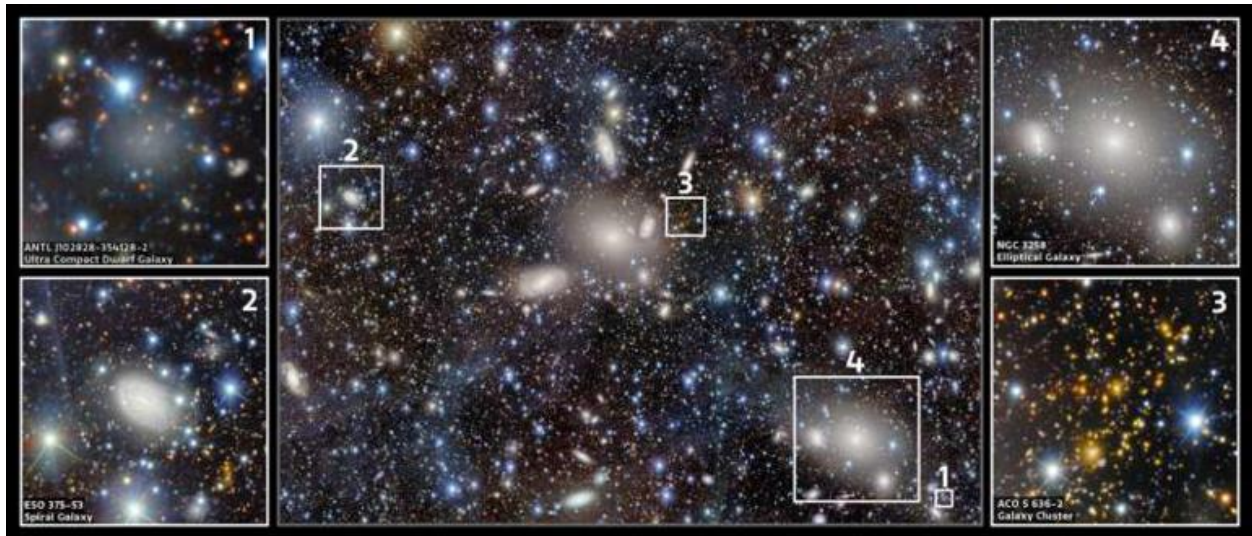
diverse array of galaxy types, each with its unique characteristics and evolutionary history.

The Composition and Structure of the Cluster

[The Antlia Cluster](#) is dominated by two large elliptical galaxies, **NGC 3268** and **NGC 3258**, which anchor the structure. Surrounding these giants is a rich mix of galaxy types that illustrate the cluster's complexity. Elliptical galaxies, characterized by their smooth, featureless shapes and lack of active star formation, are complemented by lenticular galaxies, which bridge the gap between elliptical and spiral galaxies but contain little interstellar matter to fuel new stars. Beyond these, irregular galaxies and dwarf systems add to the cluster's diversity, reflecting different stages of galactic evolution.

Interestingly, the cluster also contains rarer galaxy types such as ultra-compact dwarfs and blue compact dwarfs. These small, low-luminosity systems are particularly intriguing because they provide clues about how galaxies form in dense environments. Observations suggest that many of these **dwarf galaxies** are rich in [dark matter](#), which plays a critical role in holding them together and shaping their behavior within the cluster.

There is evidence that the two massive elliptical galaxies at the cluster's core may be in the process of merging, supported by X-ray observations that reveal a rope-like line of globular clusters in the region. This interaction could signal the eventual unification of smaller galaxy groups within the cluster, further highlighting the dynamic nature of such cosmic assemblies.



A small selection of the myriad picturesque galaxies that can be found within the Antlia Cluster — a group of at least 230 galaxies located about 130 million light-years away. This image was taken with the 570-megapixel Department of Energy-fabricated Dark Energy Camera (DECam) © Daily Galaxy

Technological Advancements Unlocking New Frontiers

The stunning image of the **Antlia Cluster** was made possible by the advanced capabilities of the DECam. Originally designed for the Dark Energy Survey, the camera has since become an essential tool for capturing high-resolution images of the cosmos. Its ability to detect faint objects and produce wide-field views has revolutionized the study of galaxy clusters.

The DECam's ultra-deep imaging has allowed astronomers to observe features of the Antlia Cluster that were previously inaccessible. These include faint intracluster light—diffuse glows resulting from stars being ejected during gravitational interactions between galaxies. This light serves as a crucial marker for understanding the effects of galactic collisions and the distribution of dark matter within the cluster.

Beyond intracluster light, the camera's sensitivity has revealed a level of detail in the **cluster's composition** that was unattainable with earlier instruments. This has enabled scientists to map out the intricate web of relationships between different galaxy types, providing deeper insights into their evolution and interaction.

The Role of Galaxy Clusters in Cosmic Evolution

The Antlia Cluster serves as a natural laboratory for studying the forces that shape galaxies and, by extension, the universe itself. Galaxy clusters like Antlia form the backbone of the large-scale structure of the cosmos. Their study reveals how galaxies evolve over billions of years, from their formation in dense environments to their eventual mergers or dispersal.

Clusters also offer a unique perspective on **dark matter**, the mysterious substance that constitutes roughly 25% of the universe. By analyzing the distribution of light and mass within clusters, astronomers can infer the presence and behavior of dark matter. In the Antlia Cluster, the gravitational interactions evident in the galaxies' movements and the diffuse intracluster light provide indirect evidence of this elusive material.

Additionally, the cluster contains remnants of past cosmic events, such as the **Antlia Supernova Remnant**, discovered in 2002. This feature adds another dimension to the cluster's story, offering insights into the life cycles of stars and the impact of supernovae on their surroundings.

Future Research and Observations

The Antlia Cluster is a stepping stone for future research into galaxy clusters and their role in the universe's evolution. Upcoming projects, such as the **Vera C. Rubin Observatory's Legacy Survey of Space and Time (LSST)**, promise to expand the scope of such studies. This groundbreaking survey will provide a comprehensive dataset on thousands of galaxy clusters, enabling scientists to compare structures across different regions of the cosmos.

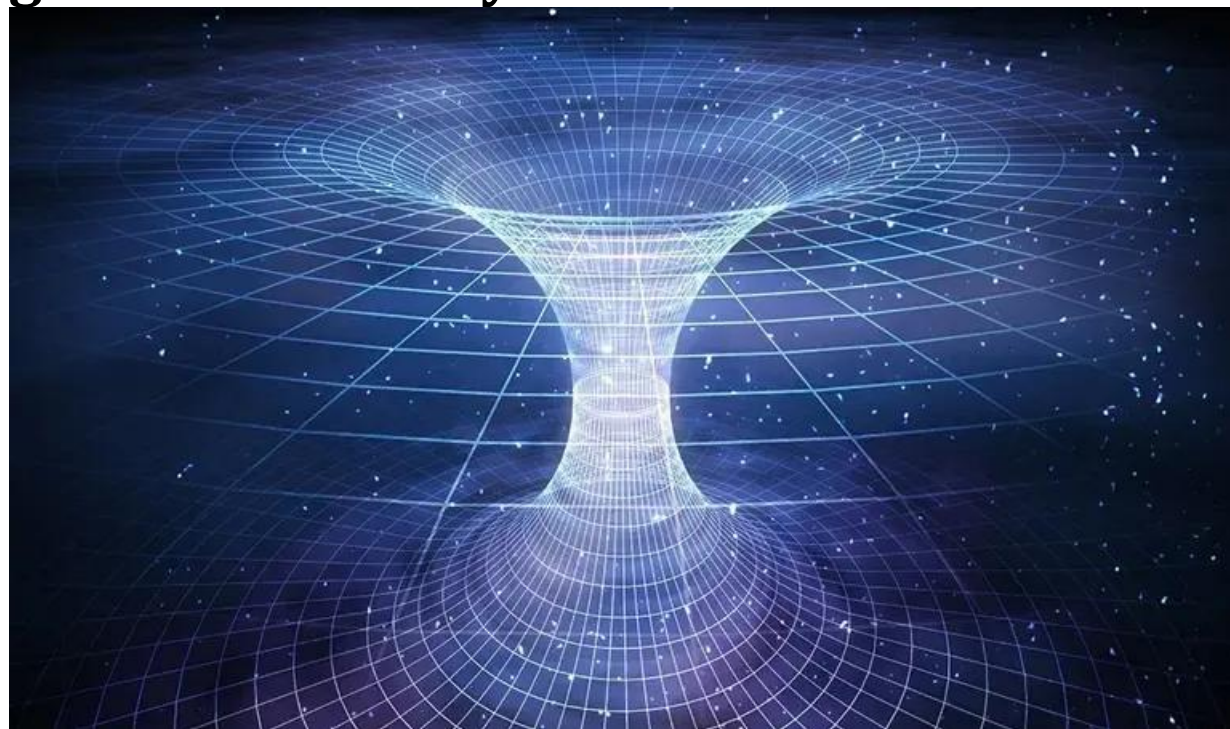
Through these comparisons, researchers aim to refine models of how galaxies form, interact, and evolve within clusters. They also hope to uncover new insights into dark matter's role in shaping the universe's large-scale structure. The LSST will be particularly useful in detecting faint intracluster light, helping to map the distribution of dark matter with unprecedented precision.

A Window Into the Universe

The image of the **Antlia Cluster** captured by the **DECam** is more than just a stunning visual achievement—it is a powerful tool for unlocking the mysteries of the cosmos. By revealing the intricate relationships and processes within this galaxy cluster, astronomers are gaining a better understanding of the universe's fundamental workings.

As technology continues to advance, discoveries like the **Antlia Cluster** will deepen our appreciation of the universe's complexity and beauty, reminding us of the vast, interconnected systems that define our cosmic home. This cluster, with its rich variety of galaxies and ongoing processes, stands as a testament to the dynamic and ever-evolving nature of the universe.

Quantum gravity discovery could reconcile quantum mechanics with general relativity



Dive into discoveries transforming science: dynamic molecular interactions in MOFs for chemical separation and visible singularities revealing cosmic mysteries. (CREDIT: CC BY-SA 4.0)© The Brighter Side of News

Scientific breakthroughs often stem from the persistent pursuit of understanding complex phenomena. From the nanoscale intricacies of molecular diffusion in advanced materials to the vast cosmic enigma of [singularities](#), these discoveries illuminate new paths for innovation and understanding.

Recent advancements in these fields—dynamic molecular interactions in nanoporous materials and the discovery of visible cosmic singularities—promise transformative applications across science and technology.

Molecular diffusion, the movement of molecules through confined spaces, underpins many technologies, from chemical separation to catalysis and storage. Nanoporous materials like metal-organic frameworks (MOFs) are celebrated for their high porosity, chemical tunability, and structural versatility. Yet, fine-tuning molecular diffusion within these materials remains a daunting challenge, primarily due to the interplay of several factors.

Diffusion is influenced by pore size, channel orientation, chemical functionality, adsorption enthalpy, and framework flexibility. While these elements have been studied individually, understanding their combined effects is a more complex endeavor. This complexity makes designing MOFs for applications like membrane-based separations or catalytic reactions especially challenging.

Researchers recently explored this issue by investigating brominated alkane isomers—commercially important feedstocks used in producing lubricants, pesticides, and PVC. Using a specially designed MOF thin film, they studied the diffusion selectivity of 1-bromopropane (1BP) and 2-bromopropane (2BP).

The study, published in the journal, [Nature Communications](#), sought to manipulate dynamic chemical interactions to reverse the natural diffusion selectivity of these isomers.

The MOF employed was a pillared-layer structure featuring Cu²⁺ paddle-wheel nodes linked by benzenedicarboxylic acid (bdc) and azobipyridyl (azbpy) molecules. This design created two distinct pore windows— $7.3 \times 4.3 \text{ \AA}$ and $9.7 \times 6.9 \text{ \AA}$ —optimized for separating the isomers.

The film was fabricated using a layer-by-layer epitaxial growth technique, ensuring precise nanochannel alignment. Advanced imaging techniques like [X-](#)

[ray diffraction](#) and electron microscopy confirmed the structural integrity of the MOF and its pore alignment.

Combining molecular simulations with kinetic experiments revealed that chemical interactions between the adsorbate (the isomers) and the MOF framework could modulate diffusion rates.

Researchers found that the orientation of nanochannels and the chemical functionality on pore surfaces worked synergistically to control molecular movement. Dynamic interactions allowed the team to reverse the diffusion selectivity of 1BP and 2BP, demonstrating how molecular pathways could be manipulated at an atomic scale.

These findings hold significant implications for industrial processes requiring precise chemical separations. "Dynamic chemical interactions within MOFs not only regulate molecular diffusion but also offer a pathway to fine-tune material properties for specific applications," the researchers noted. By leveraging these interactions, MOFs could make separation technologies more energy-efficient and [environmentally sustainable](#).

On a vastly different scale, astrophysicists are challenging conventional understandings of the universe by investigating singularities—points of infinite density resulting from gravitational collapse.

Traditionally, singularities are thought to exist only within black holes, concealed behind event horizons that prevent observation. However, recent research suggests the existence of naked or visible singularities, which could offer unprecedented insights into the universe's fundamental structure.

In [related research](#), Professors Pankaj Joshi and Sudip Bhattacharyya proposed that gravitational collapse in the early universe could have produced primordial naked singularities (PNaSs). Unlike black holes, PNaSs are not shrouded by event horizons, making them observable. These singularities could represent a significant fraction of [dark matter](#), which constitutes about 25% of the universe's total mass-energy content.

Their research builds on earlier hypotheses by Stephen Hawking and others, who suggested that quantum fluctuations in the early universe could lead to the

formation of primordial black holes. Joshi and Bhattacharyya extended this idea, showing that sufficiently dense regions of matter could form PNaSs instead.

Diffusion selectivity in oriented nanochannel. (CREDIT: Nature Communications)© The Brighter Side of News

These naked singularities may provide a rare opportunity to study quantum gravity—a theoretical framework that seeks to reconcile quantum mechanics with general relativity. "Understanding quantum gravity is one of the last major frontiers of physics," the researchers stated. "PNaSs offer a unique opportunity to observe phenomena that are otherwise inaccessible in black holes."

If PNaSs form a substantial portion of dark matter, they could fundamentally change how we perceive the universe. Unlike traditional dark matter, which interacts only through gravity, PNaSs could be directly observed and studied. This accessibility opens new avenues for investigating the [quantum effects](#) of gravity, which could help physicists develop a unified theory of the universe.

Despite their differences in scale and subject matter, the studies of molecular diffusion in MOFs and cosmic singularities share a common pursuit: understanding complex systems to uncover their underlying principles. Advances in [computational modeling](#) and experimental techniques have been critical to both endeavors.

In the realm of MOFs, molecular dynamics simulations provide valuable insights into diffusion pathways and chemical interactions. These tools allow researchers to predict how structural changes in the MOF framework affect molecular movement.

Similarly, in astrophysics, theoretical models and simulations help visualize phenomena like gravitational collapse and quantum fluctuations, guiding researchers in exploring the extreme conditions of the universe.

Framework dynamics and diffusion control. (CREDIT: Nature Communications)© The Brighter Side of News

Both fields also highlight the importance of interdisciplinary collaboration. Chemists, physicists, and computational scientists work together to enhance the functionality of MOFs, while astrophysicists draw on quantum theory and general

relativity to develop models of singularities. Such collaborations accelerate progress and open new possibilities for scientific discovery.

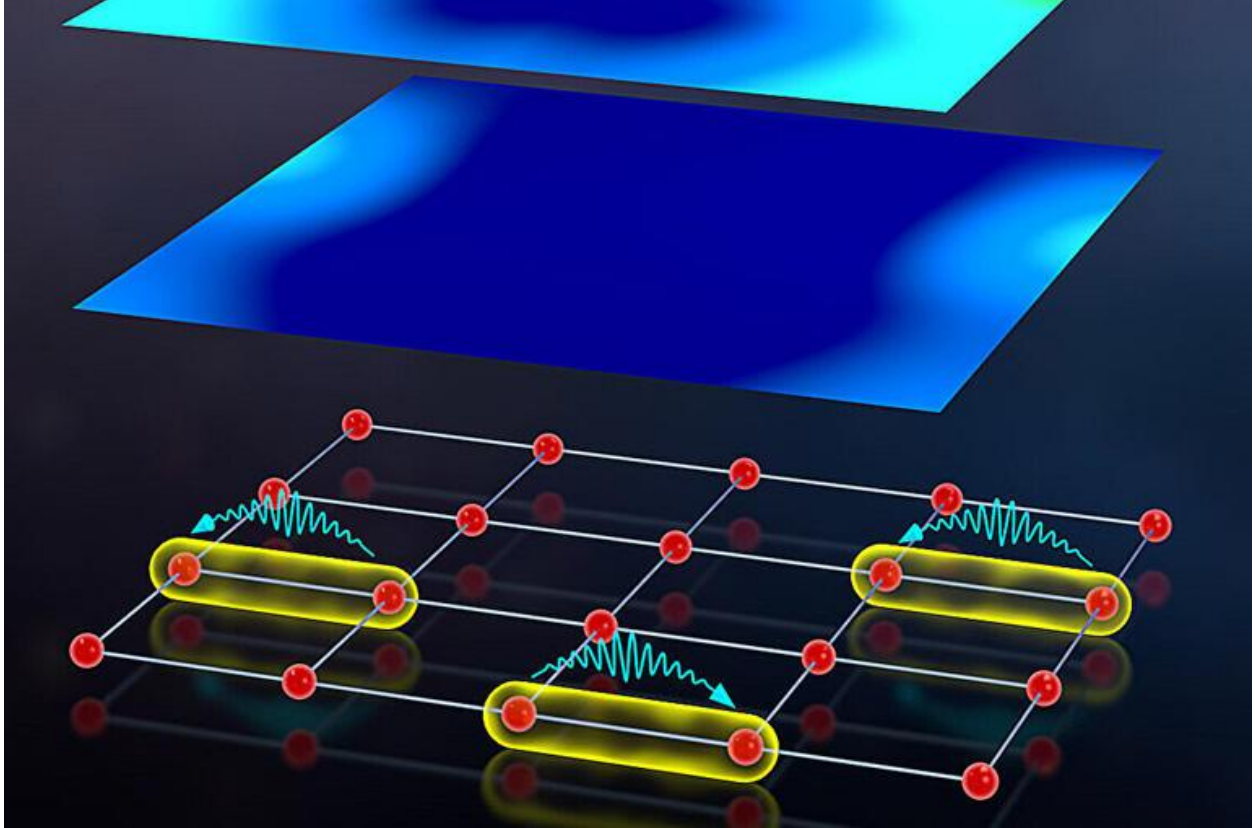
The potential applications of these findings are vast. MOFs with tunable diffusion properties could revolutionize industries reliant on chemical separations, such as petrochemicals, [pharmaceuticals](#), and environmental remediation. Their energy efficiency and adaptability make them ideal for developing sustainable technologies, such as carbon capture and hydrogen storage.

In astrophysics, PNaSs could hold the key to understanding dark matter and quantum gravity, two of the most profound mysteries in modern science. These singularities may reveal quantum effects in [gravitational systems](#), offering insights that were previously considered unattainable. They could also serve as natural laboratories for testing proposed theories of quantum gravity, bridging the gap between quantum mechanics and general relativity.

Both studies underscore the value of pushing scientific boundaries. By delving into the nanoscale world of MOFs and the cosmic realm of singularities, researchers are unlocking the secrets of the universe at both ends of the scale. These discoveries not only advance scientific knowledge but also lay the groundwork for transformative technologies and theoretical breakthroughs.

As science continues to explore the unknown, the lines between disciplines blur, and the potential for discovery grows. Whether in the confined pores of a MOF or the [infinite density](#) of a singularity, the quest for understanding unites us in our search for meaning in the natural world.

Harnessing atom-light interactions: A step towards stable quantum systems



Schematic of the multi-level atomic array structure used in this study. Credit: Steven Burrows/Rey and Thompson groups

Interactions between atoms and light rule the behavior of our physical world, but at the same time, can be extremely complex. Understanding and harnessing them is one of the major challenges for the development of quantum technologies.

To understand light-mediated interactions between atoms, it is common to isolate only two atomic levels, a ground level and an excited level, and view the atoms as tiny antennas with two poles that talk to each other. So, when an atom in a crystal lattice array is prepared in the excited state, it relaxes back to the ground state after some time by emitting a photon.

The emitted photon does not necessarily escape from the array, but instead, it can become absorbed by another ground-state atom, which then gets excited. Such an exchange of excitations, also referred to as dipole-dipole interaction, is key for making atoms interact, even when they cannot bump into each other.

"While the underlying idea is very simple, as many photons are exchanged between many atoms, the state of the system can become correlated, or highly entangled, quickly," explains JILA and NIST Fellow and University of Colorado Boulder physics professor Ana Maria Rey.

"I cannot think of a single atom as an independent object. Instead, I need to keep track of how its state depends on the state of many other atoms in the array. This is intractable with current computational methods. In the absence of an external drive, the generated entanglement typically disappears since all atoms relax to the ground state."

Atoms can, however, have more than two atomic levels. Interactions in the system can change drastically if more than two internal levels are allowed to participate in the dynamics.

In a two-level system (weak excitation) with only one photon and, at most, one excited atom in the array, one just needs to track the single excited atom. While this is numerically tractable, it is not so helpful for quantum technologies since the atoms could be thought of more as classical antennas.

In contrast, by allowing just one additional ground level per atom, even with a single excitation, the number of configurations accessible to the system grows exponentially, drastically increasing the complexity. Understanding atom-light interaction in multi-level settings is an extremely difficult problem, and up to now it has eluded both theorists and experimentalists.

Rey explains, "However, it can be extremely useful, not only because it can generate highly entangled states which can be preserved in the absence of a drive since atoms in the ground levels do not decay."

Now, in a study [published](#) in *Physical Review Letters*, Rey and JILA and NIST Fellow James K. Thompson, along with graduate student Sanaa Agarwal and researcher Asier Piñeiro Orioli from the University of Strasbourg, have studied atom-light interactions in the case of effective four-level atoms, two ground (or metastable) and two excited levels arranged in specific one-dimensional and two-dimensional crystal lattices.

"We know that including the full multilevel structure of atoms can give us richer physics and new phenomena, which are promising for entangled state

generation," says Agarwal, the paper's first author. With quantum technologies like computing and secure communications requiring entanglement, understanding how to create stable, interconnected atomic systems has become a priority.

From two to four internal states

For this study, the researchers focused on isolating four energy levels in strontium atoms, arranged in either one-dimensional (1D) or two-dimensional (2D) configurations where the atoms are loaded in a special configuration in which they are closer to each other than the wavelength of the laser light used to excite them.

The study concentrated on a set of internal levels with a much smaller energy separation than typical optical transitions. Instead of using truly ground-state levels, the team proposed using metastable levels where atoms can live for a very long time.

This very interesting set of levels has not been explored much before since it requires a special laser with a very long wavelength, but Thompson plans to have this laser in his lab.

"We plan to build the necessary capabilities in our lab to first knock the atom into an excited state that lives for a really long time," Thompson says.

"This will let us use a 2.9-micron wavelength transition between this so-called metastable-state excited-state $^3P_2$ in strontium and another excited-state $^3D_3$ state. This wavelength is about eight times longer than the usual separation between nearby atoms trapped in an optical lattice in our lab.

"By having a transition wavelength much longer than the trapping light wavelength, we will be able to realize strong and programmable interactions via this photon exchange that happens when the atoms are jammed in close to each other."

Agarwal adds, "The atoms need to be very close, as interactions weaken with distance, eventually becoming lost due to other sources of decoherence [noise].

Keeping atoms close allows interactions to dominate, preserving the growth of entanglement."

The team focused on the weak and far-from-resonance regime where atoms are allowed to virtually "trade" photons, i.e., moving them between ground states without permanently occupying an excited state.

"By exchanging photons, atoms are effectively only moving between different configurations in the ground state levels, which simplifies our calculations by reducing the number of states accessible to the system," Agarwal adds. "It's easier to eliminate the excited states and focus on the metastable state dynamics, where we observe growing correlations, which furthermore can be preserved when the laser is turned off.

Creating a spin model for entanglement

In the regime where the excited levels are only "virtually" populated, and only atoms can occupy the metastable state levels, the four-level problem can be reduced back to a two-level system at the cost of dealing with much more complex interactions, which involves not only pair-wise interactions but multi-atom interaction.

Rey explains, "We focused on the far-from-resonance regime, where in leading order, only two atoms interact at a given time. In this case, the Hamiltonian describing the metastable state dynamics maps back to a well-characterized spin model."

The team used this well-known model to study what are called "spin waves"—coordinated low-energy excitations of atomic spins—across the lattice arrangement. Moreover, by controlling the polarization and propagation direction of the photons of the laser exciting the atoms, the researchers could determine which "spin-wave pattern" became dominantly entangled.

The entanglement observed was spin-squeezing, a specific form of entanglement that has increased sensitivity to external noise and is thus useful for metrology.

"The spin squeezing in our system can be experimentally measured and serves as a witness of quantum entanglement. Our setup also has possible applications in simulating many-body physics," Agarwal says.

This finding is especially significant, as it implies that quantum systems could maintain entanglement over long periods, without needing constant intervention to prevent decoherence.

Limitations in simulations

While the team's model offered promising insights, it also faced limitations in accurately simulating the system over time. One of the key limitations arose from the dipole-dipole interactions, which—unlike simpler interactions—involve long-range forces that couple atoms both near and far in the lattice.

Furthermore, these couplings are anisotropic and depend on the relative orientation of the atomic dipoles, making the system more complex. Each atom interacts differently with its neighbors spaced along different directions in the lattice, leading to varying interaction strengths and signs across the array.

Other popular simulation techniques designed for short-range interactions fail when applied to long-range interactions, as they aren't equipped to handle the many correlations that develop over time.

Although some other methods are more appropriate for long-range atomic interactions, they are constrained to small atom numbers due to their computational complexity, limiting the researchers' ability to observe the long-time progression of correlations in a large system.

Diving further into internal states

The team's findings could open new avenues in quantum information science and quantum computing, offering a potential path for the development of highly entangled and scalable quantum systems.

"We're inching closer to systems that could sustain entanglement reliably, which is a crucial step for future quantum applications," says Agarwal.

Looking forward, the research team plans to explore how more extensive multilevel systems might enhance entanglement potential.

"In atoms like strontium, with as many as 10 ground and excited levels each, the complexity grows significantly, and we want to see how this impacts entanglement," Agarwal says.

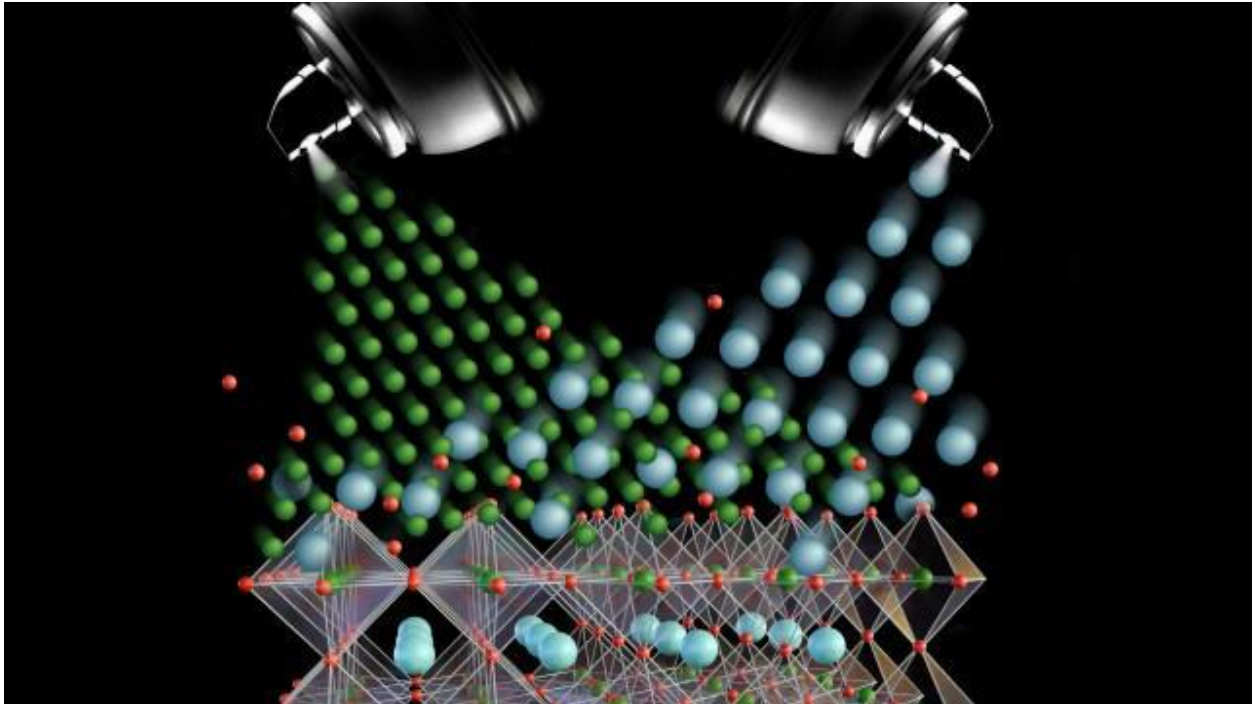
"Furthermore, while we have focused here on interactions between atoms in free space, one excited extension is to understand how these interactions can interplay with additional photon-mediated interactions [that are] built when atoms are instead placed inside an optical cavity or in nanophotonic devices," she adds.

"The competition between the infinite range interactions mediated by the cavity photons and the dipole-dipole interactions described here can open fantastic opportunities to harness light-mediated quantum gates, entanglement distribution, and programmable quantum many-body physics," says Thompson.

More information: Sanaa Agarwal et al, Entanglement Generation in Weakly Driven Arrays of Multilevel Atoms via Dipolar Interactions, *Physical Review Letters* (2024). DOI: [10.1103/PhysRevLett.133.233003](https://doi.org/10.1103/PhysRevLett.133.233003). On arXiv: DOI: [10.48550/arxiv.2405.16101](https://doi.org/10.48550/arxiv.2405.16101)

Provided by JILA

Scientists make breakthrough discovery after 'atomic spray painting' experiment: 'It's like spray-painting atoms onto a surface'



There's still work to be done as the researchers move to the next step in the process.

A research team has discovered that by using a new method of "atomic spray painting," they can tweak the atomic structure of lead-free potassium niobate in order to enhance its ferroelectric properties.

The [study](#), created by a team led by Penn State researchers, explains how molecular beam epitaxy can be employed to deposit atomic layers onto a substrate to create thin films, as a report by SciTechDaily [explained](#).

Using a technique called strain tuning, the researchers adjusted how successive layers are aligned to modify a material's properties by stretching or compressing the atoms that make up its crystal structure.

They found that they could control the thin-film properties of potassium niobate, a key material in advanced electronics. This opens up new possibilities for

greener technologies, medical devices, and space exploration, as the report detailed.

"This was the first time potassium niobate has been grown using MBE," said Venkatraman Gopalan, a professor of materials science and engineering at Penn State and a corresponding author of the study, according to SciTechDaily.

"The technique is like spray-painting atoms onto a surface." Co-author Sankalpa Hazra offered a few more details about the process in the article, saying: "This method allows the atoms in the thin films to adjust to the underlying substrate's atomic structure, causing strain.

"Even a tiny stretch of about 1% can create pressure that would be impossible to achieve by simply pulling or pressing on such a brittle material from the outside. This pressure can significantly improve how the material works from a ferroelectric perspective."

Ferroelectric metals frequently used for these applications are usually lead-based, which is [toxic](#) to humans and the environment. Strain-tuning lead-free potassium niobate allows the material to do the same work, even under high temperatures, offering a more [environmentally friendly](#) and safer way forward for the industry.

"A ferroelectric is sort of like a minibattery that is already charged up permanently by nature," Gopalan said.

"Despite not being a household name, ferroelectrics are everywhere in key technologies we take for granted in our daily lives. The internet, for example, relies on converting electrical to optical signals, which is performed by a ferroelectric crystal. These materials can reverse their electric polarity when an external electric field is applied, a quality that also makes them vital for devices like ultrasound equipment, infrared cameras, and precision actuators for advanced microdevices."

By using nontoxic materials for electronics, we can reduce the amount of harmful waste that ends up in [landfills](#) and further protect our environment. The [optical properties](#) of potassium niobate, which is classified as a [perovskite material](#), may help in the development of next-generation [solar panels](#) and other [green tech](#).

There's still work to be done as the researchers move to the next step in the process, which is growing these thin films on [silicon](#), a key material in the electronics industry.

"With further development, this novel version of the material could become a key player in the next generation of green, high-performance technologies that impact everything from our personal devices to space exploration," Gopalan said.

Quantum physics discovery: Light travels through both space and time

Physicists from [Imperial College London](#) have achieved a groundbreaking milestone in quantum physics by reimagining the classic double-slit experiment—this time in the dimension of time.

Led by Professor Riccardo Sapienza from the Department of Physics, the team studied how light interacts with a material whose optical properties can change within a few femtoseconds. This innovative approach sheds new light on the fundamental nature of light itself.

The original double-slit experiment, conducted by Thomas Young in 1801, revealed that light behaves as a wave. Subsequent experiments demonstrated its dual nature, showing that light also acts as particles.

In the classical experiment, light was passed through two physical slits, creating an interference pattern indicative of wave behavior. This landmark discovery became a cornerstone in understanding quantum mechanics, influencing how particles like electrons and atoms are studied.

In this modern reinterpretation, the experiment moves beyond physical slits and instead manipulates the frequency of light. Using lasers, the researchers altered the optical properties of a thin film of indium-tin-oxide—a material commonly used in smartphone screens—with femtosecond-level precision.

By changing the film's reflectivity, they managed to modify the color of light and produce interference-like patterns created by the interaction of different light frequencies.

Published in [Nature Physics](#), the study highlights both fundamental discoveries and practical implications. "This experiment reveals more about the fundamental nature of light while serving as a stepping-stone to creating materials that can control light in both space and time," Sapienza

explained. These advanced materials could revolutionize industries ranging from telecommunications to medicine by enabling unprecedented control over light.

One significant breakthrough from this research is its potential to enable new forms of spectroscopy. These methods could analyze the temporal structure of light pulses at the scale of a single oscillation of radiation.

As co-author Professor Sir John Pendry noted, "The double time slits experiment opens the door to a whole new spectroscopy capable of resolving the temporal structure of a light pulse on the scale of one period of the radiation."

The implications extend far beyond theoretical physics. The ability to precisely control the timing and frequency of light could transform telecommunications by enabling faster, more reliable data transmission. With improved optical switches, future communication networks could achieve higher speeds and efficiency, ultimately leading to advancements in internet connectivity and other technologies.

This research not only expands our understanding of quantum physics but also paves the way for transformative applications that could shape the future of technology and science.

In computing, the development of metamaterials that control light could result in optical processors that are faster and more energy-efficient than traditional electronic processors.

Optical computing, where light replaces electricity, has long been a goal for researchers because it promises higher data processing speeds with less [energy consumption](#). Such technology could revolutionize computing by making devices more powerful while reducing their environmental impact.

Medical technology is another field that stands to benefit from these discoveries. Light's potential to be precisely controlled in both space and time could lead to more advanced imaging tools for diagnostics and treatment.

This might allow for earlier detection of diseases or the ability to precisely target and destroy cancer cells without harming surrounding tissue, reducing side effects in treatments like chemotherapy.

The experiment also lays the foundation for further research into "[time crystals](#)," which are materials that have repeating structures not just in space but also in time.

According to co-author Professor Stefan Maier, "The concept of time crystals has the potential to lead to ultrafast, parallelized optical switches." These time crystals might help researchers achieve even more refined control over light, opening new avenues for technological advancement.

The significance of this experiment extends beyond [telecommunications](#), computing, and medicine. Metamaterials like the ones used in this research could have broader applications in industries such as energy, transportation, aerospace, and defense.

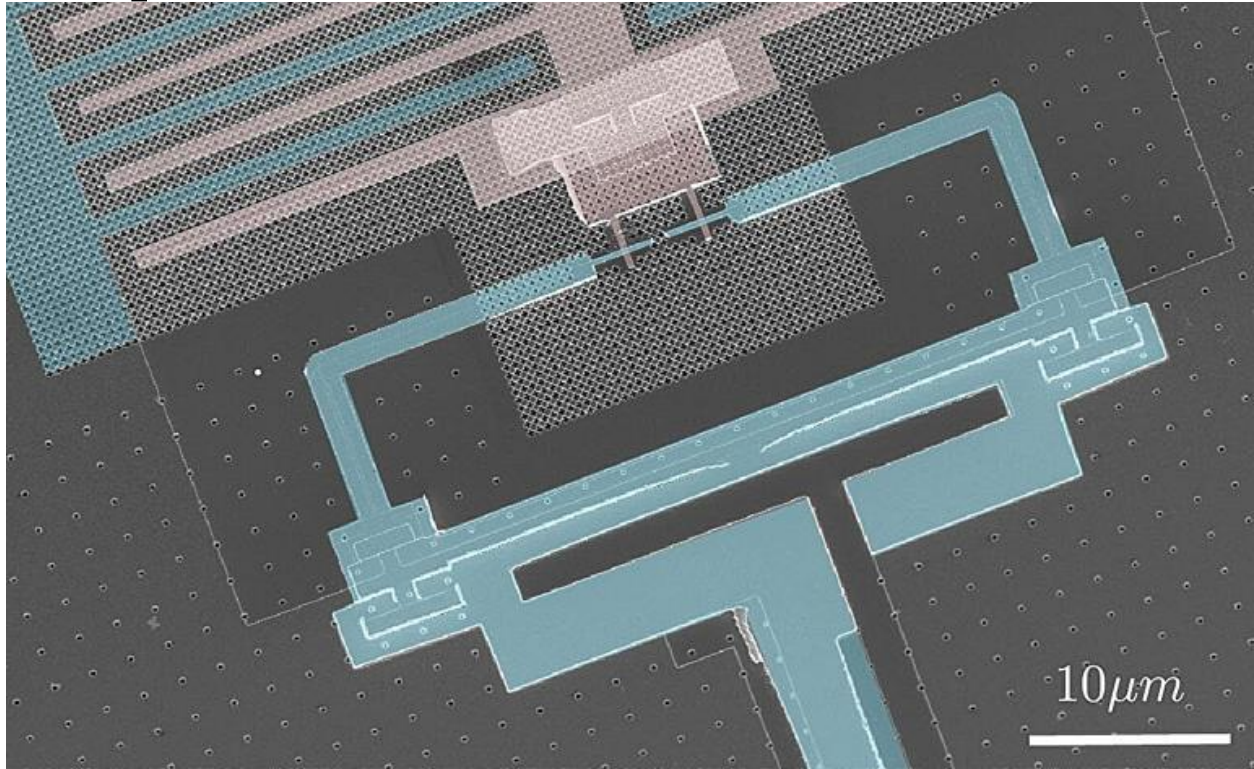
For instance, controlling light at such a fine level might enable more efficient energy systems or advanced sensor technologies for aircraft and vehicles. Even black hole physics could be explored through these new quantum experiments, adding to the wide-ranging impact of this research.

As technology advances, the role of metamaterials and [quantum physics](#) will become increasingly critical. The ability to manipulate light in space and time holds the promise of reshaping how we interact with the world, offering faster, more efficient, and more precise tools across industries.

This breakthrough by the Imperial College London team marks a significant leap in that direction, showing how curiosity-driven research can lead to innovations that ripple through many fields.

As Professor Sapienza stated, this experiment is just the beginning: "Our work serves as a stepping-stone to creating the ultimate materials." With further exploration, these innovations could lead to entirely new ways of understanding and [controlling light](#), providing tools that change everything from the devices in our pockets to the way we diagnose and treat diseases.

Using phononic bandgap materials to suppress decoherence in quantum computers



A superconducting qubit on a phononic bandgap metamaterial. Credit: Nature Physics (2025). DOI: 10.1038/s41567-024-02740-5

Quantum computers have the potential of outperforming classical computers on some optimization and computational tasks. Compared to classical systems, however, quantum systems are more prone to errors, as they are more sensitive to noise and prone to so-called decoherence.

Decoherence is a process via which a quantum system loses its quantum properties due to interactions with its surrounding environment, causing a loss of quantum information and errors. This loss of coherence can be caused by a range of external disturbances, including material defects, temperature fluctuations and electromagnetic fields.

In recent years, physicists and engineers worldwide have been trying to devise effective methods to reduce decoherence and thus improve the reliability of

quantum computers. The sources of decoherence in solid-state systems include so-called two-level systems (TLSs), which are a class of material defects that arise from the random switching between two energy states, which can disrupt the stability of qubits.

Researchers at University of California Berkeley and the Lawrence Berkeley National Laboratory have introduced a new possible method to mitigate the decoherence induced by TLSs, via what is known as phononic engineering. Their proposed approach, [outlined](#) in a *Nature Physics* paper, entails the use of a carefully designed phononic bandgap metamaterial that could suppress the interactions of qubits with TLSs.

"We are interested in understanding and engineering microscopic processes that lead to decoherence in superconducting qubits," Alp Sipahigil, senior author of the paper, told Phys.org. "Solid-state quantum hardware is fabricated from imperfect materials and needs to consider how qubits interact with material defects and phonons. This study was inspired by the following question: 'What would happen if a superconducting qubit is forbidden from losing energy via phonon radiation?'"

Sipahigil and his colleagues used phononic engineering, an approach that entails controlling phonons (i.e., quantized vibrations) in a solid material, to create a new phononic bandgap metamaterial. They then successfully used this material to suppress the interactions of superconducting qubits with TLSs.

"When a superconducting qubit decays, the energy is often lost to the environment as phonons in an irreversible Markovian process," explained Sipahigil. "We suppressed this phonon radiation process by embedding a superconducting qubit in a phononic metamaterial where phonon emission is forbidden. We used measurements on the qubit to identify the lifetime extension of material defects called TLSs and a transition to non-Markovian qubit relaxation."

In initial tests, the researchers found that their newly engineered phononic bandgap material extended the duration for which a qubit can maintain an excitation, also known as relaxation time. Moreover, they observed that qubits in the material exhibited non-Markovian behavior, which could open new possibilities for the control of quantum systems.

"We found that engineering the phonon bath of a superconductor can modify its dynamics," said Sipahigil. "Engineering the electromagnetic environment of a

qubit is well-established and is routinely done. Our work shows that co-designing the phononic environment might be necessary to improve superconducting qubit performance further."

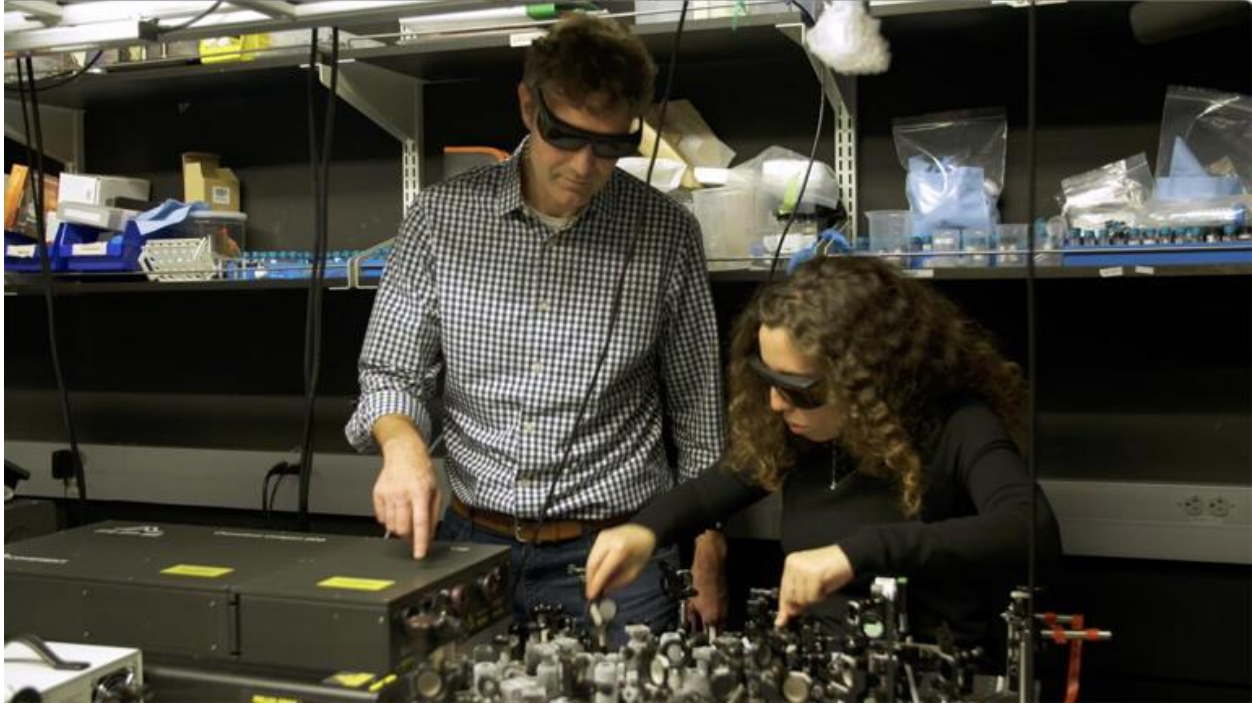
This recent study by Sipahigil and their colleagues introduces a new promising design strategy that could help to reduce decoherence in solid-state quantum computing systems. In the future, it could inspire other research groups to also explore the potential of phononic engineering strategies for improving the performance and stability of quantum systems.

"We identified a regime where qubit miniaturization and phonon engineering could dramatically improve qubit performance," added Sipahigil. "We are now developing compact qubits that co-design the electromagnetic and phonon environments to achieve longer lifetimes."

More information: Mutasem Odeh et al, Non-Markovian dynamics of a superconducting qubit in a phononic bandgap, *Nature Physics* (2025). [DOI: 10.1038/s41567-024-02740-5](https://doi.org/10.1038/s41567-024-02740-5).

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Engineering quantum entanglement at the nanoscale



Study authors P. James Schuck (left) and Chiara Trovatello from the Schuck lab at Columbia Engineering. Credit: Jane Nisselson/Columbia Engineering

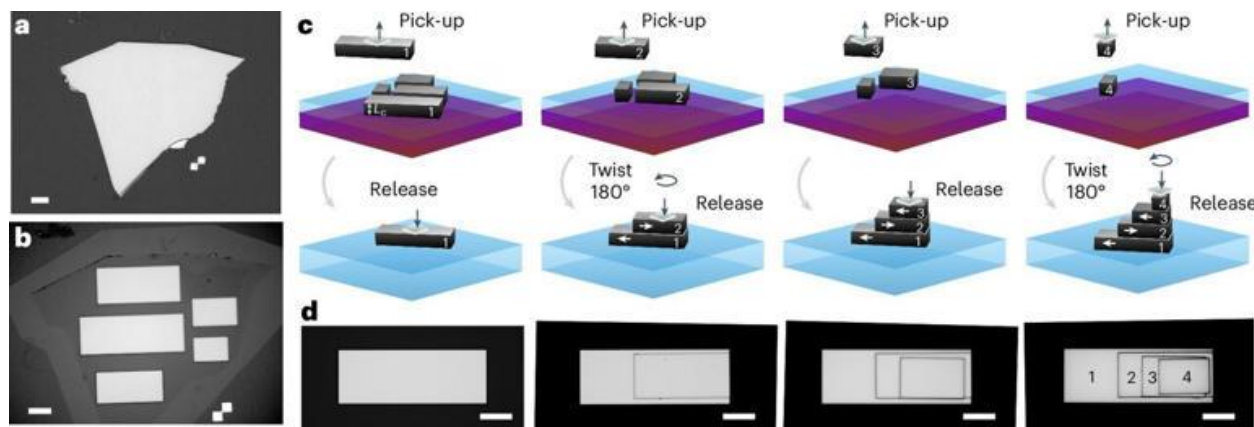
Physicists have spent more than a century measuring and making sense of the strange ways that photons, electrons, and other subatomic particles interact at extremely small scales. Engineers have spent decades figuring out how to take advantage of these phenomena to create new technologies.

In one such phenomenon, called quantum entanglement, pairs of photons become interconnected in such a way that the state of one photon instantly changes to match the state of its paired photon, no matter how far apart they are.

Nearly 80 years ago, Albert Einstein referred to this phenomenon as "spooky action at a distance." Today, entanglement is the subject of research programs across the world—and it's becoming a favored way to implement the most fundamental form of quantum information, the qubit.

Currently, the most efficient way to create photon pairs requires sending lightwaves through a crystal large enough to see without a microscope.

In a paper [published](#) in *Nature Photonics*, a team led by Columbia Engineering researchers and collaborators describe a new method for creating these photon pairs that achieves higher performance on a much smaller device using less energy. P. James Schuck, associate professor of mechanical engineering at Columbia Engineering, helped lead the research team.



PPTMDs. a,b, Micrograph of the 3R-MoS₂ flake before (a) and after (b) patterning (electron beam lithography, etching). c, Stacking procedure. Slab 1 is first transferred on a 500- μm -thick SiO₂ transparent substrate. Slab 2 is twisted by 180° and released on top of slab 1. Slab 3 is transferred on top of slab 2. Finally, slab 4 is twisted by 180° and released on top of the 3 stacked portions. d, Micrographs of each stacking step. Scale bars, 10 μm . Credit: *Nature Photonics* (2025). DOI: 10.1038/s41566-024-01602-z

These findings represent a significant step forward in the field of nonlinear optics, which is concerned with using technologies to change the properties of light for applications including lasers, telecommunications, and laboratory equipment.

"This work represents the embodiment of the long-sought goal of bridging macroscopic and microscopic nonlinear and quantum optics," says Schuck, who co-directs Columbia's MS in Quantum Science and Technology. "It provides the foundation for scalable, highly efficient on-chip integrable devices such as tunable microscopic entangled-photon-pair generators."

How it works

Measuring just 3.4 micrometers thick, the new device points to a future where this important component of many quantum systems can fit onto a silicon chip. This change would enable significant gains in the energy efficiency and overall technical capabilities of quantum devices.

To create the device, the researchers used thin crystals of a so-called van der Waals semiconducting transition metal called molybdenum disulfide. Then they layered six of these crystal pieces into a stack, with each piece rotated 180 degrees relative to the crystal slabs above and below.

As light travels through this stack, a phenomenon called quasi-phase-matching manipulates properties of the light, enabling the creation of paired photons.

This paper represents the first time that quasi-phase-matching in any van der Waals material has been used to generate photon pairs at wavelengths that are useful for telecommunications. The technique is significantly more efficient than previous methods and far less prone to error.

"We believe this breakthrough will establish van der Waals materials as the core of next-generation nonlinear and quantum photonic architectures, with them being ideal candidates for enabling all future on-chip technologies and replacing current bulk and periodically poled crystals," Schuck says.

"These innovations will have an immediate impact in diverse areas including satellite-based distribution and mobile phone quantum communication."

How it happened

Schuck and his team built on their previous work to develop the new device. In 2022, the group demonstrated that materials like molybdenum disulfide possess useful properties for nonlinear optics—but performance was limited by the tendency of light waves to interfere with one another while traveling through this material.

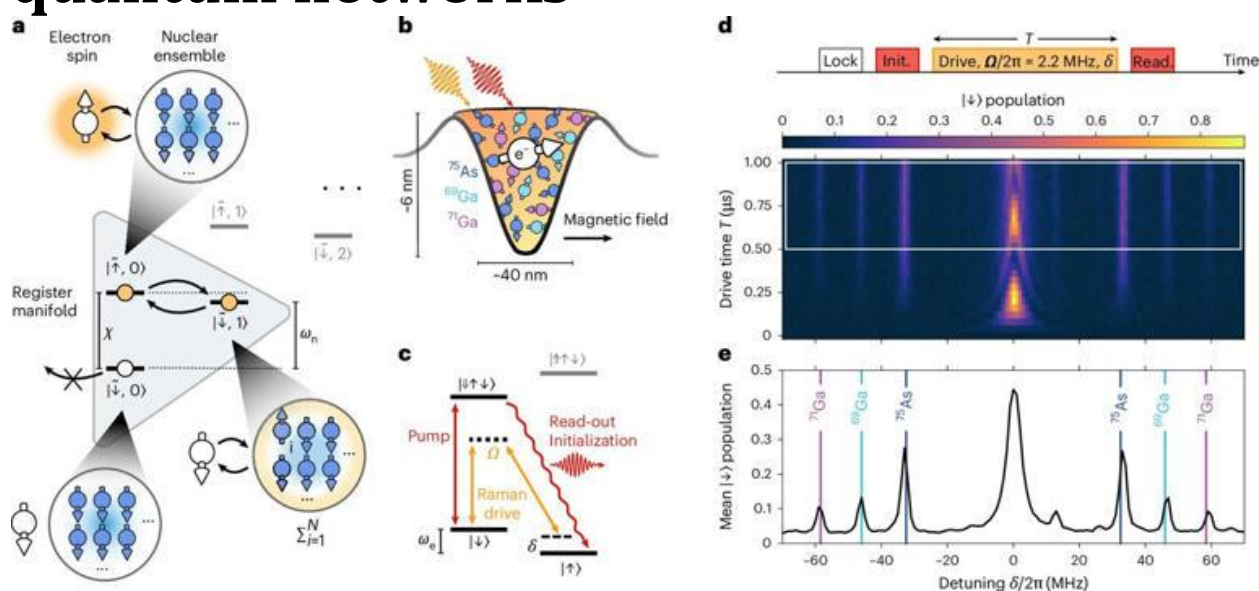
The team turned to a technique called periodic poling to counteract this problem, which is known as phase matching. By alternating the direction of the slabs in the stack, the device manipulates light in a way that enables photon pair generation at miniscule length scales.

"Once we understood how amazing this material was, we knew we had to pursue the periodic poling, which could allow for the highly efficient generation of photon pairs," Schuck says.

More information: Chiara Trovatello et al, Quasi-phase-matched up- and down-conversion in periodically poled layered semiconductors, *Nature Photonics* (2025). DOI: [10.1038/s41566-024-01602-z](https://doi.org/10.1038/s41566-024-01602-z)

Provided by Columbia University School of Engineering and Applied Science

Scientists create new register with thousands of entangled nuclei to scale quantum networks



Isotope-resolved electro-nuclear interface. Credit: *Nature Physics* (2025). DOI: [10.1038/s41567-024-02746-z](https://doi.org/10.1038/s41567-024-02746-z)

In an advance for quantum technologies, researchers at the Cavendish Laboratory, University of Cambridge, have created a functional quantum register using the atoms inside a semiconductor quantum dot.

[Published](#) in *Nature Physics*, the work demonstrates the introduction of a new type of optically connected qubits—a critical advance in the development of quantum networks, where stable, scalable, and versatile quantum nodes are essential.

Quantum dots are nanoscale objects with unique optical and electronic properties that come from quantum mechanical effects. These systems are already used in technologies like display screens and medical imaging, and their

adoption in quantum communication has been mostly due to their ability to operate as bright single-photon sources.

However, effective quantum networks need more than just single-photon emission; they also require stable qubits that can interact with the photons and store quantum information locally. The new research builds on the inherent spins of the atoms forming the quantum dots as a functioning many-body quantum register to store information over extended periods.

A many-body system refers to a collection of interacting particles—here, the nuclear spins inside the quantum dot—whose collective behavior gives rise to new, emergent properties that are not present in individual components. By using these collective states, the researchers created a robust and scalable quantum register.

The Cambridge team, in close collaboration with colleagues at the University of Linz, successfully prepared 13,000 nuclear spins into a collective, entangled state of spins known as a "dark state." This dark state reduces interaction with its environment, leading to better coherence and stability, and serves as the logical "zero" state of the quantum register.

They introduced a complementary "one" state as a single nuclear magnon excitation—a phenomenon representing a coherent wave-like excitation involving a single nuclear spin flip propagating through the nuclear ensemble. Together, these states enable quantum information to be written, stored, retrieved, and read out with high fidelity.

The researchers demonstrated this with a complete operational cycle, achieving a storage fidelity of nearly 69% and a coherence time exceeding 130 microseconds. This is a major step forward for quantum dots as scalable quantum nodes.

"This breakthrough is a testament to the power many-body physics can have in transforming quantum devices," said Mete Atatüre, co-lead author of the study and Professor of Physics at the Cavendish Laboratory.

"By overcoming long-standing limitations, we've shown how quantum dots can serve as multi-qubit nodes, paving the way for quantum networks with applications in communication and distributed computing. In the 2025 International Year of Quantum, this work also highlights the innovative strides

being made at the Cavendish Laboratory toward realizing the promise of quantum technologies."

The work represents a unique marriage of semiconductor physics, quantum optics, and quantum information theory. The researchers utilized advanced control techniques to polarize nuclear spins in gallium arsenide (GaAs) quantum dots, creating a low-noise environment for robust quantum operations.

"By applying quantum feedback techniques and leveraging the remarkable uniformity of GaAs quantum dots, we've overcome long-standing challenges caused by uncontrolled nuclear magnetic interactions," explained Dorian Gangloff, co-lead author of the project and Associate Professor of Quantum Technology.

"This breakthrough not only establishes quantum dots as operational quantum nodes but also unlocks a powerful platform to explore new many-body physics and emergent quantum phenomena."

Looking ahead, the Cambridge team aims to extend the time their quantum register can store information to tens of milliseconds by improving their control techniques. These improvements would make quantum dots suitable as intermediate quantum memories in quantum repeaters—critical components for connecting distant quantum computers.

More information: Martin Hayhurst Appel et al, A many-body quantum register for a spin qubit, *Nature Physics* (2025). [DOI: 10.1038/s41567-024-02746-z](https://doi.org/10.1038/s41567-024-02746-z)

Provided by University of Cambridge

First man-made biological leaf to make oxygen for space travel



PTI

Last Updated : 01 August 2014, 00:46 IST

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An inventor in the UK has developed the world's first synthetic biological leaf that absorbs water and carbon dioxide to produce oxygen just like a plant, and it could enable long-distance space travel. Photo courtesy: Dezeen

An inventor in the UK has developed the world's first synthetic biological leaf that absorbs water and carbon dioxide to produce oxygen just like a plant, and it could enable long-distance space travel.

The leaf, created by Royal College of Art student Julian Melchiorri, consists of chloroplasts suspended in a matrix made out of silk protein. "The material is extracted directly from the fibres of silk," Melchiorri said.

"This material has an amazing property of stabilising molecules. I extracted chloroplasts from plant cells and placed them inside this silk protein. As an outcome I have the first photosynthetic material that is living and breathing as a leaf does," he said.

Like the leaves of a plant, Melchiorri's Silk Leaf needs light and a small amount of water to produce oxygen, 'Dezeen' reported.

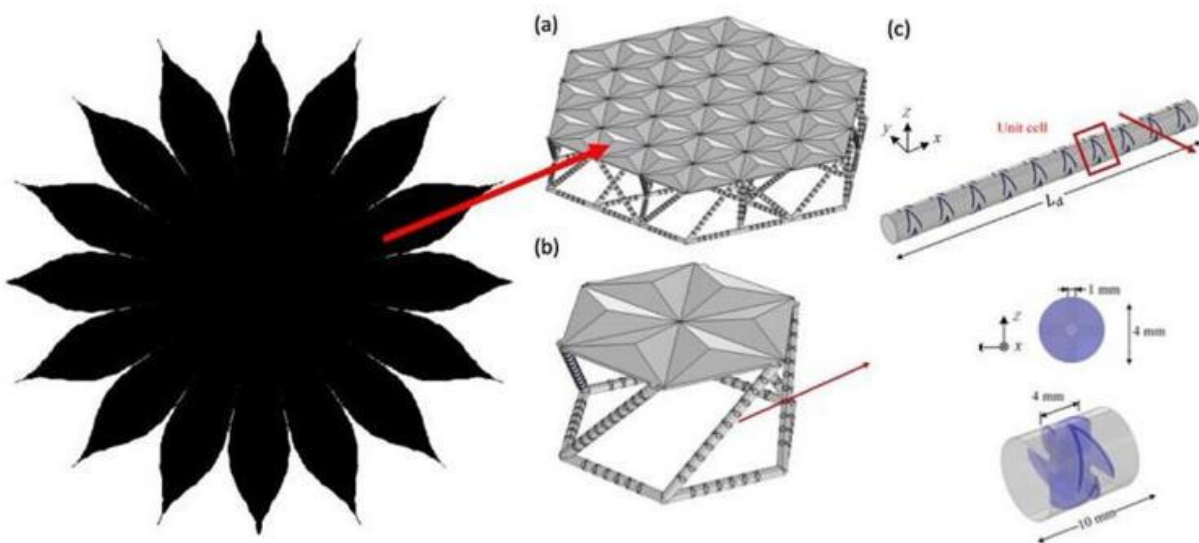
"Silk Leaf is the first man-made biological leaf. It's very light, low energy-consuming, it's completely biological," Melchiorri said.

"Plants don't grow in zero gravity. NASA is researching different ways to produce oxygen for long-distance space journeys to let us live in space. This material could allow us to explore space much further than we can now," said Melchiorri.

The Silk Leaf project was developed as part of the Royal College of Art's Innovation Design Engineering course in collaboration with Tufts University silk lab. Melchiorri said the leaf could also be used for outdoor applications.

"So facades, ventilation systems. You can absorb air from outside, pass it through these biological filters and then bring oxygenated air inside," he said.

Dynamically stable large space structures via architected metamaterials



Artist concept highlighting the novel approach. Credit: NASA/Christine Gregg

Exoplanet exploration has taken off in recent years, with over 5,500 being discovered so far. Some have even been in the habitable zones of their stars. Imaging one such potentially habitable exoplanet is the dream of many exoplanet hunters, however, technology has limited their ability to do that.

In particular, one specific piece of technology needs to be improved before we can directly image an exoplanet in the habitable zone of another star—a starshade.

Christine Gregg, a researcher at NASA Ames Research Center, hopes to contribute to the effort of developing one.

To understand the goal of Dr. Gregg and her team, it's best first to understand what starshades do and what's holding them back from being deployed.

A starshade is designed to float in tandem with a space telescope and block out the light from a specific star, allowing the telescope to capture light directly from the much-less bright planet that is orbiting the star. That light can contain information about its size, orbital period, and even its atmospheric composition that would otherwise be lost in the overwhelming brightness of the planet's star.

The shape of a starshade, which traditionally looks like a flower petal, might seem counterintuitive at first—if you're trying to block a star's light, why not just make the shape circular? But starlight coming from far away can diffract around a simple circle structure. The petals are explicitly designed to stop that from happening and completely block out even diffracted light around the shape's edges.

But it's not the shape that makes it hard to deploy—it's its size. Starshades are typically designed to be hundreds of meters across. Therefore, they are impossible to fit inside a traditional rocket fairing fully assembled. What's more, they have to move along with the telescope—if the telescope the starshade is meant to accompany is pointed at another star and redirected, the starshade has to move with it.

The wrinkle is that the starshade is likely tens of thousands of kilometers from the telescope it is designed to assist. So, a slight change of a few degrees of inclination for the telescope would mean hundreds of thousands of kilometers of

travel for its associated starshade. That kind of movement requires a lot of fuel, which is also costly due to the weight requirements of launching these objects so far away.

No wonder a starshade has yet to be successfully deployed in space. Combining gigantic sizes that don't fit inside rocket fairings and massive amounts of fuel to relocate every time the telescope needs to look at a different star are significant strikes against the concept. However, if humanity wants to directly image an exoplanet in the habitable zone of another star, there is still no better way to do so.

Enter Dr. Gregg's idea—she proposes using metamaterials for her starshade, which is robotically constructed in orbit. Metamaterials have several advantages over existing proposed starshades (one of which, by Nobel Prize winner John Mather, is another NIAC recipient this year).

First, metamaterials are lighter. As with all things launched into space, being lighter means less cost—or, in this case, the ability to bring more fuel, allowing the starshade to operate longer than alternatives.

Second, the specific kinds of metamaterials she proposes to use are much less likely to break. As she mentioned to Fraser in an interview, "The more stiffness a material has, the less damping it has. It's just sort of a natural trade-off."

So, if a starshade is made from traditional materials, it would either be stiff and rigid but prone to vibrational strain when moving between positions or being deployed, or it would be very flexible but would have difficulty holding its shape when it's supposed to.

The metamaterial Dr. Gregg and her colleagues have proposed uses a type of material that both holds its structure well but also suppresses vibration by a unique use of a material called a phononic crystal.

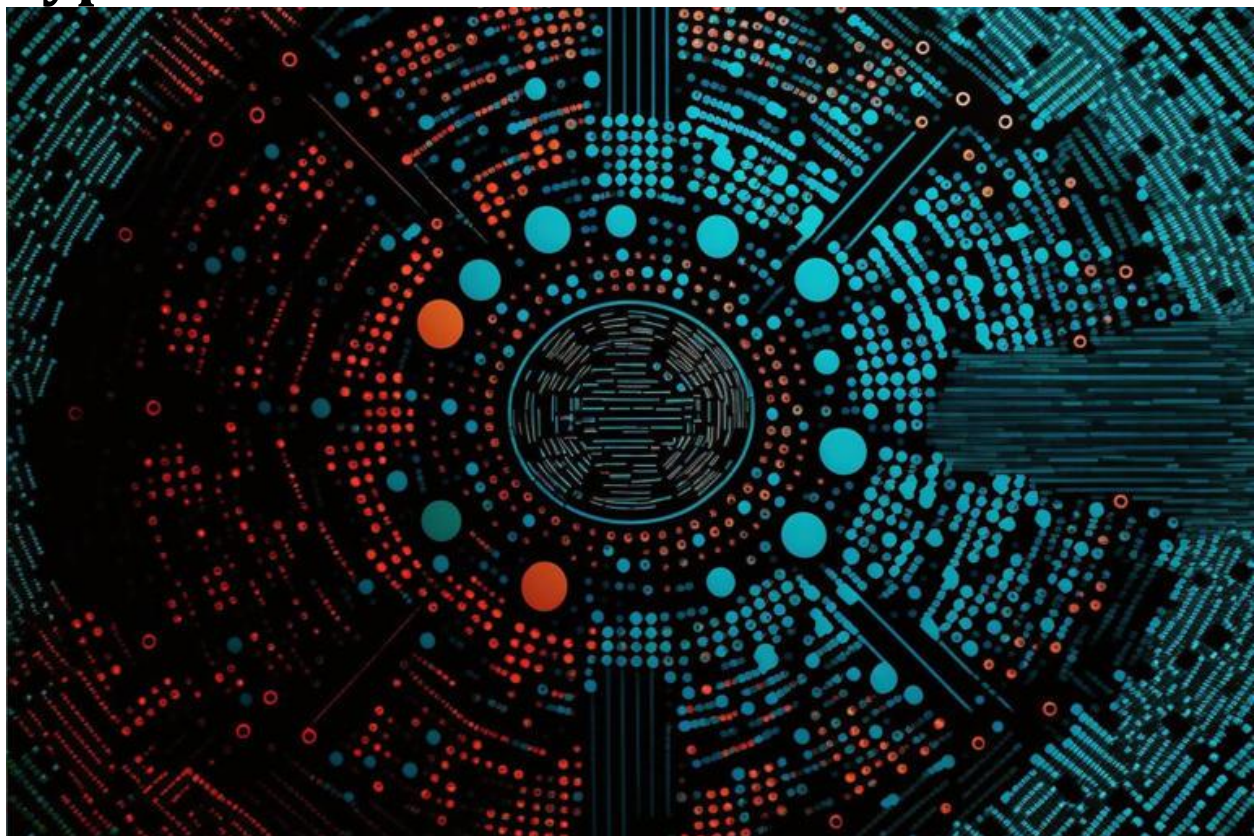
These were initially engineered to dissipate sound waves. This means that when used as a material in a starshade, it could dampen any feedback on the structure from things like micrometeoroid impacts, solar radiation, or even the process of deployment and assembly.

Using robots to deploy the starshade is another focal point of Dr. Gregg's work, as she discusses with Fraser. Still, for this Phase I NIAC project, she is focusing on developing the model for starshade itself and selecting the appropriate material.

As with all NIAC projects, she can apply for funding in a Phase II round upon completion of her Phase I. If she receives it, humanity will be one step closer to seeing a giant floating petal in space—but one with very particular mechanical and structural properties.

Provided by Universe Today

Physics-based models combined with big data could lead to systematically better hypotheses



Finding a reasonable hypothesis can pose a challenge when there are thousands of possibilities. This is why Dr. Joseph Sang-II Kwon is trying to make hypotheses in a generalizable and systematic manner.

Kwon, an associate professor in the Artie McFerrin Department of Chemical Engineering at Texas A&M University, published his [work](#) on blending traditional physics-based scientific models with experimental data to accurately predict hypotheses in the journal *Nature Chemical Engineering*.

Kwon's research extends beyond the realm of traditional chemical engineering. By connecting physical laws with machine learning, his work could impact renewable energy, smart manufacturing, and health care, outlined in his recent paper, "Adding big data into the equation."

Deriving hypotheses for experimental observations typically involves a trial-and-error process. Kwon has developed a systematic framework that integrates specialized knowledge with experimental data to create a more efficient process.

"The most impactful aspect of this research is its ability to bridge the gap between theoretical models and real-world complexity, creating a versatile framework to solve intricate problems," Kwon said. "This versatility means that the potential benefits could reach a wide range of industries and significantly impact daily life."

This research could lead to new drug discovery by incorporating experimental data into these models, Kwon said. This hybrid modeling approach integrates biological knowledge with data to accelerate drug predictions.

"Developing new drugs is expensive and time-consuming," Kwon said. "But with more advanced models, we can accelerate the discovery and manufacturing processes. Leveraging simulations and machine learning reduces the need for costly lab experiments, saving time and speeding up the discovery of new treatments."

His approach combines physics-based models with the flexibility of data-driven components that can adapt and correct predictions based on real-world experimental data.

Kwon plans to use these models as a backbone to simulate complex systems and capture underlying physical phenomena that traditional physics-based models cannot capture alone.

"This methodology allows us to continuously estimate process parameters alongside the hyperparameters of the data-driven component," Kwon said. "By doing so, we ensure that the models are applicable to a wider range of conditions, making them more versatile and better suited to handle new and varied scenarios."

"Purely data-driven models fall short when it comes to capturing the intricacies of these systems," Kwon said. "By blending the two approaches, we can improve the efficiency and reliability of industrial processes that are critical to producing everyday essentials such as energy, chemicals, and pharmaceuticals."

More information: Joseph Sang-Il Kwon, Adding big data into the equation, *Nature Chemical Engineering* (2024). [DOI: 10.1038/s44286-024-00142-1](https://doi.org/10.1038/s44286-024-00142-1)

Provided by Texas A&M University

Dec 12, 2024 08:00:00

A brave man who created a 'field emission electric propulsion engine' that obtains thrust by injecting liquid metal ions appears



This article, originally posted in [Japanese](#) on 08:00 Dec 12, 2024, may contains some machine-translated parts.

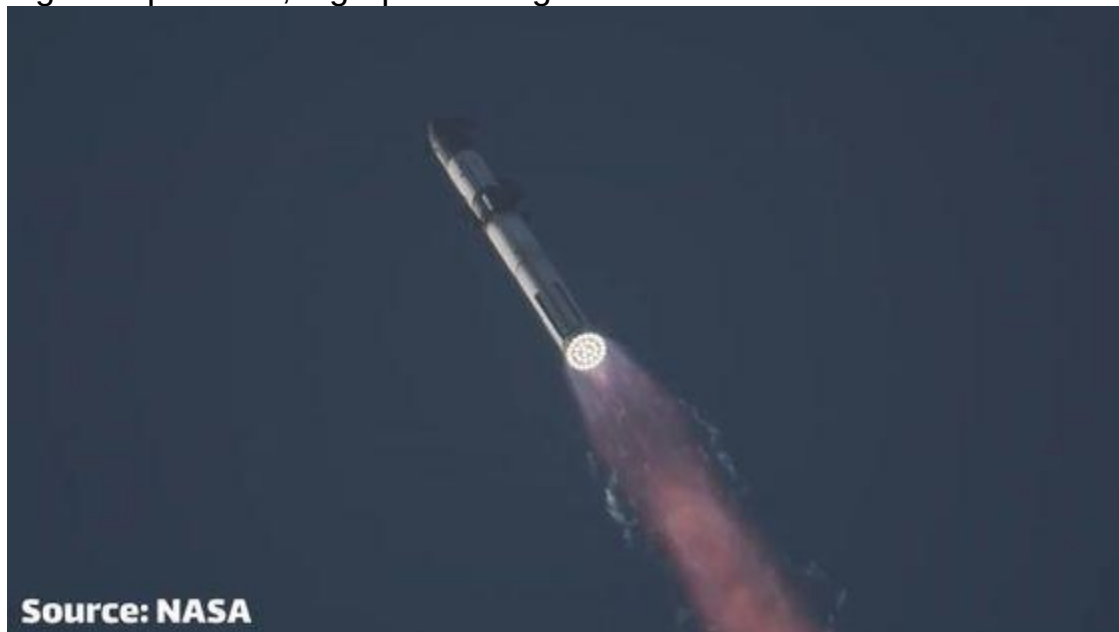
If you would like to suggest a corrected translation, please click [here](#).

[Ion engines \(ion thrusters\)](#) , a type of engine, obtain thrust by injecting plasma-like ions, and are used in the engines of artificial satellites and space probes. Among such ion engines, a **[field emission electric propulsion \(FEEP\)](#)** type engine that obtains thrust by accelerating liquid metal ions was built by **[Breaking Taps](#)** , a YouTube channel that makes various gadgets using material science and machining.

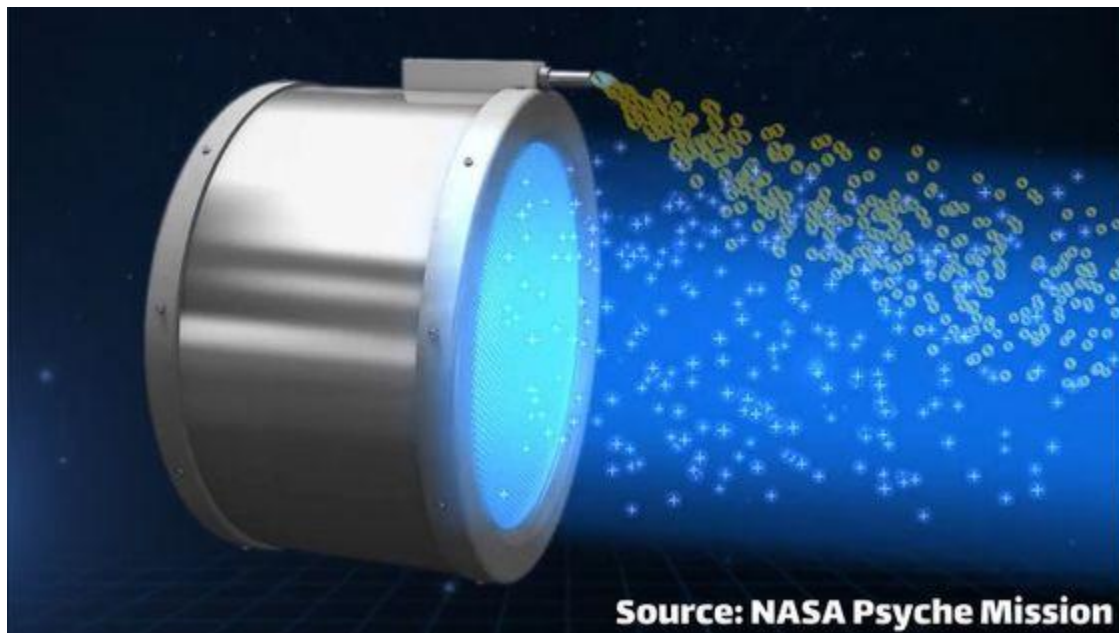
[Accelerating Gallium Ions to 0.056% light speed - YouTube](#)

To power a spacecraft, some sort of rocket engine is required. During launch, which requires a huge amount of energy, liquid or solid fuel is burned to eject

high-temperature, high-pressure gas.



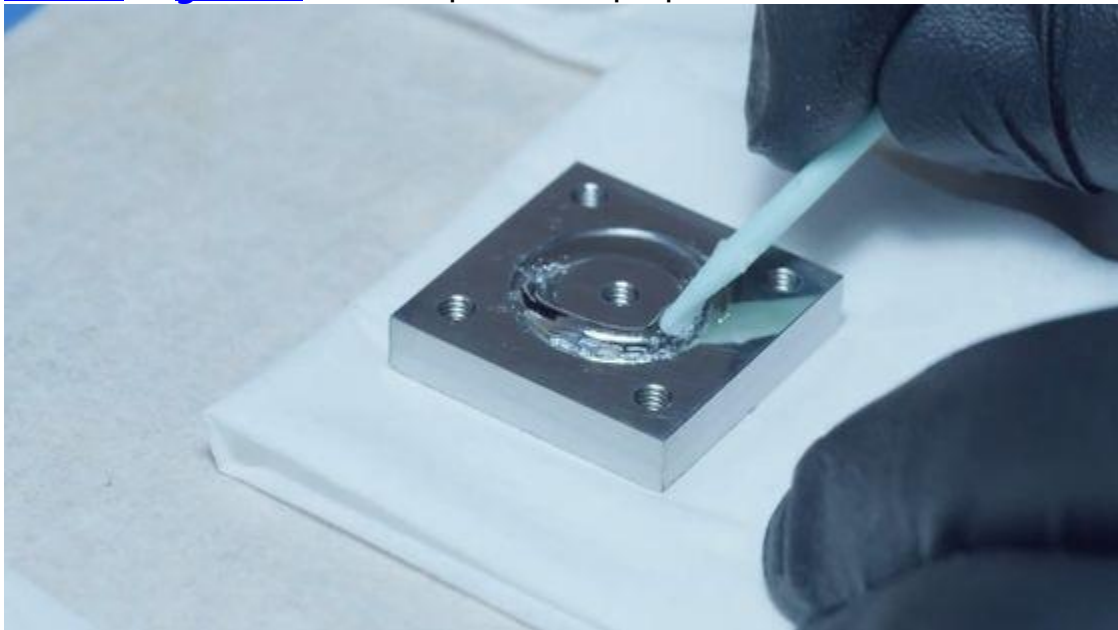
On the other hand, the thrust required for attitude control in space is significantly less, so ion thrusters that use metal ions as a propellant are also used. In either case, the mechanism is the same: some kind of mass is ejected in the opposite direction to the thrust.



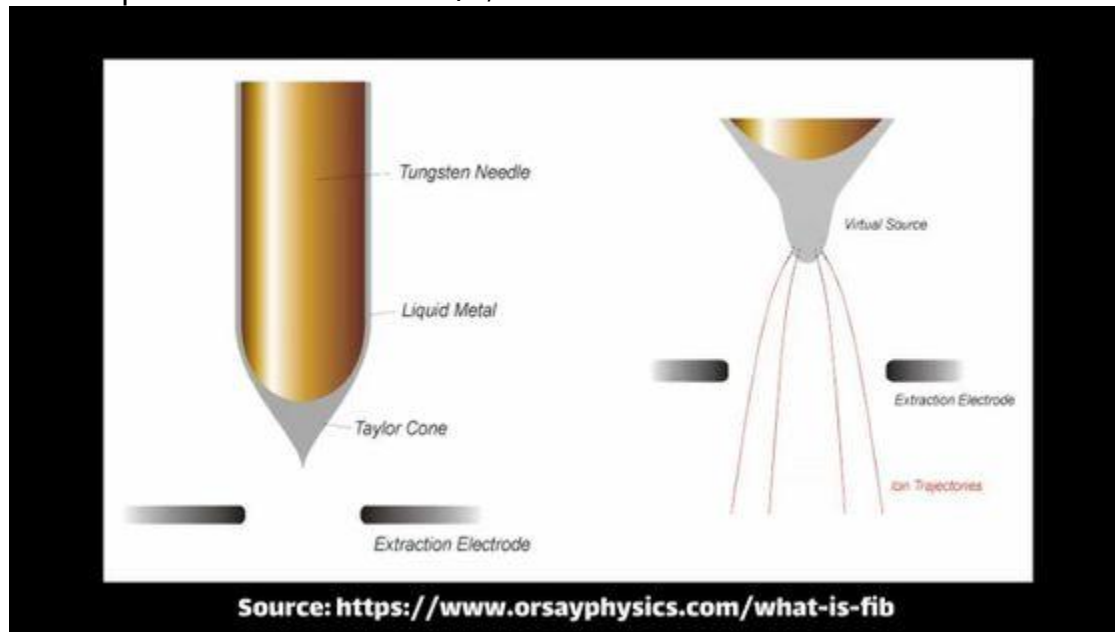
This time, Breaking Taps decided to build a homemade FEEP thruster. In principle, it is a very simple device, but it was quite difficult to implement, and over the course of about two months, they tried three different methods and built six or seven prototypes.



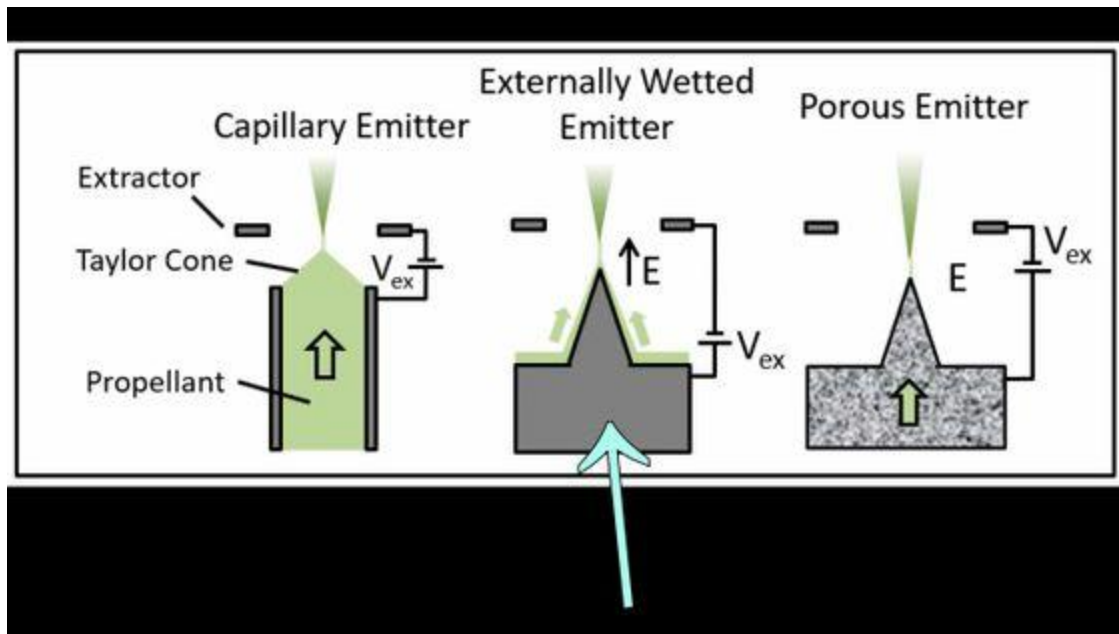
Basically, FEEP thrusters use [indium](#) or [gallium](#) as the liquid metal propellant.



The tip is formed by [capillary action](#) in a strong electric field, usually 7,000 to 10,000 volts, and at the tip, the electric field pulls the metal away from the tip, forming a cone-shaped cone (Taylor cone), and the liquid metal that has begun to ionize is pulled away from the cone. The ions released in the vacuum can reach speeds of 20 to 40 km/s, which is the thrust of the FEEP thruster.



In the FEEP thruster, the liquid metal needs to reach the tip of the engine mechanism so that ions can be emitted from there. There are three main types of mechanisms for delivering liquid metal to the tip: 'Capillary Emitter', 'Externally Wetted Emitter' and 'Porous Wmitter'.



First, Breaking Taps built a prototype using a porous emitter array made from glass, which, when saturated, effectively wicks liquid metal up to the tip.



The liquid metal used in the experiment was

Galinstan , a mixture of gallium and indium. This alloy is liquid at room temperature, which makes it easier to carry out experiments.



On the other hand, Galinstan forms an oxide coating on its surface, making it very difficult to penetrate Galinstan into a porous glass emitter.



I finally had a prototype good enough to test, so I placed it in a vacuum chamber and applied voltage to it.



As the voltage increased, sparks appeared, then went quiet. Although the first prototypes showed promise, further iterations failed to improve the results, proving that porous emitters were not the best approach.



Breaking Taps then worked on a prototype capillary emitter, machining a piece of stainless steel to create an annular slot with two parts separated by a gap of 12

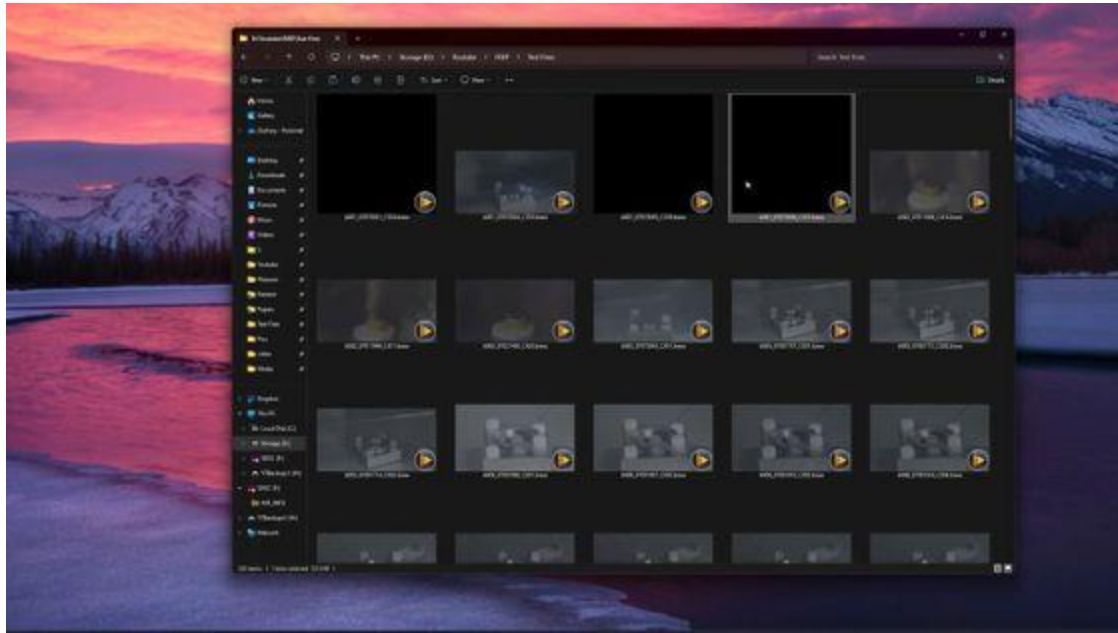
[μm \(micrometers\)](#) . The gallium propellant is loaded at the base and is drawn to the top by capillary action.



Experiment in a vacuum chamber.

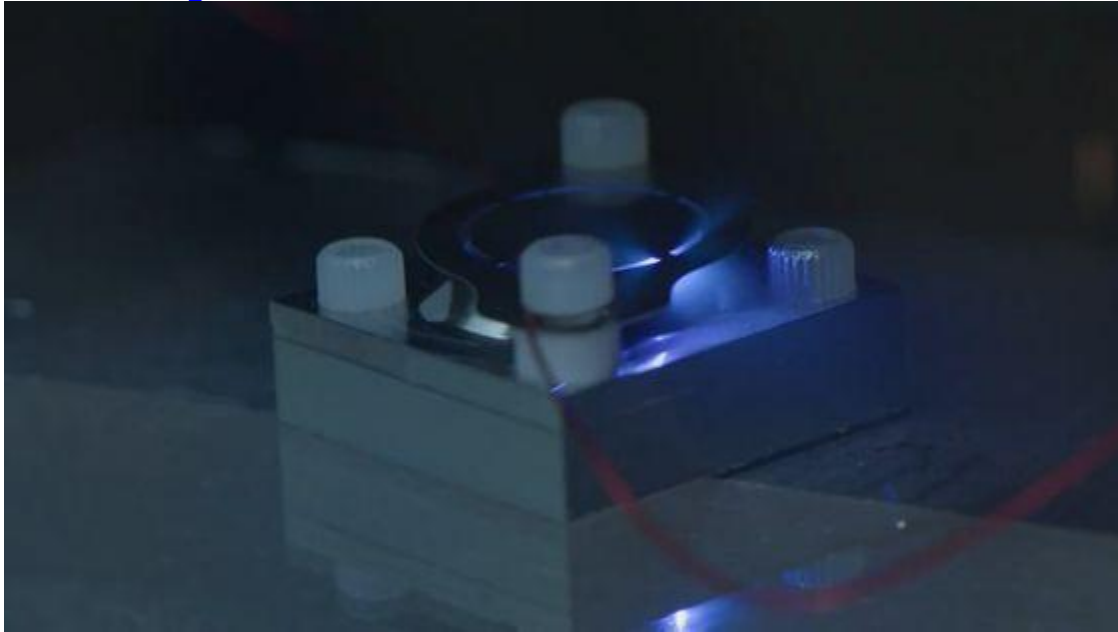


However, the footage of the first few experiments is no longer available because electromagnetic interference corrupted the video files on the camera's hard drive.

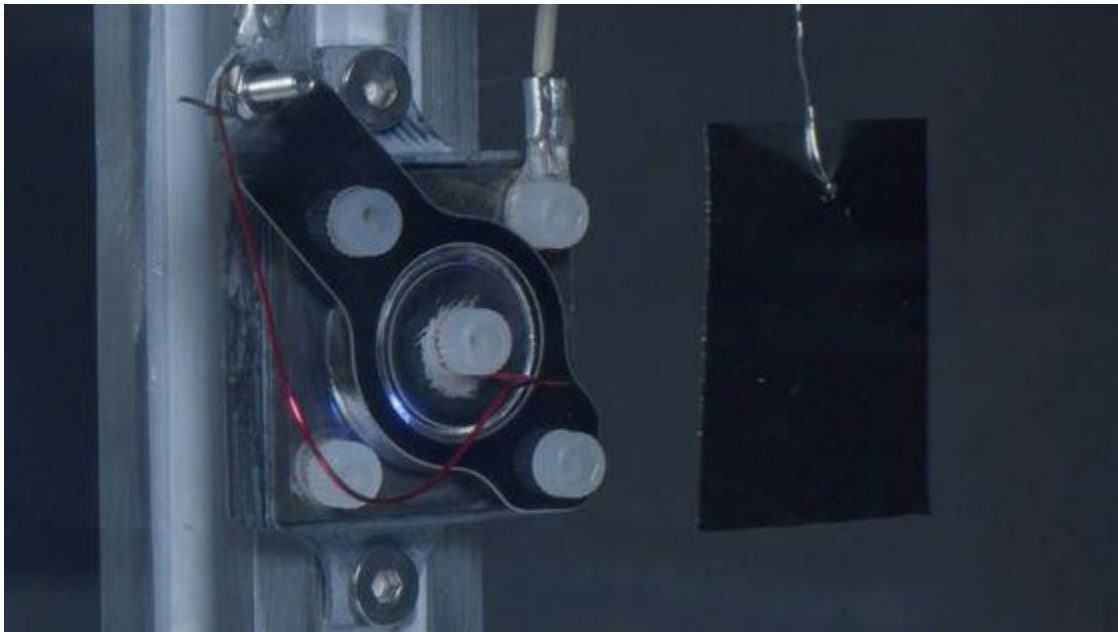


As a result of the experiments, they encountered problems such as gallium spraying out from the bridge section connecting the external and internal electrodes, and the droplets causing short circuits and

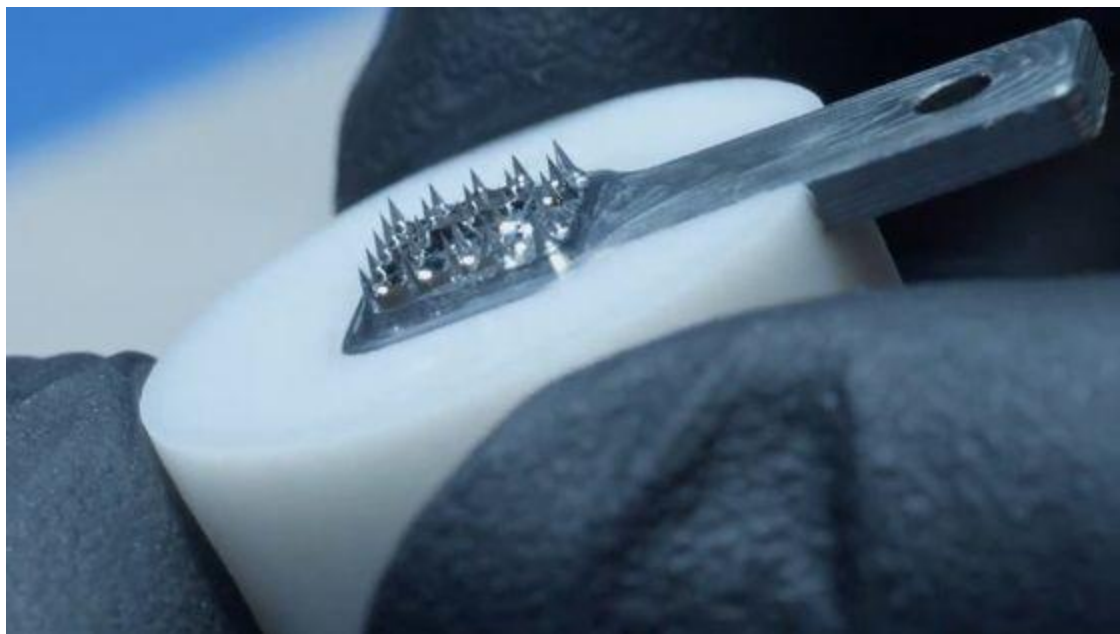
[arc discharges](#) .



They also tried connecting the electrodes with long wires instead of a bridge, but this also failed.



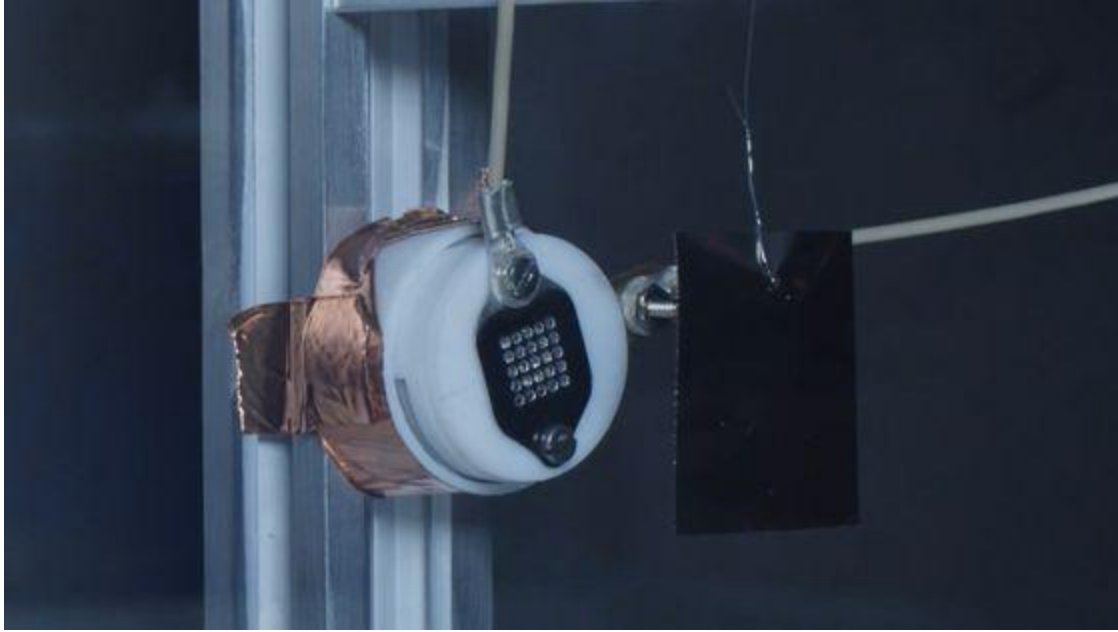
Breaking Taps has built a FEEP thruster with an external wet emitter, which uses a simpler method of applying gallium directly to an array of spikes.



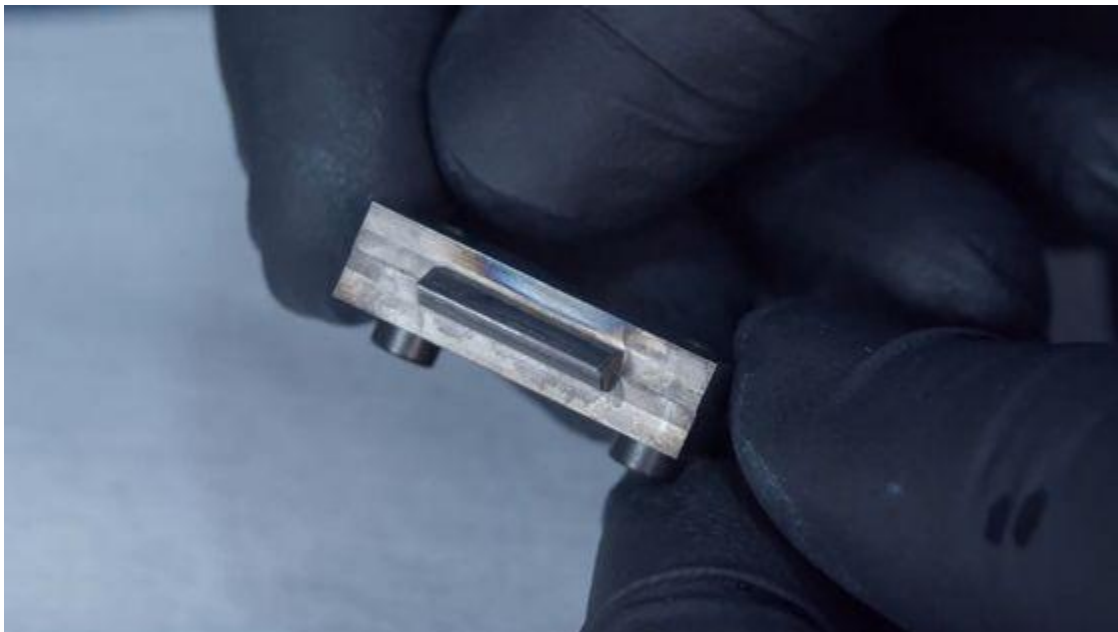
After the gallium covered the spikes, the cover was placed on top and secured in place with screws.



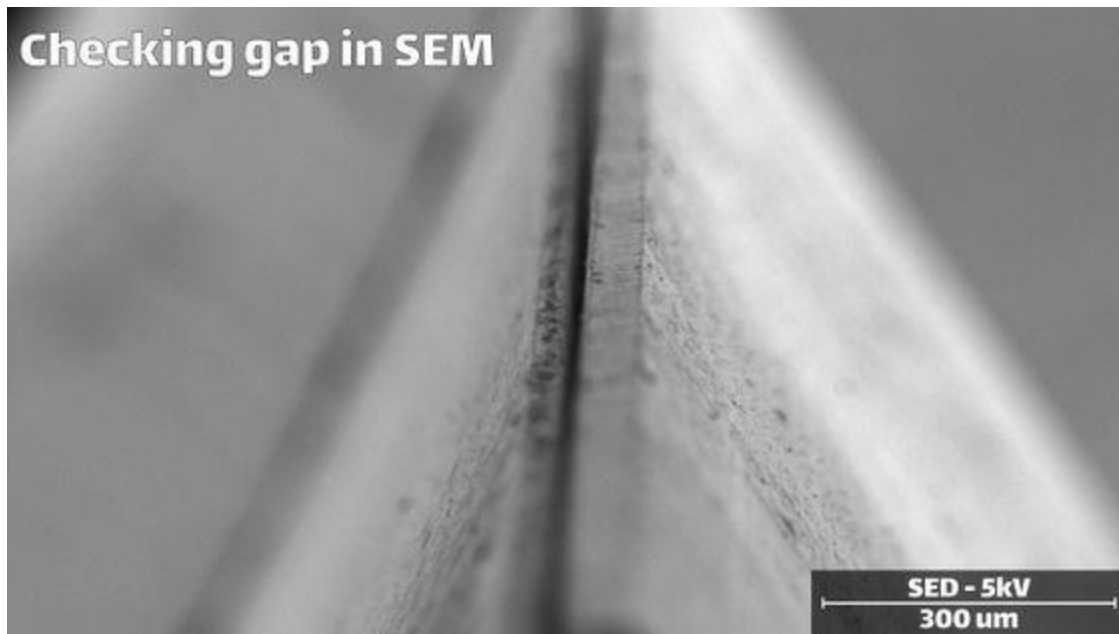
However, during testing, the reaction was unstable, and there were frequent incidents of droplets spraying out and short circuits. Various adjustments were made, but there was no improvement.



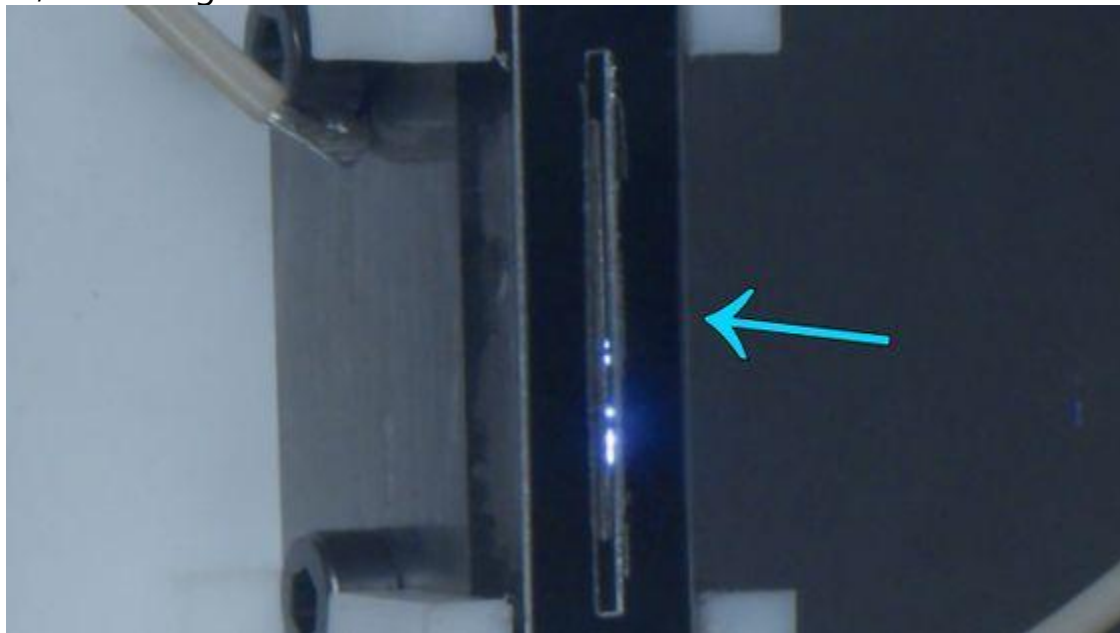
Breaking Taps then prototyped a capillary emitter that used a straight slot rather than a circular slot, which has the advantage that it is much easier to manufacture.



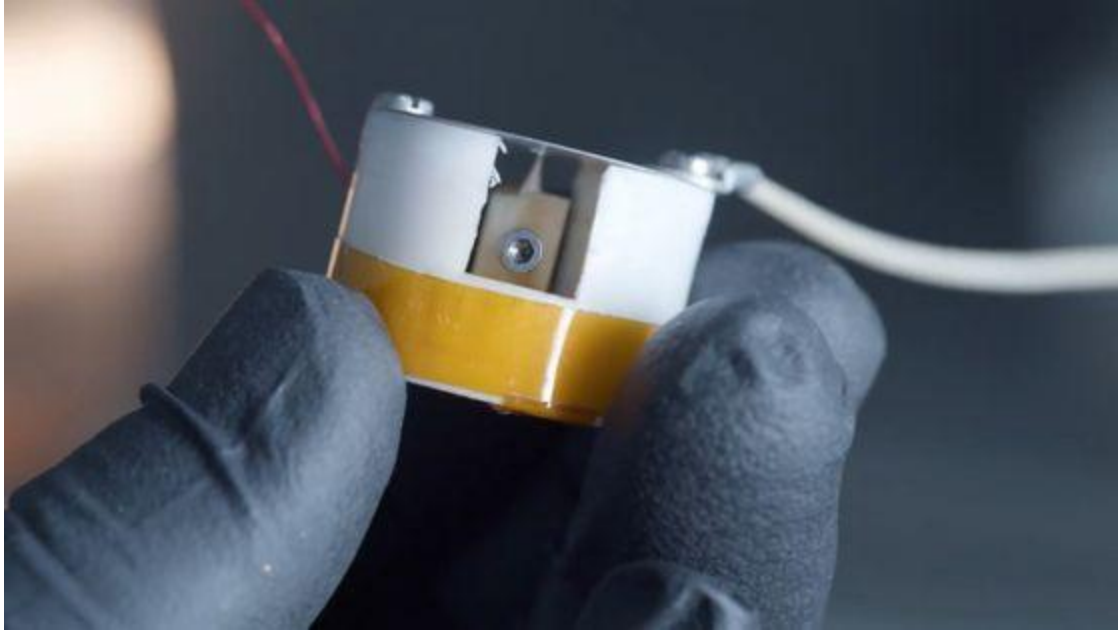
The slot gap looks like this.



Modifications were made to control the occurrence of arcing outside the emitter, but arcing still occurred when the electrodes were too close.



Breaking Taps then considered abandoning the project altogether, but built a prototype capillary emitter using a 'single tube.'



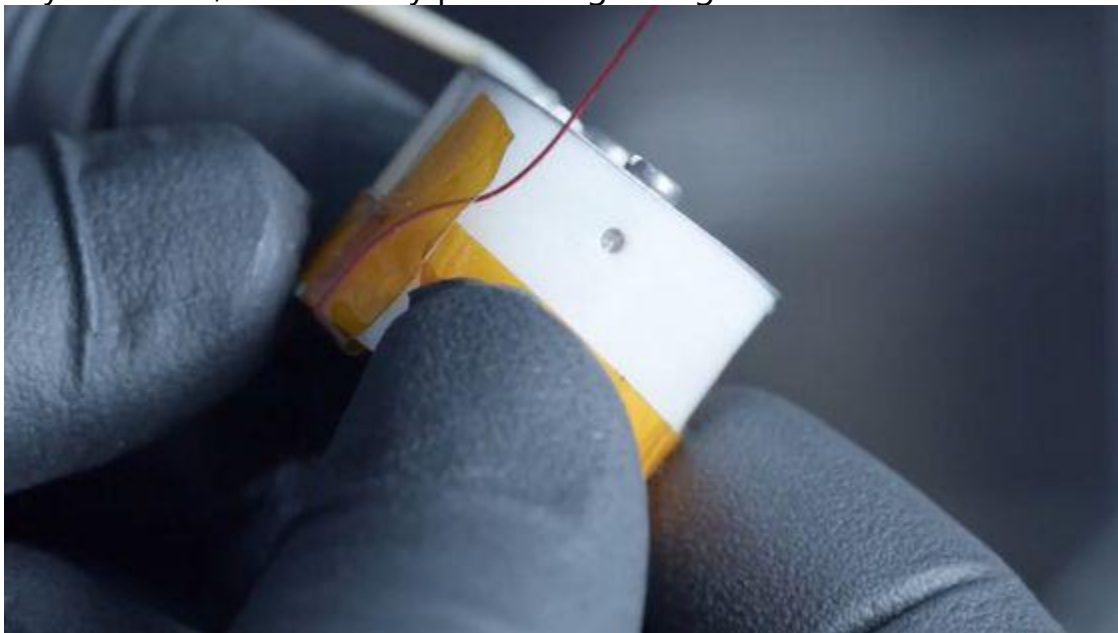
This is a glass micropipette.



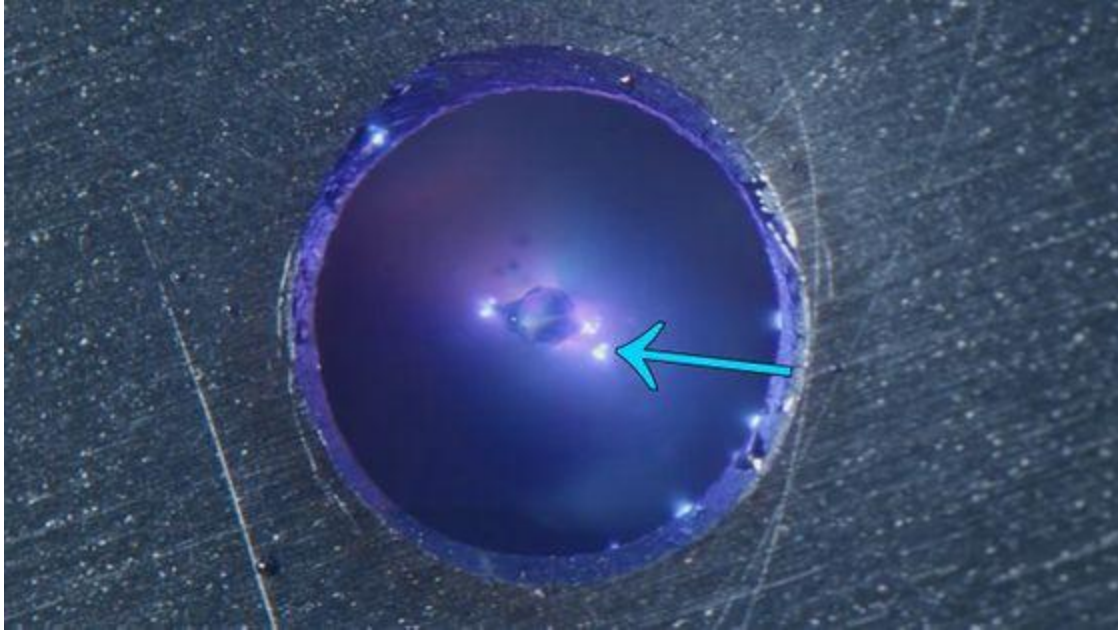
When gallium is filled inside, it is instantly sucked up to the tip, which is only 1 to 2 μm wide.



The advantage of using a single glass capillary emitter is that it can be completely insulated, theoretically preventing arcing and accidental shorts.



A close-up analysis of the experiment with a single capillary emitter revealed that a Taylor cone formed on the surface, igniting the plasma, and then releasing droplets instead of controlled ions.



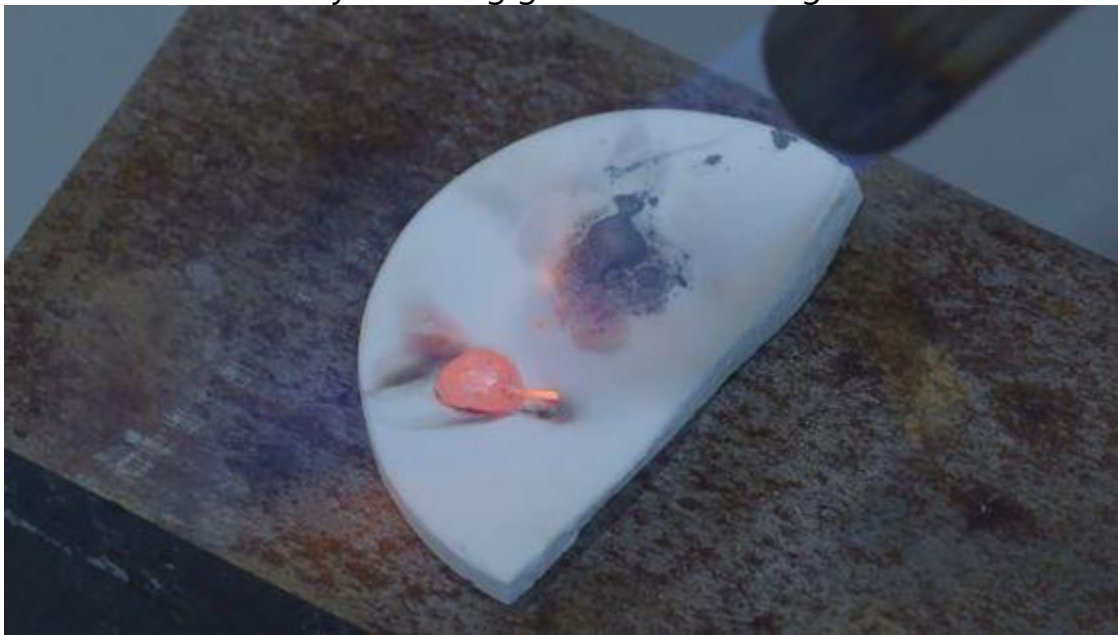
This is because the oxide film on the surface has a high surface tension, which means that a high voltage is required to form a Taylor cone. However, the fresh gallium that appears on the surface after the Taylor cone is formed does not have an oxide film, so if left alone, excessive voltage would be applied.



Breaking Taps then devised a way to suppress the arcing by controlling the voltage, and repeated the experiment using [a tungsten](#) wire as a capillary emitter, which resulted in the stable ion emission required for a stable FEEP thruster.



It was also discovered that embedding gallium in tungsten wire and heating it was effective in stably attaching gallium to the tungsten wire.



When we measured the thrust generated by this FEEP thruster, we found that it was approximately 11.80 μN ([Newtons](#)).

Basic Formula	$F = \eta_d \cdot (I_{em} - I_{ex}) \cdot \sqrt{\frac{2 \cdot m_{Ga} \cdot V_{Em}}{e}}$
Modified for Galinstan mix	$F = \eta \cdot I \cdot \sqrt{\frac{2 \cdot (0.755 \cdot m_g + 0.245 \cdot m_i) \cdot v}{e}}$

$\eta = 0.8$
 $I = 114 \mu\text{A}$
 $m_g = 1.66\text{E-}27 \text{ kg}$
 $m_i = 1.92\text{E-}25 \text{ kg}$
 $e = 1.60\text{E-}19$
 $V = 10000 \text{ V}$

11.80 μN

In addition, various prototypes were produced in this project, but many of the failures were due to lack of voltage adjustment, so if that was improved, some of the failed prototypes might have worked. Breaking Taps said.

For the First Time, Scientists Reveal the Shape of Electrons—A Leap Forward in Quantum Research



For the First Time, Scientists Reveal the Shape of Electrons—A Leap Forward in Quantum Research | The Daily Galaxy -
-Great Discoveries Channel© Daily Galaxy

For the first time, researchers have successfully measured the **shape** of an electron as it moves through a solid, opening a new window into understanding how electrons behave in different materials. This groundbreaking achievement, led by physicist Riccardo Comin of MIT, could revolutionize fields ranging from **quantum computing** to **electronics manufacturing**. By leveraging advanced techniques like **angle-resolved photoemission spectroscopy (ARPES)**, the team has uncovered insights into the geometric properties of electrons—a previously elusive aspect of their behavior.

The Wave-Like Nature of Electrons: A New Perspective

Electrons are not just tiny particles; they also exhibit wave-like properties, described by mathematical constructs called **wave functions**. These wave functions can take on complex shapes in higher-dimensional spaces, influencing how electrons interact within materials. While physicists have long studied electrons in terms of energy and velocity, their geometric properties have remained largely unexplored—until now.

Using ARPES, the research team was able to capture detailed information about the behavior of electrons as light interacted with them. “We’ve essentially developed a blueprint for obtaining some completely new information that couldn’t be obtained before,” says Riccardo Comin. This technique allowed the team to measure the **quantum geometry** of electrons in a class of materials known as **kagome metals**, which are renowned for their unique atomic lattice structure and unusual electronic behaviors.

Kagome Metals: A Playground for Quantum Geometry

Kagome metals derive their name from their atomic structure, which resembles a repeating pattern of interlocking triangles. This **lattice arrangement** creates an environment where electrons can exhibit exotic behaviors, such as advanced **superconductivity** and synchronized electron pairing. By studying these materials, the researchers were able to observe how the geometry of electron wave functions influences their movement and interactions.

The team’s findings suggest that the geometric properties of electrons play a key role in phenomena like **superconductivity**, where electrons move through a material without resistance. Understanding these properties could enable scientists to design materials with enhanced electronic traits, such as improved **conductivity** or reduced energy loss.

ARPES: A Window into the Quantum World

Angle-resolved photoemission spectroscopy (ARPES) is a powerful tool for studying the behavior of electrons in solids. During an ARPES experiment, researchers **shine a beam of photons** onto a crystal, causing electrons to be

ejected from the material. By measuring the angles and spins of these ejected electrons, scientists can reconstruct the shapes of their **wave functions** and gain insights into their geometric properties.

This method is highly demanding, requiring specialized equipment and facilities. However, it provides unparalleled access to the [quantum world](#), allowing researchers to observe phenomena on scales smaller than a billionth of an inch. The success of this technique in measuring electron geometry marks a significant milestone in the field of **quantum materials** research.

Applications and Future Directions

The ability to measure and manipulate the **quantum geometry** of electrons has far-reaching implications for technology and industry. In **quantum computing**, for example, maintaining stable electronic states is crucial for performing computations. By understanding the geometric properties of electrons, researchers could design materials that better support these states, leading to more reliable **quantum devices**.

Additionally, this discovery could advance the development of **energy-efficient electronics**. Materials with tailored electron geometries could minimize energy loss through heat, addressing a critical challenge in modern electronics.

As [energy efficiency](#) becomes increasingly important, the ability to control electron flow on such tiny scales could have a transformative impact.

A Global Collaboration Yields Groundbreaking Results

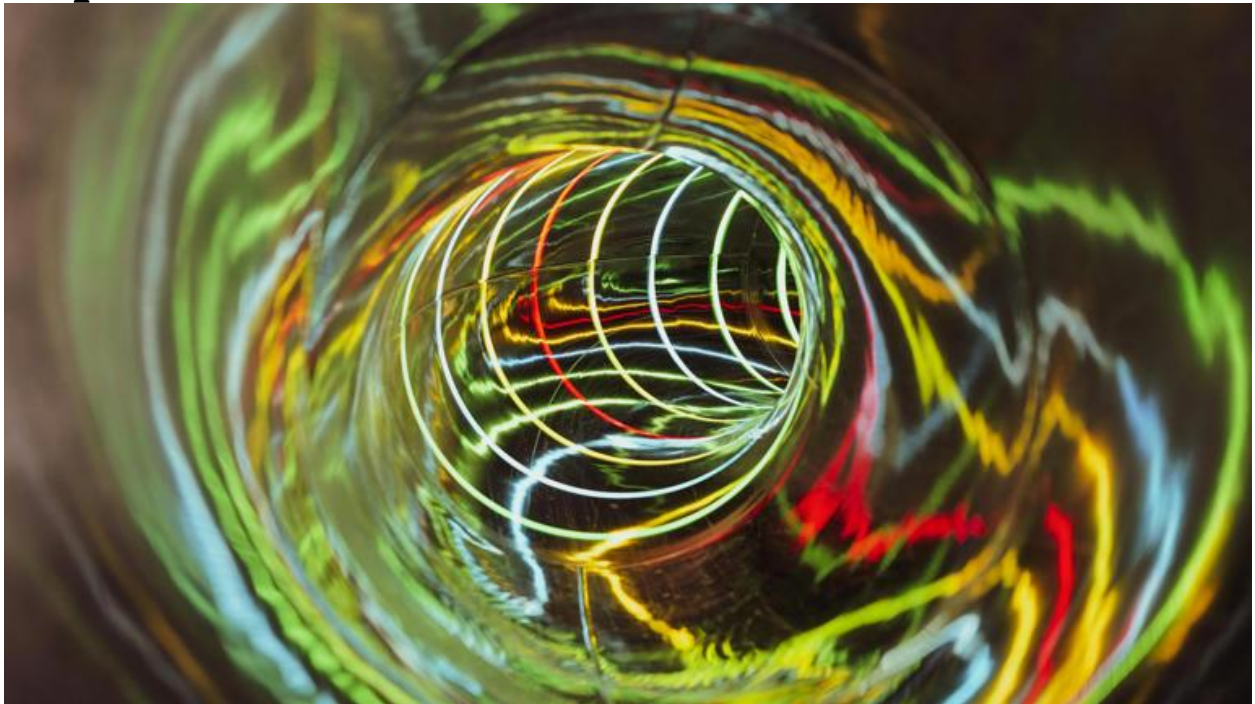
This research was the result of a collaborative effort involving institutions from around the world. Combining theoretical and experimental expertise, the team was able to synthesize and measure the **electronic structure** of a kagome metal, despite the challenges posed by the COVID-19 pandemic.

The pandemic forced some team members to work remotely, while others took on new roles in partially shut-down labs. This unexpected shift ultimately pushed

the work forward, highlighting the importance of collaboration in tackling complex scientific challenges.

The study is published in [*Nature Physics*](#).

Scientists catch spirals of Kelvin waves in superfluid helium for the first time



Scientists catch spirals of Kelvin waves in superfluid helium for the first time

A team of Japanese researchers has discovered a method to control Kelvin wave excitation in superfluid helium-4. This breakthrough can refine our understanding of how energy moves in quantum fluids, improving quantum sensors and making quantum devices more efficient.

Kelvin waves are tiny, spiral-like disturbances that move along the length of a quantum vortex in superfluids (like liquid helium at extremely low temperatures) and ultracold atomic gases. These waves are different from the large-scale [oceanic Kelvin waves](#) and play an important role in deciding energy loss and turbulence in quantum systems.

However, until now scientists have been struggling to find ways to observe and control these spiral waves. This is why not much information is available on them. The current study is the first to reveal a practical way to control Kelvin waves and confirm their helical nature.

“This work elucidates the dynamics of Kelvin waves and initiates an approach for manipulating and observing quantized vortices in three dimensions, thereby opening avenues for exploring quantum fluidic systems,” the study authors [note](#).

An accidental but exciting discovery

The researchers were not looking for Kelvin waves but were instead performing an experiment that involved applying an electric field to a tiny nanoparticle attached to [a quantum vortex](#). Their goal was to move the whole vortex structure by making the nanoparticle oscillate.

For the unversed, a quantum vortex is like a tiny whirlpool that forms in a superfluid. It’s special because it has a fixed amount of spin that can’t be changed, unlike normal whirlpools.

The scientists couldn’t move the vortex but they observed a wavy motion of the vortex core (Kelvin waves). “This unexpected result prompted us to shift our focus toward studying the excitation of Kelvin waves in-depth,” Yosuke Minowa, lead researcher and an associate professor at Kyoto University, [said](#).

So they created tiny silicon particles in [superfluid helium](#)-4 by hitting a silicon wafer with a laser. This action disturbed the fluid, trapping some particles in vortex cores, and making the vortices visible.

Next, they applied an electric field, causing the particles to oscillate, forming helical Kelvin waves along the vortices. “In previous studies, Kelvin wave-like oscillations were observed only accidentally. We developed a novel method to manipulate an ideal vortex in superfluid helium, providing a new way to study the behavior of these quantized vortices,” Minowa added.

Confirming the spiral curves of Kelvin waves

The study authors didn't stop with observing Kelvin waves. They used a dual camera setup and applied different excitation frequencies (ranging between 0.8 Hz to 3 Hz) to see how the waves behave and how they [appear in 3D](#).

"The three-dimensional image reconstruction played a critical role in confirming the helical nature of the Kelvin waves. By visualizing the vortex's three-dimensional dynamics, we obtained direct and concrete evidence that the observed oscillations were indeed Kelvin waves," Minowa said.

Moreover, the researchers also collected information related to how the wavelength and speed of Kelvin waves changed with their frequency. These findings show that the proposed approach could prove to be an effective tool for studying [quantum vortices](#), Kelvin waves, and their properties.

"We have introduced a new tool to study Kelvin waves in superfluid helium, paving the way for numerous experimental investigations," Minowa concluded.

The [study](#) is published in the journal *Nature Physics*.

Physicists May Have Just Unlocked the Secret of What's Inside a Black Hole



Physicists May Have Just Unlocked the Secret of What's Inside a Black Hole | The Daily Galaxy --Great Discoveries Channel© Daily Galaxy

Black holes have long been the **ultimate cosmic enigma**, defying conventional physics and pushing the boundaries of what we understand about space and time. Now, a groundbreaking study led by **physicist Enrico Rinaldi at the University of Michigan** has used **quantum computing and machine learning** to peer into the **core of black holes**, offering new insights into how they function at a fundamental level.

By leveraging the **holographic principle**, which suggests that **gravity and quantum mechanics are mathematically equivalent but exist in different dimensions**, Rinaldi's team has developed **mathematical models that simulate black hole structures**. The study's findings, published in **PRX Quantum**, mark a significant step toward **uniting quantum mechanics and general relativity**—two of the most important yet conflicting theories in physics.

This discovery has far-reaching implications, not just for understanding black holes, but also for **developing a quantum theory of gravity**, which could redefine the way we think about **space, time, and the very nature of reality itself**.

How Physicists Used Quantum Computing to Simulate a Black Hole Core

The study used **quantum matrix models**, mathematical constructs that help simulate **the lowest energy state of a quantum system**. These models provide insight into how **particles behave within [black holes](#)**, offering a deeper understanding of their structure.

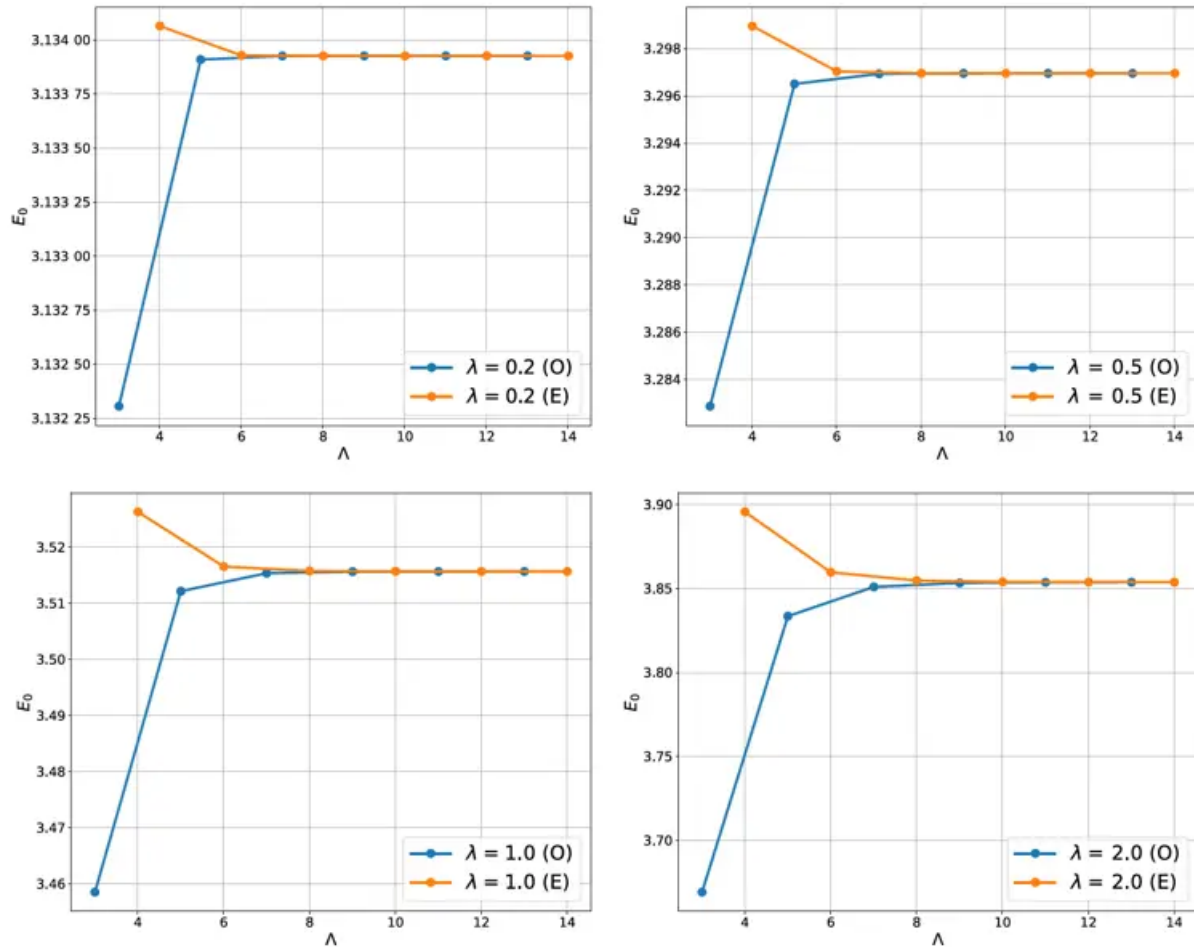
“We hope that by understanding the properties of this particle theory through numerical experiments, we understand something about gravity,” **Rinaldi explained**. However, solving these **complex equations manually** is nearly impossible, which is why the research team turned to **quantum circuits and deep learning algorithms**.

These quantum circuits act like **networks of interconnected “wires”**, each representing a **qubit**, the fundamental unit of [quantum](#) information. Gates, which dictate how quantum information flows, are placed within these circuits, **allowing the simulation to evolve dynamically**.

Rinaldi likens this process to **composing music**:

“You can read them as music, going from left to right,” he explains. “If you read it as music, you’re basically transforming the qubits from the beginning into something new each step. But you don’t know which operations you should do as you go along, which notes to play.”

By “tuning” these **quantum operations**, the researchers successfully **modeled the ground state of black hole matrix models**, revealing new information about their fundamental nature.



The ground-state energy E_0 as a function of the cutoff for various couplings $\lambda = g^2 N = 0.2, 0.5, 1.0$, and 2.0 for the $SU(2)$ bosonic model. Even (E) and odd (O) values of are plotted with different colors. The other parameters are $m^2 = 1$ and $d = 0$. (CREDIT: PRX Quantum)© Daily Galaxy

The Holographic Principle: How Black Holes and the Universe May Be Connected

One of the most intriguing aspects of this research is its **connection to the holographic principle**—a revolutionary idea that suggests **our entire universe may be a projection of quantum information encoded on a lower-dimensional surface**.

The principle states that:

- **Gravity operates in three dimensions**, curving spacetime due to mass and energy.

- **Particle physics functions in two dimensions**, as quantum fields interact on a flat surface.

- **The two models are mathematically equivalent**, meaning that understanding **one system (quantum mechanics) can help explain the other (gravity)**.

This means that black holes, rather than being singularities that **swallow all information forever**, may actually store their information **on their event horizon**, where it can be mathematically reconstructed.

Key Findings from the Black Hole Simulation

What's Really Inside a Black Hole?

While popular science often describes black holes as “**bottomless pits**” where gravity is so strong that nothing—not even light—can escape, this study suggests a more **complex picture**.

A black hole consists of **several key components**:

- **Singularity** – The **infinitely dense point** where gravity is at its maximum.
- **Event Horizon** – The **point of no return**, beyond which nothing can escape.
- **Photon Sphere** – A region where **light orbits** before being absorbed or escaping.
- **Accretion Disk** – The **glowing ring of material** spiraling around the event horizon.
- **Jets and Magnetic Fields** – High-energy **plasma streams ejected from the black hole's poles**.

What's inside the **singularity** remains one of the biggest mysteries in physics. This new research suggests that **the core of a black hole may not be a singularity at all**, but rather a **highly structured quantum state**, governed by principles that we are only just beginning to understand.

How This Research Could Lead to a Quantum Theory of Gravity

One of the greatest unsolved problems in physics is the **unification of general relativity and quantum mechanics**.

- **Einstein's General Relativity** describes **gravity and the curvature of spacetime**, working well on large cosmic scales.
- **Quantum Mechanics** explains **subatomic particles and their interactions**, but struggles to incorporate gravity.

By showing that **quantum systems can replicate gravitational behavior**, this research **brings us closer to a unified theory**—one that could explain **how black holes work, what happens inside them, and even the true nature of spacetime itself**.

Rinaldi emphasized that this breakthrough is just the beginning:

"Because these matrices are one possible representation for a special type of black hole, if we know how the matrices are arranged and what their properties are, we can know, for example, what a black hole looks like on the inside."

This work could **pave the way for entirely new approaches to understanding quantum gravity**, with implications that stretch **far beyond black holes**, potentially revealing **new insights about the universe itself**.

What's Next? Expanding the Research

The study is a **major milestone**, but physicists still have **many questions to answer**. Next steps in the research include:

- Expanding the **quantum models** to simulate **larger and more complex black hole structures**.
- Using **more powerful quantum computers** with greater numbers of qubits to refine calculations.

- Investigating whether these quantum models **apply to other cosmic phenomena**, like neutron stars and wormholes.

This groundbreaking research is helping to **bridge the gap between quantum mechanics and gravity**, opening new doors to **understanding the most extreme environments in the universe**.

The Story of Hugh Everett III: The Father of the “Multiverse” and Parallel Worlds

Hugh Everett III is famous as the man who devised the many-worlds interpretation of quantum physics.

Everett’s theory concerns a mysterious puzzle that lies at the heart of quantum physics and suggests that measurement causes the universe to branch out into infinite different versions, all with the tiniest of differences. This may sound like pure science fiction, but the idea is supported by the mathematics of quantum mechanics.

The rejection of the concept would lead Everett to leave physics to pursue mathematics in the military and industry. A heavy drinker and smoker, he passed away at just 51 years of age.

Despite the fact it is not the consensus, many physicists still prefer the many-worlds interpretation of quantum physics over alternatives. Everett would not live to see the respect earned by his fellow physicists for the idea of “many worlds” or the incredible success that the idea would have in popular fiction.



Hugh Everett III whose many-worlds interpretation of quantum physics inspired physics and writers of science fiction alike for decades. (Robert Lea)© ZME Science

Everett's Journey Into Physics

Everett was born in 1930 and was raised around Washington D.C. initially by his mother, and then later by his father Hugh Everett Jr, and his stepmother. He attended St. John's College High School before moving to the Catholic University of America graduating in 1953 with a degree in chemical engineering.

After Everett received a National Science Foundation fellowship, the budding mathematician continued his studies at Princeton. It was here in 1953 that Everett took his first introductory course in quantum mechanics.

In a 2007 article for *Scientific American*, Peter Byrne says that Everett's journey to many worlds was kick-started in 1954 as he drank sherry with Charles Misner, a fellow Princeton student. The two began to discuss the counter-intuitive nature of quantum physics, and the young physicist began to consider the idea of many worlds as a solution to a lingering problem.

What is the Many Worlds Interpretation of Quantum Physics?

Ever since the inception of quantum physics in the 1920s, the so-called collapse of [superposition](#)—when a quantum system can be described as existing in potentially contradictory states—has troubled researchers.

The states of a system describe the possible values it can take. So if a coin is considered a physical system it can take two states—heads or tails.

In quantum physics, these states are described by wave mathematics. Because waves can overlap in what is known as a wavefunction, it means that a quantum system can theoretically exist in a superposition of multiple states simultaneously.

This affects subatomic particles like electrons and photons and describes qualities such as their velocity or spin. It isn't seen on a macroscopic or "everyday" scale. But, a macroscopic hypothetical example is perhaps the easiest way to think about it.

A good way of picturing this is with Erwin Schrödinger's infamous Schrödinger's cat thought experiment. This sees a cat placed in a box with a diabolical device—a lethal poison that is released only if an atom within the device decays.

The box is sealed for an hour, enough time for the atom to possibly decay. But, because atomic decay is a quantum process, and thus completely random, there is no way to tell if the poison has been released.

This means that, if we treat the cat, box, and device as a quantum system it is possible to describe it as a superposition of states. And in this case, those states are "dead" and "alive."

Its contradictory state is only resolved when the experimenter opens the box—analogue to taking a measurement on the system. This causes the superposition to collapse—a process also called decoherence—and resolve into a single state.

But, quite what it is about measurement that causes this collapse has remained a mystery. This would come to be known as the "measurement problem."

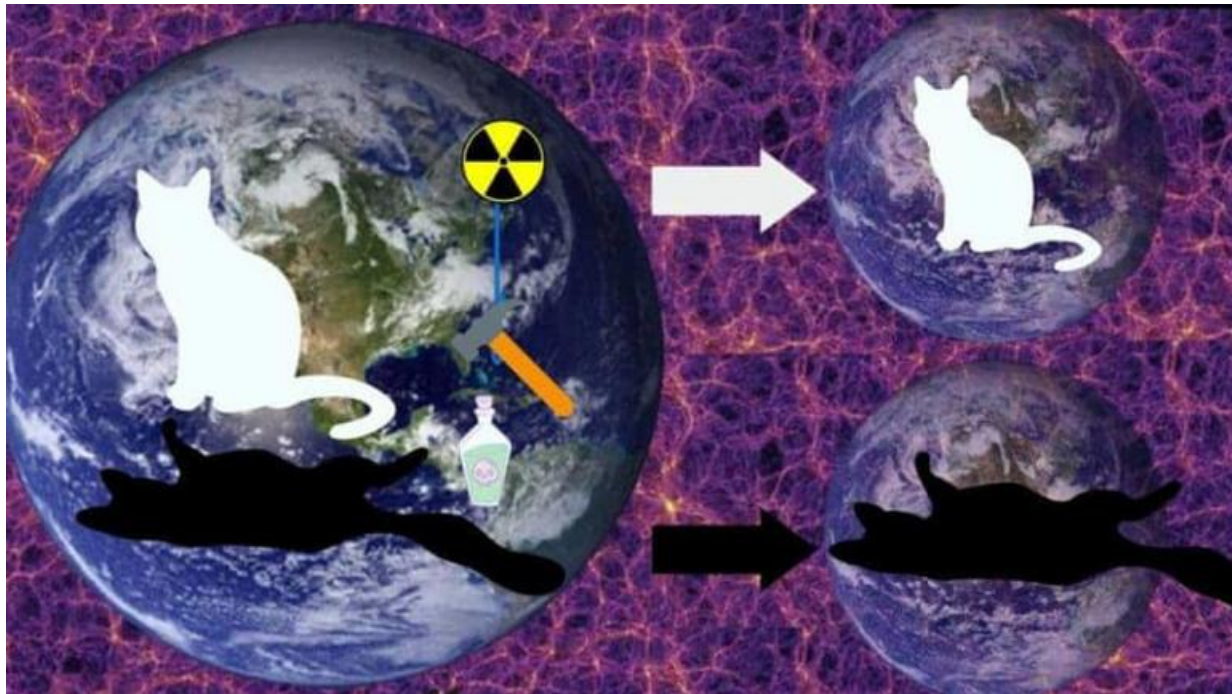
Everett's suggestion of "many worlds" takes a very different approach. It posits the idea that the wavefunction doesn't collapse at all.

Instead, when a measurement is made on a quantum system, the wavefunction grows to envelop the measurement equipment, the experimenter and eventually the entire Universe.

In effect, this means framing the many-worlds interpretation of quantum physics with the Schrödinger's cat thought experiment there is no wavefunction collapse.

Each possible state of a quantum system exists in its own universe, separated from the rest.

"From the viewpoint of the theory, all elements of a superposition (all 'branches') are 'actual,' none any more 'real' than the rest," Everett wrote in a thesis produced on the interpretation.



The many-worlds interpretation of quantum physics suggests that wavefunctions do not collapse at all but branch out and create a new universe for each possible state (Robert Lea)© ZME Science

Instead of opening the box and resolving a state in which the cat is dead or alive, the experimenter opens the box to discover if she is in a universe in which the cat survived or a universe in which it died. Thus, Everett solves the measurement problem by doing away with decoherence altogether.

There is of course a consequence to this. Quantum systems are not large systems like cats in boxes, they actually concern particles on a subatomic level. This means every particle interaction creates a nearly unfathomable amount of worlds.

Consider the act of flicking on a light for instance. To emit 60 Joules a second a light bulb must blast out about 1.8×10^{23} photons per second.

Each of these photons would have billions of possible paths, each of which would have its own universe. Just considering the possible combinations in this situation suggests an unfathomably large number of worlds born in this one very mundane act.

Considering every possible quantum event in the Universe this quickly swells the number of created worlds to something approaching infinity. This is troubling to physicists and is perhaps the reason the many-worlds concept has never trumped

the wavefunction collapse idea of quantum physics suggested by the widely accepted Copenhagen interpretation.

Indeed, when released in 1957, Everett's paper on the many-worlds interpretation was met with almost complete indifference from the physics community.

Early quantum theorist and Everett's academic adviser at Princeton John Wheeler had many discussions with the physicist about his theory. In a 2006 interview, Wheeler remarked: "[Everett] was disappointed, perhaps bitter, at the nonreaction to his theory. How I wish that I had kept up the sessions with Everett. The questions that he brought up were important."

Everett would meet with Niels Bohr, another prominent quantum physicist in 1959 several times over a period of six weeks. He would also perfect a technique to search for optimum solutions to complex problems—the Everett algorithm. But, despite this, Everett was done with quantum physics research for good.

He didn't even return to research in the 1970s when his concept finally began to gain traction. This doesn't mean Everett rested on his laurels, however.

After Many Worlds



Hugh Everett framed by a nuclear explosion. After leaving quantum physics research Everett's work on the effects of nuclear weapons may have ensured pre-emptive strikes were not an option. (Robert Lea)© ZME Science

Everett would earn his doctorate from Princeton in 1957, a year after he had begun to work for the Pentagon. This employment saw him conduct important work such as the calculation of mortality rates that could potentially arise as a consequence of radioactive fallout resulting from a nuclear war.

He would advise officials in both the Eisenhower and Kennedy administrations regarding the selection of hydrogen bomb targets and the development of delivering a nuclear strike via missiles, submarines and planes.

Everett's work and its terrifying implications may well have persuaded world leaders that a nuclear war would result in "mutually assured destruction." Perhaps it even swayed officials who were considering preemptive strikes an option, that instead, a perpetual stand-off was a preferable approach to nuclear conflict.

Everett would go on to found several companies, including, in 1964, Lambda Corporation, which developed mathematical models for anti-ballistic missile systems and nuclear wargames.

In 1971 he devised a Bayesian computer program capable of learning from experience to assess possible outcomes which would be used to develop strategies for tracking incoming ballistic missiles.

As the years progressed, Everett's heavy drinking and smoking began to take their toll. He was an unsympathetic character to colleagues, one of whom later recalled that Everett was cold and logical but had no time for human concepts like civil rights.

Most damningly perhaps, was the fact that Everett barely knew his children Elizabeth and Mark. As a teenager, the latter would find Everett dead in his bed on July 19, 1982, at the age of 51.

Mark, who would go on to become the lead singer for the band the Eels, believes that the discovery of his father's lifeless body was the first time he had touched him.

Everett's daughter, Elizabeth, would go on to take her own life in 1996. After her death as the result of an overdose, a note was discovered in her purse which said she had gone to join her father in another universe.

Many Worlds in Popular Culture

It isn't just physicists that have embraced the idea of many worlds. Storytellers across a range of mediums have adopted the concept as a powerful storytelling device.

At the end of 2021, *Spider-Man: No Way Home* would use the many-worlds idea—albeit labelling it as a [“multiverse”](#) which is quite a different concept in science—to allow Tom Holland's Peter Parker to meet previous incumbents of the role, Tobey Maguire and Andrew Garfield, and team up to tackle some familiar villains.

The film would go on to become the fifth highest-grossing film of all time and its themes have been given a horrific twist in the Sam Raimi-directed *Doctor Strange in the Multiverse of Madness* earlier this year.

Also on the silver screen this year, many-worlds was given an irreverent twist in the Michelle Yeoh starring *Everything Everywhere All at Once*. In the movie, an unlikely action hero accesses the skills of her counterparts from alternative universes to combat a multiversal foe with familial connections.

No medium of fiction has embraced the concept of many worlds quite as wholeheartedly as comic books, however. Veteran comic book writer Mark Waid who has written characters for DC Comics and Marvel including the *Justice League*, *Spider-Man*, *The Avengers*, and *The Flash*, explained to *ZME Science* why comic book fans have fallen in love with the idea of “many worlds.”

“They provide new ideas. After eighty years of stories largely featuring the same heroes, it's insanely difficult to find ideas that have not been done before,” Waid says. “There have been, and this is true, more stories told about Batman than about any other fictional hero in human history. Multiverse versions of Batman allow for new, fresh stories.”

One of the original concepts of many worlds in comics came about in 1961 in the pages of the DC Comics published Flash issue 123 in which Barry Allen vibrated from his own world—Earth 1—to one in which his predecessor Jay Garrick still operated as the Flash. Jay's world was dismissively labelled “Earth-2.”

This introduced to DC comics the concept of “infinite Earths” which would be popular throughout the 60s, 70s, and 80s, with meetings between the Justice

League and their Earth-2 counterparts the Justice Society occurring every year. The characters were even able to journey to a world occupied by their writers in which they were simply comic book characters.

This was until 1986 and an event called "Crisis on Infinite Earths" by Marv Wolfman and George Perez, which rolled all these Earths into one. In the early 2000s, Waid who currently writes Superman/Batman: World's Finest for DC Comics was part of a move to bring back "infinite Earths" albeit under a new moniker—Hypertime.

"From Crisis on Infinite Earths on through the 1990s, every single DC 'event' story made the DC Universe smaller by creating more restrictions and rules. No more parallel worlds. No more easy time travel. Everyone's superpowers had the same origins. Stuff like this. And it made me nuts," Waid explains. "Superhero comics aren't about rules, they're about flying. Hypertime was an attempt to open some doors rather than close them.

"I will always love DC's Earth-One/Earth-Two dichotomy. Simple, easy to explain, DC's 'many worlds' kicked off of the whole concept."

In his 2010 biography of Hugh Everett III, Peter Byrne describes the physicist's affection for science fiction. Byrne speculates that the idea of parallel worlds likely intrigued Everett long before he formalised his interpretation of quantum physics.

It's a testament to Everett's legacy that just as early sci-fi inspired real science, his scientific theory has inspired sci-fi tales for subsequent decades. Thus, millions of science fiction fans, cinema-goers, and comic book readers have thrilled at the concept pioneered by Everett, likely without even knowing his name.

This article originally appeared in 2022 and was republished with some small updates.

Scientists Say an Antimatter Engine Could Be the Key to Interstellar Travel

- Antimatter can produce more energy than anything else we know of, but it's very fickle.
- A new field analysis explains what we need in order to progress with antimatter propulsion.
- While an antimatter engine is very far off, researching it could yield other discoveries as well.

Scientists from United Arab Emirates University (UAEU) have laid out a suggested roadmap for developing an [antimatter engine](#). While antimatter research is very hypothetical and not yet in the experimental phase, researchers believe it could eventually be an option for space travel at higher velocities. Sawsan Ammar Omira and Abdel Hamid I. Mourad's "[state of the field](#)" [paper on the subject](#) appears now in the journal *International Journal of Thermofluids* (a research review like this is not an advocacy or position paper, and it's not an outline for how to build or even design an antimatter propulsion system—just an update on where research is at this moment in time).

"A kilogram of matter-antimatter annihilation releases a whopping energy that's over 250 times greater than that of [nuclear fusion](#) and over 8 orders of magnitude (10⁸) more than chemical combustion," the paper states. "The energy that this reaction releases is ridiculously giant and is higher than any other reaction known in physics."

Unfortunately, our theoretical knowledge of antimatter is not enough. To study it for any practical application, [scientists](#) must find a way to create and sustain more antimatter particles at a time than we currently can. Antimatter is created by colliding two particles together at high enough speed that one splits into two pieces (matter and antimatter) that fly apart. Once this division has occurred, researchers must suspend the antimatter particle so it doesn't recombine with the regular particle.

Typically, this is done using something like optical tweezers—powerful laserbeams that use light to trap a particle. But this process doesn't work like a Tupperware container, where you can just collect antimatter [particles](#) until you

have enough to build an engine. “[S]toring solid or liquid antimatter in contact with any state of matter is impossible,” Omira and Mourad wrote. “[A]ntimatter keeps on annihilating with matter at rapid rates. Therefore, the only and best option is to use magnetic, electrostatic, or electromagnetic suspension of solid antimatter in a vacuum.” These types of suspension have, so far, only held a few particles and for tiny periods of time, and they require enormous amounts of energy to even do that.

Mourad and Omira suggest that, despite these challenges, many other areas of aerospace physics will be in the position to support antimatter [technology](#) fairly soon. Scientists are making huge advances in cooling and heat resistant materials, they explain, and 3D printing could revolutionize how these materials are produced to specification. And globally, while a number of governments and institutions have invested money in antimatter and space-travel research, the duo says that more money would increase the speed of this research.

The scientists lay out an order of priorities for antimatter propulsion research going forward. The first step, and most important by far, is “establishing a stable antimatter production line with much larger storage capacities”—something we don’t have the resources to do today. After that, the storage must also be made compatible with [spacecraft](#), rather than just enormous and secure laboratories on Earth.

It’s a bit like something Brad Pitt’s character says in the movie *Ocean’s Eleven*: “This is like trying to build a house of cards on the deck of a speeding boat.” But, of course, the famous crew pulls off their improbable heist in the end—that’s the [magic](#) of movies.

Mourad and Omira are more circumspect. “If enough funding and efforts were devoted to further research on this technology,” they say, “and a solution to utilize annihilation’s energy was found, then interstellar and [human](#) interplanetary missions wouldn’t be deemed impossible.” Indeed, just “not impossible” means a lot at this point in antimatter research.

Chemists find new pharmaceutically active substances from billions of newly combined molecules



Nowadays, there's lots of buzz about spectacular new medical treatments, such as personalized cancer therapy with modified immune cells or antibodies. Such treatments, however, are very complex and expensive and so find only limited application. Most medical therapies are still based on small chemical compounds that can be produced in large quantities and thus at low cost.

The bottleneck in the development of new molecular therapies is the limited number of new active substances that can be found using current techniques. A method developed in the 2000s at Harvard and ETH Zurich promises to provide a remedy: DNA-encoded chemical libraries (DEL).

To date, DEL technology could be used to produce millions of chemical compounds and test their effectiveness in one go. However, the drawback with this was that the researchers could build only small molecules from a few chemical building blocks. Chemists at ETH Zurich have now refined and significantly improved this process.

With the help of the new method, [published](#) in the journal *Science*, researchers can now automatically synthesize and test not just a few million, but billions of different substances within a few weeks. The method can also be applied to produce much larger drug molecules, such as ring-shaped peptides, which can be used to target additional pharmacological targets.

Creating and testing all combinations

"The first active substances developed with the help of early DEL technology are currently in advanced clinical trials. This new DEL method once again massively expands the possibilities," Jörg Scheuermann explains.

He and his research group at the Institute of Pharmaceutical Sciences are among the pioneers of DEL technology, which is considered to be the key to utilizing the combinatorial possibilities in the chemical production of molecules in practice.

The aim of combinatorial chemistry is to produce as many molecular variants as possible from individual building blocks. From all these combinations, the researchers fish out those that demonstrate the desired activity. The number of different molecules grows exponentially with the number of synthesis cycles and with the number of different building blocks that are combined in each synthesis cycle.

Using DNA code to identify the active molecules

For researchers to be able to identify the individual active compounds in the rapidly growing "molecular soup" in efficacy tests, the DEL method attaches a defined short fragment of DNA to the molecule in parallel with each active-ingredient building block. This creates a unique DNA sequence as a readable barcode for each combination of building blocks.

For example, the entire soup of molecules can be tested for its ability to bind to a specific protein, and individual DNA segments can be amplified and clearly identified using the PCR (polymerase chain reaction) technique familiar from COVID tests.

Preventing exponential growth of contamination

Chemical reality, however, has thus far severely limited the possibilities of DEL technology. The process of linking the DNA fragments with the chemical building blocks is invariably reliable, but the effectiveness with which those building blocks link together chemically varies depending on the combination. As a result, the DNA code loses its uniqueness.

The same code can refer not just to the complete molecule with all building blocks, but also to truncated variants containing only some of the building blocks. These impurities also increase exponentially with each round of synthesis. In practice, this has limited the manageable size of DEL libraries to combinations of three to four connected blocks and thus to several million different compounds.

Self-purification built in

Scheuermann's research team have now found a way to prevent the increasing contamination of the molecular library: to purify the DEL that has been synthesized down to the very last building block. The ETH researchers' method is based on two main parts.

First, synthesis of the molecules is coupled to magnetic particles that can be handled easily and automatically. This enables washing cycles, among other things. Second, the team introduced a second chemical coupling component on the particles that can bind only to the last of the planned building blocks.

All truncated molecules that are missing, say, the last building block, can be removed in a single washing step. In the end, the library has only those molecules that contain all the building blocks specified in the DNA code.

Conflict with combinatorial chemistry

As elegant as the method looks on paper, it was difficult to implement, as Scheuermann says, "It was particularly challenging to find magnetic particles that

don't interfere with the enzymatic coupling of DNA fragments. In the course of their doctoral projects, Michelle Keller and Dimitar Petrov from my group invested a lot of time and energy to make sure the method works reliably."

The idea of performing such combinatorial chemistry on particles emerged back in the 1990s, but only now have the ETH researchers been able to put this into practice for library synthesis.

More diverse and larger molecules

The self-purifying DEL technology goes beyond allowing the handling of much larger libraries of several billion molecules; it also lets researchers synthesize bigger molecules consisting of five or more building blocks.

"Before, we could search for small active substances that fit like a key into the lock of the active site of therapeutically relevant proteins, but now we can search for larger ones as well. These larger active substances can dock not only in a protein's active centers, but also to other specific areas of a protein's surface, for example, in order to prevent it from binding to a receptor," Scheuermann says.

Fundamental biological research also benefits from the possibility of finding molecules that bind to certain protein surfaces, as this makes it possible to label and examine proteins in their cellular context. Moreover, the ETH method could be a boon for major international research initiatives such as Target 2035.

This initiative addresses the ca. 20,000 human proteins and aims to find, by 2035, a molecule for each of them that binds specifically to that one protein and can therefore influence its function.

Spin-off service for industry and science

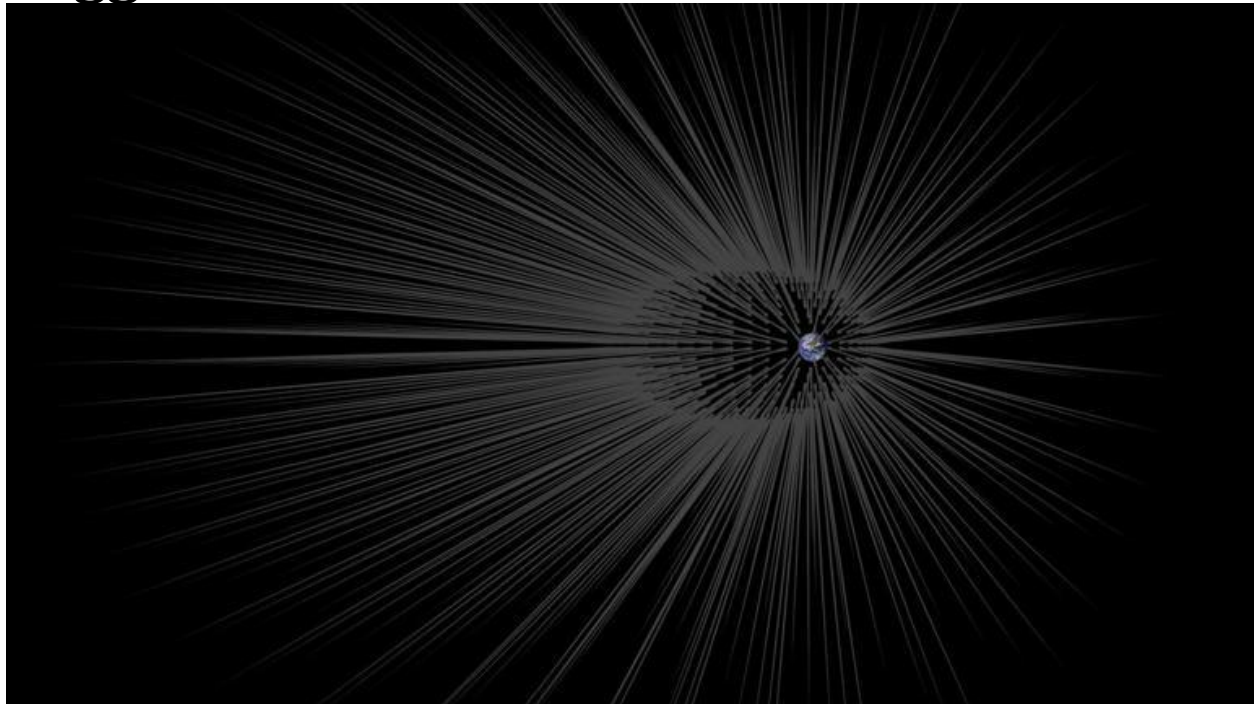
To make the technology available to the pharmaceutical industry and for basic research as efficiently as possible, Scheuermann and his team will establish a spin-off company. This company will offer the entire process: from the development of DEL collections and automated synthesis to automated efficacy testing and DNA-based identification of the molecules.

"We're seeing immense interest from industry and research, especially in cyclic molecules, which to date haven't been accessible in large numbers," Scheuermann says.

More information: Michelle Keller et al, Highly pure DNA-encoded chemical libraries by dual-linker solid-phase synthesis, *Science* (2024). [DOI: 10.1126/science.adn3412](https://doi.org/10.1126/science.adn3412)

Provided by ETH Zurich

Something invisible and 'fuzzy' may lurk at the Milky Way's center, new research suggests



An illustration of "hairy" dark matter around Earth. A new study proposes that clumps of dark matter might form huge, invisible stars at the centers of galaxies like ours. © NASA/JPL-Caltech

Galaxies may be anchored to giant "dark stars" — clumps of invisible matter sitting at their cores, new research suggests.

Although astronomers have an abundance of evidence that most of the mass in any given galaxy is invisible, they do not yet know the identity of this "[dark matter](#)." In recent decades, the most promising hypothesis has been that dark matter is made of some kind of heavy particle that rarely, if ever, interacts with light or other matter. But this hypothesis struggles to explain the relatively low densities of galaxy cores, because simulations of dark matter's behavior predict that it should easily clump up to extremely high densities, which does not match observations.

One possible answer to this problem is that the dark matter particles are incredibly light — billions of times less massive than [the neutrino](#), the lightest particle currently known. Dubbed "[fuzzy](#)" dark matter, these hypothetical particles are so light that their quantum-wave nature manifests on larger, macroscopic — even galactic — scales. This means they can stabilize into giant clumps of invisible matter, forming dark stars.

This is especially interesting because these dark stars can be extended in space for thousands of light-years but still have relatively low masses, since the particles are so light. Thus, they can potentially form the cores of galaxies, providing the bulk of these galaxies' mass without creating superhigh densities at the galactic centers.

But galaxies are made of more than dark matter — fuzzy or otherwise. They also contain normal matter, distributed in the form of diffuse gas clouds and stars, and it's those elements that astronomers can actually observe. So, to test this idea, we need to understand the link between fuzzy dark matter and normal matter within a galaxy.

The 'fuzz' in our stars

In a paper published Dec. 17, 2024 on [the preprint server arXiv](#), an international team of astrophysicists explored how galaxies might evolve in response to fuzzy dark matter. For this first step, they did not attempt to recreate an entire complex galaxy. Instead they built a simple toy model that contained only two components: a large percentage of fuzzy dark matter and a smaller percentage of a simple, ideal gas.

They then computed how these two components would evolve under their mutual gravitational influence. They found that, despite initially random behavior, the fuzzy dark matter quickly collected into a large clump in the center, with more diffuse clouds of dark matter surrounding it.

The gas followed along, mixing with the fuzzy dark matter in the center, creating what the researchers named a fermion-boson star, in reference to the two kinds of matter that mixed to form the central object. This star was totally unlike our typical conception of one. It would be gigantic — up to 10,000 [light-years](#) across — and almost entirely invisible, except for the subtle glow of the gas spread throughout it.

However, the researchers pointed out that this would serve as the ideal representation of a galactic core, which contains higher — but not too high — densities of normal matter, thereby confirming a key prediction of the fuzzy dark matter model.

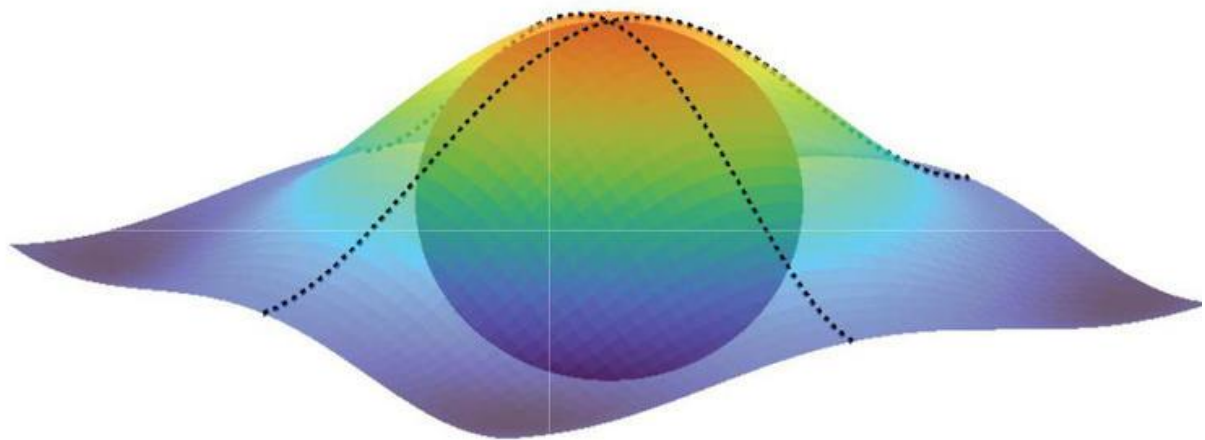
The next step is to build even more sophisticated models to explore what these "stars" might look like so that astronomers can compare the predictions to real-world observations.

Scientists Used a ‘Forbidden Fried Egg’ to Measure Quantum Geometry

- By hot swapping similar ideas, scientists built a model of quantum geometry that they can actually measure.
- The result shows how the spherical orbit of an electron qubit acts outward like a draped sheet.
- This “forbidden fried egg” could help other quantum physicists build and tune better systems.

Scientists have recently been working toward making a special [geometry](#) that describes different quantum interactions. There are a few competing theories of quantum geometry depending on who you ask, and those geometries can be used to define a variety of different phenomena. But the team behind a new study on the subject—[published](#) in the journal *Nature Physics*—sought specifically to recreate a factor called the quantum geometric tensor (QGT).

Physicists based at the Massachusetts Institute of Technology (MIT) teamed up with colleagues in Italy, Korea, and the Lawrence Berkeley National Laboratory in California to use their quasi-QGT to help define a particular type of electron. The goal was to map both the real part (a surface formed by the way the electrons behave) and the so-called imaginary part (a representation of forces acting and quantum curvature) of the [particle](#). The result looks like... well... a forbidden fried egg.



3d surface plot representing a mathematical function with a spherical shape at the center© Comin Lab

The electrons used in this experiment are from a compound of tin and cobalt (CoSn) that acts as a crystalline kagome metal—meaning it is prepared into a lattice shape that reminds scientists of Japanese baskets—and has quantum properties. Scientists use these metal preparations because they lend themselves to working as [qubits](#) (the quantum ‘bits’ that underpin quantum computing) and foster other interesting electron states for study.

In the forbidden fried egg image, the yolk is what's known as a Bloch sphere, and represents the classical geometry version of what happens in a qubit. It's the entire range of possible [behaviors](#) of that quantum state.

But then, we get into the breakthrough. To measure the quasi-QGT of the CoSn Bloch electrons, the scientists used both the Advanced Light Source at Lawrence Berkeley National Laboratory and the Elettra synchrotron in northeastern Italy. In particular, this experiment used both of those instruments to perform angle-resolved photoemission spectroscopy (ARPES), which is able to [measure](#) electron behaviors. When light collides with certain materials under certain conditions, the

results can be recorded and interpreted as photoemission spectroscopy. The technology dates back over 100 years, but advances in other instruments now allow scientists to image and measure in astonishing detail.

And, according to the study, it worked. “The quasi-QGT with well-defined physical meanings complements the QGT for the description of the intrinsic geometric properties of the Bloch electrons,” the scientists explain—meaning they can measure the quasi-QGT of this [sphere](#) and slip that into place as, more or less, the true QGT.

This work follows in the same intellectual lineage as mathematician Bernhard Riemann, whose work to help define and study curves is what scientists use to begin observing [general relativity](#) and other quantities or fields that involve spacetime. And this quasi-QGT is Riemannian in a sense, because, like his early approaches to the integral in calculus, they use a series of approximations to make a close estimate that they hope will help other scientists to keep pushing research forward.

The work may sound abstract, but it's relevant for a lot of quantum computing research, as well as our understanding of quantum states in general. The more we can see and measure both particles and their actions in quantum systems, the more scientists can continue to design materials like computing frameworks, [superconductors](#), and more.

“We’ve essentially developed a [blueprint](#) for obtaining some completely new information that couldn’t be obtained before,” lead and corresponding author Riccardo Comin [said in an MIT statement](#). Co-first author Mingu Kang added that this principle generalizes to “any kind of quantum material, not just the one we worked with.”

New theory unites Einstein's theory of relativity with quantum mechanics

For over a century, quantum mechanics and Einstein's general relativity have stood as the cornerstones of modern physics, yet their unification remains one of science's greatest challenges.

Now, researchers at [University College London](#) (UCL) have introduced a groundbreaking theory that challenges conventional approaches to this problem.

Quantum gravity seeks to bridge the gap between the microscopic world, where quantum mechanics governs particle behavior, and the macroscopic realm, where gravity shapes spacetime.

Traditionally, physicists have assumed that Einstein's theory must be modified to fit within the quantum framework. However, UCL researchers propose a striking alternative: a "[postquantum theory of classical gravity](#)" that reexamines the fundamental relationship between these two domains.

The Quantum-Relativity Divide

[Quantum mechanics](#), rooted in probability and wave functions, has been remarkably successful in describing subatomic behavior. General relativity, on the other hand, precisely explains how gravity governs the cosmos. Yet, attempts to merge these theories into a unified framework have repeatedly faced obstacles.

This latest proposal challenges conventional wisdom, suggesting that instead of forcing gravity into a quantum framework, researchers should explore a new perspective—one where classical [gravity](#) interacts with quantum systems in ways previously unexplored. The implications of this theory could reshape our understanding of the universe, offering a fresh path toward reconciling two of physics' most successful yet conflicting models.

In contrast, general relativity paints a different picture of the universe, where gravity arises from the [curvature of spacetime](#) caused by massive objects. While these theories excel in their own domains, they clash when brought together, leading to mathematical inconsistencies and contradictions.

A New Approach: Spacetime as Classical

Enter Professor Jonathan Oppenheim and his team at UCL, who have challenged the status quo with their groundbreaking theory. In two parallel papers published simultaneously, they propose a novel perspective that suggests [spacetime](#) may remain classical and unaffected by quantum mechanics.

This theory, as described in a paper published in [Physical Review X \(PRX\)](#), refrains from modifying spacetime itself and instead modifies quantum theory.

The core tenet of this theory is that spacetime remains classical, not subject to the constraints of quantum theory. Instead, quantum theory is tweaked to account for intrinsic unpredictability mediated by spacetime. The consequence?

Spacetime experiences random and violent fluctuations that exceed the expectations set by quantum theory. These fluctuations, if measured precisely enough, render the apparent weight of objects unpredictable.

To put their theory to the test, the researchers propose a groundbreaking experiment aimed at detecting fluctuations in mass over time. For instance, consider a 1kg mass – the standard measurement used by the [International Bureau of Weights and Measures](#) in France. If the measurements of this 1kg mass exhibit fluctuations smaller than those required for mathematical consistency, it would challenge the new theory.

This experiment, which has far-reaching implications for our [understanding of gravity](#) and quantum mechanics, is not just theoretical but practical. It serves as a critical juncture in the ongoing debate between competing theories of quantum gravity. Professor Oppenheim, along with Professor Carlo Rovelli and Dr. Geoff Penington, leading proponents of quantum loop gravity and string theory, respectively, have even placed a 5000:1 odds bet on the outcome.

Five Years of Rigorous Testing

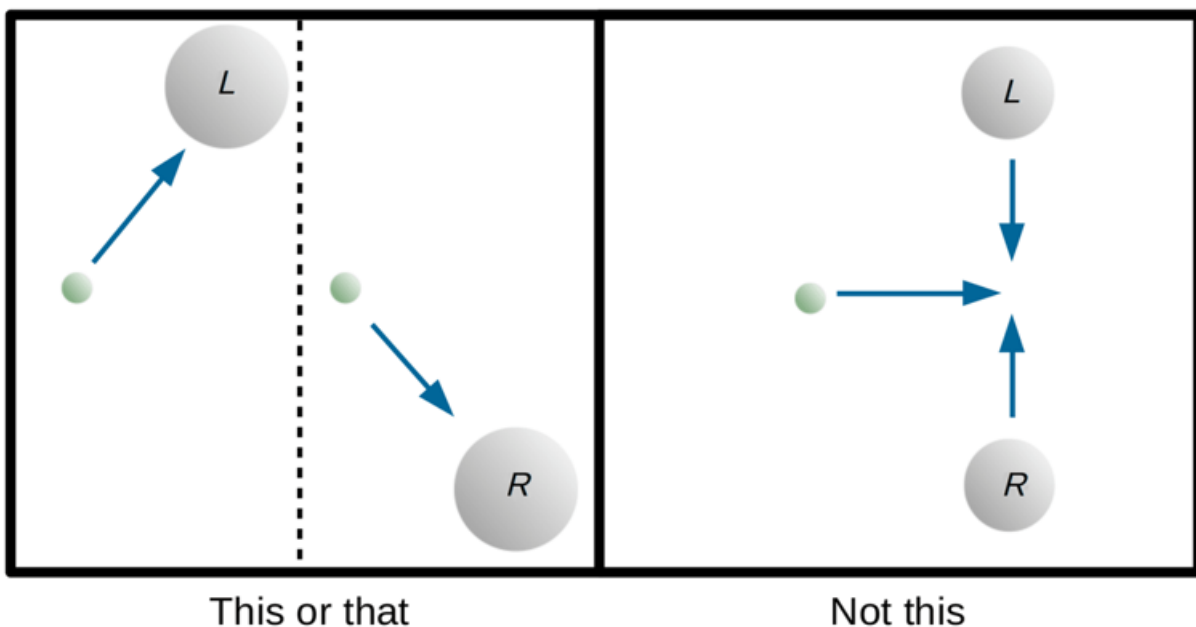
The UCL research group, led by Professor Oppenheim, has spent the past five years meticulously developing and examining their theory, scrutinizing its consequences from various angles.

As Professor Oppenheim puts it, "Quantum theory and Einstein's theory of general relativity are mathematically incompatible with each other, so it's important to understand how this contradiction is resolved."

Their journey has been marked by relentless exploration of the [fundamental nature of gravity](#) and the cosmos itself, probing the boundaries of our knowledge and challenging preconceived notions.

Beyond the Weight of Gravity: Implications of the Postquantum Theory

While the focus of the postquantum theory is on reconciling quantum mechanics and [general relativity](#), its implications extend far beyond the realm of gravity. One notable consequence is the elimination of the notorious "measurement postulate" in quantum theory.



The prediction of the semiclassical Einstein equation is depicted in the right panel, compared with what we expect to occur based on the statistical interpretation of the density matrix in the left panel. (CREDIT: PRX)© The Brighter Side of News

This postulate, which has long perplexed physicists, posits that measurements collapse quantum superpositions into definite states. In the new theory, quantum

superpositions naturally localize through their interaction with classical spacetime, obviating the need for this postulate.

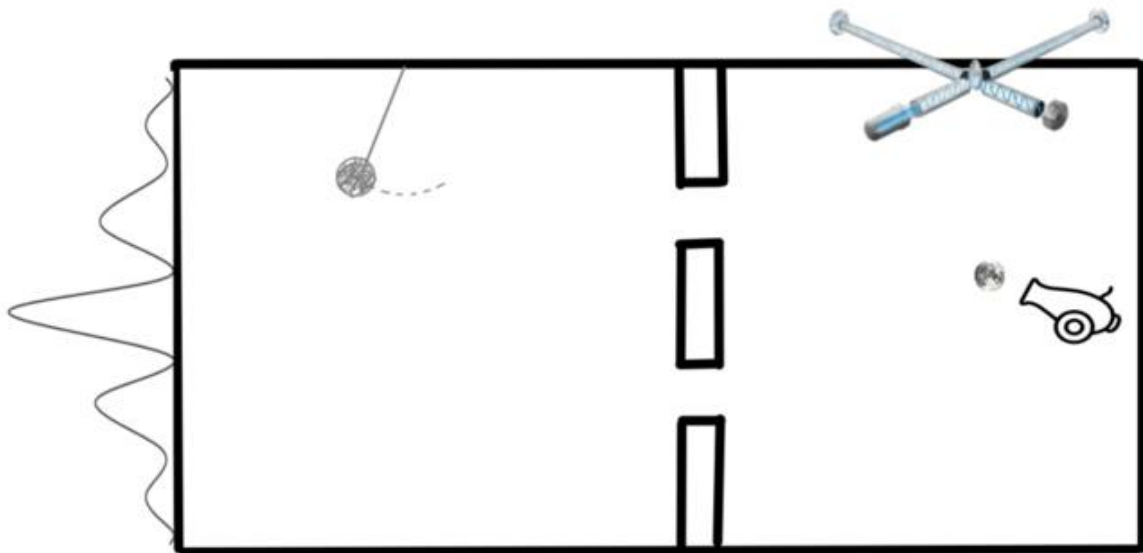
Professor Oppenheim's journey to this groundbreaking theory was motivated by his attempt to unravel the mysteries of the black hole information paradox. According to [standard quantum theory](#), information cannot be destroyed.

Therefore, an object entering a black hole should somehow radiate information back out. However, this concept directly contradicts general relativity, which posits that once an object crosses a [black hole's event horizon](#), it becomes inaccessible.

The postquantum theory offers a unique perspective, suggesting that the fundamental breakdown in predictability inherent to spacetime allows for information to be destroyed, resolving this long-standing paradox.

The proposal to test whether [spacetime](#) remains classical by detecting random fluctuations in mass is just one part of the puzzle.

Another experimental proposal aims to verify the quantum nature of spacetime through a phenomenon called "gravitationally mediated entanglement." These experiments, though challenging, hold immense promise in advancing our understanding of the fundamental laws of nature.



Consider a variation of the gedanken experiment proposed by Feynman [12,35] and Aharonov [36] in which a massive particle travels through two slits as a plane wave. Quantum theory predicts an interference pattern on the screen

behind the slits which enables a determination of the particle's momentum. (CREDIT: PRX)© The Brighter Side of News

Professor Sougato Bose, an expert in the field who was not involved in the recent UCL announcement but had previously proposed the entanglement experiment, emphasized the importance of these endeavors, stating, "Experiments to test the [nature of spacetime](#) will take a large-scale effort, but they're of huge importance from the perspective of understanding the fundamental laws of nature. I believe these experiments are within reach – these things are difficult to predict, but perhaps we'll know the answer within the next 20 years."

At the heart of this theory lies a delicate interplay between quantum particles, [such as atoms](#), and the fluctuations in classical spacetime. These fluctuations, if the theory holds, must occur on a scale yet to be detected but should be large enough to impact quantum particles' behavior.

The proposed experiments seek to find this elusive balance, shedding light on whether spacetime remains classical or succumbs to quantum mechanics at microscopic scales.

In the words of Professor Oppenheim, "Now that we have a consistent fundamental theory in which spacetime does not get quantized, it's anybody's guess." The journey has just begun, and the [future of physics](#) has never looked more intriguing.

Background information

Quantum mechanics background: All the matter in the universe obeys the laws of quantum theory, but we only really observe quantum behavior at the scale of atoms and molecules.

Quantum theory tells us that particles obey Heisenberg's uncertainty principle, and we can never know their position or velocity at the same time. In fact, they don't even have a definite position or velocity until we measure them. Particles like electrons can behave more like waves and act almost as if they can be in many places at once (more precisely, physicists describe particles as being in a "[superposition](#)" of different locations).

Quantum theory governs everything from semiconductors which are ubiquitous in computer chips, to lasers, to superconductivity to radioactive decay. In contrast, we say that a system behaves classically if it has definite underlying properties. A cat appears to behave classically – it is either dead or alive, not both, nor in a superposition of being dead and alive.

Why do cats behave classically, and small particles quantumly? We don't know, but the [postquantum theory](#) doesn't require the measurement postulate, because the classicality of spacetime infects quantum systems and causes them to localize.

Gravity background: Newton's theory of gravity, gave way to Einstein's theory of general relativity (GR), which holds that gravity is not a force in the usual sense. Instead, heavy objects such as the sun, bend the fabric of spacetime in such a way that causes the earth to revolve around it.

Spacetime is just a mathematical object consisting of the three dimensions of space, and time considered as a fourth dimension. General relativity predicted the [formation of black holes](#) and the big bang. It holds that time flows at different rates at different points in space, and the GPS in your smartphone needs to account for this in order to properly determine your location.

JANUARY 29, 2025

Superionic compound with liquid-like dynamics shows promise as solid-state battery electrolyte

by Ingrid Fadelli , Phys.org

Artist rendering of lithium ions (glowing orbs) moving through a vibrating diffusion bottleneck (triangular window) in a crystalline solid-state electrolyte with complex argyrodite structure.

Credit: Phoenix Pleasant / Oak Ridge National Laboratory

Superionic materials are a class of materials that simultaneously present properties that are characteristic of solids and liquids. Essentially, a set of ions in these materials exhibits liquid-like mobility, even if the materials' underlying atomic structure maintains a solid-like order.

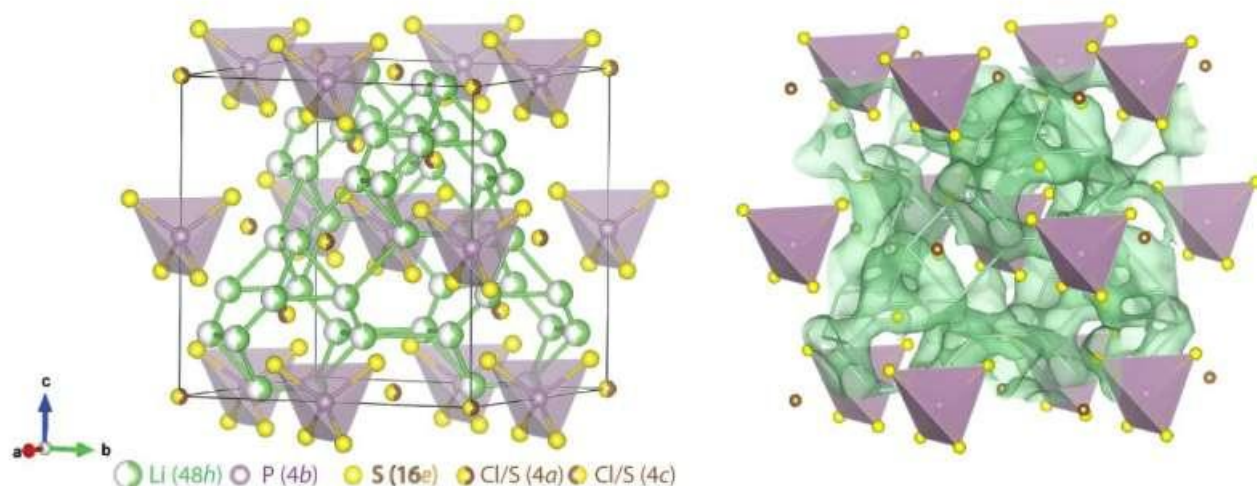
Due to their unique ionic conductivity patterns, superionic materials could be promising for developing [solid-state batteries](#). These are batteries that contain electrolytes based on solid materials instead of liquid electrolytes.

While various past studies have explored the potential of superionic materials as solid-state electrolytes, the physics underpinning their rapid ionic diffusion is not yet fully understood. Specifically, it is unclear whether this property results from liquid-like motion in the material or from the conventional lattice phonons (i.e., atom vibrations) in the material.

Researchers at Duke University and other institutes recently carried out a study exploring the mechanisms underlying the ion mobility in the superionic compound $\text{Li}_6\text{PS}_5\text{Cl}$, which could be a promising solid-state electrolyte. Their findings, [published](#) in *Nature Physics*, unveils that the ionic motion in this material is linked to its liquid-like dynamics, while also opening new possibilities for the optimization of solid-state batteries.

"Our research group has been interested in understanding the atomic dynamics in energy materials for some time," Olivier Delaire, senior author of the paper, told Phys.org.

"We have found, across many classes of materials, strong deviations from the textbook models of harmonic lattice dynamics, which are described in terms of phonon in solid-state physics. In the case of solid-state electrolyte materials, one seeks a solid framework that enables very high diffusivities of mobile ions (such as lithium or sodium), comparable to those of liquid electrolytes, while also offering good chemical and thermal stability."



The nominal crystal structure of the lithium argyrodite compound $\text{Li}_6\text{PS}_5\text{Cl}$ is illustrated below (left) with the partially-occupied lithium site in green/grey. The molecular dynamics simulations at high temperature (right) show a probability density of lithium ions broadly smeared across the host framework. Credit: Delaire group, Duke University.

The primary objective of this recent study by Delaire and his colleagues was to better understand how Li^+ cations can diffuse so rapidly in the complex crystalline framework of the lithium argyrodite $\text{Li}_6\text{PS}_5\text{Cl}$. In addition, the researchers wished to determine whether the dynamics of these ions could be understood in the context of phonons in a crystalline material, even if they predicted the presence of strong anharmonic effects.

"To probe the motions of ions in superionic materials, we performed [neutron scattering](#) experiments at the DOE's Oak Ridge National Laboratory and atomistic computer simulations, based on so-called first-principles methods and augmented with [machine-learning techniques](#)," explained Delaire.

Neutron scattering, the main technique that the researchers used to examine $\text{Li}_6\text{PS}_5\text{Cl}$, is a powerful tool designed to probe atomic vibrations and thus uncover atomic dynamics with frequencies in the GHz-THz range. Using this technique, Delaire and his colleagues were able to determine whether ions vibrate around local potential wells or hop between multiple sites in the sample material's structure instead.

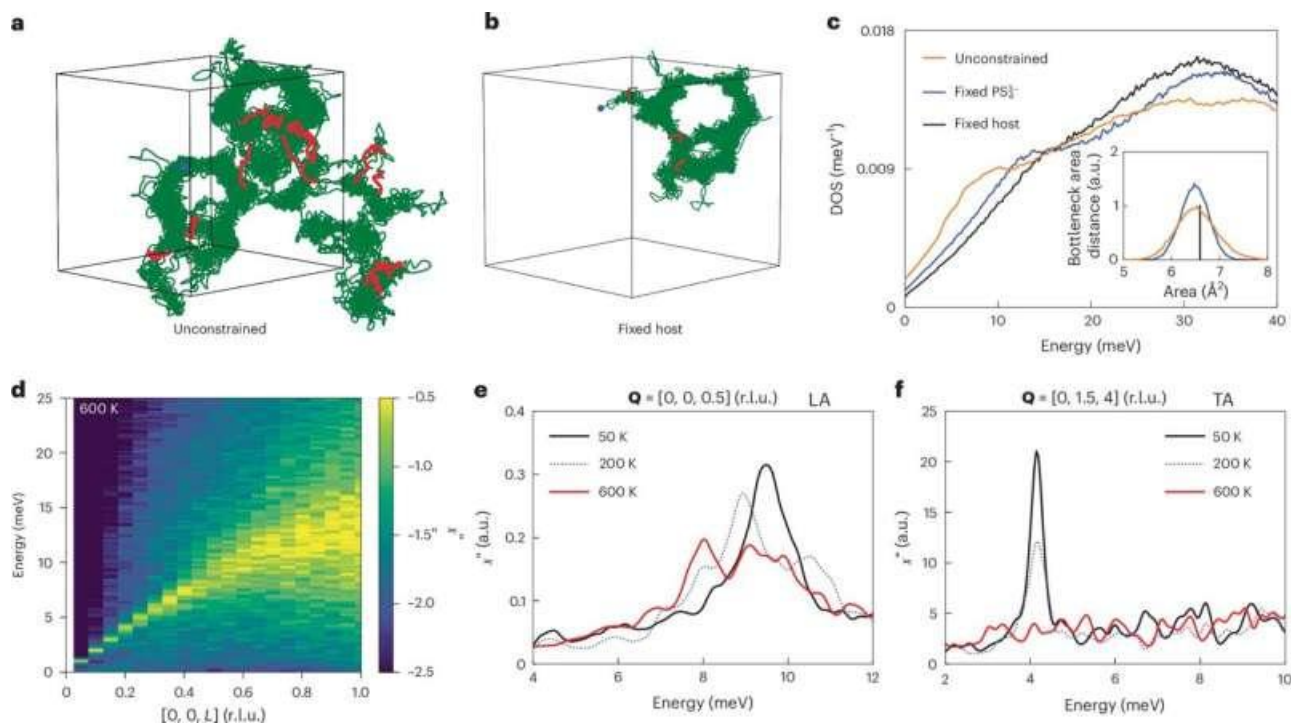
"Because the neutron scattering cross-section is well understood, we can directly compare the neutron data with the results of [molecular dynamics simulations](#)," said Delaire.

"Recent advances with machine-learning to train surrogate force-fields on accurate quantum mechanical energies/forces are opening the possibility of directly matching the experimental resolution. However, we need sufficiently large, simulated trajectories and therefore run our simulations on high-performance computers, such as the NERSC supercomputing center."

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Combining neutron scattering experiments with machine learning-generated molecular dynamics simulations, the researchers could observe how the vibrational spectra of mobile Li^+ ions in $\text{Li}_6\text{PS}_5\text{Cl}$ evolved from a crystal-like to a liquid-like phase. Overall, their findings gathered new important insight into the nature of rapid ionic motion in superionic materials.



Effect of lattice flexibility on ionic diffusion and selective breakdown of phonon quasiparticles. Credit: *Nature Physics* (2025). DOI: 10.1038/s41567-024-02707-6

"Superionic materials have quite complex atomic dynamics and often quite complex structures as well," Delaire said. "Designing materials with superionic diffusivities and good stability from the ground up has remained challenging.

"Our methods and results identify an important role of combined dynamics of the diffusive ions and the vibrational modes of the host crystal framework. Since we have experience and tools to systematically investigate and predict phonons in rather complex structures, we hope to gain new insights by going beyond a static view of materials."

The recent work by Delaire and his colleagues highlights the promise of $\text{Li}_6\text{PS}_5\text{Cl}$ as a solid-state electrolyte. In the future, it could inform the design of new solid-state batteries, opening new avenues for the optimization of superionic materials, which could help to improve the energy storage and power-conversion efficiencies of solid-state batteries. The design of materials with superionic diffusivities could also inform the development of other devices beyond solid-state batteries, including fuel cells and neuromorphic computing hardware.

"We are broadening the range of superionic material compositions we are investigating. We are very open to new collaborations," added Delaire.

"Future developments of neutron instruments could drastically accelerate our ability to probe superionic dynamics, for instance, in-situ or very small samples, and with higher throughput to screen many compositions. We are now leveraging artificial intelligence and machine learning to guide our scientific workflow and data analysis, and we see great potential in further integration of computer simulations with neutron or X-ray scattering experiments."

More information: Jingxuan Ding et al, Liquid-like dynamics in a solid-state lithium electrolyte, *Nature Physics* (2025). DOI: [10.1038/s41567-024-02707-6](https://doi.org/10.1038/s41567-024-02707-6).

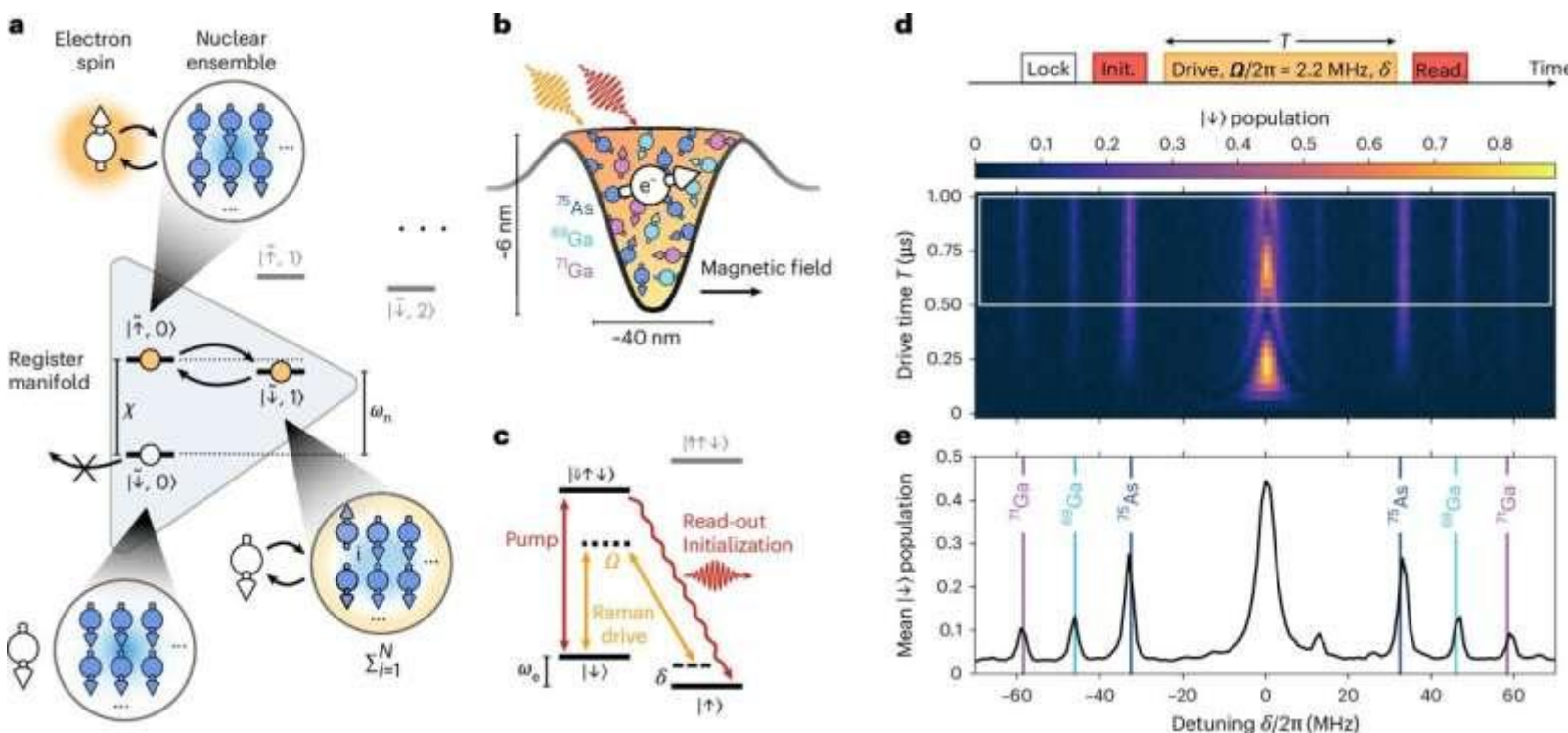
Journal information: [Nature Physics](#)

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JANUARY 29, 2025

Scientists create new register with thousands of entangled nuclei to scale quantum networks

by [University of Cambridge](#)



Isotope-resolved electro-nuclear interface. Credit: *Nature Physics* (2025). DOI: [10.1038/s41567-024-02746-z](https://doi.org/10.1038/s41567-024-02746-z)

In an advance for quantum technologies, researchers at the Cavendish Laboratory, University of Cambridge, have created a functional quantum register using the atoms inside a semiconductor quantum dot.

[Published](#) in *Nature Physics*, the work demonstrates the introduction of a new type of optically connected qubits—a critical advance in the development of quantum networks, where stable, scalable, and versatile quantum nodes are essential.

Quantum dots are nanoscale objects with unique optical and electronic properties that come from quantum mechanical effects. These systems are already used in technologies like display screens and [medical imaging](#), and their adoption in quantum communication has been mostly due to their ability to operate as bright single-photon sources.

However, effective quantum networks need more than just single-photon emission; they also require stable qubits that can interact with the photons and store [quantum information](#) locally. The new research builds on the inherent spins of the atoms forming the [quantum dots](#) as a functioning many-body quantum register to store information over extended periods.

A many-body system refers to a collection of interacting particles—here, the nuclear spins inside the quantum dot—whose collective behavior gives rise to new, emergent properties that are not present in individual components. By using these collective states, the researchers created a robust and scalable quantum register.

The Cambridge team, in close collaboration with colleagues at the University of Linz, successfully prepared 13,000 nuclear spins into a collective, entangled state of spins known as a "dark state." This dark state reduces interaction with its environment, leading to better coherence and stability, and serves as the logical "zero" state of the quantum register.

They introduced a complementary "one" state as a single nuclear magnon excitation—a phenomenon representing a coherent wave-like excitation involving a single nuclear spin flip propagating through the nuclear ensemble. Together, these states enable quantum information to be written, stored, retrieved, and read out with high fidelity.

The researchers demonstrated this with a complete operational cycle, achieving a storage fidelity of nearly 69% and a coherence time exceeding 130 microseconds. This is a major step forward for quantum dots as scalable quantum nodes.

"This breakthrough is a testament to the power many-body physics can have in transforming quantum devices," said Mete Atatüre, co-lead author of the study and Professor of Physics at the Cavendish Laboratory.

"By overcoming long-standing limitations, we've shown how quantum dots can serve as multi-qubit nodes, paving the way for quantum networks with applications in communication and distributed computing. In the 2025 International Year of Quantum, this work also highlights the innovative strides being made at the Cavendish Laboratory toward realizing the promise of [quantum technologies](#)."

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The work represents a unique marriage of semiconductor physics, [quantum optics](#), and quantum information theory. The researchers utilized advanced control techniques to polarize [nuclear spins](#) in [gallium arsenide](#) (GaAs) quantum dots, creating a low-noise environment for robust quantum operations.

"By applying quantum feedback techniques and leveraging the remarkable uniformity of GaAs quantum dots, we've overcome long-standing challenges caused by uncontrolled nuclear magnetic interactions," explained Dorian Gangloff, co-lead author of the project and Associate Professor of Quantum Technology.

"This breakthrough not only establishes quantum dots as operational quantum nodes but also unlocks a powerful platform to explore new many-body physics and emergent quantum phenomena."

Looking ahead, the Cambridge team aims to extend the time their quantum register can store information to tens of milliseconds by improving their control techniques. These improvements would make quantum dots suitable as intermediate quantum memories in quantum repeaters—critical components for connecting distant quantum computers.

More information: Martin Hayhurst Appel et al, A many-body quantum register for a spin qubit, *Nature Physics* (2025). [DOI: 10.1038/s41567-024-02746-z](https://doi.org/10.1038/s41567-024-02746-z)

Journal information: [Nature Physics](#)

Provided by [University of Cambridge](#)

JANUARY 28, 2025

Super-Earth discovery reveals an exoplanet potentially capable of sustaining life

by [University of Geneva](#)



Credit: CC0 Public Domain

Thirty years after the discovery of the first exoplanet, astronomers have detected more than 7,000 of them in our galaxy. But there are still billions more to be discovered. At the same time, exoplanetologists have begun to take an interest in their characteristics, with the aim of finding life elsewhere in the universe. This is the background to the discovery of super-Earth HD 20794 d by an international team including the University of Geneva (UNIGE) and the NCCR PlanetS.

The new planet lies in an [eccentric orbit](#), so that it oscillates in and out of its star's habitable zone. This discovery is the fruit of 20 years of observations using the best telescopes in the world. The results are [published](#) in the journal *Astronomy & Astrophysics*.

"Are we alone in the universe?" For thousands of years, this question was confined to philosophy, and it is only very recently that [modern science](#) has begun to provide solid hypotheses and evidence to answer it. However, astronomers are making slow progress.

Each new discovery, whether theoretical or observational, adds to the edifice by pushing back the limits of knowledge. This was the case with the discovery in 1995 of the first planet

orbiting a star other than the sun, which earned two UNIGE researchers, Michel Mayor and Didier Queloz, the 2019 Physics Nobel Prize. The current scientific consensus points to the existence of a planetary system for every star in our galaxy.

Astronomers are now looking for exoplanets that are easier to characterize or have interesting features to test their hypotheses and consolidate their knowledge. This is the case of planet HD 20794 d, which has just been detected by a team that includes members of the UNIGE Astronomy Department.

In the habitable zone of its star

This promising planet is a super-Earth, a telluric planet larger than the Earth. It is part of a planetary system containing two other planets. It orbits a G-type star, like the sun, at a distance of just 19.7 light-years, which is, on the scale of the universe, in the very close neighborhood of the Earth.

This "closeness" makes it easier to study, as its light signals are more visible and stronger. "HD 20794, around which HD 20794 d orbits, is not an ordinary star," explains Xavier Dumusque, Senior Lecturer and researcher in the Department of Astronomy at the UNIGE and co-author of the study.

"Its luminosity and proximity makes it an ideal candidate for future telescopes whose mission will be to observe the atmospheres of exoplanets directly." The habitable zone around the star HD 20794 (in green) and the trajectory of the three planets in the system. Credit: Gabriel Pérez Díaz, SMM (IAC)

The interest in planet HD 20794 d lies in its position in the habitable zone of its star, the zone that delimits the place where [liquid water](#) can exist, one of the conditions necessary for the development of life as we know it. This zone depends on several factors, mainly the stellar properties.

For stars such as the sun or HD 20794, it can extend from 0.7 to 1.5 astronomical units (AU), encompassing not only the orbit of the Earth but also that of Mars in the case of the sun. The exoplanet HD 20794 d takes 647 days to orbit its star, around 40 days less than Mars.

Instead of following a relatively circular orbit, like the Earth or Mars, HD 20794 d follows an elliptical trajectory with large changes in the distance to its star during its revolution. The planet thus oscillates between the inner edge of its star HZ (0.75 AU) and outside of it (2 AU) along its orbit.

This configuration is of particular interest to astronomers because it allows them to adjust [theoretical models](#) and test their understanding of the notion of a planet's habitability. If there is water on HD 20794 d, it would pass from the state of ice to the liquid state, conducive to the appearance of life, during the planet's revolution around the star.

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Many years of observations

Detecting this super-Earth was not easy and the process was iterative. The team analyzed more than 20 years of data from state-of-the-art instruments such as ESPRESSO and HARPS. For the latter, the scientists were able to rely on YARARA, a data reduction algorithm recently developed at the UNIGE.

For years, planetary signals had been obscured by noise, making it difficult to discern whether planets actually existed. "We analyzed the data for years, carefully eliminating sources of contamination," explains Michael Cretignier, a post-doctoral researcher at Oxford University, co-author of the study and developer of YARARA during his Ph.D. at UNIGE.

The discovery of HD 20794 d provides scientists with an interesting laboratory for modeling and testing new hypotheses in their search for life in the universe.

The proximity of this planetary system to its bright star also makes it a prime target for next-generation instruments such as the ANDES spectrograph for ESO's Extremely Large Telescope (ELT). Knowing whether this planet harbors life will still require a number of scientific milestones and a transdisciplinary approach.

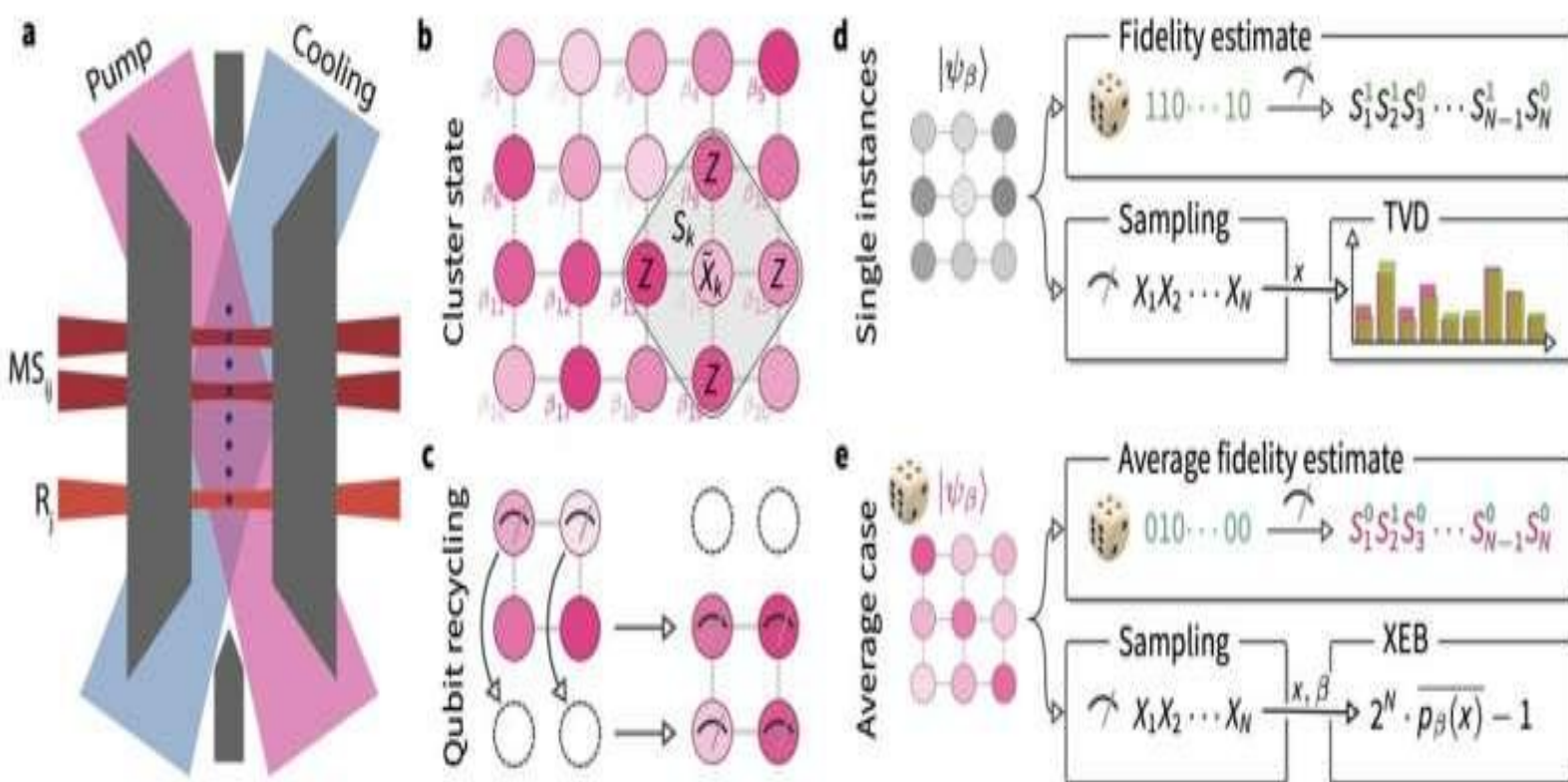
The conditions for its habitability are already being studied by the new Center for Life in the Universe (CVU) at the UNIGE's Faculty of Science.

More information: N. Nari et al, Revisiting the multi-planetary system of the nearby star HD 20794. Confirmation of a low-mass planet in the habitable zone of a nearby G-dwarf, *Astronomy & Astrophysics* (2024). [DOI: 10.1051/0004-6361/202451769](https://doi.org/10.1051/0004-6361/202451769)

Journal information: [Astronomy & Astrophysics](#)

Provided by [University of Geneva](#)

Trapped-ion processor demonstrates verifiable quantum random sampling



Overview of the experiment. Credit: *Nature Communications* (2025). DOI: 10.1038/s41467-024-55342-3.

One of the key goals within the field of quantum computing is to achieve what is known as a quantum advantage. This term essentially describes the point after which a quantum computer can outperform a classical computer on a specific task or solve a problem that is beyond the reach of classical computers.

One task that could be used to demonstrate a [quantum advantage](#), known as quantum random sampling, entails the generation of samples from a probability distribution. This task

is very difficult for classical computers to perform, but it could theoretically be completed by quantum computers.

While past studies have successfully tackled random sampling tasks using quantum computers, actually verifying that a system effectively performs these tasks has proved challenging. This is because many existing verification techniques based on classical data are either too computationally demanding or difficult to apply to larger quantum systems.

Researchers at Universität Innsbruck, Freie Universität Berlin and other institutes have introduced a new protocol to verify quantum random sampling, which draws from the measurement-based model of quantum computation (MBQC). This protocol, outlined in a [paper](#) published in *Nature Communications*, was successfully demonstrated on a trapped-ion quantum processor.

"Originally, we were inspired by questions on what computational tasks could be solved on a quantum computer that could not be solved on a classical computer efficiently," Jens Eisert, co-author of the paper, told Phys.org.

"At that time, the first ideas of what are now called 'quantum advantages' came up, referring to problems for which there is strong evidence that a quantum computer could outperform classical supercomputers."

Random sampling problems, the tasks that the researchers focused on in their paper, entail taking raw data from a quantum experiment and trying to classically sample it from a distribution close to the correct quantum distribution. The successful implementation of these schemes could help to generate outputs that would be very difficult to predict using classical computers.

"Surprising as this may sound, this is something quantum computers are good at," explained Eisert, "We started out from work in the group that was aimed at finding the simplest possible such prescription. This amounted to preparing a simple product state arranged in an array, performing one layer of quantum circuits and performing local simple measurements."

While conducting their previous research, the researchers were surprised to discover that a set of simple schemes could give rise to sampling problems. They then decided to try to apply these schemes in an experimental setting, using a trapped-ion quantum processor.

"We thought to ourselves, 'Hey, if such a simple setting can give rise to a quantum advantage, then can we transform this into an experimentally feasible setting that works for a trapped ion-settings and that recycles the ions?'" said Eisert. "We were intrigued."

When they started conducting their experiments, the team soon realized that the random sampling scheme they identified was efficiently verifiable. Given its lower computational demands compared to previous approaches to verify quantum random sampling, it could also be easier to apply to larger quantum computers.

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"A key challenge for random sampling schemes is that one cannot efficiently verify their correctness based on classical data alone," explained Eisert.

"Yet if one has some trust in the quantum measurement apparatus, one can do this. We efficiently verify the correctness of the scheme, even though the classical sampling from a close to the quantum distribution is hard and would not be possible for a larger scheme of the same type."

This study could contribute to the study of classical and quantum computers, helping researchers to understand the limits of classical systems and where an algorithmic quantum advantage sets in. This knowledge could in turn help to build increasingly larger and better performing quantum computers.

To demonstrate their protocol, the researchers applied it to a quantum processor comprised of trapped single ions that can be precisely manipulated in their [quantum state](#). Within this processor, they prepared a so-called cluster state, which is a state known to play a key role in measurement-based quantum computing.

"The experiment samples from measurement outcomes obtained from measuring a 4x4 cluster state, involving 16 qubits, where some of the qubits could be recycled," said Thomas Monz and Martin Ringbauer, the team leads of the experimental team in Innsbruck.

"The cute aspect is that we could verify the correctness of the state preparation and sampling by estimating the state fidelity and have compared this with more conventional approaches such as cross-entropy benchmarking."

Using their protocol, the researchers were able to reliably estimate the fidelity of the cluster state in their quantum processor. Notably, they found that the samples produced by the processor were very close to those they had predicted.

"We think that our work has various key contributions, the first of which is a technological one," said Eisert, "The trapped ion platform that makes use of single trapped ions more than once constitutes an advancement."

"In addition, its conceptual advancement is that it provides an understanding that the correctness of sampling experiments is efficiently possible even if one cannot efficiently classically sample from almost the right distribution. This is intriguing, as one can say some experiment has been correctly performed even if one cannot make predictions about it."

With many research teams worldwide working to improve the performance of quantum computers, Eisert and his colleagues hope that their efforts will help to understand where their quantum advantage sets (i.e., on what tasks they could perform better than classical computers).

In the future, the scheme they devised could be used by other teams to test the performance of their quantum computing systems on [random sampling](#) tasks.

"We see this as an important step towards devising more sophisticated quantum computing platforms," added Eisert.

"These days, for example, there are substantial steps taken towards making quantum schemes more resilient against errors. We see these efforts as contributing to the bigger research scheme of building quantum computers. There is also a meta-message coming out of this: [technological progress](#) is only ensured if theoretical and experimental considerations come together."

More information: Martin Ringbauer et al, Verifiable measurement-based quantum random sampling with trapped ions, *Nature Communications* (2025). DOI: [10.1038/s41467-024-55342-3](https://doi.org/10.1038/s41467-024-55342-3).

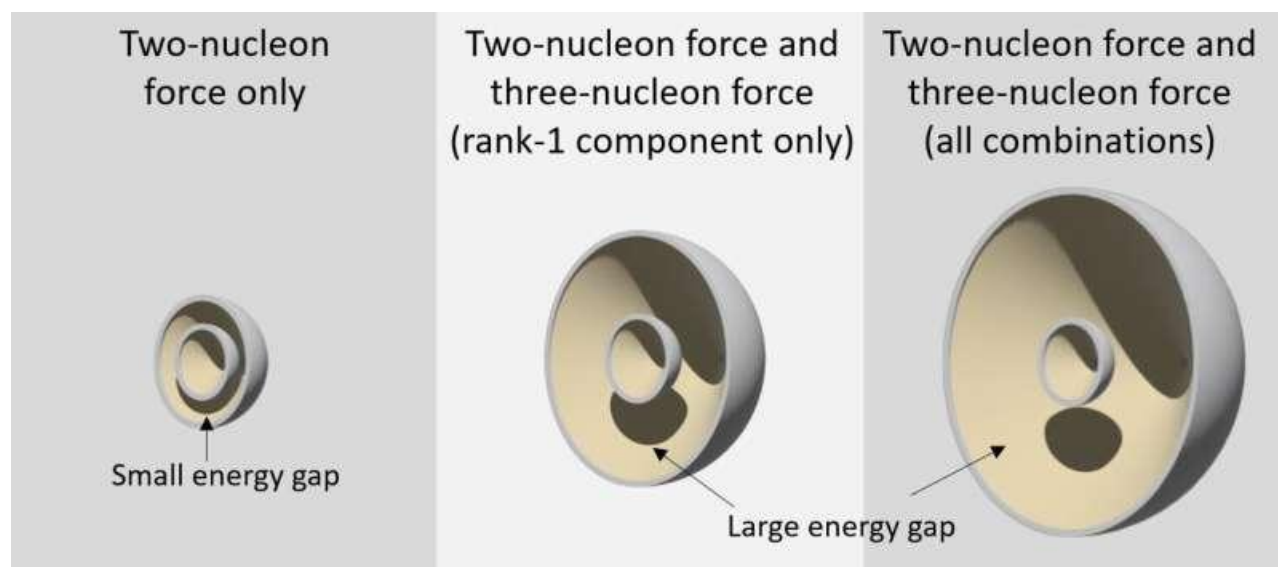
Journal information: [Nature Communications](#)

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JANUARY 28, 2025

An overlooked nuclear force helps keep matter stable, study reveals

by [Kyushu University](#)



The three-nucleon force enhances spin-orbit splitting, which causes a larger energy gap between nuclear shells and stabilizes the nucleus. Credit: Tokuro Fukui / Kyushu University
Researchers from Kyushu University, Japan have revealed how a special type of force within an atom's nucleus, known as the three-nucleon force, impacts nuclear stability. The

study, published in [Physics Letters B](#), provides insight into why certain nuclei are more stable than others and may help explain astrophysical processes, such as the formation of heavy elements within stars.

All matter is made of atoms, the building blocks of the universe. Most of an atom's mass is packed into its tiny [nucleus](#), which contains protons and neutrons (known collectively as nucleons). Understanding how these nucleons interact to keep the nucleus stable and in a low energy state has been a central question in [nuclear physics](#) for over a century.

The most powerful nuclear force is the two-[nucleon](#) force, which attracts two nucleons at long range to pull them together and repels at short range to stop the nucleons from getting too close.

"Scientists have formed a good understanding of the two-nucleon force and how it impacts nuclear stability," says first author Tokuro Fukui, Assistant Professor of Kyushu University's Faculty of Arts and Science. "On the other hand, three-nucleon force, which is when three nucleons interact with each other simultaneously, is much more complicated and poorly understood."

Fukui describes [nuclear forces](#) by likening them to a game of catch. With the two-nucleon force, two players, or nucleons, interact by throwing a ball to each other. The ball, a [subatomic particle](#) called a meson, can vary in heaviness, with the lightest meson, known as a pion, responsible for the long-range attraction between nucleons.

With the three-nucleon force, there are three players, or nucleons, and balls, or mesons, are passed between them. At the same time as throwing and catching the balls, the players, or nucleons, also spin and move in an orbit within the nucleus.

Nuclear forces can be compared to a game of catch. With the two-nucleon force, two players, or nucleons, interact by throwing a ball to each other. The ball, a subatomic particle called a meson, can vary in heaviness, with the lightest meson, known as a pion, responsible for the long-range attraction between nucleons. With the three-nucleon force, there are three players, or nucleons, and balls, or mesons, are passed between them.

Credit: Tokuro Fukui / Kyushu University

Although the three-nucleon force has historically been considered to be of little significance when compared to the two-nucleon force, a growing number of recent studies have highlighted its importance. Now, this new study clarifies the mechanism of how the three-nucleon force enhances nuclear stability, and demonstrates that as the nucleus grows, the force gains in strength.

In their research, Fukui and his colleagues used advanced nuclear theory and supercomputer simulations to study the exchange of pions between three nucleons. They found that when two pions are exchanged between three nucleons, the nucleons are constrained in how they move and spin, with only four combinations possible. Their calculations revealed that one of these combinations, known as the "rank-1 component," plays a crucial role in promoting nuclear stability.

Increased stability occurs, Fukui explains, due to enhancing a process known as spin-orbit splitting. When nucleons spin and orbit in the same direction, the alignment of these nucleons leads to a reduction in energy. But when nucleons spin and orbit in opposing directions, these nucleons exist in a higher energy state. This means that nucleons "split" into different energy shells, providing the nucleus with a stable structure.

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"Our [supercomputer simulations](#) showed that while the three-nucleon force increases the energy state of the nucleons with an aligned spin and orbit, it causes the nucleons with opposing spins and orbits to gain even more energy. This results in a larger energy gap between the shells, making the nuclei even more stable," reveals Fukui.

Importantly, this effect becomes more pronounced in heavier nuclei that contain more nucleons. In the heaviest element examined—carbon-12, which has 12 nucleons—the three-nucleon force caused the energy gap to widen by a factor of 2.5.

"This effect is so large that it has almost equal weighting to the impact of the two-nucleon force. We expect the effect to be even stronger for elements heavier than carbon-12, which we plan to study as part of our next steps," says Fukui.

The three-nucleon force could play a key role in understanding how heavy elements form from the fusion of lighter elements in stars. As this force grows stronger in heavier nuclei, it increases their stability by creating larger energy gaps between nuclear shells.

This stability makes it more challenging for the nucleus to capture additional neutrons, which are essential for forming heavier elements. In cases where the nucleus already contains a "magic number" of protons or neutrons that completely fills its shells, the nucleus becomes exceptionally stable, which can further hinder the fusion process.

"Knowing the energy gap between different nuclear shells is crucial information for scientists trying to predict the formation of [heavy elements](#), which they cannot achieve without understanding the three-nucleon force. For magic number nuclei, conditions that provide colossal amounts of energy may be needed," says Fukui.

Finally, the researchers discovered another surprising effect of the three-nucleon force on nucleon spins. With only the two-nucleon force, the spin states of both nucleons can be measured individually. However, the three-nucleon force creates [quantum entanglement](#), where two of the three nucleons have spins that exist in both states at once until measured.

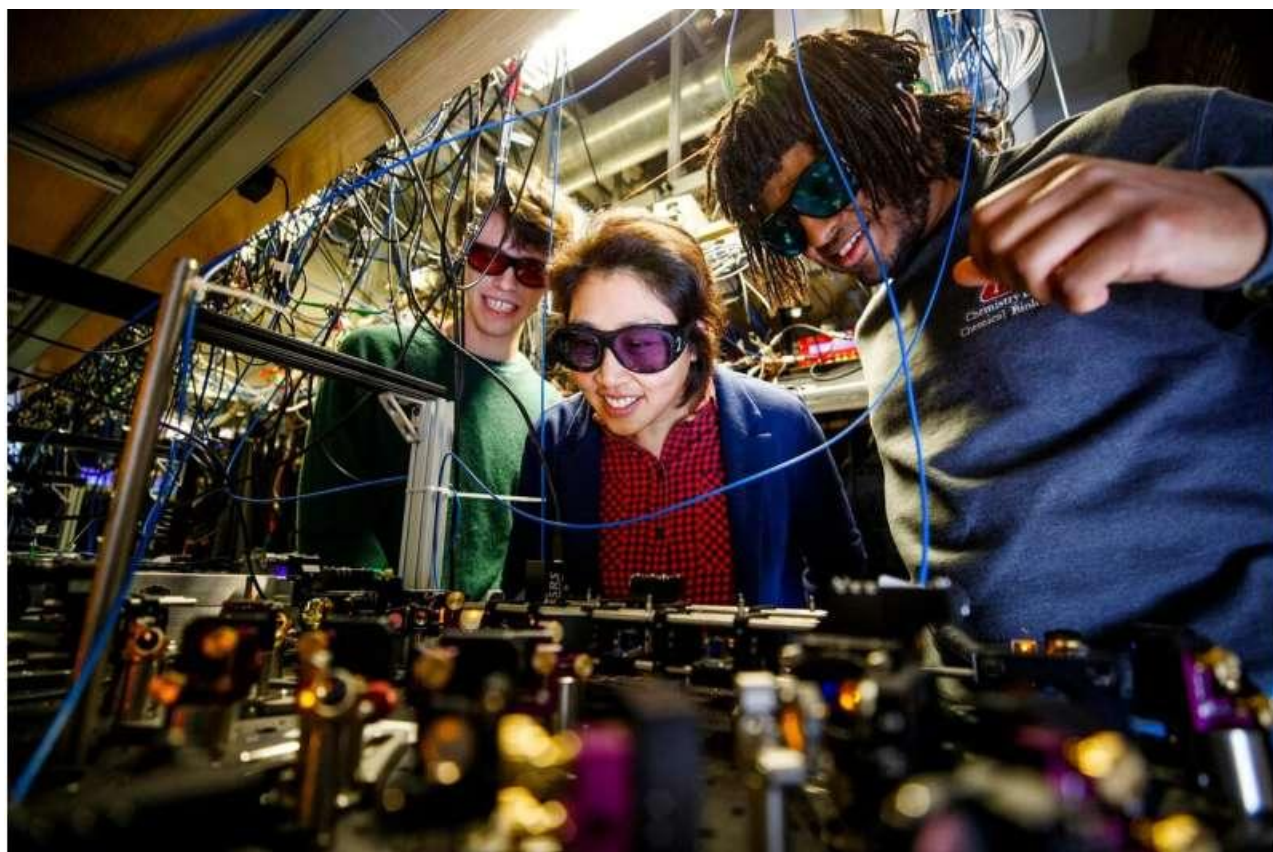
"Quantum entanglement of nucleons can occur just like with electrons, although the larger mass of nucleons presents different challenges. These differences may have implications for future research, including in emerging technologies like quantum computing," concludes Fukui.

More information: Tokuro Fukui et al, Uncovering the mechanism of chiral three-nucleon force in driving spin-orbit splitting, *Physics Letters B* (2024). [DOI: 10.1016/j.physletb.2024.138839](https://doi.org/10.1016/j.physletb.2024.138839)
Journal information: [Physics Letters B](#)
Provided by [Kyushu University](#)

JANUARY 21, 2025

Scientists succeed in trapping molecules to perform quantum operations for the first time

by Yahya Chaudhry, [Harvard University](#)



A team led by Kang-Kuen Ni (center), including Gabriel Patenotte (left) and Samuel Gebretsadkan, among others, successfully trapped molecules to perform quantum operations for the first time. Credit: Grace DuVal

Molecules haven't been used in quantum computing, even though they have the potential to make the ultra-high-speed experimental technology even faster. Their rich internal

structures were seen as too complicated, too delicate, too unpredictable to manage, so smaller particles have been used.

But a team of Harvard scientists has succeeded for the first time in trapping molecules to perform [quantum operations](#). This feat was accomplished by using ultra-cold polar molecules as qubits, or the fundamental units of information that power the technology. The findings, recently [published](#) in the journal *Nature*, open new realms of possibility for harnessing the complexity of molecular structures for future applications.

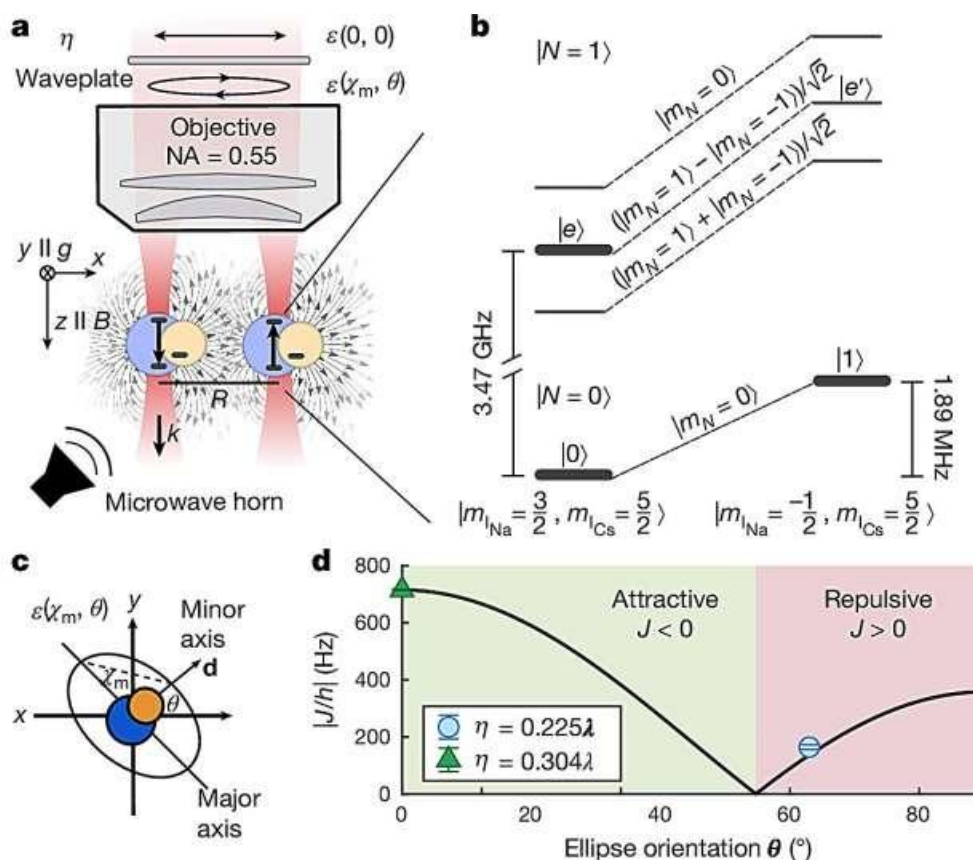
"As a field we have been trying to do this for 20 years," said senior co-author Kang-Kuen Ni, Theodore William Richards Professor of Chemistry and professor of physics. "And we've finally been able to do it."

Physicists and engineers have been working to develop [quantum computing](#) for several decades. The technology, which exploits aspects of quantum mechanics for computation, promises speeds exponentially faster than classical computers, which could enable game-changing advances in fields including medicine, science, and finance.

Dominating the world of quantum computing are experiments with trapped ions, neutral atoms, and superconducting circuits. In these systems, tiny individual particles can be reliably trapped to serve as qubits and form quantum [logic gates](#). The Harvard team's paper details the far more complicated process involved with using molecules to form an iSWAP gate, a key quantum circuit that creates entanglement—the very property that makes quantum computing so powerful.

The researchers started by trapping sodium-cesium (NaCs) molecules with [optical tweezers](#) in a stable and extremely cold environment. The electric dipole-dipole (or positive-negative) interactions between the molecules were then used to perform a quantum operation. By carefully controlling how the molecules rotated with respect to one another, the team managed to entangle two molecules, creating a [quantum state](#) known as a two-qubit Bell state with 94 percent accuracy.

Logic gates enable information processing in quantum computers just as they do in traditional computers. But while classical gates manipulate binary bits (0s and 1s), quantum gates operate on qubits—which can achieve what are called superpositions, existing in multiple states simultaneously. That means quantum computers can do things that would be impossible for traditional machines, such as creating entangled states in the first place—or even performing operations in multiple computational states at once.



NaCs molecules in optical tweezers for dipolar interactions and quantum logic gates.

Credit: *Nature* (2024). DOI: 10.1038/s41586-024-08177-3

Quantum gates are also reversible and capable of manipulating qubits with precision while preserving their quantum nature. The iSWAP gate used in this experiment swapped the states of two qubits and applied what is called a [phase shift](#), an essential step in generating entanglement where the states of two qubits become correlated regardless of the distance in between.

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"Our work marks a milestone in trapped molecule technology and is the last building block necessary to build a molecular quantum computer," said co-author and postdoctoral fellow Annie Park. "The unique properties of molecules, such as their rich internal structure, offer many opportunities to advance these technologies."

Scientists have dreamed since the 1990s of harnessing molecular systems, with their nuclear spins and nuclear magnetic resonance techniques, for quantum computing. A series of early experiments showed encouraging results, but molecules proved generally unstable for use in quantum operations due to their unpredictable movements. That can interfere with coherence, the delicate quantum state necessary for reliable operations.

But trapping molecules in ultra-cold environments, where the molecule's intricate internal structures can be controlled, helps overcome this hurdle. Once holding these molecules with optical tweezers—with precisely focused lasers for controlling tiny objects—researchers were able to minimize the [molecules'](#) motion and manipulate their quantum states.

Making this breakthrough possible were several members of Ni's lab including Lewis R.B. Picard, Annie J. Park, Gabriel E. Patenotte, and Samuel Gebretsadkan, as well as physicists with the University of Colorado's Center for Theory of Quantum Matter.

To evaluate the whole operation, the research team measured the resulting two-qubit Bell state and studied errors caused by any motion that did occur. This left them with ideas for improving the stability and accuracy of their setup in future experiments. Switching between interacting and non-interacting states also enabled researchers to digitize their experiment, providing additional insights.

"There's a lot of room for innovations and new ideas about how to leverage the advantages of the molecular platform," Ni said. "I'm excited to see what comes out of this."

More information: Lewis R. B. Picard et al, Entanglement and iSWAP gate between molecular qubits, *Nature* (2024). [DOI: 10.1038/s41586-024-08177-3](https://doi.org/10.1038/s41586-024-08177-3)

Journal information: [Nature](#)
Provided by [Harvard University](#)

JANUARY 23, 2025

New tool enables phylogenomic analyses of entire genomes

by [University of California - San Diego](#)



DNA, which has a double-helix structure, can have many genetic mutations and variations.

Credit: NIH

Researchers led by electrical engineers at the University of California San Diego have developed a better way to perform the comparative analysis of entire genomes. This approach can be used to study relationships between different species across geological time scales.

This new approach is poised to unlock discoveries regarding how evolution has shaped present-day genomes and also how the tree of life is organized. The new method, named CASTER, is [described in a paper](#) published in *Science* on 23 January 2025.

CASTER is poised to offer biologists a far more scalable approach than state-of-the-art for comparing full genomes. This is especially relevant given the exploding number of sequenced genomes of both living and also [extinct species](#).

All these genomes are available for [comparative study](#) through phylogenomic analyses. CASTER provides interpretable outputs that will help biologists understand not only the species relationships but also the mosaic of evolutionary histories across the [genome](#).

"Since the early 2000s, countless studies have claimed 'genome-wide' phylogeny reconstruction; however, these have been all based on subsampling regions scattered across the genomes, totaling only a small fraction of each full genome that is part of any given study. Analyzing all genomic positions while using complex models had seemed out of reach," said Siavash Mirarab, an electrical engineering professor at UC San Diego and the corresponding author of the *Science* paper.

"What excites me is that we can now perform truly genome-wide analyses using every base pair aligned across species with widely available computational resources."

"Arriving at this milestone required combined efforts from many disciplines, including statistics, [computer science](#), and biology," said Chao Zhang, the first author on the paper.

Zhang completed his Ph.D. at UC San Diego in the Bioinformatics and Systems Biology program. He is now on the faculty of the University of Copenhagen.

More information: Chao Zhang et al, CASTER: Direct species tree inference from whole-genome alignments, *Science* (2025). [DOI:](#)

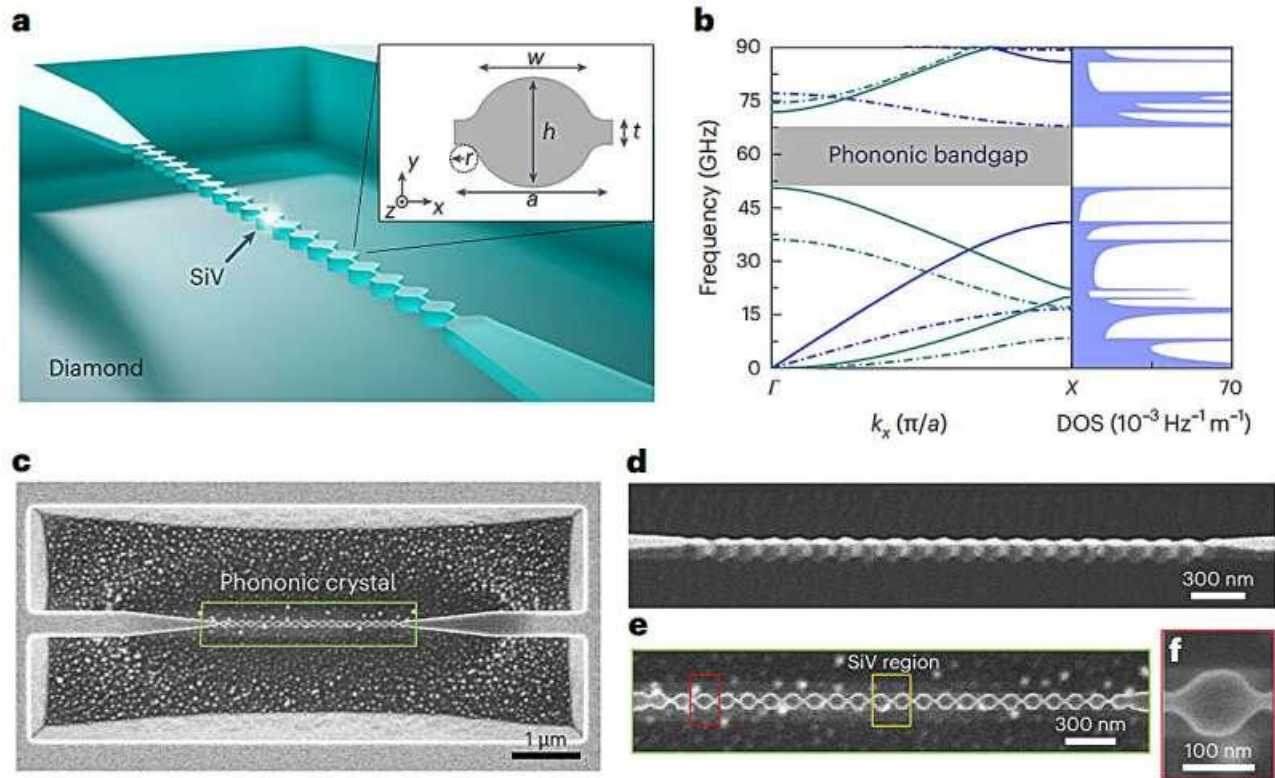
[10.1126/science.adk9688](https://doi.org/10.1126/science.adk9688). www.science.org/doi/10.1126/science.adk9688

Journal information: [Science](#)

Provided by [University of California - San Diego](#)

JANUARY 21, 2025

Newly fabricated crystals control interactions between high-frequency phonons and single quantum systems



Diamond phononic crystals for suppressing high-frequency phonons that induce decoherence in single silicon-vacancy (SiV) centers. Credit: Kuruma et al. (*Nature Physics*, 2024. DOI: 10.1038/s41567-024-02697-5)

Phonons, the quantum mechanical vibrations of atoms in solids, are often sources of noise in solid-state quantum systems, including quantum technologies, which can lead to decoherence and thus adversely impact their performance.

Strategies to reliably control phonons and their interactions with quantum systems could help to mitigate the adverse effects of these vibrations on the systems.

Researchers at Harvard University and other institutes have introduced a new approach to control the interactions between high-frequency phonons and single solid-state quantum systems. Their proposed method, outlined in a paper [published](#) in *Nature Physics*, relies on new diamond phononic crystals that they designed and fabricated, which can be used to engineer the local density of states in a host material.

"The ability to control phonons in solids is key since they often act as a source of noise and decoherence for solid-state quantum systems," Kazuhiro Kuruma, first author of the paper, told Phys.org.

"The primary objective of our study was to demonstrate the control of the phononic local density of states of the host matrix using phononic crystals to suppress spontaneous single-phonon processes that induce the decoherence in individual quantum systems."

Kuruma and his colleagues were able to design and fabricate diamond-based phononic crystals with nanoscale precision, embedding silicon-vacancy color centers within them. Using their newly fabricated crystals, the team observed an 18-fold reduction in the phonon-induced orbital relaxation rate, suggesting that these crystals suppress single-photon processes in the color centers.

"One of the most difficult parts of this study was the fabrication of phononic crystals in diamond," explained Kuruma. "We carefully optimized a diamond etching process to fabricate these crystals with very small features down to 20 nm into single crystal diamond."

The new diamond phononic crystals designed by the researchers were successfully used to control the interactions between the high-frequency phonons and color centers. Specifically, Kuruma and his colleagues found that these crystals could suppress interactions between single phonons and a quantum emitter at temperatures up to 20K.

"We demonstrated phononic crystals that can suppress high-frequency phonons from 50 to 70 GHz," said Kuruma. "In addition, we demonstrated that spontaneous single-phonon processes in single quantum systems are suppressed by the phononic crystals even when increasing temperatures up to 20 K."

In the future, the approach employed by this team of researchers and the phononic crystals they fabricated could contribute to the development of advanced [quantum technologies](#) that can benefit from the reliable control of phonon interactions, such as quantum phononic networks and quantum acoustic systems.

In addition, this recent study could inform future research rooted in acoustodynamics, an emerging field that focuses on quantum phenomena involving acoustic waves.

"Our results not only open the possibility of efficiently controlling specific high-frequency [phonons](#) for applications in [radio-frequency signal processing](#), optomechanics, nonlinear phononics and thermoelectrics, but also could improve the properties of solid-state [quantum systems](#) at higher temperatures."

More information: Kazuhiro Kuruma et al, Controlling interactions between high-frequency phonons and single quantum systems using phononic crystals, *Nature Physics* (2024). [DOI: 10.1038/s41567-024-02697-5](https://doi.org/10.1038/s41567-024-02697-5).

Journal information: [Nature Physics](#)

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JANUARY 21, 2025

First fast radio burst traced to old, dead, elliptical galaxy

by [Northwestern University](#)



Astronomers first detected the new FRB, dubbed FRB 20240209A, in February 2024 with the Canadian Hydrogen Intensity Mapping Experiment (CHIME). Credit: CHIME, Andre Renard, Dunlap Institute for Astronomy & Astrophysics, University of Toronto
For the first time, astronomers have traced a fast radio burst (FRB) to the outskirts of an ancient, dead, elliptical galaxy—an unprecedented home for a phenomenon previously associated with much younger galaxies.

Detailed in two complementary studies led by Northwestern University and McGill University, the discovery shatters assumptions that FRBs solely emanate from regions of active star formation. The new observational evidence, instead, hints that the origins of these mysterious cosmic events might be more diverse than previously thought.

Both studies were published on Jan. 21 in the *Astrophysical Journal Letters*.

"The prevailing theory is that FRBs come from magnetars formed through [core-collapse supernovae](#)," said Northwestern's Tarraneh Eftekhari, who led one of the studies and coauthored the other.

"That doesn't appear to be the case here. While young, [massive stars](#) end their lives as core-collapse supernovae, we don't see any evidence of young stars in this galaxy. Thanks to this new discovery, a picture is emerging that shows not all FRBs come from young stars. Maybe there is a subpopulation of FRBs that are associated with older systems."

"This new FRB shows us that just when you think you understand an astrophysical phenomenon, the universe turns around and surprises us," said Northwestern's Wen-fai Fong, a senior author on both studies. "This 'dialogue' with the universe is what makes our field of time-domain astronomy so incredibly thrilling."

Eftekhari is a NASA Einstein Fellow at Northwestern's Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA). Fong is an associate professor of physics and astronomy at Northwestern's Weinberg College of Arts and Sciences and a member of CIERA.

A first for the CHIME outrigger telescopes

Astronomers first detected the new FRB, dubbed FRB 20240209A, in February 2024 with the Canadian Hydrogen Intensity Mapping Experiment (CHIME). Flaring up and disappearing within milliseconds, FRBs are brief, powerful radio blasts that generate more energy in one quick burst than our sun emits in an entire year.

But this event flared up more than once. Between the initial burst in February through July 2024, the same source produced another 21 pulses—six of which were also detected by an outrigger telescope located 60 kilometers away from CHIME's main station. Smaller versions of CHIME, the outriggers, enable astronomers to precisely confine the specific locations of FRBs in the sky.

Most massive FRB host galaxy to date

After the team pinpointed the FRB's position, Eftekhari and her collaborators hurried to use telescopes at the W.M. Keck and Gemini observatories to explore the event's surrounding environment.

In a specialized room on the Evanston campus, Northwestern astronomers have remote access to Keck, which enables them to quickly observe phenomena of high interest.

Instead of finding a young galaxy, these observations surprisingly revealed that the FRB originated at the edge of an 11.3-billion-year-old neighboring galaxy, located just 2 billion lightyears from Earth.

To learn more about this unusual host galaxy, the team used high-performance computers to run simulations. They found that the galaxy is extremely luminous and incredibly massive—100 billion times the mass of our sun.

"It seems to be the most massive FRB host galaxy to date," Eftekhari said. "It's among some of the most massive galaxies out there."

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A far-flung home

But, while most FRBs originate well within their galaxies, the team traced FRB 20240209A to the outskirts of its home—130,000 lightyears from the galaxy's center where few other stars exist.

"Among the FRB population, this FRB is located the furthest from the center of its host galaxy," said Vishwangi Shah, a graduate student at McGill, who led the effort to pinpoint the FRB's origins.

"This is both surprising and exciting, as FRBs are expected to originate inside galaxies, often in [star-forming regions](#). The location of this FRB so far outside its host galaxy raises questions as to how such energetic events can occur in regions where no new stars are forming."

'Twinning' FRBs

Before this discovery, astronomers had traced only one other FRB to the outer fringes of a galaxy. In 2022, an international team of astronomers detected an FRB, which emanated from a tight cluster of stars on the edge of Messier 81 (M81), a grand design spiral galaxy located about 12 million light years from Earth. Although FRB 20240209A occurred in an [elliptical galaxy](#), the two events share several other similarities.

"A few years ago, the M81 FRB was surprisingly discovered within a dense cluster of stars called a globular cluster," Fong said.

"That event single-handedly halted the conventional train of thought and made us explore other progenitor scenarios for FRBs. Since then, no FRB had been seen like it, leading us to believe it was a one-off discovery—until now.

"In fact, this CHIME FRB could be a twin of the M81 event. It is far from its home galaxy (far away from where any stars are being born), and the population of stars in its home galaxy is extremely old. It's had its hey-day and is now coasting into retirement. At the same time, this type of old environment is making us rethink our standard FRB progenitor models and turning to more exotic formation channels, which is exciting."

Out of the nearly 100 FRBs that have been pinpointed to a galaxy so far, most have likely originated from magnetars, which are formed through core-collapse supernovae. Astrophysicists posit FRB 20240209A's origin, however, might be similar to the FRB found in M81.

Possible explanations

The McGill-led study discusses the likelihood that the new FRB originated within a dense globular cluster. Such clusters are promising sites for magnetars possibly formed through other mechanisms and associated with older stars, including through the merger of two neutron stars or from a white dwarf collapsing under its own gravity.

"A globular cluster origin for this repeating FRB is the most likely scenario to explain why this FRB is located outside its host galaxy," Shah said.

"We do not know for a fact if there is a globular cluster present at the FRB position and have submitted a proposal to use the James Webb Space Telescope for follow-up observations of the FRB location. If yes, it would make this FRB only the second FRB known to reside in a globular cluster. If not, we would have to consider alternative exotic scenarios for the FRB's origin."

"It's clear that there's still a lot of exciting discovery space when it comes to FRBs," Eftekhari said, "and that their environments could hold the key to unlocking their secrets."

More information: A repeating fast radio burst source in the outskirts of a quiescent galaxy, *The Astrophysical Journal Letters*. [iopscience.iop.org/article/10. ... 847/2041-8213/ad9ddc](https://iopscience.iop.org/article/10.1086/518472041-8213/ad9ddc) . On arXiv: [DOI: 10.48550/arxiv.2410.23374](https://doi.org/10.48550/arxiv.2410.23374)

The massive and quiescent elliptical host galaxy of the repeating fast radio burst FRB 20240209A, *The Astrophysical Journal Letters* (2025). [iopscience.iop.org/article/10. ... 847/2041-8213/ad9de2](https://iopscience.iop.org/article/10.1086/518472041-8213/ad9de2) , arxiv.org/abs/2410.23336

Journal information: [Astrophysical Journal Letters](#) , [arXiv](#)
Provided by [Northwestern University](#)

JANUARY 17, 2025

Space itself may have created galaxies

[Universe Today](#)



Credit: Pixabay/CC0 Public Domain

According to new research, the earliest seeds of structures may have been laid down by gravitational waves sloshing around in the infant universe.

Cosmologists strongly suspect that the extremely [early universe](#) underwent a period of exceptionally rapid expansion. Known as [inflation](#), this event expanded the universe by a factor of at least 10^{60} in less than a second. Powering this event was a new ingredient in the cosmos known as the inflaton, a strange quantum field that ramped up, drove inflation, and then faded away.

Inflation didn't just make the universe big. It also laid down the seeds of the first structures. It did so by taking the quantum foam, the subatomic fluctuations in spacetime itself, and expanding that along with everything else. Slowly, over time, those fluctuations grew, and hundreds of millions of years later they became the [first stars](#) and galaxies, ultimately leading to the largest structure in the universe, the cosmic web.

But mysteries remain. We do not know the identity of the inflaton, or what powered it, or why it turned off when it did. And we have no conclusive evidence that inflation actually happened.

So researchers are always looking for alternatives, especially ones that don't invoke some new and mysterious ingredient. In [a recent paper](#) posted to the *arXiv* preprint server, a team

of astrophysicists describe a model where inflation happens, leading to the large-scale structure of the universe, all without an inflaton.

The model described by the researchers is set in the backdrop of an expanding universe that is accelerating in its expansion, just like the modern-day universe is. In that expanding universe, the quantum foam releases [gravitational waves](#). Those ripples in space spread outwards, colliding with each other and amplifying themselves.

Gravitational waves usually can't create structures on their own, but the researchers found that in certain special cases the gravitational waves can amplify each other in just the right way. When that happens, the imprints they make in space are nearly the same at a wide variety of length scales.

This is precisely what cosmologists observe in the [cosmic microwave background](#), the leftover light from the early universe. This radiation contains a faint impression of the echoes of inflation, and it shows that whatever set the seeds of structure, it had to have that kind of pattern.

There are slight differences between the kinds of structures generated in this inflation-without-inflaton scenario and traditional inflation. In this first paper, the researchers did not yet calculate how strong those differences are, but an important next step is to explore the observational consequences of this model and see if it's worth investigating further.

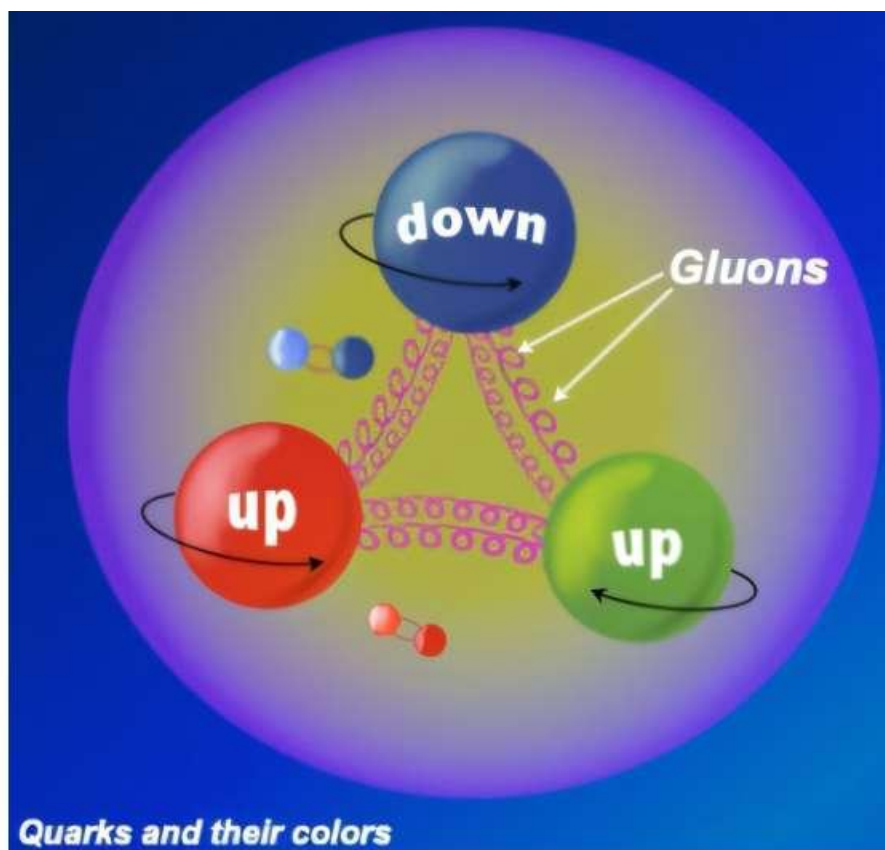
More information: Daniele Bertacca et al, Inflation without an Inflaton, *arXiv* (2024). [DOI: 10.48550/arxiv.2412.14265](#)

Journal information: [arXiv](#)
Provided by [Universe Today](#)

JANUARY 13, 2025

New approach merges theoretical fundamentals with experimental studies of the proton's structure

by [US Department of Energy](#)



Artist's depiction of a proton's interior. In quantum chromodynamics, the constituent quarks come in three "colors," along with up and down "flavors." Also shown are virtual quark-antiquark pairs and the gluons that bind the quarks together. Credit: Ted Rogers

Protons and other subatomic particles that are subject to the strong nuclear force have a complex structure that involves even more fundamental constituents called quarks and gluons. These quarks and gluons bind under the influence of quantum chromodynamics (QCD). QCD is the theory of strong interaction of quarks and the role of color symmetry.

However, the mechanisms that lead to [quarks](#) and [gluons](#) combining to form the particles we see in nature are very mysterious and poorly understood. For example, virtual quarks and gluons constantly appear and disappear within our current picture of the dynamics in the proton. So, which quarks and gluons are actually "in" a proton is a difficult question to answer.

Much of the experimental work related to extracting the quark and gluon structure of protons occurs at existing [particle accelerators](#) like the Thomas Jefferson National Accelerator Facility and the [Relativistic Heavy Ion Collider](#), and in the future at the [Electron Ion Collider](#).

A major part of QCD research is driven by the goal of solving open fundamental questions at the heart of how QCD operates and how quantum mechanical theories can be merged with the theory of relativity.

Recent progress in theoretical QCD has opened the way to connecting questions about the structure of particles like the proton with high-energy particle collision measurements.

As theorists generate new ideas about QCD, other researchers plan experiments to test those ideas. These tests involve colliding particles like electrons and protons at high energies and then examining the results.

By extrapolating backwards in time, physicists will use the remnants of the collisions to infer information about the structure of the original particles.

However, the same theoretical difficulties that motivated these studies have left a key question unresolved. Namely, how do scientists relate the physics of the specific collisions with the physics of the internal structure of the particles themselves?

Now, work [published](#) in the journal *Physical Review D* provides the toolbox needed to resolve this question while also accounting for the theoretical subtleties.

A large part of current research into the structure of the proton, both theoretical and experimental, involves identifying, extracting, and analyzing the bound state distributions of quarks and gluons in the proton, mapping out their motion, and understanding how this relates to the overall observed properties of the proton like its spin and mass.

In the past, researchers found inconsistencies in the way physicists combined fundamental QCD theory to the study of data. The new theoretical results provide a clear recipe and boost confidence that data taken in future experiments can be reliably interpreted.

More information: F. Aslan et al, Phenomenology of TMD parton distributions in Drell-Yan and Z0 boson production in a hadron structure oriented approach, *Physical Review D* (2024). [DOI: 10.1103/PhysRevD.110.074016](https://doi.org/10.1103/PhysRevD.110.074016)

Journal information: [Physical Review D](#)

Provided by [US Department of Energy](#)

JANUARY 15, 2025

'Magic-wavelength optical tweezers' achieve quantum entanglement of molecules

by [Durham University](#)

An illustration of two entangled molecules which are individually trapped in magic-wavelength optical tweezers. Credit: Durham University

Researchers at Durham University have successfully demonstrated long-lasting quantum entanglement between molecules, opening new doors for future advancements in quantum computing, sensing, and fundamental physics. The paper is [published](#) in the journal *Nature*.

In a world-first, scientists used precisely controlled [optical traps](#), known as "magic-wavelength [optical tweezers](#)," to create a highly stable environment that supports long-lasting entanglement, a key capability for next-generation quantum technology.

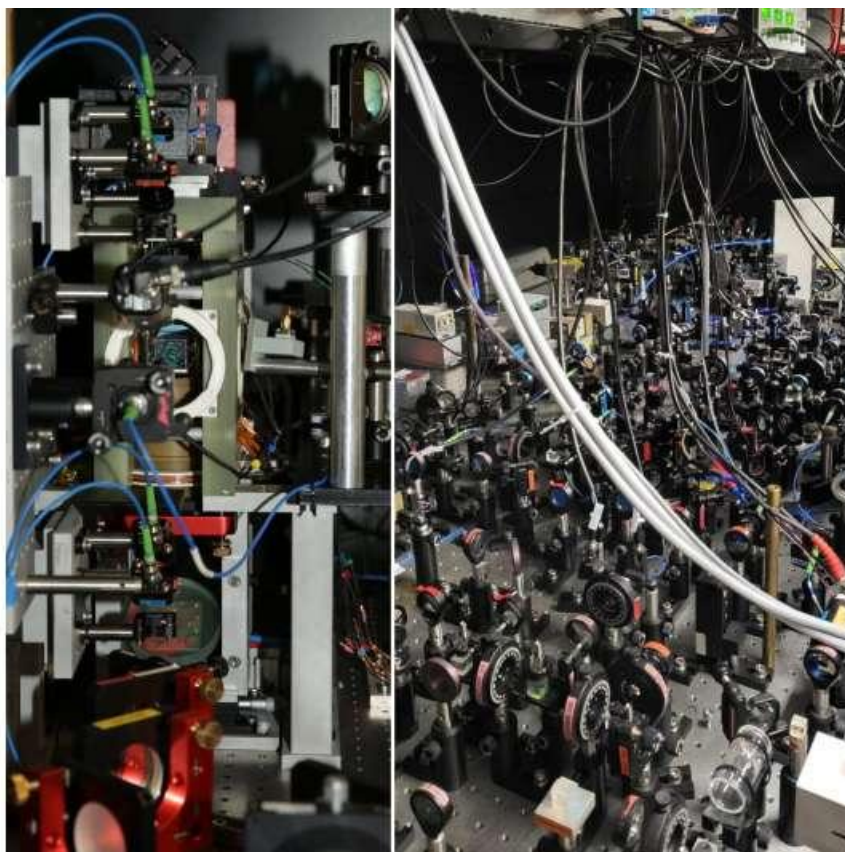
Quantum entanglement is a fundamental phenomenon where two particles become linked, and the state of one particle directly influences the other, regardless of the distance between them.

This phenomenon is essential for [quantum computing](#) and other advanced technologies.

While entanglement has been achieved with atoms, achieving it with [complex molecules](#) is a significant step forward because molecules offer additional structures and properties, such as vibration and rotation, that can be leveraged in advanced quantum applications.

Lead author of the study, Professor Simon Cornish of Durham University, said, "The results highlight the remarkable control we have over individual molecules. Quantum entanglement is very fragile, yet we can entangle two molecules using incredibly [weak interactions](#) and then prevent loss of the entanglement for a time approaching one second."

This breakthrough was made possible by the development of a stable environment that maintains coherence in entangled molecules over extended periods.



The team trap molecules in a vacuum chamber (left) using magic-wavelength tweezers and other laser beams (right). Credit: Durham University

By using specially tuned [laser light](#) in the optical tweezers, the researchers are able to control molecules with unprecedented precision, paving the way for more complex quantum operations.

Co-author of the study, Dr. Daniel Ruttley of Durham University, said, "Our work demonstrates the incredible potential of molecules as building blocks for next-generation quantum technologies. Long-lived molecular entanglement could be exploited to construct quantum computers or precise quantum sensors and to understand the quantum nature of complex materials."

The research achieved exceptionally high entanglement fidelity, reaching levels over 92% and even higher when accounting for correctable errors. This stability in molecule entanglement is critical for applications requiring long measurement periods and storage of quantum information.

Long-lived entanglement in molecules could enhance precision measurements in quantum sensing, simulate complex quantum materials, and enable new forms of quantum computation.

Additionally, this research supports the development of "quantum memories"—devices that store quantum information for longer durations, essential for advanced quantum networks.

The breakthrough is the latest in a series of advancements in quantum science and represents a major leap towards using molecules in complex quantum technology.

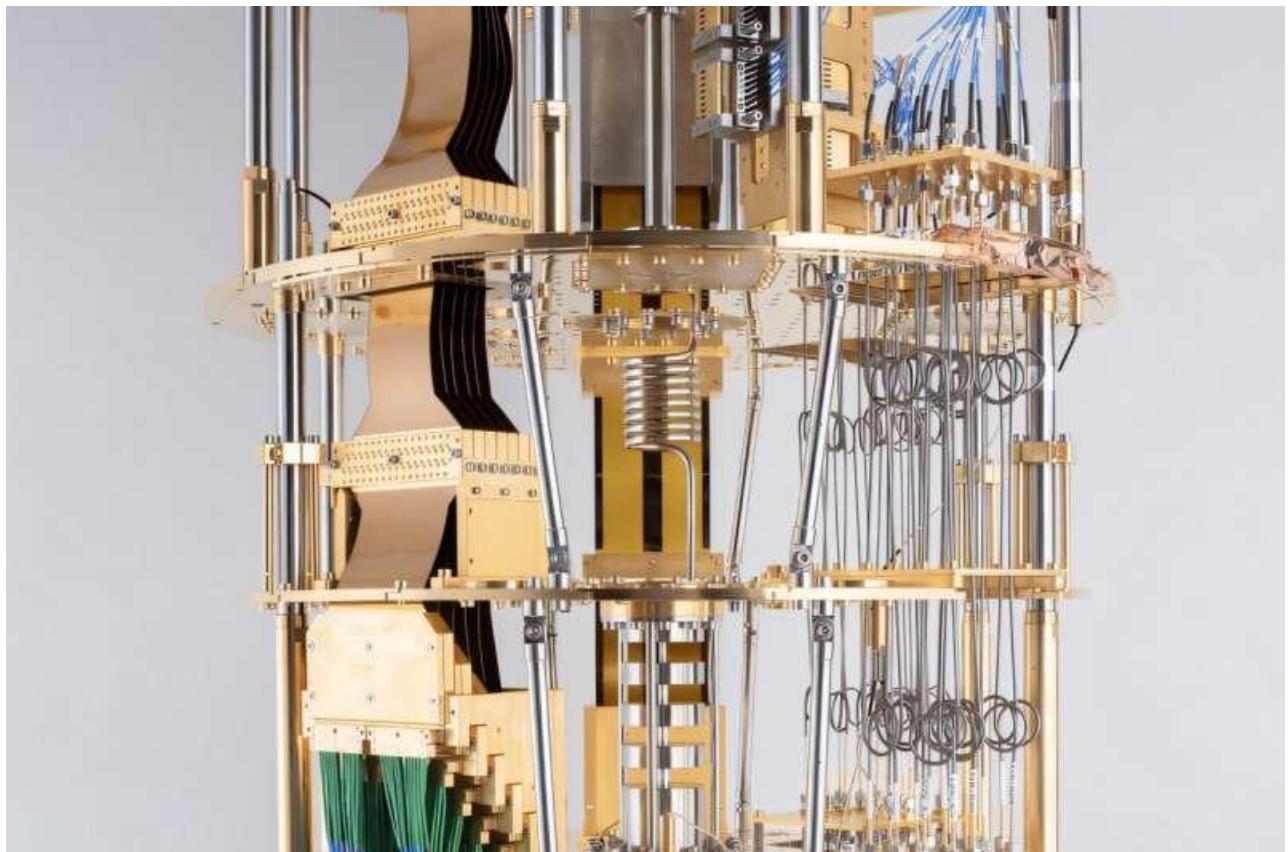
More information: Simon Cornish et al, Long-lived entanglement of molecules in magic-wavelength optical tweezers, *Nature* (2025). DOI: [10.1038/s41586-024-08365-1](https://doi.org/10.1038/s41586-024-08365-1). www.nature.com/articles/s41586-024-08365-1

Journal information: [Nature](#)
Provided by [Durham University](#)

JANUARY 14, 2025

Quantum experiment generates long-range entanglement in 54-qubit system

by Ingrid Fadelli , Phys.org



IBM Quantum dilution refrigerator. Credit: IBM.

The operation and performance of quantum computers relies on the ability to realize and control entanglement between multiple qubits. Yet entanglement between many qubits is inherently susceptible to noise and imperfections in quantum gates.

In recent years, [quantum physicists](#) and engineers worldwide have thus been trying to develop more robust protocols to realize and control entanglement. To be most effective for real-world applications, these approaches should reliably support long-range entanglement, or in other words ensure that qubits remain entangled even when they are separated by large distances.

Researchers at IBM Quantum, University of Cologne and Harvard University set out to demonstrate one of these protocols in an experimental setting.

Their paper, [published](#) in *Nature Physics*, demonstrates the generation of long-range entanglement and a mixed state phase transition in a system comprised of 54 qubits on the `ibm_sherbrooke` quantum computer, which is powered by a 127-qubit IBM Eagle quantum processor.

"In 2022, teams at the University of Cologne's Institute for Theoretical Physics and Harvard's Department of Physics [posted an arXiv pre-print](#) in which they proposed a theoretical protocol to produce a widely studied long-range entangled state," Edward H. Chen, co-first author of the paper and researcher at IBM Quantum, told Phys.org.

"This paper caught the attention of our team at IBM. The protocol it introduced was not only relevant for the broad condensed matter community, but it also had relevance to the long-term interest of performing quantum error correction."

The recent study by Chen and his colleagues builds on the previous theoretical work of researchers at University of Cologne and Harvard, who introduced a new protocol to realize a long-range entangled state, known as the Ising order in a system with multiple qubits.

As IBM Quantum has an active collaboration with Harvard, they reached out to the university and initiated a collaboration with some of the researchers who introduced the protocol.

"The protocol entails the use of very few layers of [quantum gates](#) to create a minimal amount of entanglement between two sets of qubits and then measure out one set of them so as to consolidate the other set, leveraging the backaction of quantum measurements," explained Gui-Yi Zhu, co-first author of the paper.



The IBM Quantum Eagle process. Credit: Carl De Torres of StoryTK for IBM.

"Another indispensable ingredient is the communication between the measured classical bits and the unmeasured qubits, akin to the idea of quantum teleportation, which was essentially the game that Ed and I were playing."

In their experiments, Chen, Zhu and their colleagues used classical decoding to extract and stabilize the quantum order in their 54-qubit system that was masked by noise. They found that this order persisted despite the errors in the system, up until the system entered a so-called Nishimori transition.

This critical phase transition was rare and classical systems require fine-tuning to reach this state. In contrast, the researchers found that this state emerged naturally in their quantum system, due to a rule that governs quantum measurement, known as Born's rule. Moreover, this phenomenon, which is rare in classical systems, was recently found to be ubiquitous in the open quantum systems, such as [quantum error correction](#) and topological phase of matter.

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"Ours is the first quantum experiment that harnesses Born's rule to create the celebrated Nishimori critical state without the need of fine-tuning as in the classical world," said Zhu.

"In retrospect, it realizes a generalized version of the spontaneous symmetry breaking in the open quantum system, dubbed strong-to-weak spontaneous symmetry breaking, which is a hot topic in theoretical physics recently motivated by the advent of quantum technologies."

The findings of this recent study could have important implications for the development of quantum computing systems. In the future, the protocol and methods used by Chen, Zhu and their colleagues could contribute to the scaling of quantum processors, while also informing research assessing the performance of large quantum computers in noisy environments.

"As authorities at the intersection of quantum information and condensed matter physics, Guo-Yi Zhu and Simon Trebst extended the insights from this work to consider the impact of sequential rounds of the protocol in different bases and the possibility of simulating spin liquids," added Chen.

"Ruben Verresen, along with Nathanan Tantivasadakarn and Ashvin Vishwanath, had the foresight years ago to study the impact of measurements and feed-forward in general for strongly interacting systems, and are also pioneers in this area. We are currently considering ways to mitigate the leading errors so that we could, in fact, perform multiple rounds of the protocol on our latest devices."

Chen and his colleagues at IBM Quantum are now working on improving the protocol they employed, while also developing new hardware that will be released over the next few years. By 2029, they expect to realize a highly performing quantum system that is capable of error correction.

More information: Edward H. Chen et al, Nishimori transition across the error threshold for constant-depth quantum circuits, *Nature Physics* (2024). [DOI: 10.1038/s41567-024-02696-6](https://doi.org/10.1038/s41567-024-02696-6)
Journal information: [Nature Physics](#) , [arXiv](#)

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JANUARY 14, 2025

Diamond continues to shine: New properties discovered in diamond semiconductors

by [Case Western Reserve University](#)



Metal nanoparticles in glass create the colors in stained glass when light hits them and generates plasmons. Credit: John Luty

Diamond, often celebrated for its unmatched hardness and transparency, has emerged as an exceptional material for high-power electronics and next-generation quantum optics. Diamond can be engineered to be as electrically conductive as a metal, by introducing impurities such as the element boron.

Researchers from Case Western Reserve University and the University of Illinois Urbana-Champaign have now discovered another interesting property in diamonds with added [boron](#), known as boron-doped diamonds.

Their findings could pave the way for new types of biomedical and quantum optical devices—faster, more efficient, and capable of processing information in ways that classical technologies cannot. Their results are published in *Nature Communications*.

The researchers found that boron-doped diamonds exhibit plasmons—waves of electrons that move when light hits them—allowing electric fields to be controlled and enhanced on a nanometer scale. This is important for advanced biosensors, nanoscale optical devices, and for improving solar cells and quantum devices.

Previously, boron-doped diamonds were known to conduct electricity and become superconductors, but not to have plasmonic properties. Unlike metals or even other doped semiconductors, boron-doped [diamonds](#) remain optically clear.

"Diamond continues to shine," said Giuseppe Strangi, professor of physics at Case Western Reserve, "both literally and as a beacon for scientific and technological innovation. As we step further into the era of [quantum computing](#) and communication, discoveries like this bring us closer to harnessing the full potential of materials at their most fundamental level."

"Understanding how doping affects the optical response of semiconductors like diamond changes our understanding of these materials," said Mohan Sankaran, professor of nuclear, plasma and radiological engineering at Illinois Grainger College of Engineering.



The stunning blue color of the famous Hope Diamond comes from trace amounts of boron in the crystal. Credit: Julian Fong

Plasmonic materials, which affect light at the nanoscale, have captivated humans for centuries, even before their [scientific principles](#) were understood. The [vibrant colors in medieval stained-glass windows](#) result from [metal nanoparticles](#) embedded in the glass.

When light passes through, these particles generate plasmons that produce specific colors. Gold nanoparticles appear ruby red, while silver nanoparticles display a vibrant yellow. This ancient art highlights the interaction between light and matter, inspiring modern advancements in nanotechnology and optics.

Diamonds, composed of transparent crystals of the element carbon, can be synthesized with small amounts of boron, adjacent to carbon on the periodic table. Boron contains one less electron than carbon, allowing it to accept electrons. Boron essentially opens up a periodic electronic "hole" in the material that has the effect of increasing the ability of the material to conduct current. The boron-doped diamond lattice remains transparent, with a blue hue. (The famous Hope Diamond is blue because it contains small amounts of boron).

Because of its other [unique properties](#)—it's also chemically inert and biologically compatible—boron-doped diamond could potentially be used in contexts that other materials could not, such as for [medical imaging or high-sensitivity biochips or molecular sensors](#).

Diamonds synthesized at low pressure were pioneered at Case Western Reserve (then Case Institute of Technology) in 1968 by faculty member John Angus, who died in 2023. Angus was also the first to report on the electrical conductivity of diamond doped with boron..

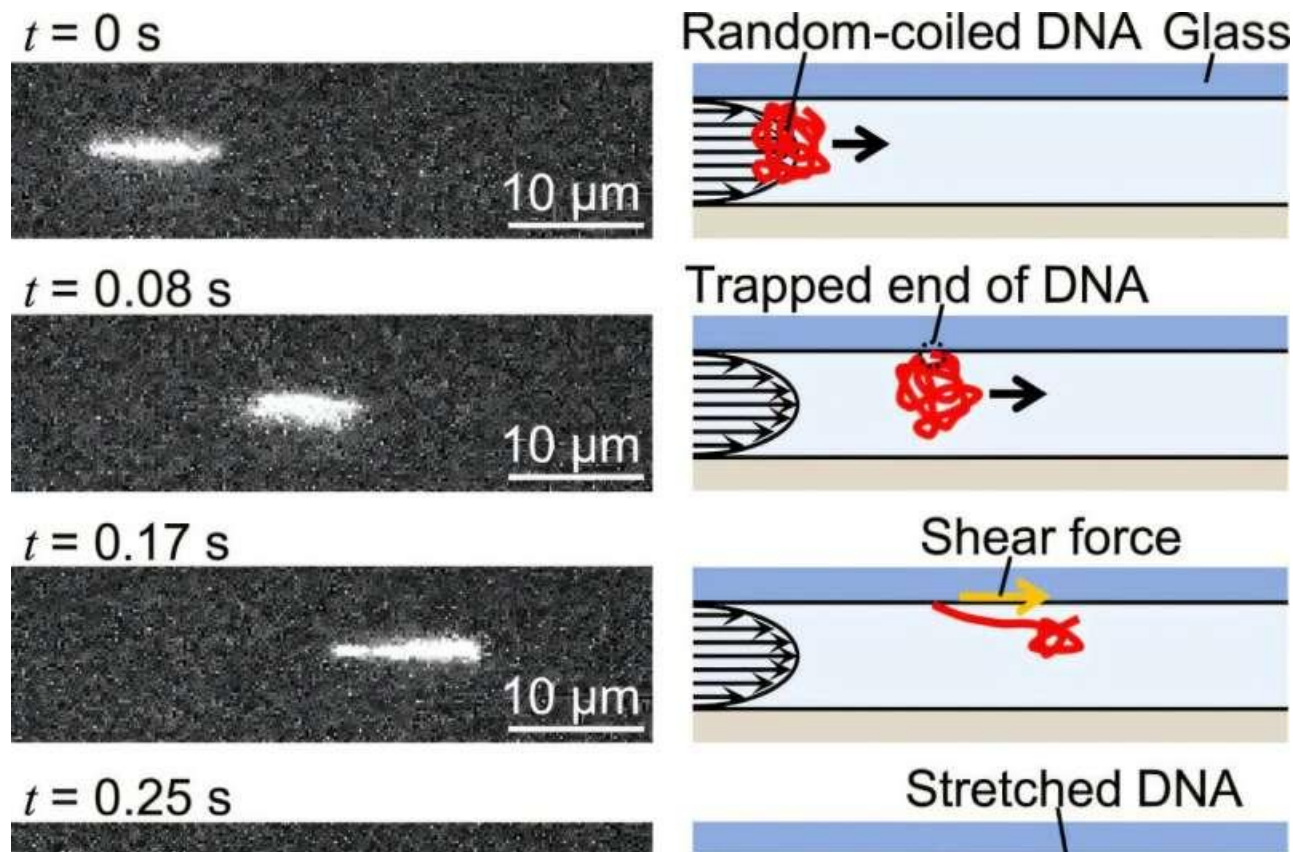
More information: Intervalence plasmons in boron-doped diamond, *Nature Communications* (2025). <https://doi.org/10.1038/s41467-024-55353-0> . On arXiv: [DOI: 10.48550/arxiv.2403.12221](https://arxiv.org/abs/2403.12221)

Journal information: [arXiv](#) , [Nature Communications](#)
Provided by [Case Western Reserve University](#)

JANUARY 14, 2025

Uncurling a single DNA molecule and gluing it down helps sharpen images

by [American Institute of Physics](#)



Fluorescence observation of a single DNA molecule migrating in the microchannel and schematic of the stretch and immobilization processes. The DNA molecule was stained with YOYO-1. After one DNA molecule was trapped on the surface treated by APTES, the DNA molecule was stretched by pressure flow and immobilized. Credit: *AIP Advances* (2025).

DOI: 10.1063/5.0223375

Most microscopes can only illuminate objects down to a certain size before tiny features blur together. This blurring is known as the diffraction limit of light. Super-resolution imaging techniques, however, can distinguish between tiny biomolecular features, especially when thermal fluctuations are minimized.

Using advanced imaging techniques and precise microfluidics control to [stretch](#) out curly DNA into a straight line, research published in *AIP Advances* demonstrates techniques for stretching and immobilizing DNA with minimum thermal fluctuation to enable detailed analysis.

"Immobilizing the molecule essentially 'glues' it to a substrate, preventing any movement caused by thermal fluctuations," author Naoki Azuma said. "Super-resolution imaging often requires just seconds or minutes to capture the image. During this time, thermal fluctuations—random vibrations caused by the molecule's thermal energy—result in blurry images and decreased lateral resolution."

Researchers have previously tried sticking down one end of a DNA molecule to stretch it out, but found that the [thermal fluctuations](#) could still cause movement and blurring.

"Stretching DNA refers to the process of stretching a single DNA molecule, which is originally coiled in a random coil, into a straight line," Azuma said. "The length and structure of a single DNA molecule, its specific base sequence, and its interactions with proteins must be observed by stretching it for detailed analysis."

Azuma and his colleagues at Nagoya University experimented with ways to uncurl a DNA molecule using pressure applied to liquid flowing in a channel, with the pressure flow providing shear force that uncurled the DNA molecule. They found that controlling the flow velocity of the liquid helps fine-tune the [shear force](#) applied and allows precise adjustments of the stretch ratio of the DNA.

Controlling the stretch ratio was a key factor for accurate analysis. In the process, they also used a specialized chemical that creates [chemical bonds](#) between the DNA and a glass substrate to "glue" the DNA molecule in place.

"While it is not yet possible to directly visualize individual base pairs, these methods enable much higher precision in observing molecular-scale structures," Azuma said. "We aim to refine these methods to achieve higher fidelity in stretching and immobilizing DNA molecules for more accurate analysis."

More information: Naoki Azuma et al, Stretching and immobilizing a single DNA molecule on a glass surface using pressure flow in a microchannel for super-resolution imaging, *AIP Advances* (2025). [DOI: 10.1063/5.0223375](https://doi.org/10.1063/5.0223375)

Journal information: [AIP Advances](#)

Provided by [American Institute of Physics](#)

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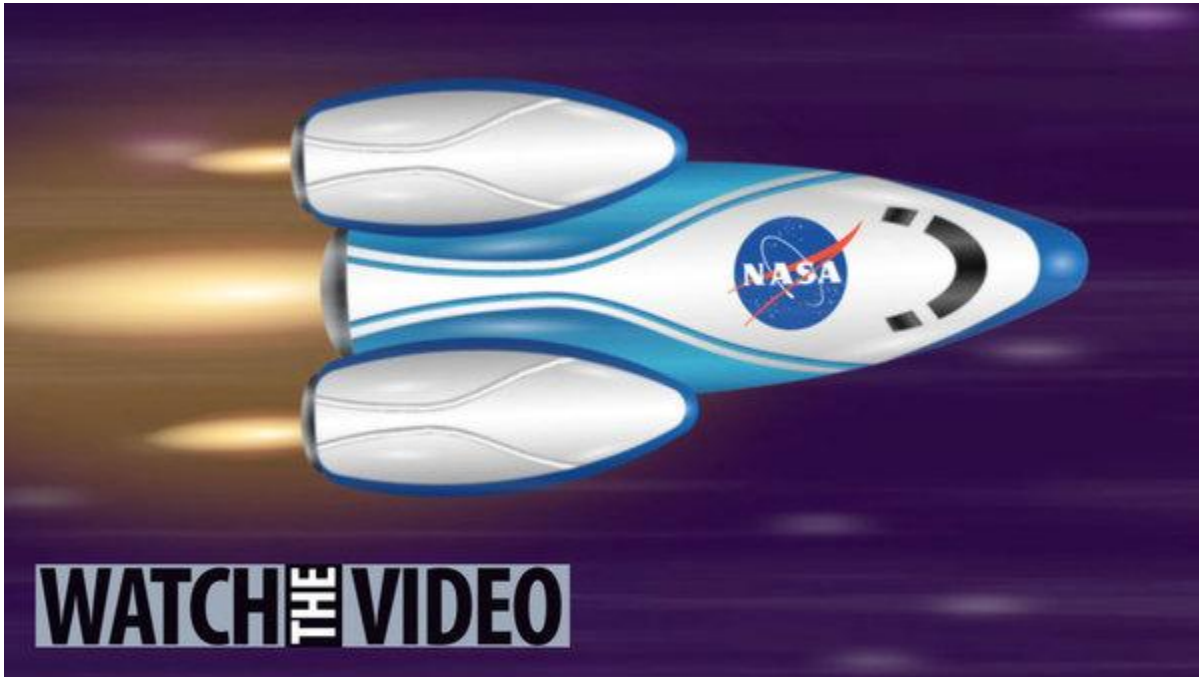
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JUMP TO HYPERSPACE

Nasa genius invents engine concept that travels at 99% the speed of light

- [Harry Pettit](#), Senior Digital Technology and Science Reporter
- Published: 11:19, 15 Oct 2019
- Updated: 14:10, 15 Oct 2019

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A NASA scientist has cooked up plans for a bonkers new rocket engine that can reach close to the speed of light – without using any fuel.

Travelling at such speeds, the theoretical machine could carry astronauts to Mars in less than 13 minutes, or to the Moon in just over a second.

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NASA'S 'HELICAL ENGINE'

A new Nasa engine concept could theoretically accelerate 300million metres per second without using any



However, the real purpose of the so-called "helical engine" would be to travel to distant stars far quicker than any existing tech, according to Nasa engineer Dr David Burns.

Dr Burns, from Nasa's Marshall Space Flight Center in Alabama, unveiled the idea in a head-spinning paper posted to Nasa's website.

"This in-space engine could be used for long-term satellite station-keeping without refuelling," Dr Burns writes in his [paper](#).

"It could also propel spacecraft across interstellar distances, reaching close to the speed of light."



5
Nasa engineer Dr David Burns has come up with a bonkers new engine design



5

It's not clear if it's possible to actually build the Sci-Fi engine concept (stock image)Credit: Getty

Travelling at these speeds, light would struggle to keep up with you, warping your vision in bizarre ways.

Everything behind you would appear black, and time would appear to stop altogether, with clocks slowing down to a crawl and planets seemingly ceasing to spin.

Dr Burns' mad idea is revolutionary because it does away with rocket fuel altogether.

Today's rockets, like those built by Nasa and SpaceX, would need tonnes of propellants like liquid hydrogen to carry people to Mars and beyond.

The problem is, the more fuel you stick on the craft, the heavier it is. Modern propellant tanks are far too bulky to take on interstellar flights.

The helical engine gets around this using high-tech particle accelerators like those found in Europe's Large Hadron Collider.

Tiny particles are fired at high speed using electromagnets, recycled back around the engine, and fired again.

Using a loophole in the laws of physics, the engine could theoretically reach speeds of around 297million metres per second, according to Dr Burns.

The contraption is just a concept for now, and it's not clear if it would actually work.

"If someone says it doesn't work, I'll be the first to say, it was worth a shot," Dr Burns told [New Scientist](#).



5

Bonkers engine concepts that do away with rocket fuel have been proposed before by scientists. Pictured is an artist's impression of an EM Drive, an engine that could theoretically generate thrust using rays of light

"You have to be prepared to be embarrassed. It is very difficult to invent something that is new under the sun and actually works."

In its simplest terms, the engine works by taking advantage of how mass changes at the speed of light.

In his paper, Dr Burns provides a concept to break this down that describes a ring inside a box, attached to each end by a spring.

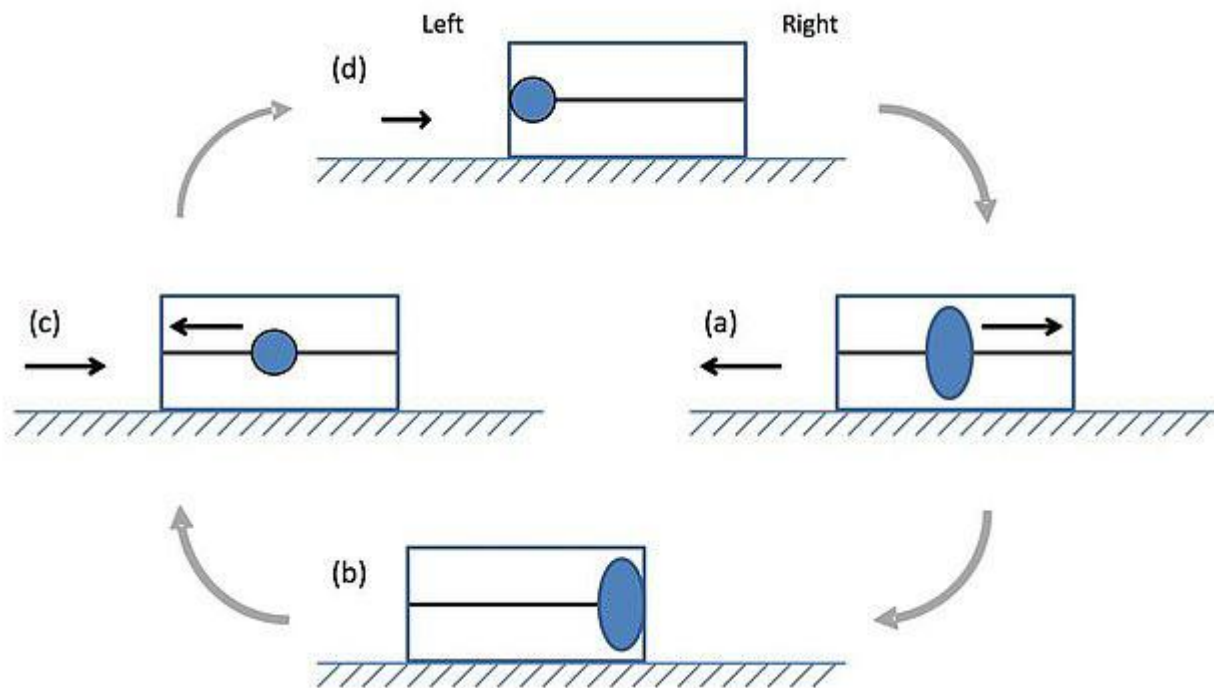
When the ring is sprung in one direction, the box recoils in the other, as is described by Newton's laws of motion: Every action must have an equal and opposite reaction.

"When the ring reaches the end of the box, it will bounce backwards, and the box's recoil direction will switch too," New Scientist explains.

However, if the box and the ring are travelling at the speed of light, things work a little differently.

At such speeds, according to Albert Einstein's Theory of Relativity, as the ring approaches the end of the box it will increase in mass.

This means it will hit harder when it reaches the end of the box, resulting in forward momentum.



5

The engine would propel a rocket a bit like a ring inside a box, attached to each end by a spring. When the ring is sprung in one direction, the box recoils in the other (a). When the ring reaches the end of the box (b), it will bounce backwards (c), and the box's recoil direction will switch too (d).

The engine itself will achieve a similar feat using a particle accelerator and ion particles, but that's the general gist.

"Chemical, nuclear and electric propulsion systems produce thrust by accelerating and expelling propellants," Burns writes in his paper.

"Deep space travel is often a trade-off between thrust and large propellant storage tanks that eventually limit performance.

"The objective of this paper is to introduce and examine a unique engine that uses a closed-cycle propellant."



5

If the idea ever comes to fruition, we could see the introduction of "warp speed" spaceships like those seen in Star Wars

Credit: Kobal Collection - Rex Features
The design is capable of producing a thrust up to 99 per cent the speed of light without breaking Einstein's theory of relativity, according to Dr Burns.

However, the plan does breach Newton's law of motion – violating the laws of physics.

That's not the only thing holding the helical engine back: Dr Burns reckoned it would have to be 650ft long and 40ft wide to work.

The gizmo would also only operate effectively in the frictionless environment of deep space.

Travelling at the speed of light – what would happen?

Here's what you need to know...

- We use light to see and understand the world around us
- Going at the speed of light would mean it could not keep up with you
- As such, everything would go dark behind you
- Light to the sides of you would likely streak past in lots of bands of colour
- Light in front of you would arrive quicker than normal and thus appear bright and intense
- Time would appear to slow down, causing clocks to look like they've stopped, or planets to look like they no longer spin
- Your field of view would narrow dramatically

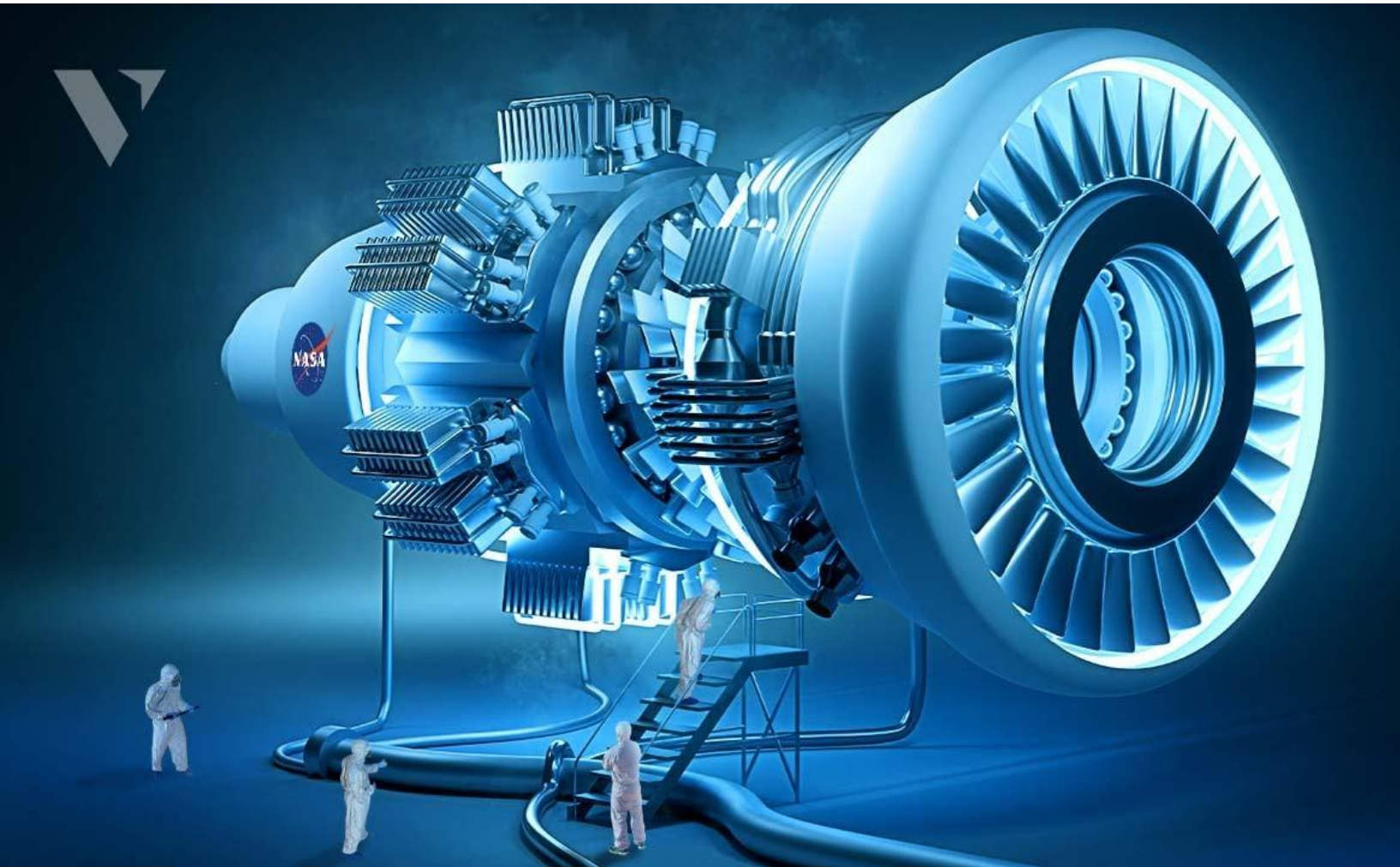
It may sound like a harebrained scheme, but engine concepts that do away with rocket fuel have been proposed before.

They include the EM Drive, a machine that could theoretically generate thrust rocket using rays of light. The idea was later proved impossible.

"I know that it risks being right up there with the EM drive and cold fusion," Dr Burns told New Scientist.

"But you have to be prepared to be embarrassed. It is very difficult to invent something that is new under the sun and actually works."

NASA designs a near-light-speed engine that breaks the laws of physics.



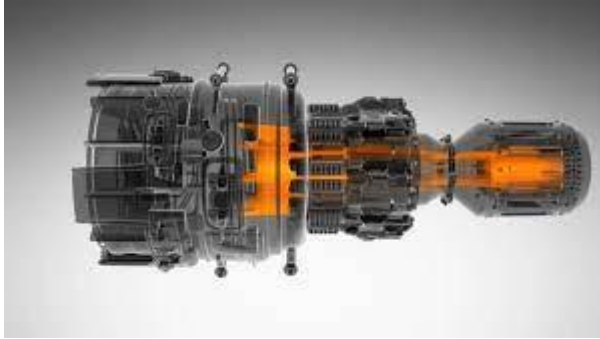
Thursday, May 5, 2022 | Chimniii Desk

Key Highlights

- An engine concept that can reach 99 percent of the speed of light while using no propellant.

- **The claims to have design an engine capable of reaching 99 percent of the speed of light without the use of propellant.**
- **Burns believes that instead of using the box and rod, the particle accelerator should be used for both lateral and circular movement, in which case the accelerator should be formed like a helix.**

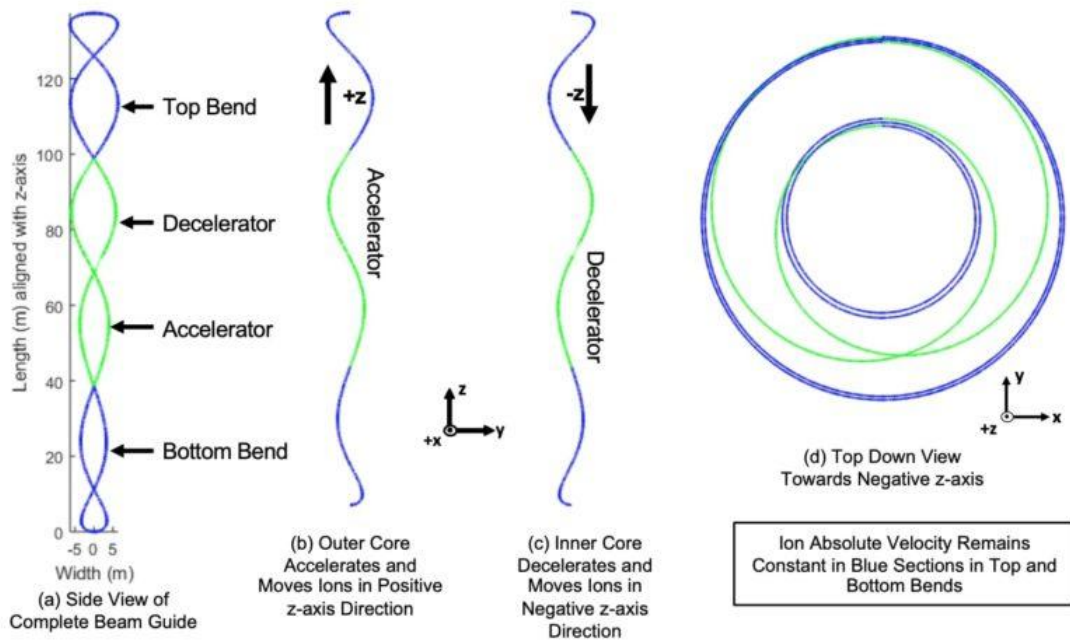
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An engine concept that can reach 99 percent of the speed of light while using no propellant. That may sound like something from a science fiction film, but it isn't. This is exactly what one of NASA's engineers is working on, and it has the potential to defy physics.

What methods will be used to develop these engines? What will it run on if it doesn't need propellant? Most importantly, will a human be able to travel in a vehicle with a thruster like this? We'll find out in a matter of seconds.

The Engine That Defies Physics



We have a problem with our human drive to travel everywhere and examine everything when it comes to space. This is a significant problem. After all, it is space. It's way too big.

Even if we travelled at the fastest possible speed, it would take us years to reach our nearest neighbouring star. Another human desire is to find solutions to major problems.

NASA engineer David Burns has been doing precisely that in his spare time. He claims to have created an engine capable of reaching 99 percent of the speed of light without the use of propellant.

He's posted it to NASA's Technical Reports Server under the title "Helical Engine," and it works on paper by exploiting how mass may change at relativistic speeds—those close to the speed of light in a vacuum. It has not yet been professionally reviewed.

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This story has created curiosity comparable to that seen in the early days of the EM Drive, which is understandable. Yes, there have been reports that the engine may 'defy physics.'

For some context, the EM Drive was NASA's first foray into the idea of actually trying to build an engine capable of travelling faster than light. So, what exactly is the EM Drive?

EM Drive is a radio frequency resonant cavity thruster concept that was first developed in 2001 by Roger Shawyer, a British Chartered Electrical Engineer with 48 years of experience in the Space and Defence industries.

Internally reflected microwaves are said to generate thrust, in violation of the law of conservation of momentum and other fundamental considerations. The device has been dubbed the "Impossible Drive" by the media.

Explanations for how the EmDrive might work go beyond what is known about physics. Perhaps it's interacting with the vacuum energy of space-quantum time, despite the fact that vacuum energy doesn't allow anything to push off of it.

Perhaps our sense of forward motion has been destroyed. Perhaps it's brand new physics, as the EmDrive tests have revealed.

There is no official design for this device, and none of the people who claim to have invented it have committed to detailing how it might work as a thruster or what components make it up, making it hard to tell whether a given thing is one.

In 2016, NASA's Advanced Propulsion Physics Laboratory reported seeing a modest apparent thrust from one of these tests, a finding that has yet to be

confirmed. The thrust observed was later determined to be a measurement error due to interactions with the Earth's magnetic field or thermal gradients.

Scientists from the Technical University of Dresden issued three papers in March 2021 claiming that the thrust was a complete coincidence caused by external causes.

While the Helical Engine is intriguing, despite the claims, it is unlikely to defy the laws of physics anytime soon. Burns feels his proposal is worth pursuing, despite the fact that it has been regarded with suspicion in some quarters.

He says, "I'm comfortable with throwing anything out there." "I'll be the first to acknowledge, if it doesn't work, it was worth a try," he says. What did he say about it working?

Well, as a thinking experiment, Burns depicts a box with a weight inside, hung on a line, and springs at either end, bouncing the weight back and forth. This would shake the entire box in a vacuum, with the weight appearing to remain static, similar to a gif stabilised around the weight.

The box would squirm in the same place overall; however, if the weight's mass grew in only one direction, it would provide a stronger push in that direction, resulting in thrust. What are our thoughts?

According to the notion of momentum conservation, which asserts that a system's momentum remains constant in the absence of any external forces, we believe this is not totally conceivable.

According to Einstein's special relativity theory, objects gain mass as they approach the speed of light, an effect that must be taken into consideration in particle accelerators.

In actuality, a simple version of Burns' notion would be to replace the ring with a circular particle accelerator, where ions are rapidly accelerated to relativistic speed during one stroke and decelerated during the other.

However, Burns believes that instead of using the box and rod, the particle accelerator should be used for both lateral and circular movement, in which case the accelerator should be formed like a helix.

However, there is one relativity issue in particular. According to special relativity, objects gain mass as they approach the speed of light. If the weight is replaced with ions and the box is replaced with a loop, the ions may flow faster at one end and slower at the other.

On the other hand, Burns' drive isn't a single closed loop. It's termed a "helical engine" because it's helical, like a stretched-out spring. The engine accelerates ions trapped in a loop to relativistic speeds and then modifies their velocity to vary their mass slightly.

The engine then produces thrust by moving ions back and forth along the path of motion, "he stated. "The engine has no moving parts save for ions going in a vacuum line, locked between electric and magnetic fields," he continued.

According to New Scientist, the helical chamber would have to be quite large. It is 200 metres long (about 656 feet) and 12 metres wide (roughly 40 feet).

To produce one newton of thrust, 165 megawatts of energy would be required. That is the force required to accelerate a kilogramme of mass per second squared, which is roughly equivalent to a power plant. However, proposals for propulsion-free vehicles such as Helical are not entirely new.

In the late 1970s, a US inventor named Robert Cook invented an engine that reportedly converted centrifugal energy into linear motion. Then, in the early 2000s, a British inventor named Roger Shawyer proposed the EM drive, suggesting that trapped microwaves could be transformed into thrust.

Neither idea has been proven conclusively, and both are widely believed to be impossible due to a violation of a fundamental physical rule, the conservation of momentum.

Physicists at the Technical University of Dresden, who tested the EM Drive, believe the helical engine will most likely have the same issue. One of them claims that "To my knowledge, no inertial propulsion system has ever functioned in a friction-free environment."

Unlike the others, this machine uses special relativity, which confuses the image, he explains, but "unfortunately, there is always action-reaction." Burns developed his concept in secret, without NASA's approval, and he admits that it is inefficient.

He maintains, however, that the majority of the energy lost by the accelerator through heat and radiation can be captured. He also proposes momentum conservation measures, such as the spin of propelled ions.

"I know it has the potential to be right up there with EM drive and cold fusion," he admits. "However, you must expect to be ashamed." It's quite difficult to come up with something completely unique that also works. " As you can see, science is still in its early stages.

This is most likely where we inform you that your scepticism is well-founded, but don't be fooled. We shouldn't be surprised if a faster-than-light capable engine appears in the future, given the rate at which aeronautical technology advances. But once that happens, all of our science fiction fantasies will be on their way to becoming scientific truth.

| *Advertisement*

This Engine's Frequently Asked Questions

Is NASA working on a super-fast engine?

There is a lot of speculation about this engine; some official websites have even written stories about it, and NASA engineers claim that this new engine would defy physics.

What is the name of the new NASA engine that defies physics?

The engine's name is the "Hexagonal Engine."

What is the speed of NASA's helical engine?

According to NASA engineers, this engine can transport astronauts to Mars in less than 13 minutes.

What is the name of the scientist who proposed the "helical engine" concept?

Dr. David Burns is a NASA scientist.

Is this engine fuel-powered?

According to Dr. David Burns, this revolutionary rocket engine can achieve near-light speed without using any fuel, instead relying on high-tech particle accelerators.

What is NASA's new engine's precise speed?

This engine, according to Dr. Burns, has a top speed of 297 million kilometres per second.

How much push can it generate?

The engine, according to Dr. Burns, can produce a thrust of up to 99 percent of the speed of light without breaching Einstein's theory of relativity.

What will the engine's capacity be?

According to Dr. Burns, it would need to be 198 metres long and 12 metres wide to function effectively.

We are curious about the Universe, are you?

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PHYSICS

NASA Engineer Reveals Physics-Defying Engine That Can Go 99% the Speed of Light



That's not stopping one NASA engineer from testing theories around the EmDrive — a conceptual “**helical**” engine that could defy the laws of physics and create forward thrust without fuel.

Such a creation would allow us to travel the far reaches of space and would arguably be the most exciting technological advancement of the century.



What is the EmDrive?

Back in 2001, British scientist Roger Shawyer theorized that we could generate thrust by pumping microwaves into a conical chamber.

Shawyer suggested that the microwaves would, in theory, bounce exponentially off the chamber walls, creating enough propulsion to power a spacecraft without fuel.

Some researchers do claim to have generated thrust in EmDrive experiments. The amount was so low, though, that the detractors believe the thrust may have even been caused by outside influences. These could be seismic vibrations or the Earth's magnetic field.



New Research

Over the last few months, several engineers and scientists have come out with contradictory positions on the EmDrive.

Some have claimed it's impossible, while others continue to work at what might be a futile task, justifying their work by saying the payoff would be enormous.

The most recent of these is NASA engineer David Burns, as New Scientist reports.

**“THE ENGINE ITSELF WOULD BE ABLE TO
GET TO 99 PERCENT THE SPEED OF LIGHT
IF YOU HAD ENOUGH TIME AND POWER,”
BURNS TOLD NEW SCIENTIST.**

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NASA engineer's 'helical engine' may violate the laws of physics

By [Jon Cartwright](#)

11 October 2019



Rocket engines that don't need propellant have been proposed before: this is an illustration of the EM-drive

Illustration by luismmolina/iStock / Getty Images Plus

For every action, there is a reaction: that is the principle on which all space rockets operate, blasting propellant in one direction to travel in the other. But one NASA engineer believes he could take us to the stars without any propellant at all.

Designed by David Burns at NASA's Marshall Space Flight Center in Alabama, the "helical engine" exploits mass-altering effects known to occur at near-light speed. Burns has posted [a paper describing the concept](#) to NASA's technical reports server.

It has been met with scepticism from some quarters, but Burns believes his concept is worth pursuing. "I'm comfortable with throwing it out there," he says. "If someone says it doesn't work, I'll be the first to say, it was worth a shot."

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To get to grips with the principle of Burns's engine, picture a box on a frictionless surface. Inside that box is a rod, along which a ring can slide. If a spring inside the box gives the ring a push, the ring will slide along the rod one way while the box will recoil in the other. When the ring reaches the end of the box, it will bounce backwards, and the box's recoil direction will switch too. This is action-reaction – also known as Newton's third law of motion – and in normal circumstances, it restricts the box to wiggling back and forth (see video below).

Helical engine with same mass

0 seconds of 28 secondsVolume 90%

But, Burns asks, what if the ring's mass is much greater when it slides in one direction than the other? Then it would give the box a greater kick at one end than the other. Action would exceed reaction and the box would accelerate forwards (see video below).

Helical engine with relativistic masses

0 seconds of 45 secondsVolume 90%

This mass changing isn't prohibited by physics. Einstein's theory of special relativity says that objects gain mass as they are driven towards the speed of light, an effect that must be accounted for in particle accelerators. In fact, a

simplistic implementation of Burns's concept would be to replace the ring with a circular particle accelerator, in which ions are swiftly accelerated to relativistic speed during one stroke, and decelerated during the other.

But Burns thinks it would make more sense to ditch the box and rod and employ the particle accelerator for the lateral as well as the circular movement – in which case, the accelerator would need to be shaped like a helix.

Discover more about NASA's missions: [Explore four NASA space centres on a New Scientist Discovery Tour](#)

Frictionless space

It would also need to be big – some 200 metres long and 12 metres in diameter – and powerful, requiring 165 megawatts of power to generate just 1 newton of thrust, which is about the same force you use to type on a keyboard. For that reason, the engine would only be able to reach meaningful speeds in the frictionless environment of space. “The engine itself would be able to get to 99 per cent the speed of light if you had enough time and power,” says Burns.

Propellant-less proposals aren't new. In the late 1970s, Robert Cook, a US inventor, patented an engine that supposedly converted centrifugal force into linear motion. Then, in the early 2000s, British inventor Roger Shawyer proposed the EM drive, which he claimed could convert trapped microwaves into thrust. Neither concept has been successfully demonstrated and both are widely assumed to be impossible, due to violation of the conservation of momentum, a core physical law.

Martin Tajmar at the Dresden University of Technology in Germany, who has [performed tests on the EM Drive](#), believes the helical engine will probably suffer the same problem. “All inertial propulsion systems – to my knowledge – never worked in a friction-free environment,” he says. This machine makes use of special relativity, unlike the others, which complicates the picture, he says, but “unfortunately there is always action-reaction”.

Read more: [‘Impossible’ EM drive doesn't seem to work after all](#)

Burns has worked on his design in private, without any sponsorship from NASA, and he admits his concept is massively inefficient. However, he says there is potential to harvest much of the energy that the accelerator loses in heat and radiation. He also suggests ways that momentum could be conserved, such as in the spin of the accelerated ions.

“I know that it risks being right up there with the EM drive and cold fusion,” he says. “But you have to be prepared to be embarrassed. It is very difficult to invent something that is new under the sun and actually works.”

NASA engine capable of travelling at nearly the speed of light detailed in new report

As more countries join the race to explore space, a NASA scientist has revealed a new propulsion method that could give his agency the edge.

...

The new space agency will focus on strengthening competencies and growing capabilities making Australia less reliant on other countries for communication.

A NASA scientist has cooked up plans for a bonkers new rocket engine that can reach close to the speed of light — without using any fuel.

Travelling at such speeds, the theoretical machine could carry astronauts to Mars in less than 13 minutes, or to the Moon in just over a second.

However, the real purpose of the so-called “helical engine” would be to travel to distant stars far quicker than any existing tech, according to NASA engineer Dr David Burns.

Dr Burns, from NASA’s Marshall Space Flight Centre in Alabama, unveiled the idea in a head-spinning paper posted to NASA’s website.

“This in-space engine could be used for long-term satellite station-keeping without refuelling,” Dr Burns writes in his [paper](#).

“It could also propel spacecraft across interstellar distances, reaching close to the speed of light.”

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Travelling at these speeds, light would struggle to keep up with you, warping your vision in bizarre ways.

Everything behind you would appear black, and time would appear to stop altogether, with clocks slowing down to a crawl and planets seemingly ceasing to spin.

Elon Musk's New Light Speed Engine Defies Physics

by [Admin](#) on [March 06, 2024](#) in [science](#)



Elon Musk and NASA just announced their new rocket called the Light Speed Engine, which defies physics and could take us to Mars in weeks instead of months.

They're now testing it on their new spaceship called the Interplanetary Transport System. The following article will explain what the Speed Engine actually is, how it works, and why it could be such a game-changer in space travel!

The mission

To design an in-house, disruptive engine that would cut launch costs. The target: \$5 million. NASA calls it a breakthrough, and Elon Musk calls it awesome. Why? Because a small team of engineers at NASA just tested what is being called a new type of rocket engine that can operate much more efficiently than anything currently

on Earth. And if you're thinking, how does one top something like that? Well...what if I told you that there are plans to make it even better? Much better.

Basically, NASA has just successfully test-fired a new type of engine that promises to make space travel cheaper and faster. Currently, most commercial and military rockets use chemical fuels which have to be pre-made on Earth and then loaded into rocket boosters prior to launch. Not only is this expensive and extremely complex, but it also limits how much weight can be lifted off of Earth's surface. The new experimental engine? It runs on an alternative form of fuel: electricity...the kind you plug into your wall socket. It might sound crazy at first, but when you consider that 95% of everything you do in life involves using electricity at some point (from running your vacuum cleaner to flipping on a light switch), it doesn't seem so far-fetched anymore.

In September, Musk and a team of scientists at NASA announced their design for a revolutionary rocket they called The Raptor. It can withstand more than 500,000 pounds of thrust and run on liquid methane rather than traditional kerosene—meaning it would produce 30 percent less carbon dioxide emissions.

But to make its way into space, engineers first need to successfully demonstrate that it works here on Earth. I'm hopeful that we'll be able to do short flights, sort of up-and-down flights, probably sometime in the first half of next year, Steve Jurczyk, associate administrator for NASA's Space Technology Mission Directorate, told Mashable in an interview.

But what are they building? Basically, it's a giant super-heavy-lift launch vehicle and booster rocket combo, capable of lifting 170 metric tons into low Earth orbit. To put that in perspective, Falcon Heavy, SpaceX's newly operational heavy-lift rocket is capable of lifting 54 metric tons. That means a single Raptor engine could potentially replace all three first-stage Merlin engines used on today's Falcon 9 launch vehicle.

The Raptor is also different from most traditional rockets in that it will run on liquid methane rather than kerosene—which has been used since the 1950s. Methane is cleaner and easier to produce than traditional rocket fuel, but also extremely difficult to handle. The amount of energy needed to liquefy methane means conventional rocket engines can't use it as a propellant; they would burn up because they couldn't contain such high pressure and heat. But SpaceX seems poised to figure out how to harness that power with Raptor. The experimental engine generates a whopping 420,000 pounds of thrust using methane as fuel and liquid oxygen (LOX) as an oxidizer, exceeding the current U.S.

The EM Drive produces thrust by bouncing microwaves back and forth inside a closed chamber. The electromagnetic fields that result from these back-and-forths also produce an equal and opposite reaction, causing acceleration in one direction. In order to power it, you need to use solar energy or some other kind of outside energy supply, which could be another spacecraft (like a satellite) or even a ground station receiving radio waves. But so far, experiments with systems like these have been unable to create enough force to

overcome drag—the slowing force created by friction between air molecules as an object moves through them—or make any meaningful changes in trajectory.

And now, researchers working on a NASA-funded study have found that what's supposed to be impossible actually is—at least in some cases. A team at Eagleworks Laboratories has completed tests of an electromagnetic drive (EM Drive) under conditions similar to those you might experience in deep space. And they claim that these tests confirm a thrust-to-power ratio of 1 to 4, which is greater than any of their calculations predicted for such a device and could open up new possibilities for deep space exploration. The results have yet to be confirmed by other scientists, so we won't know if they can be reproduced until independent teams get their hands on their own EM Drives and perform their own experiments—something that should happen in 2017.

Where does the power come from?

The EM Drive is a controversial device. It goes against Newton's third law, which states that everything must have an equal and opposite reaction. So, if you fire something out of a rocket ship, there will be something propelling it in another direction—even if it's just air molecules bouncing off that thing when it leaves. The EM Drive doesn't do that; it only produces thrust in one direction.

How does it work?

Elon Musk is taking science fiction a step closer to reality. His company, SpaceX, says it has created a thruster system that defies physics and has successfully tested it. The rocket propulsion system uses electrically charged gas and can achieve speeds up to 65 kilometers per second, or about 135 thousand miles per hour. The engine is made from super-lightweight carbon-fiber fuel tanks with cold gas thrusters. It doesn't use any type of propellant, meaning it does not expel any byproducts into space. Instead, as Wired explains: The engine produces thrust by accelerating superheated plasma with magnetic fields, which also means there are no fumes being expelled from combustion.

These types of engines are known as electric thrusters, but they work very differently from those used in SpaceX's Falcon 9 rockets. These thrusters create thrust by propelling pressurized gas, whereas electric ones produce a charged plasma that emits ions to push a craft forward. The electric engine developed by SpaceX is reportedly more powerful than conventional gridded ion thrusters and could power manned missions to Mars and beyond. It could also cut down on travel time for space-bound cargo because it requires less propellant, which can be expensive to launch into orbit. The technology is still being tested and further development is needed before it will be ready for space flight. It has been submitted for peer review, and NASA experts think it has potential – at least on paper.

Can we really travel in space at such high speeds?

Some say it's impossible to travel at high speeds through space, but that hasn't stopped Elon Musk from claiming he can do it. His idea is to create a light-speed engine that will take us to Mars in just 70 days. Such an engine

defies physics and would mean traveling faster than 186,000 miles per second, but why has he chosen to do it? Why did NASA choose him to fund his idea? And if Elon can pull off what he claims is possible, what could we accomplish in space? To answer these questions let's examine how light speed engines work.

There are a few ways that we could travel at light speed, but first, we need to understand how light works. As it travels through space, every atom in its path interacts with it. This slows it down and even stops it completely if there's no matter around to pass through. Because of these interactions, light has a maximum velocity of 186,000 miles per second—meaning that's as fast as it can go through empty space. Since nothing can travel faster than light without breaking physics rules, if we want to catch up with a distant star in our lifetime we have to find another way to get there besides traveling directly towards it.

How far away are we from light speed?

The current way that we measure speed is the distance over time. In order to travel at light speed, or 186,000 miles per second, you would need to accelerate past that velocity until your speed was 186,000 MPs, then hold it there for an infinite amount of time. This velocity is referred to as c and was defined by Albert Einstein in his theory of special relativity. We haven't yet reached what most consider to be light speed although many experiments and theories suggest that we may one day be able to approach it or even surpass it within our lifetimes.

Until very recently, it has been generally accepted that nothing in our current state of technology could even begin to move at a velocity close to what we consider light speed. Some estimates place us thousands or even tens of thousands of years away from ever reaching it. That being said, we are often surprised by what science and technology are able to accomplish and scientists have now managed to make an engine capable of reaching a mere 10% of light speed, defying these previously held assumptions about what is possible for our technological capabilities in today's day and age. The invention of an engine that could reach such high speeds would allow us to travel through space much more efficiently than before.

The competition

While it will take some time to perfect, if NASA has their way, within a decade we could see much faster space travel thanks to their revolutionary Light Speed engine. Though currently there is no word on who they'll be competing against. (NASA) The two biggest competitors in commercial space travel are SpaceX and Blue Origin; these companies are both focused on moving into orbit and beyond using new tech developed by founder Elon Musk (SpaceX) and Amazon co-founder Jeff Bezos (Blue Origin). All three companies have met with varying levels of success so far; Blue Origin just successfully tested its BE-4 rocket engine last week while SpaceX also recently launched its Falcon Heavy rocket, though that didn't quite end as well as they'd hoped since one of its rockets fell back to Earth.

Both SpaceX and Blue Origin have made vast leaps and bounds in space travel, with SpaceX making history a few years ago when it became one of only three private companies to ever launch a spacecraft into orbit and return it safely to Earth. In fact, earlier this year SpaceX launched its most powerful rocket yet with plans to send two tourists around the moon next year; if all goes according to plan they'll be just two of seven private citizens ever to leave Earth's orbit. (CNBC) All three companies are doing their best to make space travel commonplace, however, as both Blue Origin and SpaceX say they're focused on transport rather than tourism NASA could very well be looking at sending people further afield than either company has planned for.

Final Thoughts

Musk's engine represents a huge leap in mankind's capability to traverse space and a massive point of progress for humanity. The technology could revolutionize our ability to travel among other planets, explore deeper parts of our solar system and even leave our galaxy. If successful, Elon Musk will go down in history as not only one of Silicon Valley's most popular figures but also as a giant among scientists and engineers alike. This is definitely an exciting time to be alive!

But, what exactly is it? How does it work? To get answers to these questions and more, here are a few important things to know about Elon Musk's engine: what it is, how it works, and why it's been so hard for others to achieve before now. The technology behind hyper-speed travel has existed for quite some time but had always seemed something of a pipe dream. In order to travel faster than light—something scientists refer to as superluminal speed—you need a way to dramatically increase an object's velocity through space.

Though physicists have known for years that you can only travel faster than light using a wormhole or warp drive, neither of these has ever been achieved by humans. Even with top minds across multiple fields focused on the issue, our most advanced technology still couldn't achieve those speeds. We knew what we needed but just couldn't figure out how to make it work. But, now we might have a way to get there. The ramifications of Musk's new engine could be huge not only for space exploration but also here on Earth as well.

NASA Designs Near Light Speed Engine That Breaks Laws Of Physics

by [Admin](#) on [January 22, 2023](#) in [Nasa](#)



NASA Designs Near Light Speed Engine That Breaks Laws Of Physics:

An engine idea that can accelerate to 99 percent of the speed of light, all without the need for propellant. That may sound like something out of a science fiction movie, but it's not. This is exactly what one of **NASA engineers is developing, and it promises to break the law of physics.**

How will these engines be developed? If it is going to work without propellant, then what will be its fuel? And most importantly, will a human be able to travel in a vehicle with such an engine as its thruster? Well, we will find out in just a second.

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ENGINE THAT BREAKS LAWS OF PHYSICS

When it comes to space, we have a problem with our human need to travel everywhere and observe everything. This is a major issue. It is, after all, space. It's far too large.

Even if we traveled at the greatest speed permitted by the Universe, it would take us years to reach our nearest neighboring star. Another human urge is to discover answers to large challenges.

In his leisure time, NASA engineer David Burns has been doing just that. He's developed an engine idea that he claims can accelerate to 99 percent of the speed of light, all without the need for propellant.

He's uploaded it to NASA's Technical Reports Server under the title "Helical Engine," and it works on paper by taking advantage of how mass may change at relativistic speeds – those near to the speed of light in a vacuum. It has not yet been reviewed by a professional.



Understandably, this article has sparked interest comparable to that witnessed in the early days of the EM Drive. Yes, there have been some stories suggesting that the engine may 'break the rules of physics.'

For a bit of context, it's important to know that the aforementioned EM Drive was NASA's first foray into the idea of actually trying to build an engine capable of faster than light travel. So what exactly is EM Drive all about?

Rocket

First introduced by Roger Shawyer, a British Chartered Electrical Engineer with 48 years experience in the Space and Defence industries, in 2001, EM Drive is a radio frequency resonant cavity thruster idea with possible uses as a spaceship thruster.

It is claimed to create thrust by internally reflecting microwaves, in violation of the law of conservation of momentum and other physical principles. The media has frequently referred to the gadget as the Impossible Drive.

Explanations for how the EmDrive could function go beyond the limits of known physics. Perhaps it's interacting with space-quantum time's vacuum energy, despite the fact that space-quantum time's vacuum energy doesn't enable anything to push off of it.

Perhaps our notion of momentum has been shattered. Perhaps it's brand-new physics, as announced by the EmDrive tests.

There is no official design for this device, and neither of the persons who claim to have developed it has committed to explaining how it may function as a thruster or what elements constitute it, making it impossible to determine whether a particular object is an example of such a device.

NASA's Advanced Propulsion Physics Laboratory reported observing a small apparent thrust from one such test in 2016, a result that has not since been replicated. Subsequent studies have indicated that the thrust observed was a measurement error caused by interactions with the Earth's magnetic field or thermal gradients.

In March of 2021, scientists from the Technical University of Dresden published three papers explaining that it was a total fluke, the thrust was explained by outside forces.

As for the Helical Engine, while it is intriguing, it is unlikely to defy the laws of physics anytime soon despite the claims. Although it has been met with skepticism from some quarters, Burns believes his concept is worth pursuing.

The view of the engines on a Saturn 5 rocket.

“I’m comfortable with throwing it out there,” he says. “If someone says it doesn’t work, I’ll be the first to say, it was worth a shot,” he says. How did he say it’s going to work?

Well, burns depict a box with a weight inside, strung on a line, and spring at either end, bouncing the weight back and forth as a thought experiment to demonstrate his notion. In a vacuum, such as space, this would jiggle the entire box, with the weight appearing to remain motionless, much like a gif stabilized around the weight.

Overall, the box would continue to wiggle in the same location; however, if the weight’s mass increased in only one direction, it would create a stronger push in that direction, hence thrust. What do we think?

We think this should not be entirely feasible, according to the concept of momentum conservation, which states that the momentum of a system remains constant in the absence of any external influences.

Einstein’s theory of special relativity says that objects gain mass as they are driven towards the speed of light, an effect that must be accounted for in particle accelerators.

In fact, a simplistic implementation of Burns’s concept would be to replace the ring with a circular particle accelerator, in which ions are swiftly accelerated to relativistic speed during one stroke, and decelerated during the other.

But Burns thinks it would make more sense to ditch the box and rod and employ the particle accelerator for the lateral as well as the circular movement – in which case, the accelerator would need to be shaped like a helix.

However, there is a particular relativity flaw. Objects gain mass when they approach the speed of light, according to special relativity. So, if the weight is replaced with ions and the box with a loop, the ions can potentially move quicker at one end of the loop and slower at the other.

Burns’ drive, on the other hand, isn’t a single closed loop. It’s helical, like a stretched-out spring, which is why it’s called a “helical engine.” “The engine accelerates ions confined in a loop to moderate relativistic speeds and then varies their velocity to make slight changes to their mass.

The engine then moves ions back and forth along the direction of travel to produce thrust,” he wrote. He further added: “The engine has no moving parts other than ions traveling in a vacuum line, trapped inside electric and magnetic fields.”

The helical chamber would have to be rather huge, according to New Scientist. To be accurate, it is 200 meters which is approximately 656 feet long, and 12 meters which is approximately 40 feet in diameter.

It would also require 165 megawatts of energy to produce one newton of thrust. That is the force necessary to accelerate a kilogram of mass per second squared, which is comparable to a power plant. Proposals for propulsion-free vehicles like Helical aren’t exactly new though.

Robert Cook, a US inventor, patented an engine in the late 1970s that allegedly turned centrifugal energy into linear motion. Then, in the early 2000s, British inventor Roger Shawyer suggested the previously mentioned EM drive, claiming that trapped microwaves might be converted into thrust.

Neither notion has been satisfactorily proved, and both are commonly considered to be impossible owing to a breach of a fundamental physical rule, the conservation of momentum.

Again, physicists from the Technical University of Dresden who have performed tests on the EM Drive, believe the helical engine will probably suffer the same problem. “All inertial propulsion systems – to my knowledge – never worked in a friction-free environment,” one of them says.

This machine makes use of special relativity, unlike the others, which complicates the picture, he says, but “unfortunately there is always action-reaction”. Burns has worked on his idea in secret, without the support of NASA, and he admits that it is enormously inefficient.

He claims, however, that there is the possibility to capture most of the energy that the accelerator loses through heat and radiation. He also offers techniques to conserve momentum, such as in the spin of the propelled ions.

“I know that it risks being right up there with the EM drive and cold fusion,” he says. “But you have to be prepared to be embarrassed. It is very difficult to invent something that is new under the sun and actually works.” As you can see, the science is still rather spotty.

This is probably where we tell you that your skepticism is rather justified but don't let it fool you. With the rate at which aerospace technology is advancing, we shouldn't be surprised if a faster than light capable engine does appear in the future. When that happens though, all of our science fiction fantasies will be on a definite fast-track to becoming science fact.

FEBRUARY 4, 2025

Collaboration uncovers how gravity influences qubits

by [Stockholm University](#)

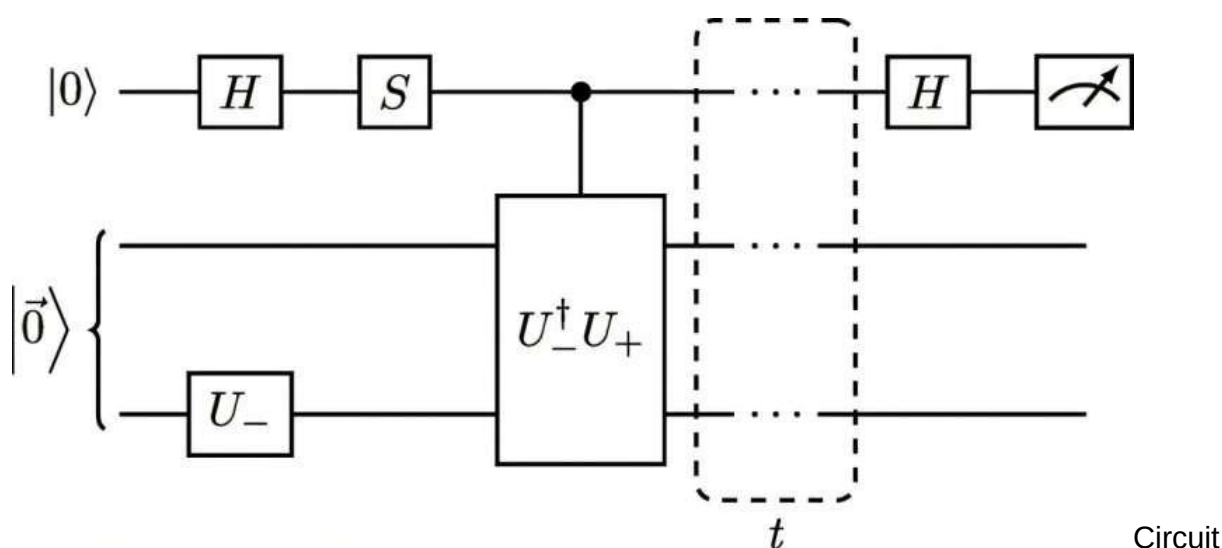


diagram of the gravitational phase measurement protocol, where the uppermost line denotes the ancilla qubit and the other qubits have been split according to the sign of their gravitational phase. Credit: *Physical Review A* (2025). DOI: 10.1103/PhysRevA.111.012411 A collaboration between Nordita, the Nordic Institute for Theoretical Physics, hosted by Stockholm University, KTH and Google Quantum AI explores how gravitational fields influence quantum computing hardware, laying the foundation for advances in quantum sensing.

Physicists from Nordita, together with Google Quantum AI, have published a pioneering study that investigates how classical gravitational fields can influence the performance of [quantum computing](#) hardware.

The research, led by Professor Alexander Balatsky (Nordita and KTH) and Pedram Roushan (Google's project leader in quantum computing), highlights a surprising interplay between gravity and [quantum systems](#), breaking new ground in quantum technology. The team also includes Patrick Wong and Joris Schaltegger, researchers at Nordita.

"We live in an era of a global technology race for universal quantum computation," says Balatsky. "Our research reveals that the same finely tuned qubits engineered to process information can also serve as precise gravity sensors—so sensitive, in fact, that future quantum chips may double as practical gravity sensors. This approach is opening a new frontier in quantum technology."

The team's findings, detailed in the manuscript "Quantum sensing from gravity as a universal dephasing channel for qubits," [published](#) in *Physical Review A* on Jan. 7, show that even the weak gravitational forces near Earth can influence quantum systems.

Gravitational effects, though typically overlooked in quantum computing hardware, cause minor shifts in a qubit's energy levels based on its height. For a single qubit, these effects are minimal. However, for an ensemble of qubits—such as Google's vertically aligned Sycamore chip—the effect becomes more pronounced, creating measurable "dephasing" across the system.

This discovery provides insight into how gravity could impact quantum hardware, offering new opportunities for error correction and advanced sensing capabilities.

"Gravitation is unique—it cannot be shielded like electromagnetic radiation," says Wong. "As quantum devices grow in complexity, these [gravitational effects](#) may become increasingly significant, influencing the future of quantum technologies."

Toward GPS-free navigation and beyond

The study also lays the groundwork for designing specialized quantum chips optimized for gravitational sensing. Such advancements could lead to revolutionary technologies like GPS-free navigation, enabling precise location tracking without reliance on satellites.

"Quantum technologies applications grow across many fields and [quantum sensing](#) stands out as a near-term, practical application," says Balatsky. "Growing investments in quantum technology in Sweden positions Nordita, KTH and SU as an important center for quantum computing and applications."

Jonas Weissenrieder, professor in materials physics (KTH), comments, "Quantum materials constitute a cornerstone of tomorrow's quantum innovations. We at KTH envision great opportunities in the space of materials for quantum applications with examples including novel photon detectors, magnetic field sensors, and strain sensors. SU, KTH and Nordita are partnering with WACQT and Novo Nordisk Quantum Computing Center to develop the materials for a quantum pillar."

More information: Alexander V. Balatsky et al, Quantum sensing from gravity as a universal dephasing channel for qubits, *Physical Review A* (2025). [DOI: 10.1103/PhysRevA.111.012411](#)

Journal information: [Physical Review A](#)

Provided by [Stockholm University](#)

Extending a paradox: Quantum mechanics experiment measures a pulse of light in 37 dimensions

[illegible]

A team of physicists affiliated with multiple institutions in China has measured a pulse of light in 37 dimensions. In their paper [published](#) in *Science Advances*, the group explains that their experiment was meant to demonstrate that quantum mechanics is more nonclassical than thought.

Physicists have tried and failed to unite the two theories for decades. The problem has only grown more difficult in recent years as research efforts have shown that the differences between them are greater than thought. In this new effort, the researchers in China sought to see how far nonclassical [quantum mechanics](#) differs from classical theory by carrying out an experiment to demonstrate the Greenberger–Horne–Zeilinger (GHZ) paradox.

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To demonstrate the GHZ paradox in a real-world setting, the research team found a way to produce photons that exist in 37 dimensions using coherent light from a laser, entanglement and a fiber-based photonic processor. This achievement involved far more dimensions than the three required to satisfy the GHZ [paradox](#).

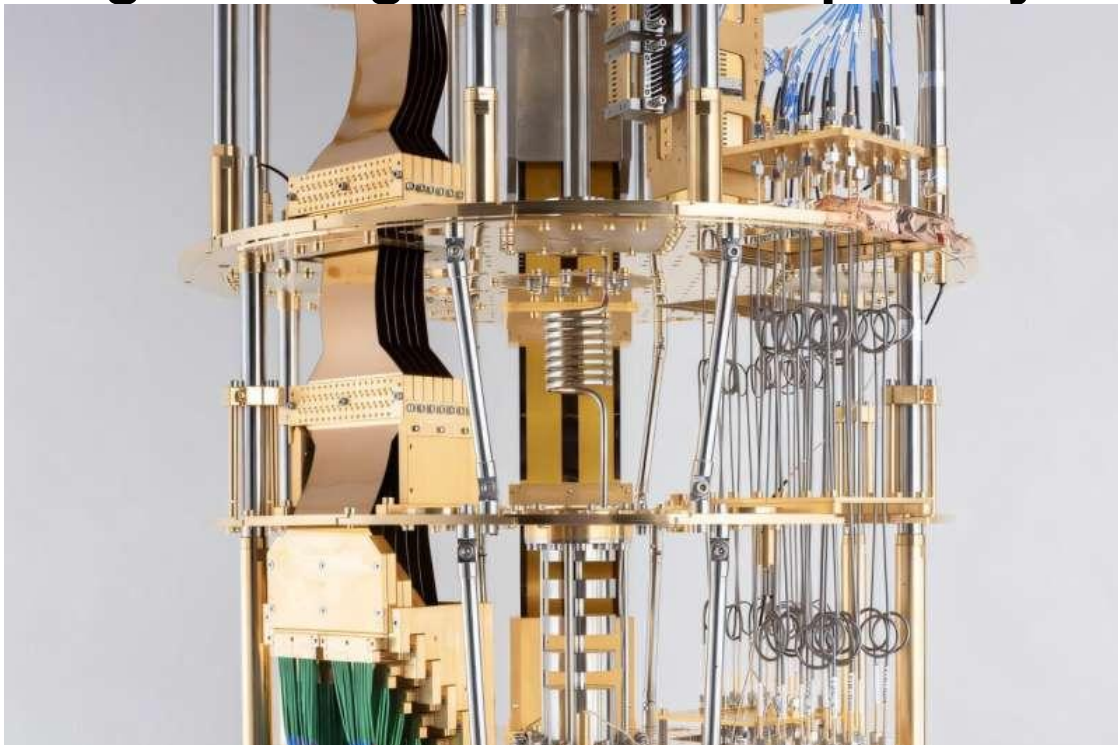
According to the researchers, the experiment helps to clarify some of the unknowns in quantum theory on a deeply fundamental level. They also suggest that quantum mechanics is even more nonclassical than physicists have thought. They say that despite a century of study, scientists are still just seeing the very tip of the quantum iceberg. They conclude that their experiment opens the door to new avenues of research surrounding various aspects of quantum mechanics.

More information: Zheng-Hao Liu et al, Exploring the boundary of quantum correlations with a time-domain optical processor, *Science Advances* (2025). [DOI: 10.1126/sciadv.abd8080](https://doi.org/10.1126/sciadv.abd8080)

Journal information: [Science Advances](#)

JANUARY 14, 2025

Quantum experiment generates long-range entanglement in 54-qubit system



IBM Quantum dilution refrigerator. Credit: IBM.

The operation and performance of quantum computers relies on the ability to realize and control entanglement between multiple qubits. Yet entanglement between many qubits is inherently susceptible to noise and imperfections in quantum gates.

In recent years, [quantum physicists](#) and engineers worldwide have thus been trying to develop more robust protocols to realize and control entanglement. To be most effective for real-world applications, these approaches should reliably support long-range entanglement, or in other words ensure that qubits remain entangled even when they are separated by large distances.

Researchers at IBM Quantum, University of Cologne and Harvard University set out to demonstrate one of these protocols in an experimental setting.

Their paper, [published](#) in *Nature Physics*, demonstrates the generation of long-range entanglement and a mixed state phase transition in a system comprised of 54 qubits on the `ibm_sherbrooke` quantum computer, which is powered by a 127-qubit IBM Eagle quantum processor.

"In 2022, teams at the University of Cologne's Institute for Theoretical Physics and Harvard's Department of Physics [posted an arXiv pre-print](#) in which they proposed a theoretical protocol to produce a widely studied long-range entangled state," Edward H. Chen, co-first author of the paper and researcher at IBM Quantum, told Phys.org.

"This paper caught the attention of our team at IBM. The protocol it introduced was not only relevant for the broad condensed matter community, but it also had relevance to the long-term interest of performing quantum error correction."

The recent study by Chen and his colleagues builds on the previous theoretical work of researchers at University of Cologne and Harvard, who introduced a new protocol to realize a long-range entangled state, known as the Ising order in a system with multiple qubits.

As IBM Quantum has an active collaboration with Harvard, they reached out to the university and initiated a collaboration with some of the researchers who introduced the protocol.

"The protocol entails the use of very few layers of [quantum gates](#) to create a minimal amount of entanglement between two sets of qubits and then measure out one set of them so as to consolidate the other set, leveraging the backaction of quantum measurements," explained Gui-Yi Zhu, co-first author of the paper.



The IBM Quantum Eagle process. Credit: Carl De Torres of StoryTK for IBM.

"Another indispensable ingredient is the communication between the measured classical bits and the unmeasured qubits, akin to the idea of quantum teleportation, which was essentially the game that Ed and I were playing."

In their experiments, Chen, Zhu and their colleagues used classical decoding to extract and stabilize the quantum order in their 54-qubit system that was masked by noise. They found that this order persisted despite the errors in the system, up until the system entered a so-called Nishimori transition.

This critical phase transition was rare and classical systems require fine-tuning to reach this state. In contrast, the researchers found that this state emerged naturally in their quantum system, due to a rule that governs quantum measurement, known as Born's rule. Moreover, this phenomenon, which is rare in classical systems, was recently found to be ubiquitous in the open quantum systems, such as [quantum error correction](#) and topological phase of matter.

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"Ours is the first quantum experiment that harnesses Born's rule to create the celebrated Nishimori critical state without the need of fine-tuning as in the classical world," said Zhu.

"In retrospect, it realizes a generalized version of the spontaneous symmetry breaking in the open quantum system, dubbed strong-to-weak spontaneous symmetry breaking, which is a hot topic in theoretical physics recently motivated by the advent of quantum technologies."

The findings of this recent study could have important implications for the development of quantum computing systems. In the future, the protocol and methods used by Chen, Zhu and their colleagues could contribute to the scaling of quantum processors, while also informing research assessing the performance of large quantum computers in noisy environments.

"As authorities at the intersection of quantum information and condensed matter physics, Guo-Yi Zhu and Simon Trebst extended the insights from this work to consider the impact of sequential rounds of the protocol in different bases and the possibility of simulating spin liquids," added Chen.

"Ruben Verresen, along with Nathanan Tantivasadakarn and Ashvin Vishwanath, had the foresight years ago to study the impact of measurements and feed-forward in general for strongly interacting systems, and are also pioneers in this area. We are currently considering ways to mitigate the leading errors so that we could, in fact, perform multiple rounds of the protocol on our latest devices."

Chen and his colleagues at IBM Quantum are now working on improving the protocol they employed, while also developing new hardware that will be released over the next few years. By 2029, they expect to realize a highly performing quantum system that is capable of error correction.

More information: Edward H. Chen et al, Nishimori transition across the error threshold for constant-depth quantum circuits, *Nature Physics* (2024). [DOI: 10.1038/s41567-024-02696-6](https://doi.org/10.1038/s41567-024-02696-6)
Journal information: [Nature Physics](#) , [arXiv](#)

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The universe had a secret life before the Big Bang, new study hints



The [Big Bang](#) may not have been the beginning of the universe, according to a theory of cosmology that suggests the universe can “bounce” between phases of contraction and expansion. If that theory is true, then it could have profound implications about the nature of the cosmos, including two of its most mysterious components: black holes and dark matter.

With this in mind, a recent study suggests that dark matter could be composed of [black holes](#) formed during a transition from the universe's last contraction to the current expansion phase, which occurred before the Big Bang. If this hypothesis holds, the gravitational waves generated during the black hole formation process might be detectable by future gravitational wave observatories, providing a way to confirm this dark matter generation scenario.

Observations of stellar movements in galaxies and the cosmic microwave background — an afterglow of the Big Bang — indicate that about 80% of all matter in the universe is [dark matter](#), a substance that doesn't reflect, absorb or emit light. Despite its abundance, scientists have not yet identified what dark matter is made of.

In the new study, researchers explored a scenario where dark matter consists of primordial black holes formed from density fluctuations that occurred during the universe's last contraction phase, not long before the period of expansion that we observe now. They published their findings in June in the [Journal of Cosmology and Astroparticle Physics](#).

Video Player is loading.
 Live Science

See the Milky Way's Sagittarius A* black hole in an amazing polarized Event Horizon Telescope image

The bouncing cosmos

The traditional cosmological view of the universe suggests that it started from a singularity, followed by a short period of extremely rapid expansion, called inflation. However, the authors behind the new study analyzed a more exotic theory, known as non-singular matter bouncing cosmology, which posits that the universe first underwent a contraction phase. This phase ended with a rebound due to the increasing density of matter, leading to the Big Bang and the accelerated expansion we observe today.

In this bouncing cosmology, the universe contracted to a size about 50 orders of magnitude smaller than it is today. After the rebound, photons and other particles were born, marking the Big Bang. Near the rebound, the matter density was so high that small black holes formed from quantum fluctuations in the matter's density, making them viable candidates for dark matter.

[primordial black holes](#) can be produced during the very early stages of the universe, and if they are not too small, their decay due to Hawking radiation [a hypothetical phenomenon of black holes emitting particles due to quantum effects] will not be efficient enough to get rid of them, so they would still be around now," [Patrick Peter](#), director of research at the French National Centre for Scientific Research (CNRS), who was not involved in the study, told Live Science in an email. "Weighing more or less the mass of an [asteroid](#), they could contribute to dark matter, or even solve this issue altogether."

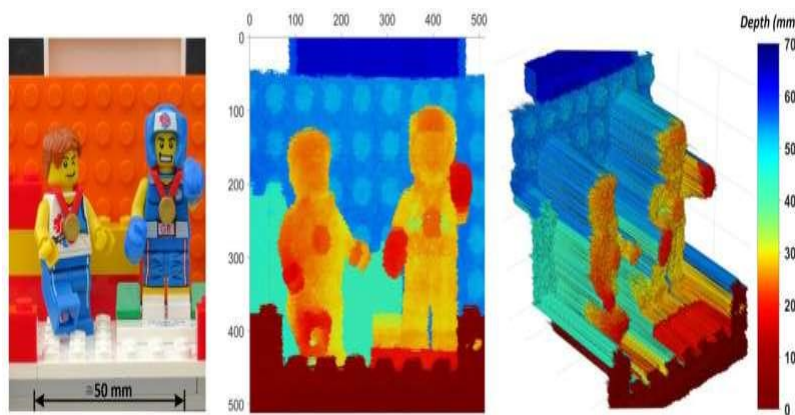
The scientists' calculations show that this universe model's properties, such as the curvature of space and the microwave background, match current observations, supporting their hypothesis.

To further test their predictions, the researchers hope to make use of next-generation gravitational wave observatories. The scientists calculated the properties of the [gravitational waves](#) produced during black hole formation in their model and found that they could be detected by [upcoming gravitational observatories like the Laser Interferometer Space Antenna \(LISA\)](#) and the [Einstein Telescope](#). These detections could confirm whether primordial black holes are indeed dark matter; however, it could take more than a decade before either facility sees first light.

"This work is important in the sense that it provides a natural way of forming small yet still present black holes forming dark matter in a framework which is not the usual one based on inflation," Peter said. "Other works currently investigate the behavior of such tiny black holes around stars, potentially leading to a way of detecting them in the future."

Single-photon LiDAR delivers detailed 3D images at distances up to 1 kilometer

by [Optica](#)



The researchers also used the new imaging system to image Lego characters from 32 m away. Credit: Aongus McCarthy, Heriot-Watt University

Researchers have designed a single-photon time-of-flight LiDAR system that can acquire a high-resolution 3D image of an object or scene up to 1 kilometer away. The new system could help enhance security, monitoring, and remote sensing by enabling detailed imaging even in challenging environmental conditions or when objects are obscured by foliage or camouflage netting.

"Our system uses a single-photon detector approximately twice as efficient as detectors deployed in similar LiDAR systems reported by other research groups and has a system timing resolution at least 10 times better," said research team member Aongus McCarthy, from Heriot-Watt University in the UK.

"These improvements allow the [imaging system](#) to collect more scattered photons from the target and achieve a much higher spatial resolution."

In *Optica*, a multi-institutional group of researchers from the UK and U.S. shows that the new system can construct a 3D image depicting a clearly recognizable human face of a person 325 meters away.

The researchers were from Gerald Buller's group at Heriot-Watt University, Robert Hadfield's group at the University of Glasgow, Matthew Shaw's group at the NASA Jet Propulsion Laboratory, and Karl Berggren's group at MIT.

"This type of measurement system could lead to improved security and monitoring systems that could, for example, acquire detailed depth images through smoke or fog and of cluttered scenes," said McCarthy, first author of the new paper.

"It could also enable the remote identification of objects in various environments and monitoring of movement of buildings or rock faces to assess subsidence or other potential hazards."

Light-based range finding

The single-photon time-of-flight depth imaging system uses the time it takes for a laser pulse to travel from the system to a point on an object and back to calculate the distance to the object. These time-of-flight measurements are then repeated for points across the object to obtain 3D information.

The new system uses an ultrasensitive detector called a superconducting nanowire single-photon detector (SNSPD) developed by the MIT and JPL research groups. The SNSPD can detect a single photon of light, which means that lasers with very low powers, including eye-safe lasers, can be used to perform measurements in a very short time and over long distances.

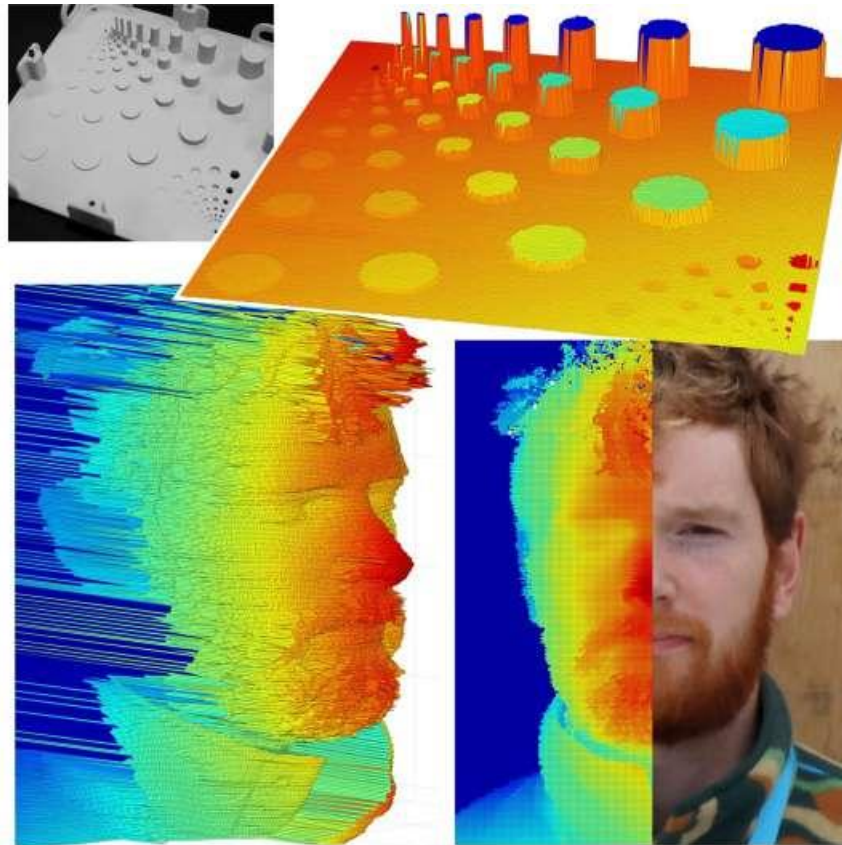
To reduce noise levels, the detector was cooled to just below 1 Kelvin in a compact cryocooler system designed and built by the University of Glasgow group.

The researchers combined the cooled SNSPD with a new custom single-pixel scanning transceiver operating at a 1550-nm wavelength that was designed by McCarthy at Heriot-Watt University. They also added advanced timing equipment to measure extremely precise time intervals—accurate down to trillionths of a second (picoseconds).

To put that into perspective, in just 1,000 picoseconds, light can travel about 300 millimeters (about 1 foot). This precision made it possible to distinguish surfaces separated by about 1 mm in depth from 325 meters away.

"These factors all provide improved flexibility in the trade-off between standoff distance, laser power levels, data acquisition time and depth resolution," said McCarthy.

"Also, since SNSPD detectors can operate at wavelengths longer than 1550 nm, this design opens the door to developing a mid-infrared single-photon LiDAR system, which could further enhance imaging through fog and smoke and other obscurants."



Researchers have designed a single-photon time-of-flight LiDAR system that can produce high-resolution 3D images of objects and faces that are some distance away. The top images show 3D printed pillars imaged from 45 m away in broad daylight. The lower images depict a recognizable human face from a person 325 m away. Credit: Aongus McCarthy, Heriot-Watt University

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3D measurements of distant objects

The researchers performed field tests of their LiDAR system on the Heriot-Watt University campus by taking measurements from objects that were 45 meters, 325 meters or 1 kilometer away.

To evaluate the spatial and depth resolution, they scanned a custom 3D-printed target with varying pillar sizes and heights. The system resolved features as small as 1 mm in daylight at 45 and 325 meters—a depth resolution approximately 10 times better than they had achieved previously. They also captured a 3D image of a human face at these distances using a 1 ms per-pixel acquisition time, an eye-safe 3.5 mW laser, and minimal data processing.

"The excellent depth resolution of the system means that it would be particularly well suited for imaging objects behind clutter, such as foliage or camouflage netting, a scenario that

would be difficult for a digital camera," said McCarthy. "For example, it could distinguish an object located a few centimeters behind a camouflage netting while systems with poorer resolution would not be able to make out the object."

While the [field trials](#) for the LiDAR system were limited to a range of 1 kilometer, researchers plan to test the system at distances of up to 10 km and explore imaging through atmospheric obscurants like smoke and fog.

Future work will also focus on using advanced computational methods to accelerate data analysis and enable imaging of more distant scenes.

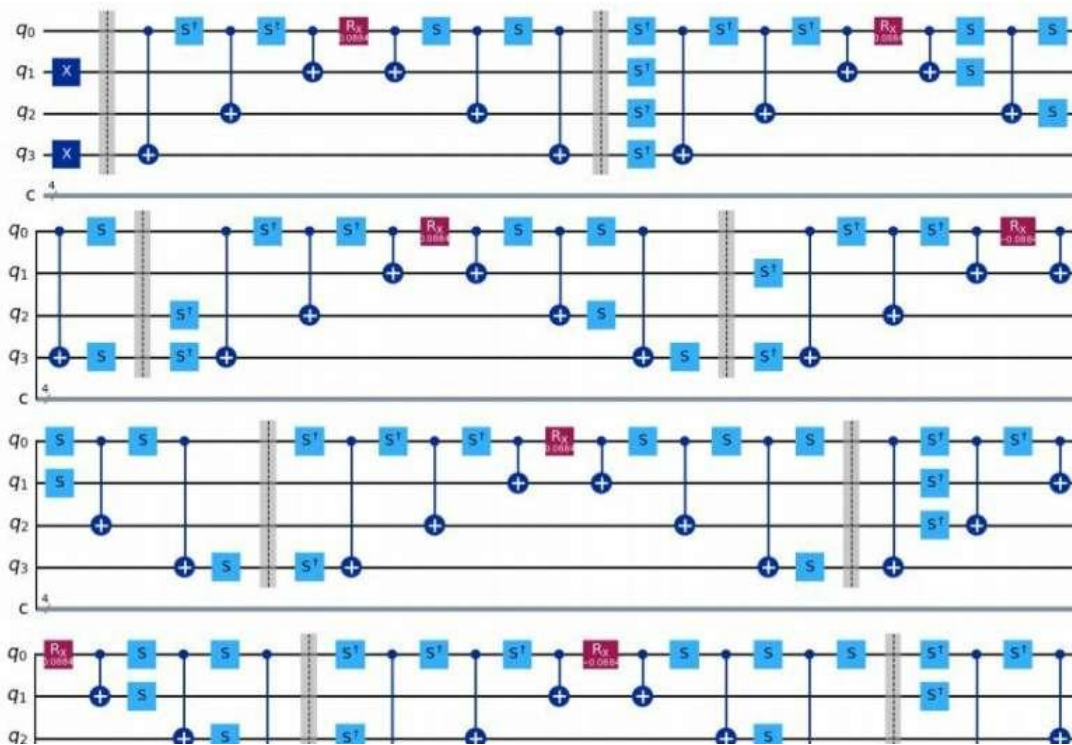
More information: Aongus McCarthy et al, High-resolution long-distance depth imaging LiDAR with ultra-low timing jitter superconducting nanowire single-photon detectors, *Optica* (2025). [DOI: 10.1364/OPTICA.544877](https://doi.org/10.1364/OPTICA.544877)

Journal information: [Optica](#)

Provided by [Optica](#)

FEBRUARY 7, 2025

Simulating particle creation in an expanding universe using quantum computers



The complete circuit for measuring the number of particles created in an expanding universe. Credit: *Scientific Reports* (2025). DOI: 10.1038/s41598-025-87015-6.

A new study [published](#) in *Scientific Reports* simulates particle creation in an expanding universe using IBM quantum computers, demonstrating the digital quantum simulation of quantum field theory for curved spacetime (QFTCS).

While attempts to create a complete quantum theory of gravity have been unsuccessful, there is another approach to exploring and explaining cosmological events.

QFTCS maintains spacetime as a classical background described by general relativity, while treating the matter and force fields within it quantum mechanically. This allows physicists to study [quantum effects](#) in "curved spacetime" without needing a complete theory of quantum gravity.

This semi-classical theory has already predicted phenomena like Hawking radiation from [black holes](#) and particle creation in expanding spacetimes. However, these predictions have been hard to verify experimentally.

Scientists have therefore used analog quantum simulations, such as Bose-Einstein condensates, to verify these phenomena, leaving digital quantum simulations unexplored.

Phys.org spoke to the first author of the study, Marco Díaz Maceda, a graduate student at Universidad Autónoma de Madrid.

"I believe [quantum computing](#) has a promising future for advancing research in physics. I have always loved studying the universe and its phenomena, so I was naturally drawn to quantum fields in curved spacetime. This research represents a fascinating intersection of these two fields, making it a natural and inspiring choice for me," said Maceda.

Error mitigation vs. error correction

In the present "noisy intermediate-scale quantum" (NISQ) era, quantum computers have three main characteristics. This includes noise, meaning the qubits and quantum gates are susceptible to environmental noise, and these devices roughly have tens or a few hundred qubits.

While these devices are powerful and can be used for applications like optimization problems and machine learning tasks, they have a major bottleneck, which is hardware.

Quantum error correcting codes (QECCs) have been shown to work theoretically, but are hard to implement. They require many physical qubits to create a single logical qubit.

This overhead requirement makes QECCs impractical to implement on current quantum computers that only have tens or hundreds of physical qubits.

In the present study, the researchers overcome this by suggesting error mitigation as opposed to [error correction](#). The idea behind this is to understand how the system's errors scale with noise.

Once understood, researchers can work backward to estimate the error-free result.

Maceda explained the importance of this technique with respect to the study, "We used only four qubits, one for each possible state of the field. However, since our circuit involved a large number of quantum gates, errors accumulated throughout the execution. To obtain reliable results, we applied error mitigation techniques, which helped improve the fidelity of our computations."

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Particle creation

In QFT, a flat spacetime is assumed, known as "Minkowski space." However, when spacetime is curved or dynamic (like in an expanding universe), the physics changes.

As spacetime stretches or expands (during inflation), the vacuum state (or zero-point energy state) becomes excited in this new spacetime, leading to the creation of new particles. This particle creation process is believed to have happened in the early universe.

To simulate this process, the researchers chose the Friedman-Lemaitre-Robertson-Walker (FLRW) universe metric to describe spacetime. This metric describes how spacetime expands homogeneously and isotropically.

For the quantum field, they consider a massive scalar field that evolves according to the modified Klein-Gordon equation to account for the curved, expanding spacetime.

Finally, to describe the particle creation process, the researchers used Bogoliubov transformations. These transformations provide a way for the researchers to calculate how many particles would be created in changing spacetimes, i.e., initial and final states.

Implementing the quantum circuit

The researchers designed a quantum circuit to simulate this process using IBM's 127-qubit Eagle processor.

The initial state of the universe was designed to start in the vacuum state or "zero-point energy" state, with a restriction of one excitation per mode.

Following this, the researchers implemented the quantum circuit for the particle creation process.

Maceda explained the process of designing the quantum circuit, saying, "The first step in designing the quantum circuit was to determine the time evolution operator of the system. This was achieved by relating the initial and final states through Bogoliubov transformations."

This step allowed them to calculate the number of particles created during the process.

Maceda continued, "Once we established this relationship, we assigned the excited states of the scalar field to specific qubits in the quantum computer."

The researchers encoded the quantum field states to actual physical qubits, each corresponding to the four excitation levels of the system. This included the ground state, one excitation each in the positive and negative modes, and one in both modes.

"Finally, applying techniques developed by my mentor Dr. Sabín, we mapped the time evolution operator to unitary operations acting on these qubits, ensuring that their evolution accurately reflected the dynamics of the scalar field in an expanding universe," said Maceda.

To achieve the mapping of the time evolution operator to unitary operators that can act on qubits, the researchers used hundreds of quantum gates.

For error mitigation, the researchers applied "zero-noise extrapolation" (ZNE). This method works by deliberately adding noise to the system in a controlled manner, measuring how the noise affects the results, and then extrapolating backward to the zero-noise state.

A feasible tool for future research

The simulations successfully demonstrated particle creation in expanding [spacetime](#), with results matching theoretical predictions. Although the results from the quantum computer showed higher noise, it demonstrated feasibility.

Additionally, the ZNE techniques significantly improved the results, demonstrating the viability of using quantum simulations for studying complex systems.

Explaining the impact of their work on cosmology, Maceda said, "Our work provides a new way to simulate particle creation in the early universe, offering deeper insights into fundamental processes that shape the cosmos."

The researchers also believe digital quantum simulations are already becoming and will continue becoming viable tools for investigating cosmological phenomena.

"Digital quantum simulations have already been used by my mentor Dr. Sabín to research topics such as gravitational entanglement, Rindler transformations that account for black hole evaporation, and the causal structure of the universe," commented Maceda.

More information: Marco D. Maceda et al, Digital quantum simulation of cosmological particle creation with IBM quantum computers, *Scientific Reports* (2025). [DOI: 10.1038/s41598-025-87015-6](#).

Journal information: [Scientific Reports](#)

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Feb 07, 2025

New composite material converts light and humidity into mechanical motion and power for smart tech

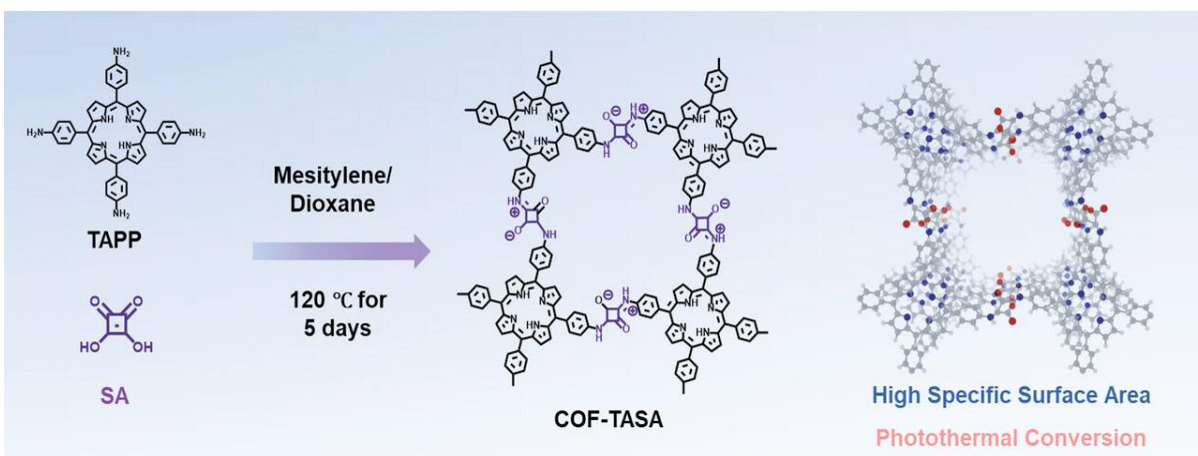
(*Nanowerk Spotlight*) Scientists have struggled to create synthetic materials that can sense and respond to their environment with the precision needed for advanced robotics and smart devices. A key challenge has been developing materials that can efficiently convert multiple types of environmental changes - like variations in light or moisture - into controlled mechanical movements. While responsive materials exist, they typically react slowly, work with only one type of stimulus, or lose effectiveness over repeated use.

Existing approaches using [cellulose nanofibers](#) can respond to moisture but do not inherently absorb light. Previous attempts to make them light-responsive involved adding materials like [graphene](#) and [MXene](#), but these combinations struggled with structural limitations that slowed response times. A new composite material overcomes these challenges by integrating a specially designed covalent organic framework, which not only enhances light absorption but also creates ordered channels that accelerate water transport, significantly improving both speed and efficiency.

Recent advances in molecular engineering have enabled the creation of precisely ordered crystalline structures at the [nanoscale](#) level. These developments have opened new possibilities for materials that can efficiently absorb light and channel water molecules through their internal structure.

Researchers from the Harbin Institute of Technology have now developed a composite material that demonstrates significant advances in addressing these challenges. Their work, published in *Advanced Functional Materials* ("[Multi-Responsive COF-Enhanced Smart Actuator](#)"), describes a material that can quickly bend and move in response to both near-infrared light and humidity changes, while also generating electrical energy from these movements.

The team's innovation centers on a new type of crystalline polymer called a [covalent organic framework](#) (COF). They created this framework by combining two chemical compounds: tetra (p-amino-phenyl) porphyrin and squaric acid (dubbed COF-TASA by the researchers). The resulting material can convert 79.9% of absorbed near-infrared light into heat - the highest efficiency reported for this class of materials. They combined this framework with cellulose nanofibers and a specialized polymer called polyvinylidene fluoride (PVDF) that can generate electricity when bent or deformed.

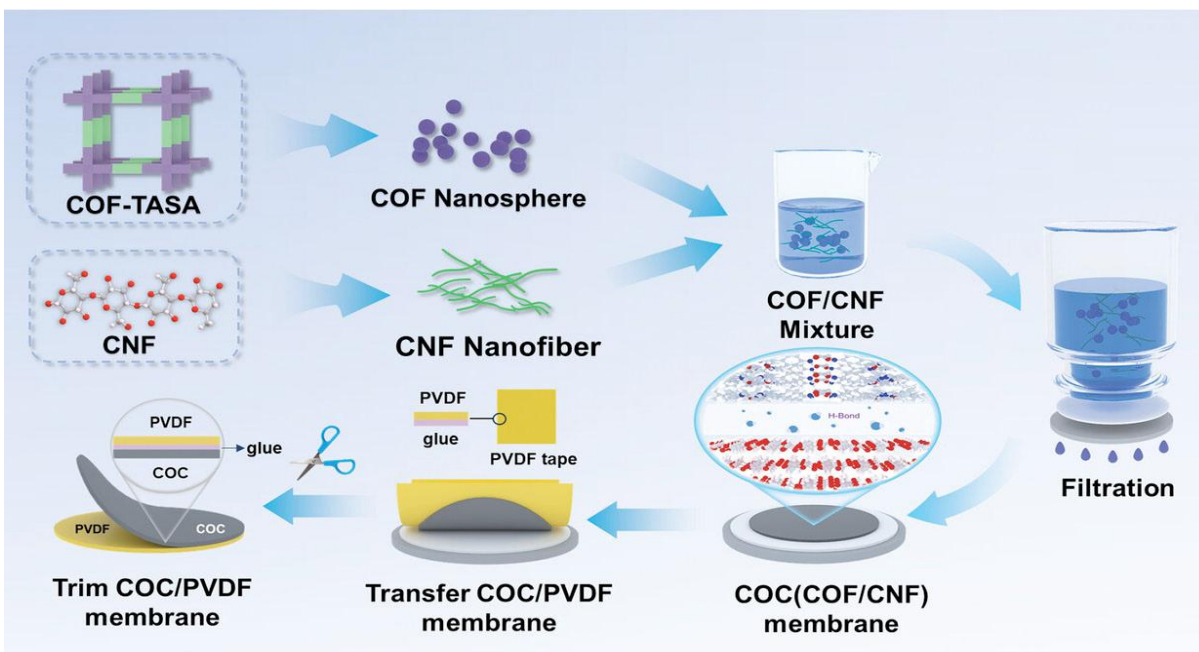


Schematic of the reaction system for COF-TASA. (Image: Reprinted with permission by Wiley-VCH Verlag)

The resulting composite shows remarkable improvements in both speed and reliability. When exposed to near-infrared light, it can bend to a specific shape in just 7 seconds, significantly outperforming previous materials. When humidity levels change, the material bends in the opposite direction. Importantly, it maintains these capabilities over multiple cycles without degradation - a crucial requirement for practical applications.

The material's structure explains its enhanced performance. The new framework creates organized channels within the composite that allow water molecules to move efficiently through the material. Computer simulations revealed that these channels significantly improve how water diffuses through the structure, explaining the material's faster response times compared to previous attempts.

A key aspect of the team's work was creating a bilayer membrane that could translate environmental changes into physical movement. The researchers constructed this by combining two distinct layers: one made of their COF-enhanced cellulose nanofiber composite, and another of polyvinylidene fluoride (PVDF). When exposed to near-infrared light, the COF layer heats up and loses moisture, causing it to shrink, while the PVDF layer expands due to heat. This asymmetric deformation causes the entire membrane to bend. Similarly, when exposed to humidity, only the COF layer absorbs moisture and expands, while the PVDF layer remains unchanged, causing the membrane to bend in the opposite direction. This dual-response mechanism, combined with PVDF's ability to generate electrical charges when deformed, allows the material to both move and generate electricity in response to environmental changes.



Schematic fabrication process of the COC/PVDF bilayer membrane. (Image: Reprinted with permission by Wiley-VCH Verlag)

The researchers demonstrated several practical applications. They created a humidity control system where the material acts as a switch, automatically opening and closing electrical circuits based on moisture levels. They also developed simple robots that could lift and transport small objects by bending in response to either light or humidity changes.

Perhaps most significantly, the material can convert its mechanical movements into electrical energy through its PVDF component. When the material bends in response to environmental changes, the PVDF generates small electrical voltages. This capability suggests applications in self-powered sensors and energy harvesting devices that could collect and use energy from environmental changes.

The team's comprehensive understanding of the underlying mechanisms, supported by both experimental data and computer simulations, provides a foundation for future improvements. Their analysis showed that the ordered internal structure created by the framework not only improves water molecule movement but also enhances the material's ability to absorb and convert light energy.

This advancement brings us closer to creating truly adaptive materials for applications ranging from soft robotics to environmental sensing. The combination of fast response times, multi-stimulus sensitivity, and energy harvesting capability offers new possibilities for self-powered devices that can automatically respond to environmental changes. Future applications could include adaptive building materials that respond to weather conditions, smart textiles that react to body moisture, and autonomous systems that can operate without external power sources.

The research demonstrates that precisely engineered molecular structures can create materials with multiple advanced capabilities, setting a new direction for the development of smart, responsive materials that can both sense and adapt to their environment while generating useful energy.

A Physicist Claims Gravity Can Exist Without Mass

- Some clusters of galaxies may not need dark matter in order for their physics to work.
- In new research, a physicist describes a “shell singularity,” where gravity applies without mass.
- Today’s theories for dark matter include many sizes and types for different situations.

In the wide landscape of physics, researchers are exploring dozens of ways to either identify or rule out [dark matter](#), all to help humans understand how our visible and invisible worlds work together. In a new paper, which [appears in the peer-reviewed journal](#) *Monthly Notices of the Royal Astronomical Society*, scientists suggest that the fundamental idea of gravity may not need the corresponding fundamental idea of mass in order to make physical sense.

If they’re right—if everything we thought we knew is still not the whole story of [gravity](#)—then dark matter may not even exist at all. Has it been experimental physics’ imaginary friend all this time?

That’s a provocative question—but, of course, this is one paper on one theory within a large landscape of dark matter theories. So, the short answer is “no, but what if?” In the paper, physicist Richard Lieu of the University of Alabama describes a specific scenario in which gravity affects a system, but that gravitational field does not contain underlying [mass](#).

It’s an edge case of a “shell singularity” around a bump in empty space. As he computes his way through the [physics](#) of what the shell will do, the shell itself moves toward zero mass and seems to disappear. So far, so good.

But, his [math](#) supports that the area including the zero mass shell still maintains the characteristics of gravity. "With a sufficient number of such unresolvably closely spaced singular shells," he concludes, "the potential Φ is effectively a continuous function." In other words, put enough zero mass shells in a tiny enough space, and you'll have a sort of ersatz gravitational field with no mass responsible for it.

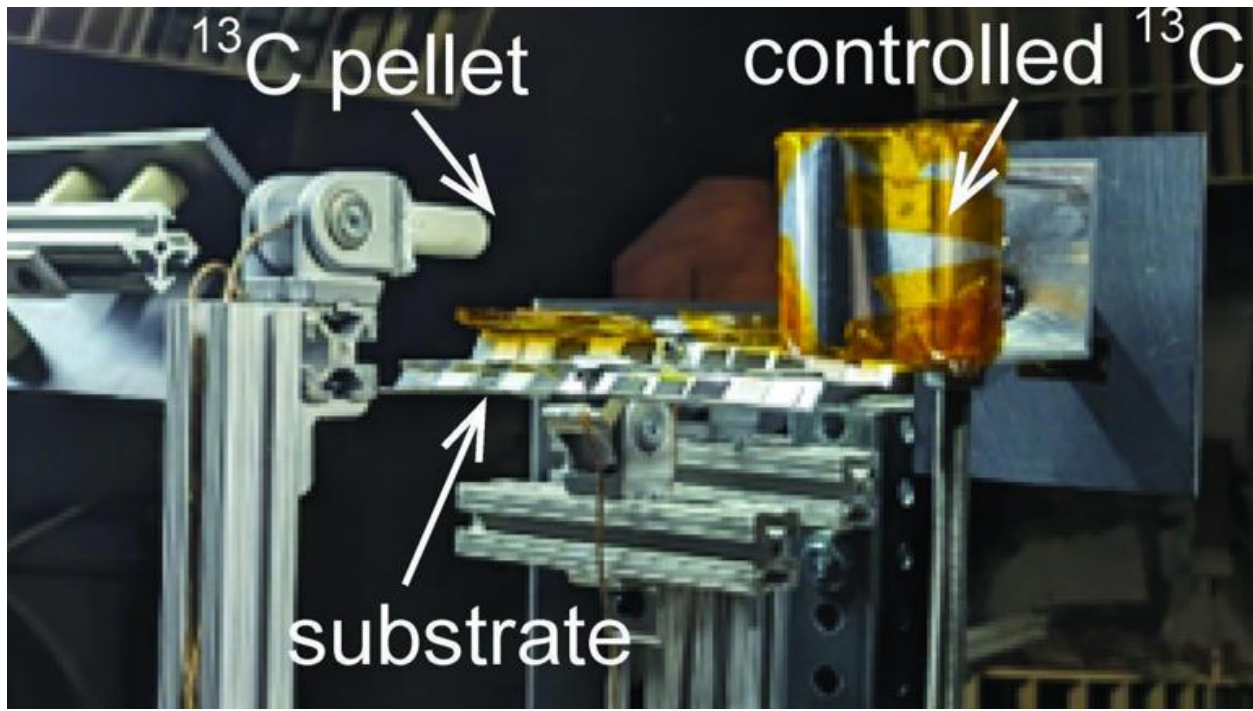
That seems like a cool math trick—much like the way manufacturers can say diet soda has "0 calories" because the true value of .4 falls under the legal threshold that allows it to be rounded down. But it's *not* just a cool trick. The zero mass shells can flesh out a scenario that allows scientists to calculate gravity in a neat way that unites the [quantum](#) and classical versions of physics without having to include an X factor of dark matter (DM). "[T]he need for enlisting DM is mitigated, at least in part," Lieu wrote.

There's a bit of a twist underpinning this work, though. Lieu's scenario requires another, somewhat unusual (or, at least, less verifiable) phenomenon of spacetime—a topological defect. "An example is a thin sheet of negative mass wrapping around a wormhole to maintain cylindrical symmetry," Lieu wrote. That's kind of a long shot on top of a long shot, and it's not an everyday scenario that someone will see through a high powered observatory [telescope](#) anytime soon.

At the same time, Lieu described the topological defect as "reasonably corroborated," which is more than we can say right now for dark matter. He concluded that, while his idea does not rule out dark matter or majority of applications that currently rely on the concept, it might apply to specific configurations of [galaxies](#) that could cluster and create these topological effects and shell singularities.

And of course, if one edge case exists, there may be others. Lieu discussed some other theories of dark matter within large structures like galaxies, because these behave differently in a huge arena like that than at the micro scale. It could be that the idea "dark matter" contains multitudes—including versions that fill differently sized gaps in our [understanding](#).

Experiment validates electric ion thruster simulations



Credit: AIAA SCITECH 2024 Forum (2024). DOI: 10.2514/6.2024-1135

Predicting the lifetime of an electric ion thruster is notoriously difficult. You have to account for the chamber wall effects, which are not present in space environments. Researchers within several different aerospace disciplines in The Grainger College of Engineering, University of Illinois Urbana-Champaign worked together to simulate the ion activity, then validate it in a unique experiment that will help predict the lifespan of electric thrusters.

"We can simulate the damage to the engine caused by sputtering, but until now, we could not validate that our simulations were correct," said Professor Huck Beng Chew.

"Because both the engine and chamber walls are coated with impact-resistant carbon, we didn't know whether the coating damage was from accelerated ions directly hitting the engine or whether the coating damage was artificially mitigated by the deposition of carbon from ion bombardment off the chamber walls."

Chew said validation of his simulations came from a collaborative effort. Professor Joshua Rovey and his grad students conducted an experiment proving where the carbon fragments originated by testing two different carbon-coated plates in the vacuum chamber—one with ^{12}C and the other with ^{13}C —making the identification clear.

"It's difficult to track the carbon particles being deposited back on the surfaces because they're atomic-sized," Chew said. "We can't see them, but we can observe the damage they cause. But because we knew the location origins of the two types of carbon, we could identify them on the other surfaces."

Another collaborator on the project was Professor Deborah Levin. "Debbie simulates how the carbon is transported. She developed a code that calculated the amount of carbon atoms that are displaced. I work on the plasma/material interface, and Josh is the experimentalist," said Chew.

The team was also able to examine how the angle of impact from the dislocated carbon particles affected the surfaces.

Huy Tran, Chew's former Ph.D. student, created a scale bridging model. He used molecular dynamics, to run the simulations and combine Monte Carlo models—which rely on repeated random sampling to obtain numerical results—to look at the sputtered species surfaces.

Chew explained that there are many different species of carbon. It can be crystalline diamond or graphite, or amorphous carbon.

"We ran simulations and found that the specific type of carbon didn't matter. When the Xenon or Krypton ions impact the surface, the result is a very random, amorphous arrangement of atoms. This means the substrate doesn't matter. The regular crystalline structure becomes a mixed liquid. This finding simplifies the analysis."

The study, "Carbon Transport in Electric Propulsion Testing—I: Multiscale Computations for Carbon Sputtering by Low Energy Ion Bombardment," was [published](#) in the journal *AIAA SCITECH 2024 Forum*.

Another significant finding from the research concerned surface roughness.

"Because the set of simulations were done on a molecular level using molecular dynamics, we could not account for surface roughness. We performed a simulation that assumes initial surface roughness. After the surface is bombarded with a normal incident angle, the rougher surface became smoother as the surface is being chipped off.

"When the surface was impacted with a sharper, oblique ion incident angle, the material shaved off in more of a zigzag profile. The question was: Are the simulation results real? Josh Rovey's experiment verified the answer to be yes."

He said, what this means is that now they can expect the surface morphology will become flatter or rougher depending upon the incident angle.

"We can be confident that the sputter yield—the rate at which the carbon film wears off—is correct."

In terms of informing predictions about the lifespan of a thruster in space, Chew said, "That's the ultimate goal, but because this is fundamental research, we're still a long way from that. However, knowing the angle is an important piece. With that knowledge, you can design surface topology—surface structures—to mitigate sputtering. That's a grand challenge, and now there's a solution forward.

"Experiments are real. Simulations are based on a set of assumptions and involve a lot of simplification. What the experiments told us is that the simulations are on the right track. Confirming our assumptions brings more trust into the simulation data."

More information: Huy D. Tran et al, Carbon Transport in Electric Propulsion Testing – I: Multiscale Computations for Carbon Sputtering by Low Energy Ion Bombardment, *AIAA SCITECH 2024 Forum* (2024). [DOI: 10.2514/6.2024-1135](https://doi.org/10.2514/6.2024-1135)

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FEBRUARY 10, 2025 FEATURE

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The ALPHA experiment moves towards the increasingly precise study of antihydrogen

by Ingrid Fadelli , Phys.org



ALPHA-

2. Credit: Jeffrey Scott Hangst.

Antimatter is a fascinating kind of matter made up of antiparticles, which have a mass equivalent to that of their normal matter counterparts, yet they exhibit an opposite charge and distinct quantum properties.

While normal matter has been extensively studied over the past decades and is now well understood, investigating the properties of antimatter with the same precision using existing experimental techniques has proved more challenging.

The ALPHA experiment, a research effort involving researchers at different institutes worldwide, has been trying to unveil the physical properties of antimatter using the Antiproton Decelerator at CERN, specifically those of anti-hydrogen atoms confined in a magnetic trap.

Their most recent [paper](#), published in *Nature Physics*, presents new measurements of the properties of antihydrogen's 1S–2S transition, which is an electronic energy transition in antihydrogen atoms.

"This is the latest in a long line of results of studies exploring the internal structure of antihydrogen," Jeffrey Scott Hangst, spokesperson for the ALPHA antihydrogen experiment, told Phys.org.

"The ALPHA collaboration is unique in the world in the ability to produce, confine and then study antihydrogen atoms, with studies taking two forms primarily. One is the spectroscopy of the internal structure, the internal energy levels of the anti-hydrogen atom to compare them to hydrogen, which is something we understand very well. The other entails understanding how antimatter behaves in a [gravitational field](#), and we're the only ones who have published anything about this so far."

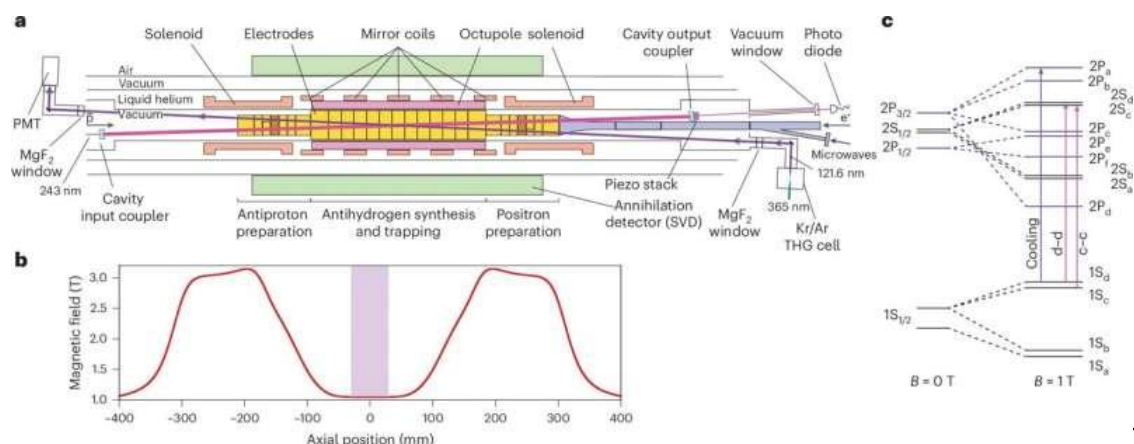
The structure and properties of hydrogen atoms have been extensively studied at high precision and are thus now well-understood. The key objective of the ALPHA experiment is to collect the same [precise measurements](#) for its antimatter counterpart, antihydrogen.

These measurements could help to shed light on the extent to which matter and antimatter obey the same physics laws, as is required by the Standard Model. To achieve this, the ALPHA collaboration is using a combination of techniques, including a new laser cooling method.

"Our new technique of laser cooling trapped antihydrogen atoms can make the spectrum narrower," said Hangst.

"In the end, you're trying to find one frequency, which is the center line of this spectral line that's perturbed in many ways: by magnetic fields, by the motion of the atoms and so on. Our paper demonstrates the capability of the modern experiment that we now have that traps anti-hydrogen and then cools it to very low temperatures.

"We're now making great strides in trying to understand something in antimatter that is known to a precision of 10^{-15} in normal hydrogen."



The

ALPHA-2 experiment, magnetic-field profile and level diagram of antihydrogen.

Credit: *Nature Physics* (2025). DOI: 10.1038/s41567-024-02712-9

The recent work by Hangst and his colleagues yielded some of the most precise measurements of antihydrogen reported to date. Specifically, the researchers

simultaneously observed both accessible hyperfine components of the 1S–2S transition in trapped hydrogen atoms.

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"Hydrogen has quantum levels, principal quantum levels (i.e., $n=1$, $n=2$, $n=3$, etc.), which are essentially the orbits in the cartoon model of the hydrogen atom," explained Hangst.

"The one that we're studying ranges from $n=1$ to $n=2$. When you're in a magnetic field, however, this line splits into multiple levels and we're able to probe the two levels that are accessible in our trap. In fact, we're able to examine them both in a single run of the experiment."

The two separate frequencies examined by the ALPHA collaboration offer valuable information about the internal structure of antihydrogen atoms. A key milestone of their paper is the new laser cooling-based technique they employed, which allowed them to investigate both these frequencies at low temperatures.

"One of the frequencies is more susceptible than the other to the laser cooling, but we mastered the technique of accumulating a lot of [antihydrogen atoms](#) and this allows us to measure this spectrum in about an hour," said Hangst. "We can now accumulate our anti atoms overnight and then measure in a very short time."

When they conducted a similar experiment back in 2017, the researchers were only able to collect measurements over a period of 10 weeks. With the new techniques they employ, they can now routinely collect the same measurements in just one day.

"The notable achievement is not just that we can do it fast, but also that we can study small changes in the equipment (i.e., systematic effects on the measurement)," said Hangst. "The more measurements you can repeat, the better an idea you have of how stable your apparatus is, for example, how reproducible your lasers are."

For Hangst and his colleagues, the speed and hyperfine sensitivity they achieved in their most recent experimental runs represent a paradigm change in the study of anti-hydrogen. Their recent findings highlight the potential of the methods they devised, showing that they will soon yield even more precise measurements.

"For us, this is a notable step forward in our ability to study this very exotic physics," said Hangst. "This article focuses more on the techniques we employ, showing what's possible. Since this data was collected, we've already made better progress, which we plan to publish in future papers. Our next steps will be to perform the very careful measurements we need to extract a precise number."

Later this year, the ALPHA collaboration could publish even more precise measurements associated with the internal structure and physical properties of anti-hydrogen. The

researchers' long-term goal will be to reach the same levels of precision as those attained for regular hydrogen atoms, to closely compare matter and antimatter.

These equivalent measurements could help to settle long-standing theoretical debates. Specifically, if anti-hydrogen measurements agree with those of hydrogen, this would confirm that the physics of [antimatter](#) is compatible with the Standard Model, which is the basis of the present understanding of elementary particles and their interactions.

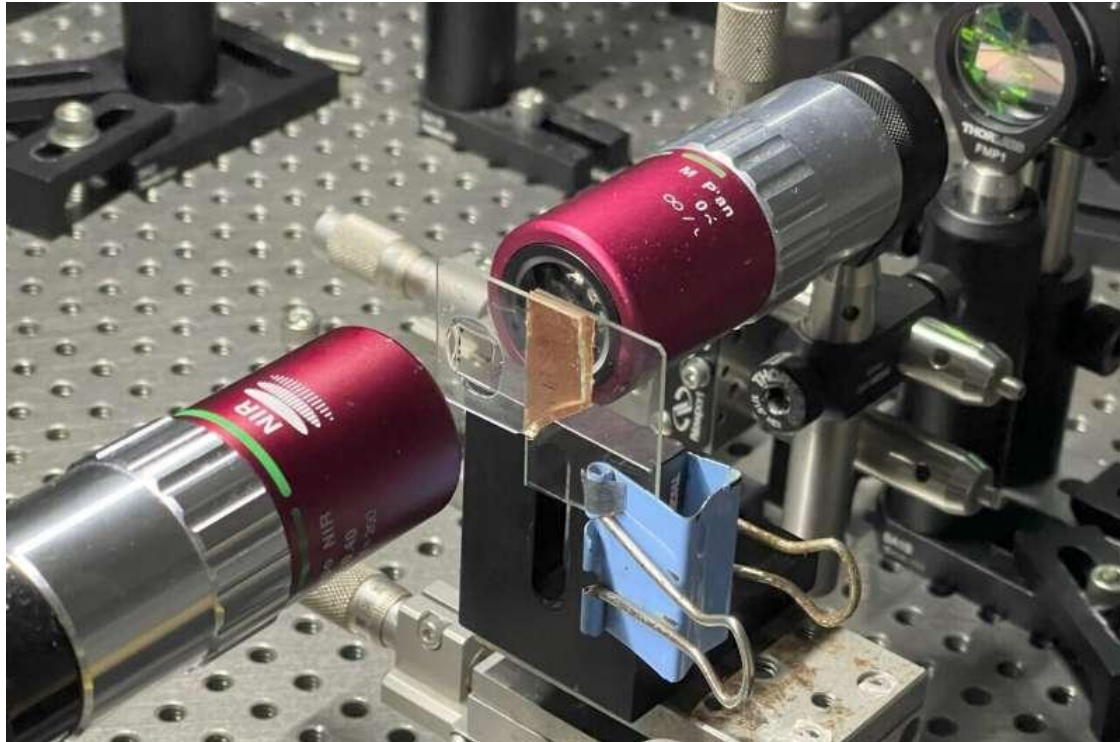
"The next step for us will be to exploit everything that we've learned to make the ultimate measurements and get closer and closer to the precision with which we understand hydrogen," added Hangst. "To put this in context, hydrogen precision is parts in 10^{15} , or one in a thousand trillion. Our best published result is about a few parts in a trillion and the next article will be much, much better."

More information: C. J. Baker et al, Precision spectroscopy of the hyperfine components of the 1S–2S transition in antihydrogen, *Nature Physics* (2025). [DOI: 10.1038/s41567-024-02712-9](https://doi.org/10.1038/s41567-024-02712-9).

Journal information: [Nature Physics](#)

FEBRUARY 10, 2025

Qubits to qudits: Using quantum mechanics to transmit information more securely [University of Pennsylvania](#)



How two red lens modules align with a glass plate, carefully tuning the path of the laser. The metal and plastic mounts allow researchers to fine-tune the angles for optimal quantum signal measurements. Credit: Yichi Zhang

In the realm of quantum information distribution, sending a signal from point A to point B is like a baseball pitcher relaying a secret pitch call to the catcher. The pitcher has to disguise the signal from the opposing team and coaches, base runners, and even onlookers in the stands so no one else cracks the code.

The catcher can't just stay in one spot or rely on the same finger pattern every time, because savvy opponents are constantly working to decipher any predictable sequence. If the signs are intercepted or misread, the batter gains an advantage, and the entire inning can unravel for the pitcher.

But what if there was a way for pitchers to bolster their signals by adding extra layers of "dimensionality" to each call, effectively increasing the chances of delivering it correctly to the catcher no matter how many eyes are watching? What if by incorporating more nuanced

gestures—a subtle shift in glove position, a specific tap on the mound—the pitcher could craftily conceal their intentions?

With this higher-dimensional approach, the coded message could zip right past the other team's efforts to steal the signs and land reliably in the catcher's mitt.

Now, research led by Liang Feng of the University of Pennsylvania and collaborator Li Ge at the City University of New York and published in [Physical Review X](#) has resulted in a newly developed compact microlaser that transmits coded information more securely.

Instead of the conventional two-dimensional quantum bits (qubits) that encode quantum information within a two-level system, the microlaser uses a higher-dimensional alternative, known as qudits, vastly expanding the capacity and resilience of quantum communication—akin to a pitcher layering multiple subtle gestures to avoid tipping pitches.

This innovation allows quantum messages to carry more information while being less prone to interference, laying the groundwork for the future of secure, high-dimensional quantum networks.

"What we did, essentially, was shrink the gigantic optical setup that researchers typically use to create quantum signals onto a small laser chip," says Feng, professor of electrical and systems engineering at the School of Engineering and Applied Science. "In this case, the corresponding energy consumption is quite low compared to what is being done today, but also the signal is far more robust."

Given its compact, [sleek design](#), Feng notes that the device can be made portable, which means a user, say a banker on Wall Street receiving encrypted tokens, can walk around with it without the noise of busy New York streets interfering with the signals being sent and received.

First author Yichi Zhang, a Ph.D. candidate at Penn Engineering, explains that quantum keys are ways to encode and decode real information. "So, imagine that every time you log onto a webpage for your bank, you need a one-time code. With this sort of quantum code, it would be theoretically impossible to crack due to the high level of specificity in the signal."

Zhang explains that their quantum key distribution (QKD) device generates spin-orbit photonic qudits, which refers to a special way of encoding information in light by manipulating both its shape (orbital angular momentum) and the way it "twists" as it travels through space (polarization). In other words, rather than encoding quantum information in just one property of a photon, the team's system can multitask, allowing for more complex, high-dimensional encoding.

"Our microlaser system fundamentally improves upon existing QKD methods, which often rely on large, delicate free-space optical setups," Zhang explains.

"Before, these kinds of quantum signals required an entire optical table filled with precise, bulky equipment. With our microlaser, we've condensed all of that into a compact chip, which can be incorporated into real-world networking applications."

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Peeking under the hood

A key driver behind the team's breakthrough was the use of non-Hermitian physics, which guides how energy and information may flow through a system. Unlike traditional Hermitian systems, where energy and information behave regularly and rigidly—like a perfectly balanced scale—non-Hermitian systems introduce new degrees of control, allowing energy exchange to be dynamically and conveniently fine-tuned.

This flexibility enables the real-time generation and manipulation of high-dimensional spin-orbit qudit states using the extreme compact microlaser. As a result, emitted light—as the qudit carrier—can be precisely controlled, ensuring stable quantum key transmission with greater efficiency.

"We designed a microlaser that can emit four distinct quantum states with perfect spatial and temporal uniformity," Feng explains. "This means we don't have to worry about dephasing effects—which is just light losing synchronicity—or signal loss due to environmental fluctuations."

The team's experiments demonstrated that their system could reliably transmit quantum keys over simulated long-distance conditions, maintaining signal integrity across distances equivalent to over 100 kilometers in atmospheric transmission.

"And our calculations suggest that, with further optimization—like replacing low-efficiency single-photon avalanche diodes with superconducting nanowire single-photon detectors—the system could push past 500 kilometers, making ground-to-satellite quantum communication a tangible reality," Zhang says.

The researchers also address a major weakness in QKD known as multiphoton pulses in weak coherent state propagation, or simply put, sophisticated eavesdropping.

"In a perfect QKD system, every transmitted pulse contains just one photon, ensuring that only the intended recipient can receive it," Feng explains. "But in practical implementations, laser-based systems sometimes generate multiphoton pulses, meaning more than one photon is emitted per signal pulse."

This means an eavesdropper could intercept one photon from a pulse, measure it, and send the remaining photons forward undisturbed—essentially copying the message without diminishing it and being detected.

To prevent this, the team implemented a decoy that introduces random variations in pulse intensity, so some pulses contain the expected number of photons, while others are deliberately weaker or just empty.

"By randomly altering the intensities of transmitted pulses, we can trick an eavesdropper into revealing themselves," Zhang explains. "If someone tries to measure the quantum keys, they won't be able to tell the difference between a real signal and a decoy, and we'll be able to detect their interference."

Looking ahead

On a device level, notes Feng, the team is trying to see if they can further increase the dimensionality of the system such that they can encode more [quantum information](#) and make its transmission more robust and more resilient.

"I guess the next step would be, first, we want to really test this in a practical environment, such as, for example, a fiber network," he says. "Second, beyond just QKD, can we see the application of this data for this small chip applied in a range of scenarios? For instance, can they serve as very important nodes in a quantum network?"

More information: Yichi Zhang et al, High-Dimensional Quantum Key Distribution by a Spin-Orbit Microlaser, *Physical Review X* (2025). [DOI: 10.1103/PhysRevX.15.011024](https://doi.org/10.1103/PhysRevX.15.011024)

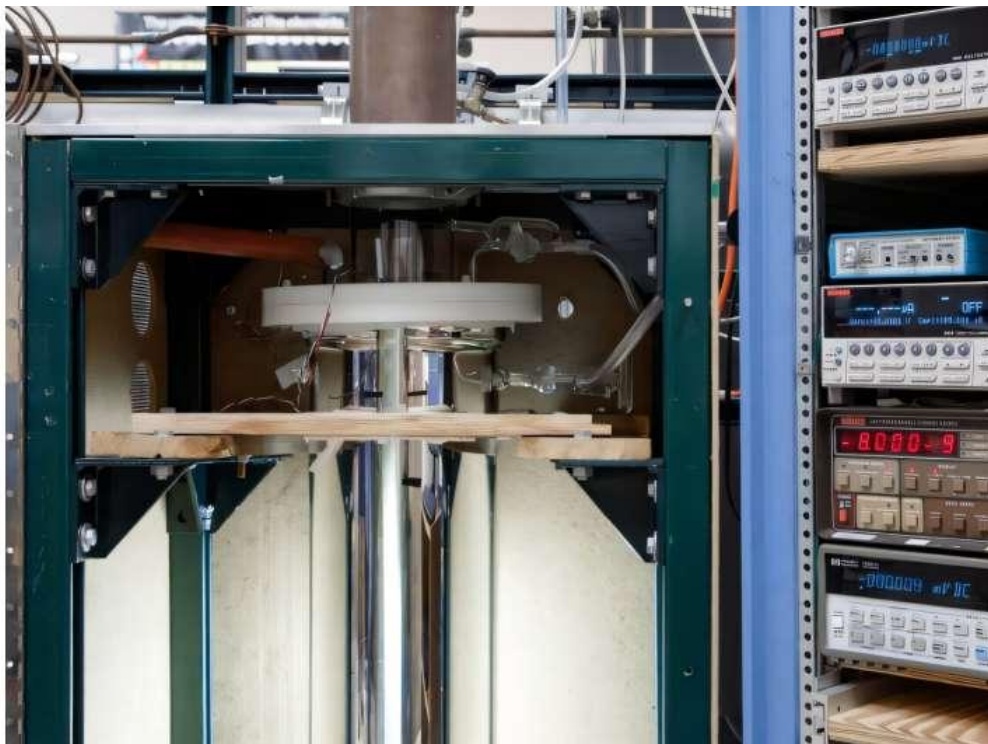
Journal information: [Physical Review X](#)

Provided by [University of Pennsylvania](#)

FEBRUARY 10, 2025

Physicists stabilize superconducting states at ambient pressure

by Bryan Luhn, [University of Houston](#)



A multi-purpose measurement device used in the pressure-quenching experiments can reach a temperature of 1.2 K (-457 F). Credit: University of Houston

Researchers at the University of Houston's Texas Center for Superconductivity have achieved another first in their quest toward ambient-pressure high-temperature superconductivity, bringing us one step closer to finding superconductors that work in everyday conditions—and potentially unlocking a new era of energy-efficient technologies.

In their study titled "Creation, stabilization, and investigation at [ambient pressure](#) of pressure-induced superconductivity in $\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$," [published](#) in the *Proceedings of the National Academy of Sciences*, professors Liangzi Deng and Paul Ching-Wu Chu of the UH Department of Physics set out to see if they could push $\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$ (BST) into a [superconducting state](#) under pressure—without altering its chemistry or structure.

"In 2001, scientists suspected that applying high pressure to BST changed its Fermi surface topology, leading to improved thermoelectric performance," Deng said. "That connection between pressure, topology and superconductivity piqued our interest."

"As materials scientist Pol Duwez once pointed out, most solids that are crucial to industry exist in a metastable state," Chu said. "The problem with that is many of the most exciting superconductors only work under pressure, making them difficult to study and even harder to use in practical applications."

That's where Deng and Chu's breakthrough comes in.



Magnetization Property Measurement System (MPMS) used in ultra-sensitive magnetization measurements. Credit: University of Houston

Using a technique they developed called the pressure-quench protocol (PQP), described in an October UH news release, Deng and Chu successfully stabilized BST's high-pressure-induced superconducting states at ambient pressure—meaning no special high-pressure environments needed.

Why does this matter? It opens up a whole new way to retain valuable material phases that usually only exist under pressure for fundamental research and practical application.

"This experiment clearly demonstrates that one may stabilize the high-pressure-induced phase at ambient pressure via a subtle electronic transition without a symmetry change, offering a novel avenue to retain the material phases of interest and values that ordinarily exist only under pressure," Chu said. "It should help our search for superconductors with higher transition temperatures."

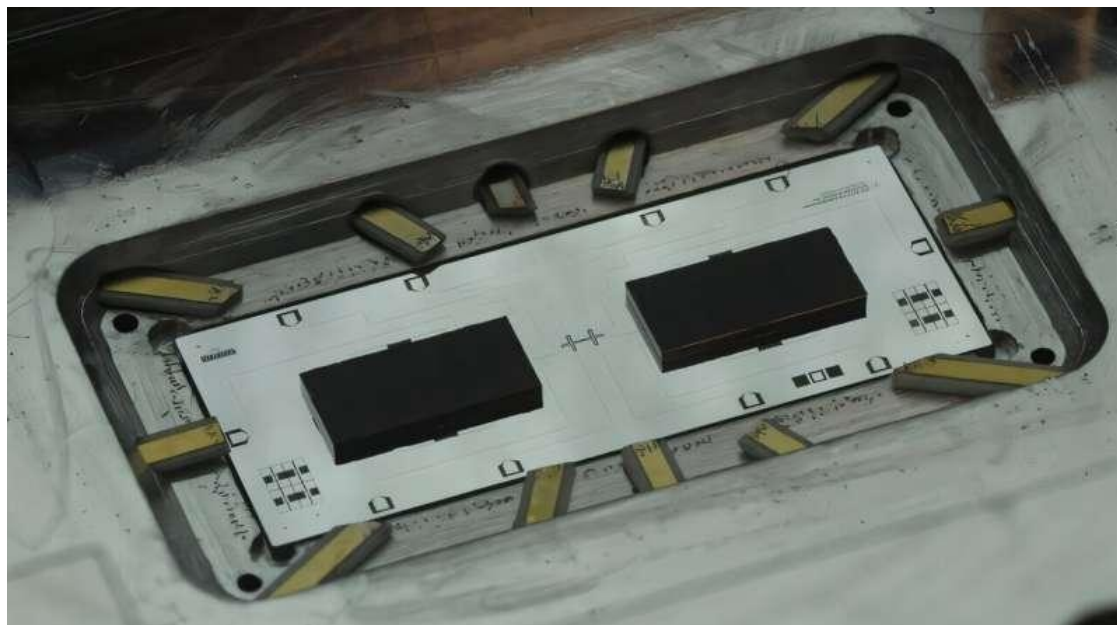
"Interestingly, this experiment revealed a novel approach to discovering new states of matter that do not exist at ambient pressure originally or even under [high-pressure](#) conditions," Deng added. "It demonstrates that PQP is a powerful tool for exploring and creating uncharted regions of material phase diagrams."

More information: Liangzi Deng et al, Creation, stabilization, and investigation at ambient pressure of pressure-induced superconductivity in $\text{Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3$, *Proceedings of the National Academy of Sciences* (2025). DOI: [10.1073/pnas.2423102122](https://doi.org/10.1073/pnas.2423102122)
Journal information: [Proceedings of the National Academy of Sciences](#)
Provided by [University of Houston](#)

FEBRUARY 10, 2025

Entangling two physically separate resonators enables a major advance in the science of quantum sound

by Paul Dailing, [University of Chicago](#)



A new paper from the lab of UChicago Pritzker School of Molecular Engineering Prof. Andrew Cleland demonstrates entanglement between two physically separate resonators. Credit: Cleland Lab

Entanglement—linking distant particles or groups of particles so that one cannot be described without the other—is at the core of the quantum revolution changing the face of modern technology.

While entanglement has been demonstrated in very small particles, new research from the lab of University of Chicago Pritzker School of Molecular Engineering (UChicago PME) Prof. Andrew Cleland is thinking big, demonstrating high-fidelity entanglement between two acoustic wave resonators.

The paper is [published](#) in *Nature Communications*.

"A lot of research groups have demonstrated that they can entangle very, very small things down to the [single electron](#). But here we can demonstrate entanglement between two massive objects," said co-first author Ming-Han Chou, a former UChicago PME and Physics doctoral researcher now at the Amazon Web Services Center of Quantum Computing. "The second thing we demonstrate in this research is that our platform is scalable. If you can imagine building a big quantum processor, our platform would be like a unit cell within that."

The entanglement isn't between the molecules, atoms or any other particles that make up the resonators, but between the "phonons" that occupy the resonators. These are the nanoscale mechanical vibrations that—were there ears small enough to hear them—would be considered sound.

"Phonons are quantum particles of sound," said co-first author Hong Qiao, a UChicago PME postdoctoral researcher in Cleland's lab. "A phonon is not an elementary particle. It's the collective motion of maybe quadrillions of particles behaving together. This is macroscopic compared to other [quantum systems](#) where you are entangling single electrons, single atoms, single photons."

The quantum concerto

Entangling this collective, sound-like motion has long been a research focus for Cleland. His lab was the first to figure out how to create and detect single phonons and the first to entangle two phonons. While they were Ph.D. candidates at UChicago PME, Qiao was on the research team for the latter breakthrough and Chou was involved with both.

More recently, the Department of Defense named Cleland a 2024 Vannevar Bush Faculty Fellow to pursue phonon-based quantum computing.

"The conventional wisdom has been that quantum mechanics rules physics at the smallest scale while classical physics rules the human scale," Cleland said. "But our ability to entangle massive objects by entangling their collective motion pushes that boundary. The domain where Erwin Schrödinger's cat exists gets bigger with each advance."

The device the team built is centered on two surface acoustic wave resonators, each on its own chip with its own mechanical support structure and each connected to its own superconducting qubit. The qubits are used to generate and detect the entangled phonon states. With this device, the researchers from Cleland's group showed that the large resonators could be quantum-entangled both while physically separate and with high fidelity.

"Previously, people have demonstrated there is entanglement, but with limited fidelity," Qiao said. "What we have shown here is we can go one step further to prepare more complicated entangled states, maybe even potentially add logical encodings."

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The next hurdle is time, lengthening the [resonator](#)'s lifetime to increase the quantum coherence. A longer-lasting [entanglement](#) would allow more powerful communication or distributed quantum computing, two major goals in building quantum networks.

"Our mechanical resonator has a relatively short lifetime, and that has quite limited the performance in this approach," Chou said. "The next step is very clear: We will try to improve the mechanical resonator lifetime."

The group hopes to extend the resonator lifetime from its current level of about 300 nanoseconds to more than 100 microseconds. It might sound daunting, but there are several existing strategies to hit this more than 300-fold increase, Chou said.

"There are different device geometries or different approaches in quantum acoustics that can already achieve such a long lifetime, but just to simplify our experiment we didn't use them in this initial research," Chou said.

More information: Ming-Han Chou et al, Deterministic multi-phonon entanglement between two mechanical resonators on separate substrates, *Nature Communications* (2025). DOI: [10.1038/s41467-025-56454-0](https://doi.org/10.1038/s41467-025-56454-0)

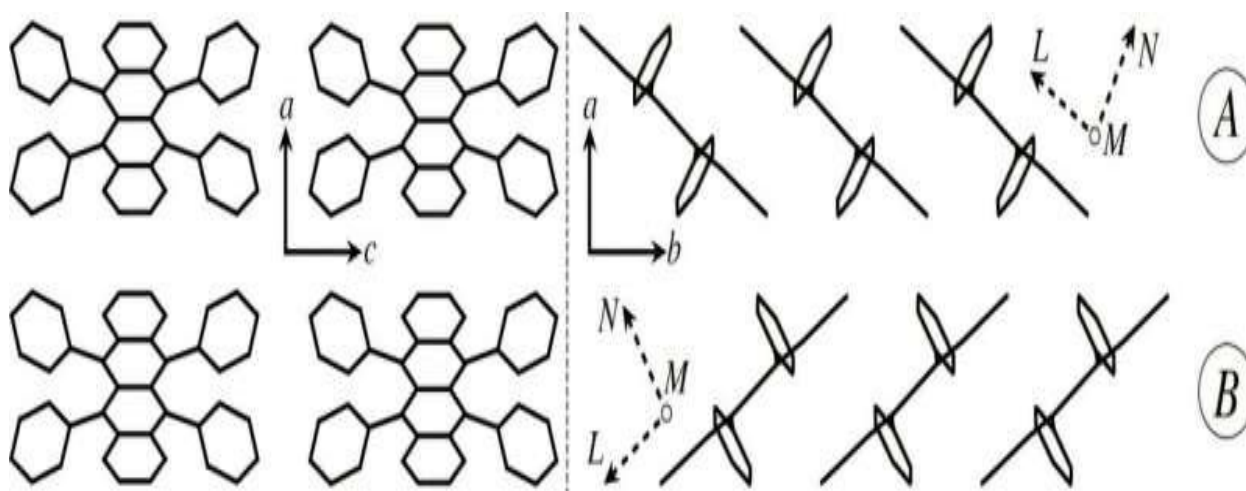
Journal information: [Nature Communications](#)

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FEBRUARY 10, 2025

Excitons in organic semiconductors: Unraveling their quantum entanglement and dynamics

by [Lehigh University](#)



Adjacent π -stacked molecular columns (represented by their carbon-carbon bonds) in the lattice of orthorhombic rubrene, in b -axis (left) and c -axis (right) projections, with the a , b , c crystal axes used in this work. Credit: Gerald Curran et al

Excitons, encountered in technologies like solar cells and TVs, are quasiparticles formed by an electron and a positively charged "hole," moving together in a semiconductor. Created when an electron is excited to a higher energy state, excitons transfer energy without carrying a net charge. While their behavior in traditional semiconductors is well understood, excitons act differently in organic semiconductors.

Recent research led by condensed matter physicist Ivan Biaggio focuses on understanding the mechanisms behind [exciton](#) dynamics, quantum entanglement, and dissociation in organic molecular crystals.

The paper is [published](#) in the journal *Physical Review Letters*.

In organic materials, excitons must first move through the material to then dissociate and generate a usable current. Biaggio's lab uses lasers to excite these particles and observe their quantum-level interactions. Researchers track exciton behavior via [short laser pulses](#) and fluorescence, analyzing "quantum beats" to study complex processes like [singlet fission](#), triplet transport, and triplet fusion. Singlet fission splits an initial excitation

(with spin 0, called a singlet) into two triplet excitons (each with spin 1) that still maintain a combined spin of 0 in an entangled quantum state.

The lab is investigating the properties of a quantum-entangled pair of triplet excitons that is generated after photoexcitation. Biaggio and his team grow rubrene crystals, an organic semiconductor that possesses [high carrier mobility](#) and allows for singlet exciton fission, then use lasers to selectively excite and detect specific excitons. They exploit the processes by which the excitons absorb light of different wavelengths, and that allow two triplet excitons to emit a photon when they meet each other.

"The detection of fluorescence decay, and the high frequency ripples caused by the quantum-entanglement, are a quantum mechanical way to observe what's going on," says Biaggio, Joseph A. Waldschmitt Chair in Physics.

"It is indirect because it relies on the detection of what these excitons do, not in terms of dissociating and creating current, but in terms of wandering around in the crystal, then at some point meeting with each other again, and re-emitting light. Or we can catch them as they are created using other laser pulses that observe their appearance and track them. In this way, we can then track the phenomenon of these excitons being born from the initial photoexcited state, which takes about 10 picoseconds."

Biaggio's latest experiments are examining how the [quantum-entanglement](#) of triplet exciton pairs can persist as the two excitons wander around independently in the crystal. His experiments unearthed a process in which the clocks of triplet-exciton pairs can get out of synch, even though each clock keeps ticking at the same frequency.

This research might possibly aid [semiconductor](#) development or quantum information science. The long-term goal is to better understand fundamental exciton behaviors, which might eventually influence applications in solar energy harvesting, or possibly, quantum computing.

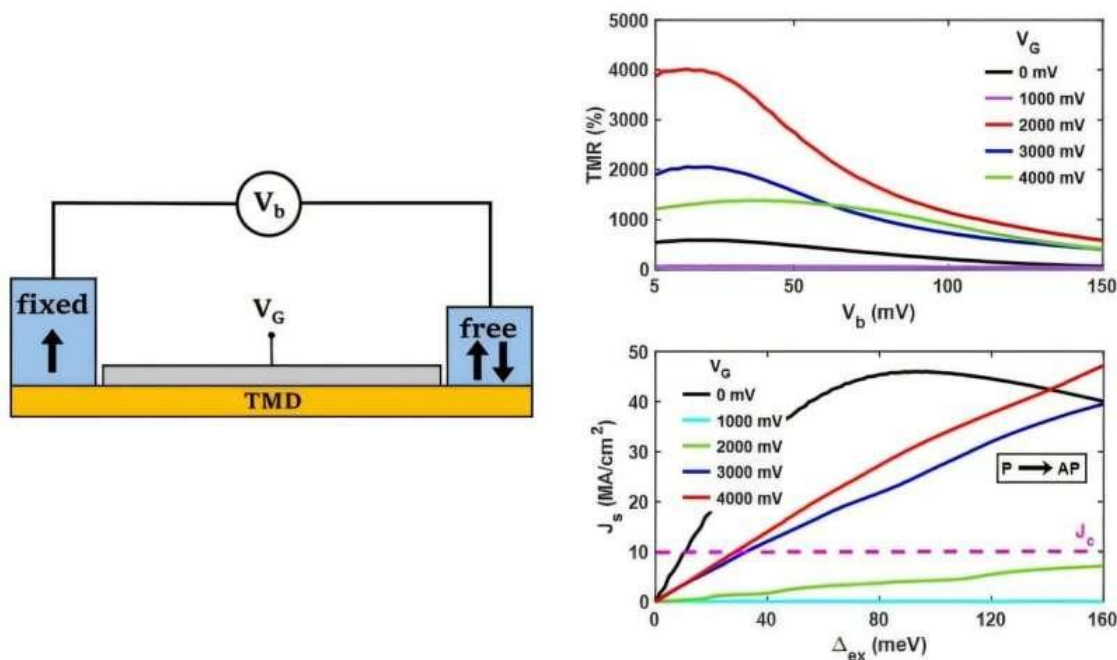
More information: Gerald Curran et al, Persistence of Spin Coherence in a Crystalline Environment, *Physical Review Letters* (2024). [DOI: 10.1103/PhysRevLett.133.056901](https://doi.org/10.1103/PhysRevLett.133.056901). On *arXiv*: arxiv.org/html/2406.02703v1

Journal information: [Physical Review Letters](#) , [arXiv](#)
Provided by [Lehigh University](#)

FEBRUARY 10, 2025

Gate-controllable two-dimensional transition metal dichalcogenides for spintronic memory

by [National Taiwan University](#)



A gate-

controllable TMD spin valve is proposed to enable energy-efficient spintronic memory, delivering exceptional read and write performance at room temperature. Credit: *Journal of Alloys and Compounds* (2024). DOI: 10.1016/j.jallcom.2024.177487 The rapid advancement of technologies like artificial intelligence (AI) and the Internet of Things (IoT) has heightened the demand for high-speed, energy-efficient memory devices. Traditional memory technologies often struggle to balance performance with power consumption.

Spintronic devices, which leverage electron spin rather than charge, present a promising alternative. In particular, TMD materials are attractive due to their unique electronic properties and potential for miniaturization.

Researchers have proposed the development of gate-controllable TMD spin valves to address these challenges. By integrating a gate mechanism, these devices can modulate spin transport properties, enabling precise control over memory operations. This approach aims to enhance tunneling magnetoresistance (TMR) ratios, improve spin current densities, and reduce [power consumption](#) during read and write processes. The study is [published](#) in the *Journal of Alloys and Compounds*.

This research indicates that gate-controllable TMD spin valves can achieve significant improvements in performance metrics. For instance, TMR ratios exceeding 4000% have been reported, indicating highly efficient spin-dependent transport. Additionally, the proposed device demonstrates ultralow power consumption, with some configurations operating at approximately 80 μW , and maintains high spin polarization ratios up to 0.9.

These findings suggest that TMD-based spintronic memory devices are well-suited for next-generation applications requiring high-speed, energy-efficient memory solutions.

More information: Shih-Hung Cheng et al, Gate-controllable two-dimensional transition metal dichalcogenides for spintronic memory, *Journal of Alloys and Compounds* (2024). DOI: [10.1016/j.jallcom.2024.177487](https://doi.org/10.1016/j.jallcom.2024.177487)
Provided by [National Taiwan University](#)